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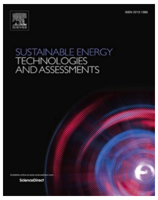

Original article

Social acceptance of photovoltaic systems in heritage buildings and landscapes: Exploring barriers, benefits, drivers, and challenges for technical stakeholders in northern Italy

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ABSTRACT

This study investigates the factors influencing the social acceptance of photovoltaic (PV) systems in heritage contexts. It aims to identify barriers, potentials, drivers, and challenges for the widespread adoption of PV technology while considering heritage conservation, land preservation, energy production, and climate mitigation. The research focuses on Italian technical stakeholders in the construction sector, including Heritage and Public Authorities, designers, and energy consultants. The survey delves into their opinions and perceptions of PV technologies, emphasizing both building and urban integration, as well as landscape integration. Noteworthy aspects of this study include its originality in addressing PV integration on heritage buildings and landscapes, the specific targeting of technical groups, interdisciplinary collaboration, and the timing of data collection during the Covid-19 pandemic and pre-energy crisis period for potential comparisons. The study finds that in heritage contexts, the acceptance of PV systems is driven by economic and aesthetic benefits. Respondents value the enhancement of historical buildings and landscapes, as well as discreet PV integration. For historic buildings, benefits include reuse of old buildings, pleasure aesthetics of innovative PV, and cost reduction for energy use. For protected landscapes, benefits include security of abandoned areas, unobtrusive PV integration, and production of renewable energy. Cultural concerns, particularly the risk of impacting historical and natural identities, are the main barriers to acceptance. Lack of knowledge about PV technology is not a significant issue. These findings emphasize the need to address cultural and aesthetic considerations when promoting PV integration in heritage settings.

Introduction

Renewable Energy Sources (RES) play an important role in achieving sustainability and energy transition goals, as they can significantly contribute to reducing electrical and thermal energy requirements in the construction sector [1]. At the international level, several policies have been established to reduce greenhouse gas (GHG) emissions through the application of RES. Indeed, the United Nations' Sustainable Development Goals (SDGs) emphasize sustainable development, with specific attention to RES for climate action [2]. The application of RES in both new and existing buildings is strongly supported also by the European regulatory framework, which has introduced a series of policies and targets for increasing RES share and improving the energy performance of buildings, while also reducing carbon dioxide (CO_2) emissions [1,3,4,5]. Moreover, European legislation has introduced the concept of "*prosumers*" [4], which refers to end consumers generating energy from RES and being compensated for the electricity they supply to the power grid. This concept promotes the self-generation of RES and supports the decentralization of energy production, greatly facilitating the dissemination of photovoltaic (PV) systems. Within RES, PV technologies are particularly promising in facilitating the energy transition towards low-carbon and clean energy systems, thanks to their on-site energy production and easily integration into existing roofs and façades [6,7]. PV systems have the potential to redefine architectural and urban design approaches, owing to their innovative application in module design and integration in both new and retrofitted buildings, urban areas, energy communities, and landscapes. The benefits acknowledged in the literature for this technology are notably associated with energy savings, climate change mitigation [14], electricity's prices reduction [15], and economic growth [16]. Furthermore, advancements in panel aesthetics foster a seamless blend of visual appeal, technological progress, and efficient energy production. These systems offer several advantages, including innovative architectural design [17,18], aesthetical appeal [7,8,13,19,20,24], multi-functionality [10,21,25,26], flexibility [25,26,22], and easy installation [17,23].

Despite these advantages, the application of PV systems remains controversial in buildings, cities, and landscapes. These concepts are related also to social preference that refers to the collective inclination

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or bias of a community towards the PV systems, based on perceived benefits, cultural inclinations, or societal priorities [27]. Social preference can be divided in social acceptability and social acceptance. While these terms might appear similar, they represent distinct aspects of the societal response to technology integration. Social acceptability pertains to the initial mental representations or preconceived ideas held by individuals or communities regarding the adoption of the PV technology [27,28]. It involves the perceived desirability or suitability of the technology, often based on factors such as cultural beliefs, aesthetic considerations, or prevailing attitudes. In contrast, social acceptance is a practical evaluation that arises following direct exposure to the PV technology. It involves the assessment of the actual performance, benefits, and drawbacks, considering real-world experiences and observations [27,28]. Social acceptance can be influenced by various factors, including the technology's reliability, cost-effectiveness, convenience, and overall impact on the community and the environment.

