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Solar Energy in Urban Planning: Lesson Learned and Recommendations from Six Italian Case Studies

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Abstract: This paper presents the results of the analysis conducted on six case studies related to solar energy integration in urban and rural environments located on the Italian territory. The analysis has been carried out within the Subtask C—Case Studies and Action Research of the International Energy Agency Solar Heating and Cooling Program Task 51 "Solar Energy in Urban Planning". Three different environments hosting active and passive solar energy systems (existing urban areas, new urban areas, and agricultural/rural areas) have been investigated to attain lessons learned and recommendations. Findings suggest that (a) it is important to consider solar energy from the early stages of the design process onwards to achieve satisfactory levels of integration; (b) a higher level of awareness regarding solar potential at the beginning of a project permits acting on its morphology, achieving the best solution in terms of active and passive solar gains; (c) when properly designed, photovoltaic systems can act as characterizing elements and as a distinctive architectural material that is able to valorize the aesthetic of the entire urban intervention; (d) further significant outcomes include the importance of supporting the decision strategies with quantitative and qualitative analyses, the institution of coordinating bodies to facilitate the discussion between stakeholders, and the need for deep renovation projects to fully impact existing buildings' stock; (e) when large solar installations are planned at the ground level, a landscape design approach should be chosen, while the ecological impact should be reduced by carefully planning the adoption of alternative solutions (e.g., agrivoltaics) compatible with the existing land use.

Keywords: solar energy; urban planning; active solar systems; passive solar strategies; Italian case studies; agrivoltaics

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1. Introduction

Cities represent the place where 80% of the gross domestic product is generated and where around half of the world population lives, with expected growth to two-thirds by the middle of the current century [1]. The combination of these two factors demonstrates why urban areas are considered responsible for up to 75% of the global energy consumption and more than 70% of energy-related carbon dioxide (CO_2) emissions [2].

In this context, the decarbonization of the energy sector, in line with the Paris Agreement's goals to keep the temperature increase below 2 °C, requires a substantial contribution from cities. A growing number of cities, mainly located in the European Union (EU) and North America, have set renewable energy targets to support the green energy transition [3]. At the municipal level, the adoption of regulations, economic incentives, and the direct financial involvement of municipalities and public authorities, combined with the storytelling of successful practices, proved to be crucial in raising public awareness and in steering private developers toward sustainable strategies [4,5]. Similarly, in the past decades, national level measures constituted a strong enabler for the exploitation of renewable energy sources (RES) [6].

Solar photovoltaic (PV) and solar thermal (ST) had respectively the first (36%) and the fourth (10.5%) highest expansion rate among the RES in the past 30 years [7]. In one of the preconfigured future scenarios, the International Energy Agency (IEA) is expecting that PVs would cover almost one-third of the new electricity demand within 2030, with an average annual growth rate of 13% [8]. Utility-scale ground-mounted systems dominate the market [9]; however, several potential issues related to their impact on the ecosystem, landscape, and competition with agricultural land are emerging [10,11].

The major alternative is distributed rooftop systems (i.e., applied and integrated systems), representing a market share of 40% in 2020 [12]. This technology has the highest potential use in the built environment, especially for photovoltaic systems fully integrated into the building envelopes (i.e., facades and roofs), which perform the double function of energy producer and building cladding. The advantages of building-integrated photovoltaics (BIPV) and solar thermal (BIST) are manifold: unused surfaces can be turned into active energy generators [13], losses associated with transmission and distribution of electricity are reduced thanks to on-site production [14], and higher energy flexibility toward extreme weather conditions is guaranteed [3]. On the other hand, the installation of such systems in urban areas, especially on vertical surfaces (i.e., facades), requires considering complex phenomena such as inter-building solar reflections and overshadowing effects [15–17], and other energy and climate-related issues, such as high surface temperature [18] and fire hazard [19]. The visibility and the socio-cultural sensitivity impact of the systems should also be considered [20–23]. In Europe, BIPV accounted for a cumulative installed capacity of 6.9 GWp at the end of 2019, with Italy covering about 38% of the total, due to the early campaign of statal incentives to boost the adoption of PV technology [24].

Other two viable alternatives, representing small market niches in rapid expansion, are floating solar and agrivoltaics [12]. These technologies allow to reduce land use for solar installations and through appropriate design can provide a series of benefits. Floating solar has the advantage of reducing the evaporation of water reservoirs. Furthermore, the presence of water helps to keep the panels' temperature low, stabilizing the efficiency of the system [25,26]. Similarly, agricultural PV can improve crop yield, limit evaporation, provide shade to livestock or crops, and protect against extreme weather conditions and soil erosion [12,27]. The potential for agrivoltaic systems in Europe is immense; if solar would be deployed on 1% of the arable land, its technical capacity would amount to over 900 GW, which is more than six times the current installed PV capacity in the EU [28].

Framework and Aim of the Work

This paper presents part of the findings related to Italian case studies within the *Subtask C—Case Studies and Action Research* (STC) framed in the International Energy Agency (IEA) Solar Heating and Cooling Program (SHC) Task 51 "*Solar Energy in Urban Planning*" [29–31]. During the whole duration (2013–2017), the international experts working in Task 51 (i.e., architects, urban planners, public authorities, researchers, etc.) promoted through their work the integration of active and passive solar solutions in the built environment. Furthermore, the collection of international case studies through a common template carried out within STC allowed to create an overview of solar energy in urban planning by highlighting potentialities and fragilities and by summarizing lessons learned for urban stakeholders, public authorities, and researchers. The developed template is here introduced and used to present six Italian case studies, which make use of solar energy in different ways and are characterized by different built environments. Five of them deal with consolidated and new urban areas, with photovoltaic or solar thermal panels fully integrated or applied to the buildings' envelopes, while one case provides an example of an agricultural PV system and its relationship with the landscape. Different from [31] where an international overview is given, in this paper, the Italian case studies are presented more in detail, and specific conclusions are drawn for solar energy implementation in the Italian context. Additionally, a comparison between the different built environments through similarities and differences is provided.

In the next section, an overview of the Italian energy planning legislation is given, followed by the presentation of the case studies and their discussion. Finally, the limitations of the study are presented, together with a conclusive summary of the main lessons learned and recommendations.

2. Background: Italian Legislative Framework

The framework of Italian legislation on urban and energy planning is characterized by a hierarchical approach stretching from the national level down to the regional, provincial, and municipal levels. According to the Constitution, urban planning and energy-related topics are a shared task between the State, the Regions, and the autonomous Provinces. Consequently, regional authorities may implement autonomous legislations as long as they do not contradict the general principles and requirements provided by national and EU regulations.

The Italian national legislation promoting energy efficiency and the diffusion of RES has been developed as an implementation of the major European directives. In 2011, the National Renewable Energy Action Plan [32] transposed the Directive 2009/28/EC setting the targets for renewable energy production by 2020. The plan also defined a minimum quota of production from RES for all new buildings and buildings subjected to major renovation. The minimum share of RES quota for domestic hot water (DHW) was set to 50% of the primary energy consumption. Furthermore, a calendar with a progressive higher RES share was established for the sum of primary energy consumptions for DHW, heating, and cooling. In December 2018, the EU targets have been revised by the European Directive 2018/2001/EC on renewable energy [33] and by the Regulation 2018/1999/EU on the governance of the energy union and climate action [34]. These regulations were part of the "Clean Energy for all Europeans Package", which promoted a 40% reduction in greenhouse gas (GHG) emissions, a goal of 32% final consumption from RES, and an energy efficiency target of 32.5%. Finally, at the beginning of 2020, the European Parliament adopted the European Green Deal, which set the objective "to increase the EU's GHG reductions target for 2030 to at least 50% and towards 55% compared with 1990 levels in a responsible way" and to achieve climate neutrality for the continent by 2050 [35]. Building on the EU legislation, and in line with the European Regulation 2018/1999/EU, which required all EU countries to develop 10-year National Energy and Climate Plans (NECPs) for the period 2021–2030, the Italian Integrated National Plan for Energy and Climate (INECP) was adopted in January 2020. The INECP set clear targets to 2030: (i) 30% of energy from RES in the final gross energy consumption, (ii) 43% reduction in primary energy consumption compared to the Price-Induced Market Equilibrium System (PRIMES) 2007 scenario, and (iii) 38% overall reduction in GHG emissions compared to 1990 [36].

2.1. National Standards

The INECP sets some growth targets for power and thermal energy from RES at the national level. In the case of solar energy, targets are set to 28,550 MW for 2025 and 52,000 MW for 2030 (in 2017, the production amounted to 19,682 MW).