The assessment of the technological acceptance of PV has enabled the identification of several barriers to PV implementation by the international literature. The main barriers encompass: (i) human resource; (ii) information; (iii) economy; (iv) policy, and (v) technical aspects. Human resource barriers involve a lack of confidence in the technology, such as a shortage of technical experts and marketing professionals, as well as deficient design and management skills (e.g., proficiency in planning, commissioning, operation, and maintenance of PV projects) [27,29]. Information barriers refer to the lack of knowledge about PV systems and inadequate training [27,29]. Economic barriers are related to the perceived higher cost of solar electricity compared to traditional electricity [30,31,32]. Also, they are related to the large initial investment [27,31], the long payback period [20], the absence of financial incentives [27], and the high installation costs compared to other technologies, such as the electrical energy grid [19,27]. Policy barriers involve the complexity of legislative frameworks [27], decision-making and authorization processes [33,34], which appear lengthy, intricate, and challenging to grasp for a non-expert audience. Similarly, the low priority given to PV systems in international policies as problematic due to the absence of funding or measures that would encourage or mandate their use [35]. On the contrary, the political debate is characterized by two opposing factions: those in favor of their installation as a source of renewable energy and clean power, and those against it as it alters the image of a building, urban environment, or landscape. Finally, technical barriers are associated with performance efficiency, design and installation, and maintenance processes [6]. In particular, the energy performance of innovative panels (e.g., thin films, colored PV, etc.) appears to be lower compared to that of conventional panels, which are also trusted to be more durable. Other concerns are related to the high specialization required for the design, installation, and maintenance of the panels, especially when integrated into the building. These factors discourage their practical implementation especially in already constructed contexts.

The social diffidence on PV technologies is more evident in protected buildings [36], towns [37], and landscapes [13,37,38] due to the presence of heritage and natural values. Many studies have been conducted in this field. On the one hand, the high technological development of PV systems is extensively demonstrated by several European research projects dedicated to their application in cultural heritage [36,39,40,41]. The contents of these research projects range from the creation of guidelines for the application of PV in specific contexts, such as historic buildings, protected landscapes, and architectural sites [42,43,44,45,46,47,48,49], to the analysis of solar potential [50,51,52,53], energy efficiency [43,44,46,47,49], and the aesthetic value of this technology [50,51]. The projects also encompass the implementation of low-impact solutions on the landscape and the development of culturally acceptable models for the large-scale application of photovoltaic systems [54,55,56,57,58]. Additionally, European guidelines are favourable towards installing PV systems in these areas [40]. The criteria for their successful integration involve a delicate balance between energy efficiency and architectural conservation [7,40,59]. Aspects such as the visual impact of the PV panels, architectural compatibility, and reversibility, tailored design are essential considerations [60,61,62,63,64]. Moreover, the implementation of PV systems must respect the historical significance of the site while contributing to its sustainable energy goals [7,39,40,59,65]. Additionally, the selection of appropriate technologies needs to be aligned with the unique characteristics of buildings, and landscapes [66]. Fortunately, the current state of PV technology on the market offers a wide variety of options that can facilitate successful PV integration. PV modules today come in a diverse range of colours, shapes, dimensions, finishes, and mechanical and electrical features, allowing for high customization potential and versatile application possibilities [67,68]. However, despite these technological advancements, the widespread integration of photovoltaic systems in built environments remains a complex and multifaceted challenge due to local resistance or discontent [41], as well as complexities in policies and authorization processes [67]. This complexity is primarily attributed to the presence of conservative attitudes and deeply ingrained perceptions that prioritize the preservation of the aesthetic and historical integrity of architectural structures. Moreover, the preservation of cultural heritage has been a central concern, leading to a cautious approach to the implementation of new technologies in historical and protected settings.

Hence, it becomes crucial to understand the barriers and potentialities of photovoltaic application in heritage contexts. So far, surveys on this theme have only been carried out within the scope of two projects. First, the European Research Project "PVACCEPT" in 2001 analysed PV acceptance in protected buildings located in tourist areas of two regions (Liguria in Italy and Rügen, Mecklenburg-Vorpommern in Germany) [24], aiming to understand relevant factors, correlations, and impacts [69]. PV acceptance was relatively high in both countries, but the situation was more challenging in Italy due to the high number of heritage buildings and areas. The cost and aesthetic appeal (e.g., *ad hoc* design based on proper colours, materials, and scales) of PV modules were identified as the most critical factors for promoting their application. Another barrier was the restriction of licensing practices by Heritage and Public Authorities. On the other hand, the creation of soft tourism and the multiplier economic effects were perceived as advantages. Subsequently, many international research efforts focused on integrated PV systems and high-quality design standards of solar architecture [19,42], considering historic buildings [24,50,43–50], towns [51–55], and protected landscapes [56–58]. Aesthetical acceptance [24,50], and the impact on heritage preservation [50,47,48] were identified as the most crucial barriers to their diffusion in these contexts. A second survey was conducted in 2010 within the International Energy Agency (IEA) Solar Heating and Cooling (SHC) "*Solar Energy and Architecture*" [19] to understand barriers for PV integration in new and existing buildings [65]. Lack of technical knowledge, economic issues, visual appearance, and reduced interest in clients emerged as the most significant barriers hindering their applications at an international level. In contrast, economic incentives, cost reductions, and product availability were identified as the main advantages for promoting their use. Summarizing, several gaps in the existing literature on social acceptance of PV systems in heritage contexts become apparent:

- Lack of recent surveys on this topic.
- Overlook of the recent advancements in PV technology.
- Lack on survey on PV systems integrated into protected landscapes.

The previous surveys appear to be outdated, failing to account for the remarkable progress made in PV technology. In particular, they have overlooked the recent architectural advancements and aesthetic appeal of the latest PV panels and integrated solutions [66]. The emergence of diverse crystalline silicon modules, coloured solar cells, thin films, and highly detailed PV designs with customizable colours and textures has yet to be examined thoroughly within this context [7,40]. The oversight of these innovative developments represents a notable gap in the existing research. Similarly, no surveys have been conducted on PV systems integrated into protected landscapes. The absence of surveys focusing on PV integration within protected landscapes is a significant limitation. Understanding public perceptions and attitudes toward PV systems is critical for guiding energy generation practices and fostering public confidence in sustainable energy sources [6,29]. Neglecting this aspect could potentially lead to haphazard development that undermines the integrity of historical structures and natural landscapes. It is essential to ascertain how various stakeholders, including designers, heritage experts, and public authorities, perceive the integration of PV systems, both traditional and state-of-the-art, in heritage environments [34]. Such insights are crucial for formulating effective policies, training programs, and capacity-building initiatives to reconcile the apparent conflict between preserving heritage sites and promoting sustainable energy practices. To respond to the above gap of knowledge, the present study aims to investigate the social acceptance of PV systems within both protected buildings and landscapes, identifying the factors that play an important role. The empirical social research aims to find barriers, potentials, drivers, and challenges to favour their diffusion and market penetration, while also balancing heritage conservation, land preservation, energy production, and climate mitigation. The study aims to identify similarities and differences between different target groups and territories.

Materials and method

The study is structured as an empirical survey aimed at comprehending the social acceptance of PV systems in protected contexts among professionals in the construction sector (e.g., Heritage and Public Authorities, designers, and energy consultants). Prioritizing the investigation of social acceptance over social acceptability within scientific contexts is vital, primarily owing to its direct association with the practical assessment of the technology, revealing insights into its real-world applications, benefits, and limitations. This approach yields a more comprehensive understanding of the ways in which technicians engage with PV systems, unraveling intricate social dynamics and aiding in the development of effective strategies for sustainable PV integration.

To this purpose, the study is structured in the following sections:

Survey design (Section 3), identifying the types of protected heritage relevant to this study (Section 3.1), the potential applications of PV systems in protected contexts (Section 3.2), the analysis territory (Section 3.3), and the questionnaire design (Section 3.4).

Survey implementation and participants (Section 4), divided into survey implementation (Section 4.1), questionnaire distribution (Section 4.2), data analysis and validation (Section 4.3).

Results of the survey (Section 5), classified into socio-demographic characteristics (Section 5.1), knowledge and experience with integrated PV (Section 5.2), perception and acceptance of PV systems in historic and traditional buildings (Section 5.3), perception and acceptance of PV systems in protected landscapes (5.4), keywords to identify the PV systems integrated in heritage contexts (5.5).

Discussion of the results (Section 6), including their implications and significance.

Each of these sections is described in detail below.

Survey design

The design of the survey is structured in the following steps:

- Identification of the types of protected heritage relevant to this study that focuses on architectural works and protected landscapes (Section 3.1).
- Identification of the potential applications of PV systems in protected contexts (Section 3.2).
- Delimitation of the analysis territory that explains the reasons for the selection of the study area (Section 3.3).
- Questionnaire design that describes the structure and the motivation of the questionnaire (Section 3.4).

Each step is detailed below.

Identification of the types of protected heritage relevant to this study

Cultural heritage has a «(…) *universal value from the point of view of history, art or science*» [70], and can be categorized into tangible and intangible artifacts [71]. Tangible artifacts encompass movable items (e.g., documents, manuscripts, paintings, sculptures, and collections), immovable structures (e.g., architectural works, monuments, and archaeological sites), and underwater physical objects (e.g., underwater ruins and cities) [72]. On the other hand, intangible heritage includes meanings, expressions, traditions, and associated spaces and objects [73].

This study specifically focuses on tangible artifacts, considering their entire connotations as:

"*Monuments*" (e.g., historic buildings).