With regard to the thermal sector, the targets are 590 ktoe in 2025 and 751 ktoe in 2030 [36]. Furthermore, the "Clean Energy for all Europeans Package" was implemented in

Italy by the "Renewables Decree" (D.Lgs 28/2011 [32]), which also led to the definition of guidelines for energy performance certification of buildings (D.M. 26 June 2015. Specifically, Article 11 of Decree D.Lgs 28/2011 introduces the obligation to integrate renewable energy sources in new buildings or buildings subject to major renovations. Indeed, in case of new construction, refurbishment, or demolition and reconstruction, RES should cover 50% of DHW consumption, and 50% of the sum of consumptions for DHW, space heating, and cooling. For public buildings, the share is increased to 55%; while in the case of private buildings located in historic city centers, the share is reduced to 25% (27.5% for public buildings) [32]. In 2021, the share of RES has been further increased, with the introduction of the D.Lgs 199/2021. From June 2022, in case of new construction and major renovations, RES should now cover 60% of the consumptions for DHW, space heating, and cooling. Conversely, a 65% coverage should be demonstrated for public buildings [37]. Concerning passive solar, minimum daylight levels in buildings are regulated by national laws (D.M. 190/1975, C.M. LL. PP. 22 November 1974 n. 1301 and D.M. n. 26/1975). These set minimum levels of the daylight factor depending on the type of building:

- Residential buildings: ≥2% and a window-to-floor ratio ≥ 1/8 is required.
- Hospitals and schools: ≥3% (rooms and labs), ≥2% (gyms and canteen), ≥1% (offices and other service rooms).

The Italian National Status of Ground-Mounted PV

The national energy target for 2030 foresees an increase in ground-mounted photovoltaics of about 35 GW. However, the actual installation trend of 1 GW/yr is far below the 6.5 GW/yr needed to fulfill the target on time [38]. The installation of PVs on the ground is currently hampered by barriers along the authorization process due to landscape preservation and land use concerns. The adoption of innovative solutions such as agricultural PV aims at overcoming these barriers by combining a dual use of land and establishing a synergy between energy production and agriculture, which can be seen as a driver. In that regard, the current legislation is in constant evolution. In April 2021, the National Recovery and Resilience Plan (RRP), part of the Next Generation EU (NGEU) program, allocated 1.1 billion euros investment for the "agrivoltaic development" with the specific objective of installing 2 GW of agrivoltaic capacity and improving the competitiveness of the agricultural sector [39]. Additional elements regarding the definition of agrivoltaics have been introduced by the National Law 29 July 2021 [40] where these systems are described as "innovative integrative solutions, with PV modules raised from the ground, also including tracking systems, which do not compromise the continuity of the agricultural activities on ground". This law introduces simplifications in the process, which would lead to a rationalization of the authorizations for PV toward the national energy targets. Despite a specific definition for agrivoltaics not being currently available in Italy, an official document is expected in a short time. Meanwhile, the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) has launched the National Network for Sustainable Agrivoltaics [41], while the Italian Electrotechnical Committee (CEI) has initiated a working group on the topic.

2.2. Municipal Standards

The targets set at the national level are pursued by Italian Regions, which can enhance the minimum quota or specify the renewable energy systems to use. Therefore, depending on regional laws, municipalities can set their own energy-related regulations in the building code. Generally, the building codes consider two major categories of built environment: historical city centers and non-historical urban areas [42].

Historical city centers are subjected to strict regulations about solar system applications due to the need to preserve the visual effect of their views and panoramas. Concerning this category, buildings codes set either prohibition of installing solar systems or restrictions on the visual effect and location of the systems (e.g., modules have to be located on roof surfaces not visible from main streets and to be building integrated). In addition to these restrictions, the approval of the Superintendence for Architectural Heritage and Landscape is required for installing solar systems on constructions subjected to landscape or heritage protection [43]. In the second category—non-historical urban areas—solar systems are generally permitted as building-integrated. For new buildings or buildings subjected to major renovations, it is required that PV or ST plants are installed integrated or adherent to the roofs, following their same orientation and inclination.

Further regulations on solar energy systems are sometimes included in municipal building codes, deriving from national laws on building energy efficiency and the promotion of renewable energy production. However, the standards regard only the design of buildings at the architectural scale. Energy performance certification is mandatory for new constructions and for selling or renting a dwelling in existing buildings [44].

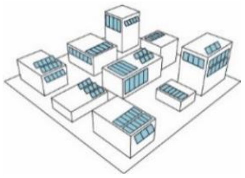
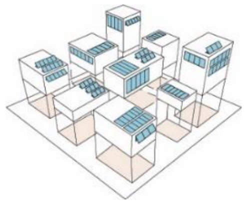
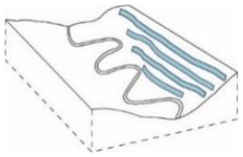
3. Materials and Methods

This section illustrates the methodology used to analyze the case studies. The method was developed within the *Subtask C—Case Studies and Action Research* of the IEA SHC Task 51 to provide experts in the field of urban planning with an exhaustive set of information and examples on the integration of solar energy in heterogeneous environments. A total of six cases located on the Italian territory are presented here.

3.1. Classification of the Environments

As a first step, the case studies were divided according to the three types of environments presented in Table 1.

Table 1. Classification of the environments.

Environment	Description
	*Existing urban areas*. The first environment, represented by two case studies, includes fill-ins and densification processes, new buildings within a consolidated built environment, or the refurbishment of existing buildings. A scale larger than a single building is considered to assess the impact of a project on its surrounding.
	*New urban areas*. The second environment includes three case studies, and it is characterized by projects where completely new infrastructures and detailed development plans are required. The involvement of urban planners since the beginning of the process can play a significant role in the successful integration of solar energy.
	*Landscape*. The third environment includes one case study, and it investigates the impacts of large solar installations in the landscape.

3.2. Template Definition and Description

The second step consisted of the creation of a template to systematically organize the information of the case studies within a homogeneous framework. Despite the adoption of a standard structure, the template has a certain degree of flexibility. A total of ten sections are available, six of which are common among all the investigated cases, while the others can be compiled according to the type of environment described and the available information. A schematic representation of the template structure is visible in Figure 1, followed by the sections' description.

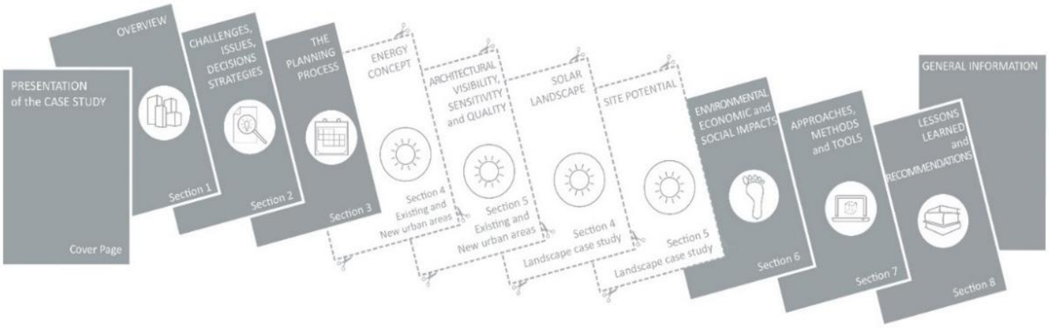
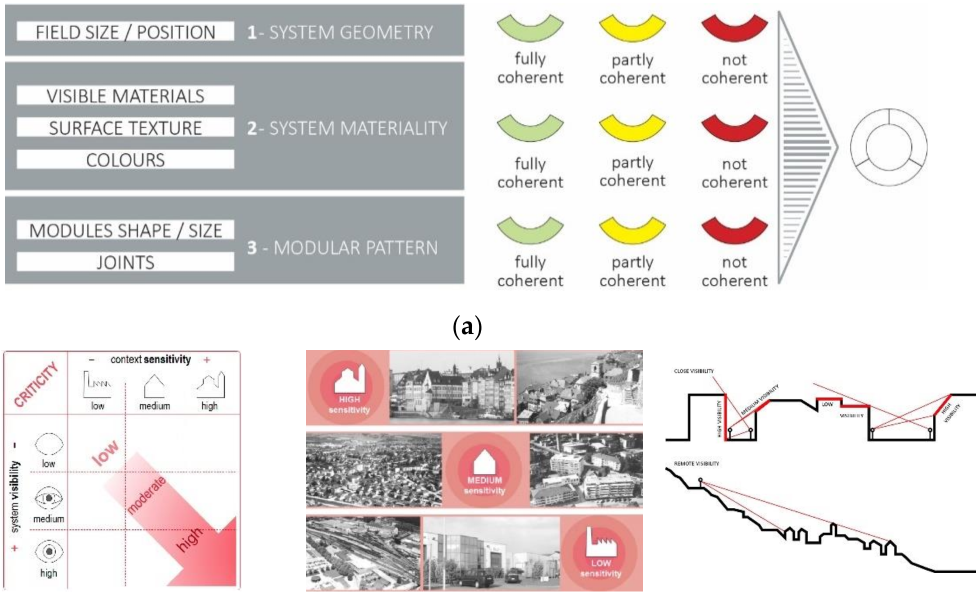


Figure 1. Representation of the different sections of the template used. In full color, the sections compiled for all the cases, while the optional ones are shown in white.

1. *Overview*. It briefly describes the context in which the case study has been developed. Particular attention is posed on the adopted solar energy strategies, local and national regulations, and future planning development.
2. *Challenges, issues, and decision strategies*. Issue and challenges encountered during the realization of the project are presented with an emphasis on relevant features of energy characterization (i.e., integrated panels, overshadowing effects).
3. *The planning process*. This section presents the timeline of the project and the different spatial scales investigated during the planning. In addition, the involvement of stakeholders and researchers and the most influential decisions taken during the planning process are presented.
4. *Energy concept*. The focus is on energy technologies, PV, ST, and passive solar gains. The energy needs and the adopted solar strategies are described.
5. *Architecture, Visibility, Sensitivity, and Quality*. This section investigates the critical issues of implementing active solar strategies into a built environment. This is completed using a methodology developed by EPFL researchers within the framework of IEA SHC Task 41 "*Solar Energy and Architecture*", which is now integrated into the tool LESO—QSV [45–47]. As a first step, the solar system installation is evaluated according to the architectural integration quality. To be considered successful, the integration should be coherent with the entire building design logic regarding system geometry (i.e., size, position), system materiality (i.e., visible materials, surface textures, colors), and system modular pattern (i.e., module shape, size, joints). The coherency of these three aspects is evaluated using a three-level scale (fully—partly—not coherent), corresponding to three colors (green—yellow—red). The second step is to assess the criticality of the surface where the solar system is installed, which is depending on its close or remote visibility from the public space (low—medium—high) and from the sensitivity (low—medium—high) of the urban context in which is located. Exemplary of a high sensitivity context is a historical city center, a medium one is a post-war residential development, and a low one is an industrial district. Regarding new realization, the evaluation should be based on the future vocation of the urban area. Figure 2 summarizes the approach.



(**a**)

(**b**) (**c**) (**d**)

Figure 2. (**a**) Architectural integration quality matrix; (**b**) Criticality matrix developed in relation to (**c**) context sensitivity and (**d**) system visibility.

6. *Solar landscape*. This section is specific to the landscape environment. It includes the definition of the solar system used, its functional features (i.e., modules' pattern, presence of edges—Figure 3), and the energy production. This is defined according to the classification proposed by ENEA on solar landscape plan [10].

Figure 3. The spatial system as a whole (pattern) (on the **left**), the photovoltaic space (in the **middle**), and the "pore" space (on the **right**).

7. *Site potential*. It refers again to the landscape environment following the methodology developed by ENEA, defining the site potential. The factors influencing the suitability of the site for the installation of PV or ST are here identified and qualitatively assessed.
8. *Environmental, economic, and social impacts*. The impact of the project under the social, economic, and environmental aspects is analyzed, with particular attention to the relation between the solar system and the surrounding environment.
9. *Approaches, methods, and tools*. It contains information about methods (i.e., procedures to assess and evaluate solar in relation to other aspects of urban planning), tools (e.g., rule of thumb, software, etc.), and tested approaches utilized during the planning process and in the integration of solar energy.
10. *Lessons learned and recommendations*. The final section presents the outcomes of the project together with potential solutions and recommendations gained from it.

An overview of the six analyzed case studies is visible in Table 2.

Table 2. Overview of the analyzed case studies. (CCHP: Combined Heating and Cooling; DH: District Heating; DC: District Cooling).

Location	Picture	Name	Classification	Area [m^2]	Energy Strategies	Highlights
Alessandria		Photovoltaic Village	Existing urban area/ Refurbishment	72,000	PV roof PV façade PV facilities	• The first example of an Italian public residential building project where solar energy is applied at an urban scale. • Photovoltaics cover 100% of electricity consumption for common areas and up to 70% in apartments.
Bolzano		SINFONIA	Existing urban area/ Refurbishment	1750	PV roof ST roof Geothermal	• European project aiming to transform Bolzano into a smart-city and to retrofit 34,000 m^2 of social housing • A successful example of the use of an Integrated Design Process (IDP)
Trento		Le Albere	New urban area	116,000	PV roof PV façade PV shading Geothermal CCHP plant	• Regeneration and reconnection to the city's fabric of a large brown-field • Building-integrated photovoltaic modules give identity and enforce the aesthetic of the project
Brescia		Violino District	New urban area	48,450	PV roof DH	• Social housing project developed according to bioclimatic design principles • Volumetric composition and orientation of buildings designed to maximize the solar exposure
Bolzano		Casanova District	New urban area	100,000	PV roof ST roof Geothermal DH-DC	• Attention to mobility and social aspects • Shape, orientation and reciprocal position of buildings are designed according to solar and wind

Table 2. *Cont.*

Location	Picture	Name	Classification	Area [m^2]	Energy Strategies	Highlights
Monticelli d'Ongina		Agrovoltaico	Landscape	21,000	PV on two axes trackers	• Double use of land combining energy and food production ad different layers. • The photovoltaic system is designed as a landscape, minimizing its ecological impact.

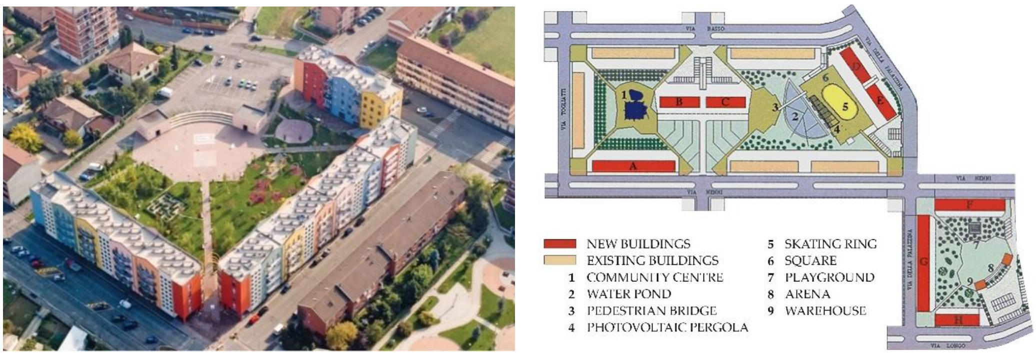
4. Results and Discussion

In this section, the six case studies are presented and discussed, starting from the ones in existing urban areas, followed by new urban areas, and concluding with the integration of solar technologies into the landscape.

4.1. Photovoltaic Village in Alessandria

4.1.1. Overview

The case study is a residential neighborhood constituted of several multistorey buildings, for a total of 192 flats, located in the southwest fringe of Alessandria (Piemonte). The project was developed within the context of a complex initiative undertaken by the Alessandria Municipal Council after the flood of 1994. It aims to regenerate a social housing community using a sustainable, environmental, and social approach through the realization of new buildings, urban facilities (i.e., a community center, recreational areas, sheltered sits, and parking lots) and the refurbishment of existing residential blocks (Figure 4) [48]. The extensive use of photovoltaic technology characterizes the project.



(**a**) (**b**)

Figure 4. The (**a**) aerial view of new buildings in the eastern part of the Photovoltaic Village (source: © Municipality of Alessandria) and a site plan of the entire area indicating the position of facilities, new and existing buildings (**b**) (source: © Municipality of Alessandria).

4.1.2. Challenges, Issues, and Decision Strategies

The challenge encountered during the realization of the project was the definition of an innovative planning process to meet the interests of both public and private actors and the promotion of energy-efficient solutions and RES. In addition, the existing urban plan was substituted due to the adoption of new legislative procedures. The decision strategy was based on three principles: (i) active participation and collaboration between the actors; (ii) a pivotal role of the municipal authorities in the whole design process; (iii) the project conception as a pilot for town planning and suburban requalification.

4.1.3. The Planning Process

The project began in 1996 with the enforcement at the regional level of the Environmental, Building and Urban Requalification Program [49], with energy saving as one of the main objectives for buildings and urban projects. This stimulated the adoption of solar energy and sustainable practices and led to create the Building Operators Council in 1997 to coordinate the actors involved in the process. The construction phase lasted five years (2000–2005). The most important phases were the large scale of comprehensive/strategic planning, represented by the Environmental, Building and Urban Requalification Program, and the architectural design stage of the existing buildings. The Municipal Town Council, the Building Operators Council constituted by private and cooperative builders from the Province of Alessandria, architects, and various other private stakeholders took part in developing this initiative. Furthermore, researchers from Politecnico di Torino contributed to the design and monitoring of solar systems [48].

4.1.4. Energy Concept

The buildings are designed to reduce their impact on the environment through energy-saving measures, and the use of RES. PV modules, with an efficiency of up to 15%, are installed on roofs with a tilt angle of 30°, on the southern facades in front of the stairways of two buildings in the community center (indicated with letters B and C in Figure 4b) and as part of a photovoltaic pergola for the public space (Figure 5). PV systems cover a total area of 3000 m^2 (i.e., 1600 m^2 panel net surface). The overall power is 163 kW with estimated energy production of 674–830 kWh/kWp per year. This is expected to cover 100% of the electricity consumption for common areas and up to 70% for the flats [48].

(**a**) (**b**)

Figure 5. Ground (**a**) and aerial (**b**) view of the pergola equipped with PV panels in the public area (source: © Municipality of Alessandria).

4.1.5. Architecture, Visibility, Sensitivity, and Quality

The LESO–QSV method illustrated in the methodology is used in this section to evaluate the integration quality of the installed solar systems. As visible from the colored segments of the ring of the matrix in Figure 6, the integration has been judged partly coherent for all the three investigated aspects. Since the modules do not perform the double function of replacing a building component and simultaneously producing energy, being just overlaid to the roofs and facades, they cannot be considered as fully integrated into the building envelope from an architectural point of view. Moreover, the blue color of the solar cells contrasts with the finishing color of the facades. The systems' visibility from a close point of view is high, especially for the facades' elements, and it remains medium from a remote distance. Nevertheless, the context can be classified as of medium sensitivity due to the low historical value and the absence of any relevant elements or monuments.