"*Groups of buildings*" with similar values linked to their architecture, homogeneity, or place in the landscape (e.g., historic towns).

"*Sites*" where works of nature and man are combined (e.g., protected landscapes) [70].

The first two categories pertain to "*architectural works*", which may or may not be protected by law. In the case of heritage-protected buildings or towns (also referred to as heritage, listed, or historic), they possess outstanding value [70], and an influential role in history [74]. They are characterized by three attributes [74]: (i) sufficient age (according to European legislation, equal to or more than 50–70 years); (ii) a relatively high degree of physical integrity; and (iii) historical significance that defines their importance for collective memories [73]. Examples include churches, old palaces, castles, listed buildings, and monuments. On the other hand, heritage non-protected buildings or towns (also known as traditional, vernacular, or historical) represent local identity using traditional materials, resources, knowledge, and skills [75], without having a universally recognized value. Examples encompass rural constructions, vernacular buildings, and historical towns. The responsibility to preserve both historic and historical buildings for future generations is universally acknowledged [76].

The category "*sites*" refers to landscapes with heritage and natural values, such as strict nature reserve, archaeological sites, national parks, wilderness areas, protected seascapes, natural monuments, and features. For the European Convention on Landscape, "*landscape*" is defined as «(…) *a certain part of the territory, as perceived by the populations, whose character is the result of the action of natural and/or human factors and their interrelations*» [77, art.1].

Identification of the potential applications of PV systems in protected context

Photovoltaic technology can be integrated into the heritage-built environment and landscapes through various methods. Numerous online platforms and databases [78,79,80] showcase examples of realized PV installations on building roofs, facades, shading devices, etc., as well as on structures like acoustic barriers, bridge railings, parking canopies, etc., and on landscape elements such as cycle paths, agricultural fields, etc. (Fig. 1).

Different approaches are employed for PV applications, and existing case studies demonstrate varying levels of PV integration. These levels can be viewed from different perspectives:

- Technological point of view: PV modules can either substitute building components like roof tiles, facade cladding elements,

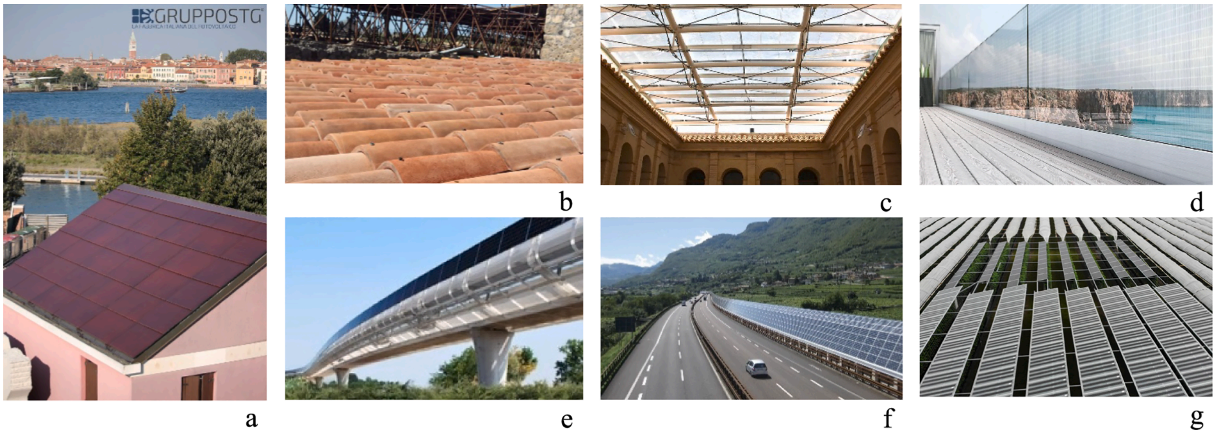

Fig. 1. Examples of PV installations: (a) hidden PV modules on roof at La Certosa Island, Venice (Source © GruppoSTG); (b) PV rooftiles at Archaeological Park of Pompeii, Naples (Source © Dyaqua); (c) PV skylight at Alzira Town Hall, Valencia (Source: © Onyx Solar); (d) PV balustrade at Torre Bassano Hotel, Naples (Source © Onyx Solar); (e) PV balustrade on Bologna People Mover infrastructure; (f) PV acoustic barrier on A22 Highway Isera (Source © Eurac Research); (g) Agrivoltaic application (Source © Bisol).

glazing surfaces, etc., as discussed in the literature [9–12]), or be installed separately from the building's original design [81,82].