(**a**) (**b**)

Figure 6. Architectural integration matrix for the PV systems in the Photovoltaic Village of Alessandria (left); (**a**) PV panels installed on facade in front of the stairways (source: © PierFranco Robotti); (**b**) aerial view of the systems installed on the flat roofs (Source: © Municipality of Alessandria).

4.1.6. Environmental, Economic, and Social Impacts

The project follows eco-sustainability and bio-compatibility principles. Particular attention was reserved to open spaces where green areas, a water pond, and urban furniture were carefully designed to create different bioclimatic zones for the users to stroll, relax, and socialize. The project is financed by a mix of public and private sources. The region financed part of the investments for its environmental sustainability implications, while approximately 70% of the total cost for the installation of photovoltaics was covered by public funds through the program "10,000 Photovoltaic Roofs" coordinated by the Italian Ministry of the Environment [48,50].

4.1.7. Approaches, Methods, and Tools

A monitoring campaign on the PV systems was carried out by researchers of Politecnico di Torino for a period of 12 months (September 2004–August 2005) to measure the electricity generated during the buildings' operation phase and correlate it to the actual energy consumption. Data were collected every 15 min and function curves for daily, weekly, monthly, and annual periods were generated. The analysis shows that PV systems can fulfill the electricity demand for seven months, but an electricity supply through the grid is still needed. In addition, in the absence of regional, national, or community incentives, the investment can be paid off in a long-term period (more than 30 years).

4.1.8. Lesson Learned and Recommendations

The Photovoltaic Village in Alessandria illustrates the limits of retrofitting existing buildings with solar technologies in the absence of a deep renovation opportunity. Despite the overall positive results, the designers were forced to consider a limited range of design options since they had to comply with existing buildings' masses and materials. A different outcome may have been obtained through an in-depth renovation process involving replacing/recladding facades and roofs. Furthermore, the integration of solar systems in public spaces has only been marginally explored. However, the institution of a Building Operators Council as a coordinating body for the different involved actors was a successful practice replicable in similar contexts.

4.2. SINFONIA Bolzano

4.2.1. Overview

The SINFONIA case study is the result of a five-year European project aiming to implement large, scalable, and integrated energy solutions in mid-sized cities. Bolzano, the capital of South-Tyrol province (Trentino Alto Adige), was selected together with Innsbruck (Austria) as a testbed for this initiative to understand the replicability of the proposed solutions in other European cities [51]. The project aimed to achieve the following:

- Obtain between a 40% and 50% reduction in primary energy use and a 20% increase in RES share for the selected districts in the two pilot cities of Bolzano and Innsbruck.
- Prove the feasibility of large-scale energy measures, retrofitting, grid optimization, and district heating and cooling systems in mid-sized European cities.
- Define district typologies and refurbishment models to ensure scalability and replicability. These last two aspects are supported by five "early adopter" cities where to test the initial outcomes of the two pilots.
- Develop a network to support and engage other European cities in strengthening their smart-energy solutions.

In this framework, refurbishment interventions were undertaken for six residential complexes in Bolzano to improve their energy performance and indoor comfort. The initiative is in line with the municipal goal to reduce energy use and increase the share of RES. The presented case study focuses on one of these interventions, consisting of two buildings blocks of 36 flats each, located in the south part of the town (Figure 7).


(**a**) (**b**)

Figure 7. North building before (**a**) and after (**b**) the intervention (source: © Ivo Corrà).

4.2.2. Challenges, Issues, and Decision Strategies

The location of the building complex has been one of the main challenges in the development of the project. Its proximity to the side of a mountain represented an accessibility issue during the refurbishment phase. Other challenges included the limited surface for the integration of solar energy systems, which was also due to the proximity to the mountain slope toward the south and the presence of overshadowing due to four stairwell towers above the roof levels. Finally, the intervention should have the minimum possible impact on the tenants, as all refurbishment activities have been carried out with lived-in flats. Regarding the decision strategy, targets for the energy concept were set at the beginning to reach: (i) a final energy balance $\leq$ 22.5 kWh/(m^2 yr); (ii) DHW from renewable energy sources $\geq$ 9 kWh/(m^2 yr); and (iii) PV installation $\geq$ 53 kWp for the entire complex. Furthermore, the optimization of the solar systems and the improvement of interior daylight conditions were also investigated. An Integrated Design Process (IDP) was followed to assure good stakeholders' involvement.

4.2.3. The Planning Process

The refurbishment was carried out in three phases. The first was the design phase, which was developed through an IDP by a multidisciplinary team of experts from the Municipality of Bolzano, the design team, research institutes, and Agenzia Casaclima (the local certification body for energy efficiency in constructions). The two following phases were the construction phase and the monitoring phase, which lasted one year. All the spatial scales were investigated during the five years of the realization (2014–2019).

4.2.4. Energy Concept

The buildings' complex was originally realized in the 1990s without energy-saving measures, apart from a thin insulation layer (4 cm) on the external walls. Hence, the project involved the refurbishment of the existing facades by using timber prefabricated multifunctional elements to improve the energy performance and the indoor thermal comfort as well as aesthetically rehabilitate the buildings. Renewable energy strategies were also adopted with the installation of PV and ST systems on the roof and a geothermal heat pump serving centralized heating. PV modules with 15.5% efficiency, covering an area of 337 m^2, are installed on the roof of the northern building (Figure 8). The system has a power of 20 kW, and the modules are mounted horizontally (0° tilt angle) to avoid mutual overshadowing effects. Conversely, the roof surface of the southern building has been used for the installation of a 477 m^2 ST system with a 10° tilt angle and with an estimated production of 11.2 kWh/(m^2 yr) for DHW. This choice was dictated by the need to comply with the national legislation, requiring to cover at least 35% of the energy need for DHW with RES [32]. Both PV and ST cannot be considered architecturally integrated into the building, since they constitute free-standing elements placed on the roofs.

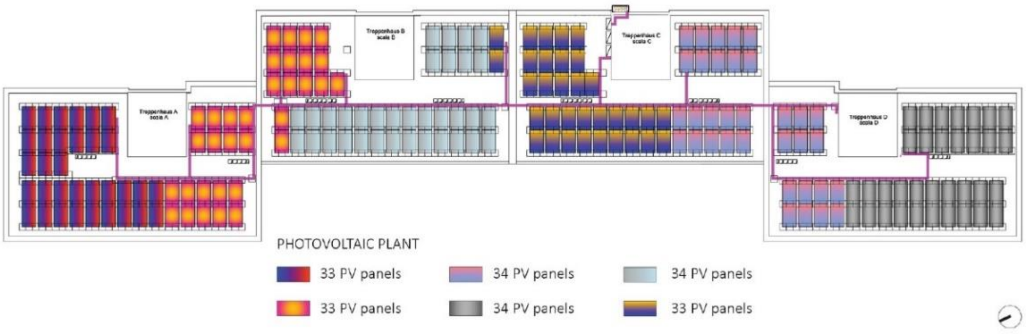


Figure 8. Technical plan of PV system on the roof of the north building (source: © EQ Ingegneria).

4.2.5. Environmental, Economic, and Social Impacts

The SINFONIA project intended to have an impact on the entire municipality of Bolzano by improving the quality of life of the citizens, turning the city into a smart city. The installation of over 100 smart points and three multifunctional interactive totems provides services such as charging electric vehicles, monitoring air quality and weather, and improving the lighting of public spaces. The installation of this diffuse technological network runs in parallel with the refurbishment of six residential housing complexes that enhanced the interior comfort and energy performance of 455 dwellings for a total of around 15 million euros of investments. From a social perspective, the tenants of the refurbished apartments have been directly involved through informative meetings and questionnaire-based surveys during the realization of the project. Additionally, displays have been installed in part of the apartments; data on energy performance and indoor conditions are shown in real-time, enabling the inhabitants to take actions to reduce their consumption. This was completed to raise awareness of the role that their behavior plays in the energy performance of buildings (i.e., ventilation rate, air temperature control, energy use) [52].

4.2.6. Approaches, Methods, and Tools

During the IDP, retrofit solutions were assessed before adopting a mixed approach combining the use of traditional insulation for the lodges and prefabricated multifunctional facades (MFF) for the rest of the building envelope. This choice did not require the use of scaffolding, simplifying and speeding up the construction phase, ensuring a low impact on the site's inhabitants. To define the best solutions for the MFF, prototypes were constructed and tested in laboratory tests. Moreover, the design focused on defining the optimal solution for solar active systems, assessing the potential energy production, and preserving the indoor visual comfort. To this aim, solar potential and daylight analyses were conducted using Diva for Rhino [53] and LadybugTools [54]. To assess the solar potential, close shading elements were modeled in the 3D environment of Rhinoceros [55], while the distant obstacles, such as the mountains, were considered by a horizon line generated from data measured with a Solmetric SunEye. The optimization process was carried out using a genetic algorithm to maximize the total annual and average irradiation and to minimize overshadowing effects. As the installation of the new prefabricated MFF caused a reduction in interior daylight availability, daylight analyses were performed to verify the compliance with the Italian national legislation (i.e., daylight factor above 2%). Details such as the windowsills' materials and loggias' colors were investigated to improve the solar mutual reflection effects. The simulations and the laboratory tests were conducted during the design phase, which allowed reducing the risks and uncertainties during the construction phase.

4.2.7. Lesson Learned and Recommendations

The main lesson learned from the SINFONIA case study is the benefit that an IDP can have on energy-related measures applied to the building.

Fundamental is an early collaboration between the different experts and stakeholders involved in the project (i.e., energy consultants, designers, owners, researchers, technicians). Furthermore, the case study demonstrates the importance of conducting solar potential and daylight analyses during the initial phase of the project by supporting the design team in the most important choices (i.e., finishing materials and colors to improve the interior daylight level, localization of active solar systems to avoid overshadow effect). Finally, it is recommended to consider how the occupants' behavior can influence the energy use of a building and try to engage and inform the users accordingly.

4.3. Le Albere in Trento

4.3.1. Overview

Le Albere is a district in the city of Trento (Trentino Alto Adige) that is constructed on a former industrial site enclosed between the railway and the river Adige. The aim of the project, designed by the Italian architect Renzo Piano, was to reconnect the site with the city center and to re-establish a relationship with its natural context. The result of the intervention is a mixed-use district that includes offices, residential buildings, a science museum (MUSE), a library for the University of Trento, and a park (Figure 9) [56]. The main feature of the project is the extensive integration of active solar systems on roofs and facades of the buildings of the whole complex. In that regard, the choice to adopt this energy strategy was autonomously taken by the actors involved since, at the time of the design, the Italian national legislation on energy and urban planning did not set any specific target for solar energy integration, despite supporting the use of RES.

(**a**) (**b**)

Figure 9. (**a**) Aerial view of the Le Albere district (source: © Google Earth) and (**b**) view from the public park (photo: © Silvia Croce).

4.3.2. Challenges, Issues, and Decision Strategies

The main challenge for the case study has been the formal integration of the photovoltaic systems in architectural design. High requirements were set by the architect in terms of the color, appearance, and dimension of PV modules due to the choice of having them as a key and visible element of the project. The strategy adopted by the municipality of Trento was to create a high-quality district, showcasing the best practices in terms of energy efficiency and sustainability, with extensive integration of RES.

4.3.3. The Planning Process

The planning process encompassed different spatial scales, spanning from the provincial down to municipal, local, and detail scales. Le Albere was a former industrial area occupied since 1937 by the tire manufacturing company Michelin. When the factory ceased its activity in 1998, a group of public and private investors, under the name of "Initiative Urbane", purchased the site to regenerate and reconnect it to the rest of the city.

In 2000, the Province of Trento included the renewal of the district into its Program for Urban Regeneration and Sustainable Development of the Territory and into the Trento

Strategic Masterplan. Two years later, the architectural firm Renzo Piano Building Workshop was designated to realize the project, and a final master plan was approved in 2004. The construction phase started in 2008 and lasted for five years when the MUSE, the mixed-use district, and the public park were inaugurated. Conversely, the university library located in the southern part of the parcel opened at the end of 2016.

4.3.4. Energy Concept

Several RES were used in the Le Albere district, such as BIPV systems integrated on many of the buildings that are present on site. The systems have a nominal power of 279 kW and cover a total area of approximately 3200 m^2. Tedlar–glass and glass–glass modules with different orientations and inclinations were specifically designed depending on their location. They are integrated into the buildings' facades and roofs or used as PV shading devices. The electricity produced by the BIPV modules covers the electrical demand of offices, common areas, pump rooms, and the lighting in the basement. The MUSE is served by a geothermal plant while a combined cooling, heating, and power plant, outside of the district's boundary, covers the heating and cooling demand for the whole area.

4.3.5. Architecture, Visibility, Sensitivity, and Quality

Following the LESO–QSV methodology, the integration of PV modules has been judged as fully coherent for all three categories of geometry, materiality, and pattern (Figure 10). Despite the different heights, inclinations, and shapes of the buildings, PVs act as unifying elements for the entire complex, further enhancing and characterizing it. The level of criticality, as a function of context sensitivity and system visibility, can be considered as medium. In fact, the case study is bordered by urban areas without any particular architectural or historical value, with the only exception of a renaissance villa/fortress on the north side. Regarding the systems' visibility, it is high from internal streets, open areas of the park, and roads bordering the site when PVs are installed on facades or integrated into glass surfaces constituting the tilted roofs. On the contrary, low perception levels for an observer located in the urban canyons of the district are achieved when the system is integrated on the opaque galvanized roofs. From an observer in the courtyards or in the park, the photovoltaics are perceived as a geometrical pattern. Finally, the remote visibility is low due to the overall height and dimensional scale of the complex, which is comparable with those of the historical center and the existing industrial structures.

(**a**) (**b**)

Figure 10. Architectural integration matrix for the PV systems in the Le Albere district in Trento (left); (**a**) the two typologies of BIPV systems: tedlar–glass modules on the galvanized roof and the glass–glass modules in the background (photo: © Silvia Croce); (**b**) detail of the glass–glass PV modules installed on the facades (photo: © Silvia Croce).

4.3.6. Environmental, Economic, and Social Impacts

Sustainability was central in the Le Albere project since the first phases of the design, starting from the construction materials sorted locally whenever possible to limit the environmental impact. The master plan was developed to preserve the natural features of the area by concentrating all the new constructions toward the east side of the plot and creating a large public park on the west side. The existing street, running parallel to the river, was transformed into an underground passage to allow the continuity of the park and directly interact with the river Adige. Regarding mobility, the realization of two-story underground parking greatly reduces the number of cars on the surface, while the traffic in the district is limited to residents, taxis, and public transport. Great attention was also placed on the design of numerous walkways and bikeways. Furthermore, the MUSE and the university library have obtained the LEED Gold certification, while residential buildings and offices, built according to passive standards, received the level B label of CasaClima (i.e., energy-efficiency classification), corresponding to a heating energy requirement below 50 kWh/(m^2 yr). The project carries a high social value thanks to the restitution of the area to the public realm with a new identity. The district has now a strong cultural and recreational vocation due to the presence of two social attractors (MUSE and university library) at the borders of the plot and a five-hectare park with residential and commercial buildings in the middle. The renewal intervention, which cost around 350 million euros, was entirely financed by a pool of banks, insurance companies, and industry associations in collaboration with the Municipality and the Province of Trento.

4.3.7. Approaches, Methods, and Tools

The approach used for the design of the case study has been strongly oriented toward sustainability. Building information modeling (BIM) tools were used along the entire process to integrate the buildings' design with energy modeling and considerations on internal and external comfort conditions.

4.3.8. Lesson Learned and Recommendations

The Le Albere case study strongly highlights the potential of solar systems integration not only as energy generators but also as architecturally valuable elements that can provide identity and enforce the aesthetic of the urban intervention. This is realized by declaring the presence of the photovoltaic modules and giving them high visibility instead of hiding or camouflaging them. When this approach is pursued, the quality of the system's integration becomes of primary importance and has to be carefully designed. In addition, the project poses sustainability, under its various declination of social, economic, and environmental, as the pivotal element to guide the design process, successfully resewing a large portion of the city with the rest of the urban fabric.

4.4. Violino District in Brescia

4.4.1. Overview

The Violino district is a new residential area located in the outskirt of the city of Brescia (Lombardia). It is constituted of 112 terraced houses and 2 multi-family houses five floors high (143 housing units), which are organized in lots defined by an orthogonal grid (Figure 11). It is the result of a new urban plan for social housing followed by an architectural competition announced by the Brescia Municipal Council [57] to design a district according to bioclimatic principles and with the extensive use of solar strategies. The area required a northeast/southwest oriented grid, which was judged to be not optimal for the full exploitation of the thermal and energy potential of the sun. The issue was overcome by adapting the terraced house' typology to the rigid grid with a partial rotation of the buildings' masses, ensuring adequate solar accessibility to all accommodations.

(a) (b)

Figure 11. (**a**) Aerial view of the terraced houses of Violino District (source: © BAMSphoto—Basilio) and (**b**) the two multi-family houses (photo: © Fabio Cattabiani).

4.4.2. Challenges, Issues, and Decision Strategies

The main challenges were the need for an adequate urban quality in social housing, elevated technical performances to reach sustainability and energy targets, and the rigid urban grid. Most of these challenges were highlighted in the call for tenders, and the participants were asked to submit proposals with quantifiable quality requirements. This allowed adopting a decision strategy based on a scoring system and conveying information on the conformity of each proposal to performance and quality requirements (i.e., thermal, acoustic, hygrometric insulation, daylight, energy production) as well as understanding the economic impact of these measures compared to standard social housing.

4.4.3. The Planning Process

The origin of the district dates back to 1980 with the Piano Regolatore Generale (PRG) of Brescia drawn up by Secchi, Viganò and Scarsato, and it emerged in its current configuration in 2002 when the Municipality of Brescia purchased the land and issued a tender for the development of a new social housing intervention in the southwest sector. Architects, installers, and consultants collaborated in the planning process, while the construction phase (from 2004 to 2006) was carried out by local cooperatives and construction companies. The intervention was financed with funding from the Lombardia Region and from Azienda Lombarda Edilizia Residenziale (ALER). All the spatial scales were investigated during the realization of the project.