- Energy point of view: PV systems interact with the building's energy systems and devices, optimizing energy usage and efficiency, or they can function independently [81,83].
- Aesthetic point of view: The visual harmony of PV modules with the overall image of the building, its structure, or the surrounding context is crucial, especially in cultural heritage contexts, to achieve social acceptance. Careful consideration should be given to integrating PV modules in a manner that respects distinctive and traditional features, materials, colours, patterns, and textures of the heritage site. PV modules need to be integrated with care of the surrounding visual appearance, respecting distinctive and traditional features, materials, colours, patterns, and textures.

In this study, PV applications are categorized as "*integrated*" or "*attached*" based on whether they meet the cultural and aesthetic requirements of the installation context. Integration involves ensuring that PV modules blend in seamlessly with the surrounding architecture and preserve the visual integrity of the cultural heritage site.

Delimitation of the analysis territory

The survey is focused on the Italian territory for various reasons: (i) Italy has the highest number of UNESCO sites; (ii) previous studies have shown a low willingness of Italian people to accept PV systems due to the large number of protected sites [69]; and (iii) the Italian legislative framework strictly emphasizes conservation policies related to the integration of renewable energy sources (RES) to protect the national natural and heritage patrimony. Additionally, to better understand the results in relation to national and local legislations and policies, the survey is focused on the cross-border area between Lombardy and Trentino-Alto Adige Regions (Fig. 2). This territory shares substantial similarities in terms of heritage values, building features, and natural landscapes but also has significant legislative and energy differences. The area comprises high-altitude mountains (e.g., Alps and Dolomites), hillsides (e.g., Franciacorta), lakes (e.g., Como Lake, Maggiore Lake, and Garda Lake), National Parks (e.g., Stelvio and Adamello National Parks), rivers (e.g., Po and Adige rivers), plains (e.g., Pianura Padana), trails, and mule tracks. It includes a large city (Milano), medium-sized heritage cities (e.g., Como, Bergamo, Brescia, Mantova, Trento, and Bolzano), and numerous monumental towns (e.g., Sabbioneta, Bressanone, Merano, Rovereto). The Lombardy Region's territory is heterogeneous, with approximately 58 % under landscape protection and 22 % included in a National or Regional Park or Natural Reserve. The Natura 2000 network sites cover 16 % of the territory, and there are 11 UNESCO sites (e.g., Castelseprio, Sabbioneta, Como, Bergamo). Many historical buildings in these areas have reduced energy performance [36] requiring a deep energy retrofit that considers RES integration due to national and local legislative constraints. These shared natural and heritage characteristics

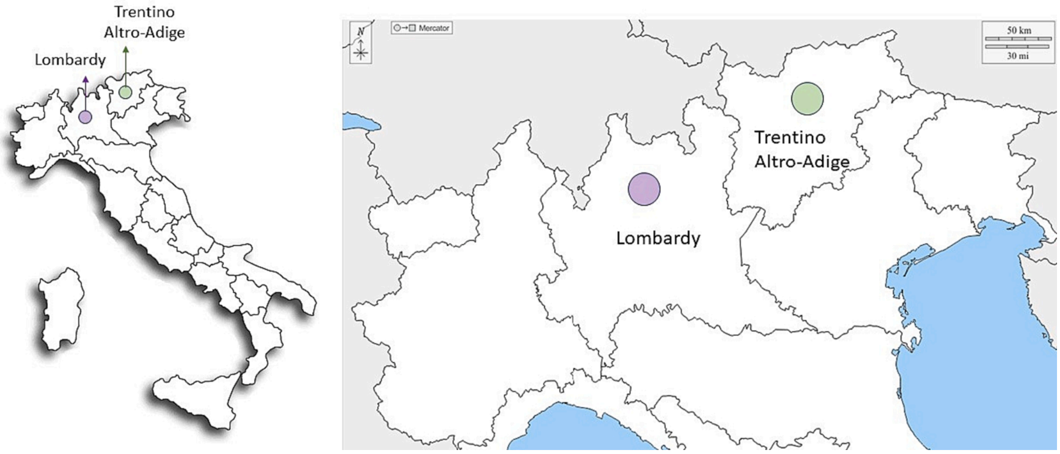

Fig. 2. The territory analysed (Source: Elaboration of the Authors).

pose common challenges for the integration of PV on architectures and landscapes. However, the territories also have significant differences in autonomy, legislative frameworks [67], population types, and economic assets. Lombardy Region, like 14 other Italian Regions, operates under an "*ordinary statute*" that implements national-level instruments, while legislative powers are limited to concurrent legislation (art. 117 Constitution). In contrast, Trentino-Alto Adige Region, similar to 4 other Italian Regions, is an autonomous region with a special statute granting higher legislative, administrative, and financial powers. It is divided into two Autonomous Provinces of Bolzano and Trento, each having legislative autonomy compared to other Italian regions. Their legislation is determined by the provincial assembly and formally adopted by the central government after bilateral relations and binding consultations. This difference also reflects in financial guarantees, as Lombardy Region (and all the Ordinary Italian Regions) is completely dependent on State economic transfers, while funds for Trentino and Alto Adige are guaranteed in their Autonomous Statutes, reaching 90 % of the revenue raised in the provinces. Additionally, the municipal regulatory framework is decided by the State for Lombardy Region and by the Provinces for Trentino and Alto Adige. Another significant difference is the population size: Lombardy is the most populated region with over 10 million inhabitants (with a stable trend in recent years), while Trentino has 540,000 inhabitants (with a negative trend) and Alto-Adige 520,000 (with a positive trend). In all cases, the population is concentrated in cities, as well as in plains and foothill areas. Moreover, both territories have different distributions of PV capacity (15.8 % for Lombardy, 0.90 % for Bolzano, and 1.90 % for Trento) [84]. Therefore, the presence of natural and heritage similarities, as well as legislative, political, economic, demographic, and RES differences, could promote a comprehensive understanding of the perception of PV across these territories.

The methodology employed in this study is designed to be replicable in other territories, primarily due to the survey technique utilized and the broad range of questions included. As a result, the survey's findings could offer valuable implications and insights for supporting and promoting the adoption of PV policies in the analysed regions. Furthermore, these findings may also prove beneficial for other Italian regions and European countries that share similar heritage cultures, legislative frameworks, government policies, and socioeconomic conditions. By understanding the key gaps and challenges in supporting PV policies, providing information, and offering training opportunities, this study can contribute to facilitating the much-needed energy transition that is becoming increasingly urgent.

Questionnaire design

A questionnaire was developed to gather information about the social acceptance of PV systems in heritage buildings and protected landscapes. For this purpose, a collaborative effort between three different research areas - heritage preservation, photovoltaic technology, and statistics - was undertaken to address all relevant disciplinary aspects. The questionnaire design was based on a thorough literature review on the social acceptance and acceptability of renewable energy sources (RES) and PV systems in buildings and landscapes across various international countries (sections 1 and 3 of the study). A content validation of the questionnaire was performed with the aim of testing reliability and validity. To this purpose, a pilot phase was conducted involving a small group of interdisciplinary researchers, including experts in PV systems, heritage conservation, building physics, and economics. The completely designed questionnaire was sent to these respondents without providing adequate information for the reviewers to provide proper feedback. This allowed us to verify whether the data was comprehensible and the responses coherent. The pilot phase aimed to test the fluidity and effectiveness of the questionnaire, ensuring that the questions were clear and comprehensible and minimizing the risk of respondents abandoning the interview. Valuable suggestions were received during this pilot phase, particularly regarding the inclusion of images and clear definitions for both PV and heritage terminologies. Based on this feedback, necessary modifications were made to enhance the respondents' understanding of the survey. Following the pilot phase, the final version of the questionnaire was prepared and translated into Italian for online administration. The questionnaire comprised 14 multiple-choice questions organized into six sections, covering various aspects related to the social acceptance of PV systems in heritage context:

Introduction to cultural heritage and PV.

Part 1: Socio-demographic characteristics of the respondents.

Part 2: Knowledge and experience on integrated PV systems.

Part 3: Perception and acceptance of PV systems in historic and traditional buildings.

Part 4: Perception and acceptance of PV systems in protected landscapes.

Part 5: Keywords to identify how PV systems integrated in heritage buildings and protected landscapes are perceived.

The introduction section of the questionnaire included definitions for various terms, such as cultural heritage, historic buildings, historic towns, protected landscape, PV (photovoltaic), BIPV (building-integrated photovoltaic), and BAPV (building-applied photovoltaic). It also explained the functioning principles of PV systems and showcased different possible integration solutions through pictures for visualization.

Part 1 of the questionnaire focused on gathering socio-demographic characteristics of the respondents, such as their origin, age, and profession, with the aim of profiling the individuals involved and understanding potential connections between PV perception and socio-demographic aspects.

Part 2 asked the participants about their experiences with PV systems to gain an overview of their knowledge about technologies, case studies, and applications in the field [24].

Part 3 consisted of three questions related to the acceptance of PV systems on historic buildings, while also investigating the reasons for acceptance or non-acceptance. Possible responses were defined based on a thorough literature review on PV integration in cultural heritage and PV acceptance in the built environment. The potential benefits mentioned in the literature included energy savings [14], reduction of cost for electricity [15,16], enhancement of building conservation [36,39,59], economic [85], environmental [40], and functional improvements [39,59]. Otherwise, barriers were: human resource [27,29], information [27,29], economic costs [30,31,32,86], financial aids [27,29,33,34], regulatory framework [27,33,34], technological maturity [6], and PV visibility [50].