4.4.4. Energy Concept

The entire district has been designed according to bioclimatic principles to benefit from climatic conditions. Therefore, each building is oriented to maximize daylight and passive solar gain as well as the generation of electricity through photovoltaic systems. A characteristic element is represented by the greenhouses integrated into the terraced houses and acting as solar collectors and thermal buffers. The sun rays that penetrate the windows are transformed into heat in contact with a massive surface: the heat is retained, thus counteracting the excessive temperature ranges. The terraced houses are all equipped with photovoltaic systems of 1.3 kWp mounted flat or with a 30° southwest inclination, while multi-family houses have systems ranging from 5 to 20 kWp with a 30° angle.

4.4.5. Architecture, Visibility, Sensitivity, and Quality

The integration of PV modules in the terraced houses can be described as fully coherent regarding system geometry and materiality, while they can be considered partially coherent for the modular pattern (Figure 12). Many gaps are visible between the panels, giving the overall impression of an uneven surface. Regarding the systems installed on the two multi-family houses, they cannot be considered as coherent with any of the listed aspects, since they are mounted inclined on a flat roof, using a metal structure. The area is characterized by a medium sensitivity level due to the absence of historical buildings, monuments, or meaningful elements. The close visibility of PV panels is also classifiable as medium, being the systems either installed on tilted roofs, visible from the street canyons, or on flat roofs. Concerning the remote visibility, the plain terrain of the site does not provide any vantage point from where the PV systems are visible, with the only exception represented by the top stories of the two multi-family houses.

(**a**) (**b**)

Figure 12. Architectural integration matrix for the PV systems at Violino District in Brescia (left); (**a**) system modular pattern (photo: © Fabio Cattabiani); (**b**) view from the roof of one of the multi-family houses (photo: © Fabio Cattabiani).

4.4.6. Environmental, Economic, and Social Impacts

The environmental dimension of the project resides in the bioclimatic approach utilized for the design of the entire intervention, where great attention was placed on the exploitation of solar radiation. From the economic and social point of view, the project was fully financed by public funds with the scope to provide an affordable and high-standard social housing solution. Some accommodations were reserved for specific age groups to create a more heterogeneous and diversified environment. For instance, 26 dwellings are for elderly people, while 12 are for young couples. The rationalization of local roads, with the interposition of three public pathways, provides a protected connection to the main area of the neighborhood and fosters public aggregation and socialization.

4.4.7. Approaches, Methods, and Tools

The approach adopted for designing the terraced houses aims to guarantee the "right of sun" to each residential unit. The interior distribution of spaces, reflected in the exterior composition of volumes, is based on their function. The south orientation is dedicated to the most used spaces, namely the living room on the ground floor and individual rooms at the upper level. Services such as bathrooms and vertical distribution are on the north side, while the west side is occupied by the kitchen and the master bedroom. The greenhouse, painted in dark hues to further enhance heat gains in winter, is integrated into the south facade. Colors have also played a significant role in the project, as a study has been carried out to diminish the perception of the repetitiveness of the terraced houses' typology using different shades of colors. Furthermore, this choice highlights the volumetric composition of the residential units and guarantees different perceptions during the day according to the various light conditions (Figure 13). Since 2007, the project was also subjected to a monitoring campaign to evaluate the performance of PV systems, their energy production, and the amount of electricity fed into the grid. Measurements show that the PV systems installed in housing units produce, on average, 4.54 kWh per day. Moreover, between 2014 and 2015, the Smart Domo Grid Project [58,59] was carried out by the energy company A2A S.p.A., the Politecnico di Milano, and the company Whirlpool.

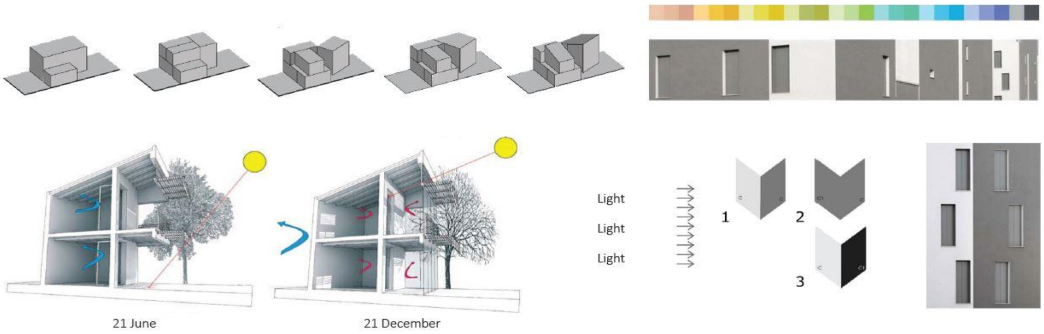


Figure 13. Volumes' composition (**top left**); section of terrace house with passive strategies (**bottom left**); color plan by Jorrit Tornquist (**right**) (source: © Boschi + Serboli Architetti Associati).

The project involved 21 families and consisted of testing a smart system to enhance energy efficiency and reduce electricity costs for the users. Using an energy management application that measures consumption and provides insight on how to minimize energy electricity costs, users could avoid overload and plan the use of appliances in the most convenient moment of the day.

4.4.8. Lesson Learned and Recommendations

The Violino District underlined the importance to work simultaneously on volume composition, internal space distribution, and technical systems to maximize the exploitation of passive strategies and achieve hygrothermal comfort conditions. The sun was used as an important bioclimatic element in the design process to determine buildings' orientation and facades' exposure. The greenhouses were used as natural temperature regulators to trap and slowly release solar heat gains, especially in winter.

4.5. CasaNova District in Bolzano

4.5.1. Overview

CasaNova is a large social housing project in Bolzano (Trentino Alto Adige). It has been developed by the municipality to provide affordable rental solutions while guaranteeing high living standards and a low ecological footprint. It is located in the southern parcel of the city, on an area of 10,000 m^2 delimited on the northern side by an existing neighborhood and the countryside, and on the southern side by the railway and the Isarco river. Groups of three to four buildings each form eight urban blocks arranged around green courtyards for a total of 950 apartments (Figure 14), which mostly comply with the highest level of CasaClima energy classification.

(**a**) (**b**)

Figure 14. (**a**) Aerial view of CasaNova district showcasing the buildings' arrangement around courtyards to form urban blocks (source: © altoadige.it); (**b**) view of the block designed by CDM Architetti Associati in the north part of the plot (photo: © Andrea Martiradonna).

4.5.2. Challenges, Issues, and Decision Strategies

Despite being the project established on a greenfield (former agricultural area), the municipality chose the lot for its position in continuity with an already urbanized area to avoid excessive decentralization. The focus was placed on creating a strong relationship between the new development and the countryside through extensive use of greenery, both at ground level and on the roofs, as well as in the design of pedestrian paths and buildings' alignments. On the other hand, several issues were encountered during the realization of the district such as the absence of a well-established connection system with the rest of the city, the presence of rural buildings within the plot, and hydrogeological risks related to the proximity to the river and the high level of the water table in the area. Furthermore, the inhabitants of the adjacent neighborhoods and the farmers firmly opposed the project due to its possible future expansion [60].

4.5.3. The Planning Process

The project started in 2001 when the Bolzano municipality acquired 10,000 m^2 of farmland and turned it into buildable land. After an architectural competition held at the European level [61], the realization of a master plan was assigned to the Dutch firm Frits Van Dongen. During the urban design phase, several workshops were carried out together with the political and technical representatives of the municipality, representatives of the owners, the neighborhood council, and other actors involved in the project. Successively, the eight lots were designed by different architectural firms after another competition organized by the Bolzano municipality. The construction phase started in 2007 and terminated in 2014 with the realization of a public space with a mix of functions in the center of the plot. Finally, a cycling path and a train station were built to improve the connectivity of the neighborhood with the rest of the city.

4.5.4. Energy Concept

Before starting the architectural urban design, the energy plan of the neighborhood was developed. It set the compliance with the highest CasaClima certification energy standard (i.e., heating index of 30 to 50 kWh/m^{2}y depending on the surface/volume ratio of each building) [62]. The energy concept included passive strategies of bioclimatic planning approach and active systems to produce electricity and DHW (Figure 15).

The compact shape of the buildings aims to maximize solar exposure and reduce overshadowing effects by placing the higher buildings in the north part of each block with sloped roofs in a unique direction. The PV and ST systems installed on most of the buildings cover almost completely the DHW need for the neighborhood. Space heating during winter and the pre-heating of the DHW is guaranteed by geothermal heat pumps and by the district heating network, which are connected to a cogeneration plant. Space cooling in summer is provided by a controlled ventilation system where the air is pre-cooled by the geothermal pumps. These solutions allow a reduction of 65% of the energy consumption compared to a traditionally built neighborhood.