Part 4 addressed PV acceptance in protected landscapes and had the same structure and questions as Part 3, aiming to collect comparable data.

Finally, Part 5 asked participants to select from a list of different keywords to identify PV integration in these contexts. It employed a dichotomous version of the semantic differential scale to gather information on people's emotional attitudes towards the topic of interest in a reliable manner. A detailed description of the questionnaire is reported below (Table 1).

Participants were asked to respond to the questionnaire anonymously instead of confidentially to promote more honest self-disclosure.

Survey implementation and participants

The implementation of the survey and the distribution to the participant are structured in the following steps:

- Survey implementation that outlines the methodology for the selection and the contacts of the candidates (Section 4.1).
- Questionnaire distribution that describes the method used for distributing the survey to the participants (Section 4.2).

Table 1
Content of the survey (Source: Authors' elaboration).

Parts	Questions	Possible replies
Part 1: socio-demographic characteristics	1. Provenience	Open question
	2. Age	a. < 20 years b. 20–40 years c. 41–60 years d. > 60 years
	3. Profession	Open question
Part 2: knowledge and experience with integrated PV	4. Did you know what integrated PV means before reading the introduction?	a. Yes b. No
	5. Have you ever seen examples of integrated PV?	a. Yes b. No
	6. Where did you see them?	a. Internet sites b. Television c. Newspapers d. Fairs e. Real examples f. Manufacturers and/or resellers g. Conferences and/or public events h. Other (specify)
Part 3: perception and acceptance of PV systems in historic and traditional buildings	7. Would you agree to add a PV system to a historic building?	a. Yes b. Depends c. No d. I don't know / I don't answer
	8. Would you agree to integrate a PV system in a historic building?	a. Yes b. Depends c. No d. I don't know / I don't answer
	9. If you replied "yes" or "depends", what aspects make it acceptable for you to integrate PV in a historic building?	a. The technology is not noticeable compared to the building b. Saves on energy usage costs c. Renewable energy produced is higher than the energy used in the life cycle of PV systems d. The economic return on investment is guaranteed in 25 years e. Allows you to redevelop and use a place otherwise in disuse or not comfortable f. It allows you to increase the economic value of the property g. I don't know / I don't answer h. Other (specify)
	10. If you replied "no", why?	a. I don't care b. I don't think it's suitable from the aesthetical point of view c. It ruins the building's historical identity d. I have little confidence in how this technology works e. It requires more maintenance than a traditional component of the building (e.g., plaster, solar shielding, …) f. It has high costs and not economically justifiable g. I am not aware of incentives and funding that can reduce the cost of implementing h. It requires a long and complex procedural and permit process i. There are other energy redevelopment interventions to prioritise k. I have little knowledge about this technology l. I don't know / I don't answer m. Other (specify)
Part 4: perception and acceptance of PV systems in protected landscapes	11. Would you agree to integrate a PV system in a protected landscape?	a. Yes b. Depends c. No d. I don't know / I don't answer
	12. If you replied "yes" or "depends", what aspects make it acceptable for you to integrate PV in a protected landscape?	a. The technology is not noticeable in the landscape b. Renewable energy produced is higher than the energy used in the life cycle of the photovoltaic system c. The economic return on investment is guaranteed in 25 years d. It allows you to enjoy previously unsafe and disused places and spaces e. I don't know / I don't answer f. Other (specify)
	13. If you replied "no", why?	a. I don't care b. I don't think it's suitable from the aesthetical point of view c. It ruins the landscape's historical and natural identity d. I have little confidence in how this technology works e. It requires more maintenance than a traditional system f. It has high costs and not economically justifiable g. Long and complex procedural and permit process h. There are other maintenance or security interventions to prioritise i. I have little knowledge about this technology k. I don't know / I don't answer l. Other (specify)
Part 5: keywords for identify the integrated PV systems	14. Choose a word for each proposed couple that makes you think of photovoltaics integrated into historic buildings and protected landscapes	Good - Bad Beautiful - Ugly Weak – Strong Rigid - Flexible Shy - Exuberant Useful - Useless Pleasant – Unpleasant Contemporary style - Old style Aggressive - Pacific Cheap - Expensive Bright - Dark Hot - Cold

- Data analysis and validation that explicates the statistical analyses conducted (Section 4.3).

Each step is detailed below.

Survey implementation

The survey implementation included three interaction phases with the potential participants:

- Step 1: mapping and selection of the strategic candidates at local level.
- Step 2: personal phone calls, face-to-face and virtual meetings to inform people on the topic, the structure, and the finality of the questionnaire for boosting their willingness to participate.
- Step 3: personal e-mails and letters to share the link to the questionnaire and to check demographic shares for trying to achieve representative data at local level.