4.5.5. Environmental, Economic, and Social Impacts

The environmental impact of the CasaNova district is kept low thanks to the design approach oriented toward a strong reduction in energy consumption. An example is in the construction method, which used reinforced concrete only for the main structure and in the slabs, and prefabricated elements for the external walls. The prefabricated elements allowed to cut the construction time nearly in half, and save electricity and water in situ due to the minor use of cranes and machines. Another environmental feature is the reuse of the rainwater thanks to the installation of four water tanks at the corners of each urban block. The collected water is used to irrigate the green areas at the ground and roof level and for toilets. The outdoor thermal comfort is addressed by arranging the buildings to exploit the fresh breeze in summer and act as a protection against cold drafts in winter and by the extensive presence of green spaces. To reduce the impact of traffic and to guarantee good air quality standards, only one road crosses the districts, and all parking spaces are located underground. Finally, the large offer of affordable rental solutions and the good accessibility achieved after the realization of a new train stop, bus connections, and cycling paths represent a relevant economic and social impact achievement of the project.

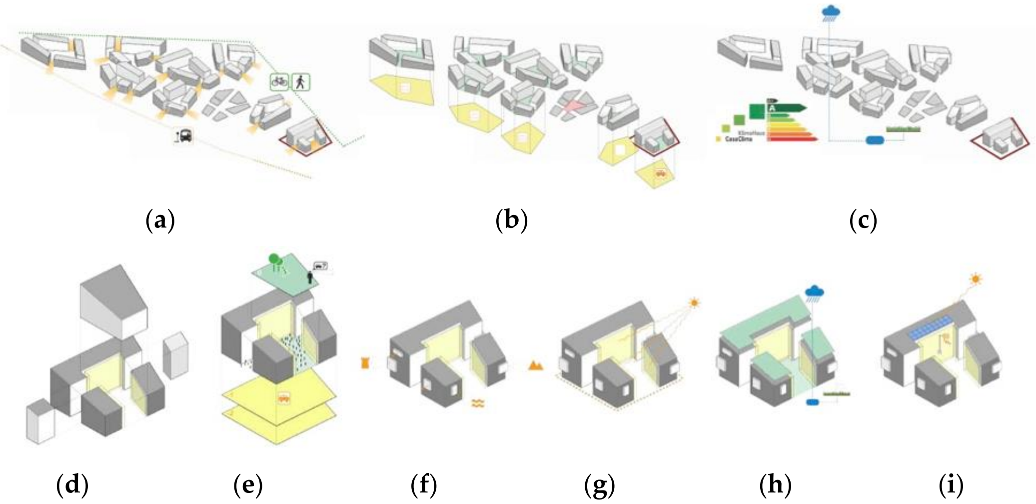


Figure 15. Design concept of CasaNova district. At the neighborhood level: (**a**) urban mobility and accessibility to the area, (**b**) social public spaces organization, (**c**) shadow cast and buildings' morphology to reach the highest energy class according to the Italian energy certificate system. At the building level: (**d**) morphology of the building block, (**e**) internal connections and social spaces, (**f**) study of the views from the building stock, (**g**) study of the solar exposure and orientation, (**h**) green roofs and water management system, and (**i**) use of RES; (Source: © Wienerbeger).

4.5.6. Approaches, Methods, and Tools

The case study aims to reduce energy consumption, maximize solar exposure, and create a permeable urban fabric able to establish a dialogue with the countryside. The architects' approach reflects these objectives in the arrangement of compact-shaped buildings around open courtyards, with taller ones located on the north side of the blocks to avoid overshadowing effects. The same attention is reserved for the composition of the single housing units, where large glazed areas are used to exploit solar heat gains and every apartment has a loggia oriented toward south or west. Finally, in 2009, Eurac Research was appointed as technical and operational support for building monitoring. A campaign was carried out to verify the energy consumption and internal comfort conditions, and to compare them to the design values. The results show that seven out of nine blocks consume more than what was calculated during the design phase. The probable causes have been identified both on technical management and user behavior [62].

4.5.7. Lessons Learned and Recommendations

The shape, orientation, and reciprocal arrangement of the buildings demonstrated how the preliminary planning allows reaching high energy and living standards. This approach contributes to the energy saving of the entire district, and it lasts for its entire lifetime. Aspects such as internal layout, choice of materials, rainwater management, use of district heating and cooling, and integration of active solar systems are considered. It is important for architects and city planners to have the right instruments to evaluate these factors since the early design phases. A continuous process of verification and optimization allows to solve technical and management problems and reach the planned energy performance. The case study shows the importance of infrastructural connections and recreative spaces: the district's attractiveness is guaranteed by a new train stop, bicycle lane, green spaces, and a multifunctional area with services.

4.6. Similarities and Differences among the Different Built Environments

Table 3 presents the similarities and differences among the built environments.

Table 3. Similarities and differences among the different built environments.

Built Env.	Similarities	Differences
Existing-Existing	Social housing projects aiming to improve the life quality of citizens and the energy performance of buildings. Active involvement of municipalities and stakeholders highlights the importance of a dialogue between public and private. Pilot studies proposing replicable solutions and developed within the context of European projects. PV systems not fully integrated into existing buildings. Provincial or Municipal regulatory frameworks to promote energy efficiency. Establishment of a monitoring phase and involvement of researchers.	SINFONIA focuses on the refurbishment of existing buildings. Photovoltaic Village includes the construction of new apartments blocks, public spaces, facilities. Different scales of intervention. SINFONIA has refurbishment projects all over the city, the realization of DH/DC grids, air quality, and smart mobility measures at city scale. In Photovoltaic Village the intervention is limited to the neighborhood scale. Different use of RES. In Bolzano PV, ST and geothermal heat pumps are used. The solar systems are installed only on buildings' roofs. In Photovoltaic Village only PV technology is adopted and the installation encompasses roofs, facades, and public areas.
New-New	Use of public tenders as an instrument to assign the design of the projects. Aim to represent the state of the art of technology in the sustainable building industry and inspire replicability. Morphologies of neighborhoods and buildings shaped to maximize use of sun. Attention in connecting the new development to the rest of the city through the realization of public paths. Use of green spaces as a unifying element for the interventions and as a way to connect it to the natural surroundings. Reduce traffic by limiting the number of roads or restricting access to vehicles. Constant dialogue between public and private stakeholders during the process.	Le Albere and Casanova use energy certification (CasaClima, LEED) to assess the sustainability level. Violino does not. Le Albere and Casanova include mixed functions within the neighborhood, while Violino has only residential buildings. Focus on social housing and affordable rental solution in Violino and Casanova. Violino and Le Albere show a higher PV integration level than Casanova. Adoption of a monitoring campaign carried out by researchers in Casanova and Violino. Le Albere was realized on a brownfield area, while the other two cases are developed on greenfield sites. Stricter urban grid limits planning freedom in Violino compared to the other two cases.

Table 3. *Cont.*

Built Env.	Similarities	Differences
New-Existing	Aim to act as inspiring and replicable projects at national/international level. Social housing constitutes a driving force for the experimentation and adoption of solar strategies at a larger scale. Municipalities play a coordinating and steering role in the projects' development. Monitoring campaign and research involvement to track energy performance. Attention to public spaces to connect the interventions with the surroundings. Use of finishing colors to address different aspects of the project (foster variety In Violino, improve daylight in SINFONIA).	Different level of active solar systems integration and quality, with new intervention generally providing better outcomes thanks to the higher morphological freedom. New areas typically result in land consumption, while acting on existing buildings' stock preserves the territory. More attention to car traffic mitigation, pedestrian-centered area, and city connectivity in new realizations compared to existing projects. Easier implementation of a mix of renewable energy sources in new projects compared to existing urban areas.

4.7. *Agrovoltaico*

4.7.1. Overview

Recent years have seen the development of solutions called "agrivoltaic" combining the dual use of food production at the ground level with electricity generation through PV modules located at an upper layer (Figure 16) [10,63]. The case study presented, the Agrivoltaico ® [64], is a patented system developed by the private company REM (Revolution Energy Maker) and tested for the first time in Pianura Padana (Emilia Romagna), a vast alluvial plain corresponding to the river Po's basin in Northern Italy. The area has a strong agricultural vocation thanks to a capillary irrigational system and a flat homogeneous morphology. These characteristics make the territory suitable for the installation of solar systems, which can however compete with the production of food.

Figure 16. View of the dual use of land with the PV track system on the upper layer and agricultural works at ground level (photo: © REM).

The solution proposed by REM exemplifies how a double use of land can be achieved. The system was built in a period of strong opposition toward the realization of utility-scale photovoltaic systems on agricultural land (Figure 17).


(**a**) (**b**)

Figure 17. (**a**) View of the PV track system during the first crop (photo: © REM); (**b**) aerial view of the solar plant in landscape (photo: © REM).

4.7.2. Challenges, Issues, and Decision Strategies

The main challenges encountered during the development of the project were related to the need to overcome the national legislation that did not allow for the installation of large PV systems (above 1 MWp) in agricultural areas [65]. This has been possible thanks to an innovative solution, where the PV modules are suspended 5 m above the ground using a metal structure. Only 2% of the land is occupied by the punctual supports holding the metal structure (in compliance with the regional regulation requiring a soil occupation for PV installation < 10%), leaving great freedom of movement to the harvest machines operating below. To balance the low density of the system compared to a standard one mounted on the ground, double-axis sun-tracking devices were used for the panels. The different configurations of the system during the day and its low density allow a minimal impact on the total radiation falling to the ground. Regarding the decision strategy used for the project, REM collaborated with several industrial partners, a university (the Institute of Agronomy, Genetics and Field crops of the Università Cattolica del Sacro Cuore of Piacenza), and local authorities to assure the design's requirements.

4.7.3. The Planning Process

The project was realized in four phases between 2010 and 2012 and addresses landscape and architectural planning scales. The scope was to overcome legislative and public acceptance barriers for the installation of PV systems in agricultural areas through an innovative solution allowing food and energy production with the regional regulation on land occupation. The private investor REM initially invested 2.5 million euros in the pilot project before replicating it in two other Italian locations for a total of 30 million euros in value including the satellite activities and nearly 700 people involved.

4.7.4. Solar Landscape

The notion of a "solar landscape" was proposed in [10], and it consists of a different approach to the design of PV systems on the ground. The focus is not anymore on the integration of the system in the landscape but rather the design of the system as a landscape. This different perspective requires shifting the focus of the PVs' planning from the sole energy performance to a new set of paradigms, which are more in line with the ecological burden that the creation of a new landscape implies. The pattern of the system (dense or porous) is determined by the spatial arrangement of the modules, the type and grain of the patch, the pattern type, and its edges (Table 4). Other important aspects are the function of the space and its connectivity. The first aspect is related to the porosity of the system that determines the amount of solar radiation reaching the ground and consequently its ecological potential. No changes in the land's function or type of cultivation were needed for Agrivoltaico due to the high porosity of the system. The second aspect depends primarily on the distance of the PV modules from the ground and if any fence or enclosures are present at the boundary of the area. The case study has a great level of connectivity with the surrounding landscape, allowing animals, people, and harvesting machines to easily cross the area. The installed nominal power is 3.2 MW, and it is composed of 11,535 polycrystalline PV modules tiltable on two axes using a wireless control.

Table 4. Formal functional features of the solar landscape for Agrivoltaico.

Patch type	Small		Large	✓
	Straight borders	✓	Convoluted borders	
Grain type	Small patches	✓	Large patches	
Pattern	Porous	✓	Dense	
Pattern type	Parallel stripes	✓	Non-parallel stripes	
Edge/borders	Continuous	✓	Discontinuous	

4.7.5. Site Potential

The site has a cultural value and requires the preservation of its features, being the product of a long human transformation of a humid area into one suitable for agriculture. Nowadays, the area is intensively exploited for the cultivation of crops thanks to the efficient network of irrigation and flat morphology. Despite the PV system suspended above the ground does not perform any other function than producing energy, the site represents an example of double use of land (i.e., agriculture/food production and energy production from PV system).

Moreover, the PV double-axis tracking system controlled by a specific algorithm allows for optimal control of the dynamic shading on the crops, aiming at optimizing agricultural production. The assessment of the sensitivity (low or high) of several selected landscape factors is visible in Table 5.

Table 5. Sensitivity of landscape factors for Agrivoltaico.

Sensitivity	**Low**	**High**
Landform	✓	
Landscape pattern and complexity	✓	
Land use		✓
Land cover		✓
Settlement and manmade influence		✓
Historic character		✓
Historic features		✓
Inter-visibility with adjacent landscape		✓
Sense of remoteness		✓
Sense of openness		✓

4.7.6. Environmental, Economic, and Social Impacts

The environmental impact of the system can be considered low, since the original use of the land is preserved and the system does not constitute a barrier in the territory. Furthermore, it is entirely made of safe, non-polluting, and recyclable materials (as the recycled aluminum that the trackers are made of) and its construction technique makes it easy to disassemble at the end of the lifecycle (25–30 years) [66]. Despite the visibility of the system changes during the day because of the tracking, no mitigation strategy was required due to the porous pattern of the modules. Finally, the collaboration established with local authorities since the early phases of the planning process helped to achieve an optimal design and raised public awareness and participation.

4.7.7. Approaches, Methods, and Tools

The company REM Tec has patented the Agrivoltaico technology worldwide. Two solutions of sun-tracking systems are currently available, having in common the length (12 m) and the height (4 to 5 m) of each tracker but differing in the system's power and the number of modules. In the first one, ten panels are installed on each tracker for a peak power spanning between 2.5 and 4.35 KW, while the second solution presents a denser configuration with 32 panels and peak power from 8.64 to 10.46 KW. Furthermore, the cooperation with the Università Cattolica del Sacro Cuore of Piacenza permitted us to understand the impact of the system on different crop species and develop optimal design solutions combining energy and food production.

4.7.8. Lesson Learned and Recommendations

The Agrivoltaico case study demonstrates that the ecological impact of large PV systems installed on the ground can be greatly reduced with the adoption of innovative solutions allowing a double use of land. Barriers posed by legislation and regulations can often be overcome through a conscious design approach and collaboration with local authorities, industrial, and scientific partners. In the final analysis, the installation of large PV systems has to be considered as a matter of landscape design, where the paradigm is shifted from the sole energy production toward a more holistic approach, taking into account the various ecological aspects of a landscape transformation.

5. Limitations of the Study

This study does not pretend to be seen as an exhaustive illustration of the status of solar energy in the Italian urban context but it rather wishes to give a satisfactory overview of it through exemplary cases selected and analyzed by experts in the field. The selection of the six case studies reflects the knowledge and available information provided by the experts during the IEA SHC Task 51 "Solar Energy in Urban Planning". The geographical distribution of the cases, all located in the northern part of Italy, can be considered as the major limitation of the study. The inclusion of projects from southern regions could have further enriched the study and investigated different climatic conditions. Furthermore, three out of six cases are located in a single region (i.e., Trentino Alto Adige), which has special administrative conditions compared to the rest of the country. More landscape PV case studies should be analyzed to provide a more complete overview of this environment as well as a critical analysis of the similarities and differences. It is also worth mentioning that IEA SHC Task 51 was terminated in 2017; therefore, potentially relevant cases realized after that year were not included in this paper. The ongoing IEA SHC Task 63 "Solar Neighborhood Planning" [67,68] will partially address this issue.

6. Conclusions

In this paper, six case studies located in the Italian territory were presented and discussed following a common template developed within Subtask C of the IEA-SHC Task 51 "*Solar Energy in Urban Planning*". The integration of solar energy in three different environments—namely existing urban areas, new urban areas, and landscape—has been investigated. General considerations can be outlined, allowing for a partial generalization of the results for the entire country or at least for the administrative territory in which the cases are located. The main lesson learned is the importance of including solar energy since the beginning of the design process to achieve a higher level of integration.

When this basic rule is not observed and a lack of communication between experts and stakeholders occurs, the risk of encountering pitfalls during the following phases exponentially increases, and only sub-optimal results can be obtained. An additional advantage of the early analysis of solar energy potential is the possibility to optimize the urban morphology and the buildings' form to maximize active and passive solar strategies. Several design aspects can be controlled in the early design phases, although they tend to crystallize rapidly as the project progress. Furthermore, an optimized design of buildings' masses is a passive measure that can have positive and long-lasting impacts. This aspect is particularly visible when dealing with existing buildings, often offering limited design solutions if not subject to deep renovation interventions. Finally, an important lesson is the need to consider solar systems beyond their electricity generation function. This is true when the integration occurs into buildings as well as with utility-scale landscape systems. A set of recommendations specific for the three different analyzed environments can be summarized as follows.

I. *Existing urban areas (refurbishment):*
    - Deep renovation processes involving morphological and material changes represent potential successful solutions for solar systems integration as demonstrated by the case studies SINFONIA Bolzano and Photovoltaic Village in Alessandria.
    - The use of solar systems in public areas (e.g., shading devices on pergola as in the Photovoltaic Village in Alessandria) has a high unexploited potential.
    - The institution of coordinating bodies and the adoption of an integrated design process can have a significant role in the application of energy-related measures while improving interdisciplinarity and collaboration among stakeholders as happened in both SINFONIA Bolzano and Photovoltaic Village in Alessandria.
    - It is important to use simulation software since the early-design phases and to focus on final-user behavior as in SINFONIA Bolzano.

II. *New urban areas:*
    - Photovoltaics can be utilized as a distinctive architectural element and material, which can enforce the identity and aesthetic of urban interventions as in the case studies of the Le Albere district, Violino District in Brescia, and CasaNova.
    - The shape, orientation, reciprocal arrangement of volumes, materials, internal layout, and opening distribution are long-term passive strategies that can maximize the contribution of solar energy to building efficiency and comfort, as visible in the case studies of the Violino District in Brescia and CasaNova in Bolzano.
    - The last two points listed in the existing urban areas are also applied for new urban areas as demonstrated in all the presented case studies such as Le Albere district, Violino District in Brescia, and CasaNova.

III. *Landscape*
    - The ecological impact of ground-mounted PV can be greatly reduced using innovative solutions that combine a dual use of land.
    - Barriers represented by regulations and legislation can be often overcome with a conscious design and an early collaboration between the different involved actors.
    - PV installation at the ground level should be considered as a landscape design matter, where the pattern, patch, grain, and borders of the system are carefully planned.

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