The selection of candidates was carried out using a map of the main stakeholders in the area. A total of 152 local stakeholders were identified, including individuals from companies, administration, authorities, universities, and professional bodies. From this group, individuals from the Public Administration, Heritage Authorities, and Professional Bodies were selected and invited to participate in three separate working tables, one for Heritage Authorities, one for Public Administration, and one for Technical Designers. During these working tables, participants were informed about the questionnaire and were requested to distribute it to all their members or inscriptions.

Due to the Covid-19 pandemic and the associated lockdowns, conducting in-person data collection was not feasible. Therefore, three different online methods were considered for distributing the questionnaire: (i) the Computer-Assisted Personal Interviewing (CAPI) where the interviewer uses his laptop screen to read the questions and to collect the answers; (ii) the Computer-Assisted Telephones Interviewing (CATI) where the interviewer asks the questions by telephone and records the responses on a computer; and (iii) Computer Aided Web Interviewing (CAWI) where the questionnaire appears in a browser as a web-page, the respondents are free to reply question by question, and the answers get immediately to the server to be tracked continuously. Considering factors like time, costs, and the technical proficiency of the target population (mainly composed of architects, engineers, surveyors, and designers who regularly use the internet and digital tools), the CAWI method was deemed the most suitable. This method offered advantages such as low costs, real-time access to data, design flexibility, absence of geographical constraints, skews due to input errors, adequate time to reply and the ability to include images and photos. Additionally, Otherwise, traditional problems related to the representative targets (e.g., low participation of senior citizens, and high contribution of young people, net surfers, and working population) were overcome thanks to the high access to internet for professionals. Thus, the population target reached by the CAWI was enough representative for this survey.

Questionnaire distribution

The questionnaire was distributed through CAWI technique during the period July 2020-July 2022. Opinio 7 software (Copyright 1998–2018 ObjectPlanet) was employed to set up and administrate the online survey. The function for IP-address check in Opinio was deactivated to ensure privacy protection requested by the GDPR.

The questionnaire was sent personally by e-mail to all the 24 local entities that represents local designers (Architects, Engineers, and Surveyors Chambers), Heritage Authorities, Public Authorities through the National Association of Municipalities, energy consultant (energy agencies, and trade associations). In total, 271 completed questionnaires were collected. No partially completed questionnaires were received, as the system required respondents to provide complete answers to all the questions.

Data analysis and validation

Statistical analysis was conducted using IBM SPSS Statistics for Windows version 26.0 statistical software (IBM Corp, Armonk, NY). Since the sample was a nonprobability sample, the data analysis was confined to descriptive and explorative aspects. Incomplete questionnaires and questions with inadequate response rates were excluded from the analysis to ensure data consistency. For instance, an item concerning the significance of different interventions for enhancing the energy efficiency of buildings exhibited poor comprehension and response inconsistency. Hence, it was excluded to safeguard result accuracy. Subsequently, respondents were segmented into homogeneous subgroups to facilitate targeted comparisons. Prior to inputting the survey data into electronic files, data coding was undertaken. This step involved the conversion of nominal and ordinal scale data from diverse response categories. Absolute and relative frequencies were calculated to explore distributions of categorical variables. To visualise the results appropriate plots were chosen. Additionally, to evaluate the existence of associations between two categorical variables, the Chi-square Test For Independence was applied with significance level 0.05. The analysis of the sociodemographic profile of respondents focused on the aspects related to the specific objective of the paper.

Results of the survey

The results of the survey are categorized in the following parts:

- Socio-demographic characteristics (Section 5.1).
- Knowledge and experience with integrated PV (Section 5.2).
- Perception and acceptance of PV systems in historic and traditional buildings (Section 5.3).
- Perception and acceptance of PV systems in protected landscapes (5.4).
- Keywords to identify the PV systems integrated in heritage contexts (5.5)

Following the main findings of the survey are explained in detail.

Socio-demographic characteristics

This section aims to profile the characteristics of the survey respondents. The majority of the respondents are from Lombardy Region, with a smaller representation from Trentino-Alto Adige Provinces. Additionally, respondents from other territories include energy consultants from the Energy Agency of the Province of Bolzano (Casaclima Agency), who operate in the local territory but come from other regions in Italy, such as Veneto, Friuli Venezia Giulia, Emilia-Romagna, and Tuscany. The respondents' age group is predominantly between 41 and 60 years old, accounting for 55.7 % of the total. As for their profession category, the respondents are divided into architects, architectural engineers, and technicians (surveyors and building consultants). This division is based on the different fields of action outlined in the Italian legislation on cultural heritage. Specifically, only architects are allowed to work on restoration and conservation activities, while engineers can be involved in tasks related to structural consolidation, direction of structural works, HVAC, and electrical design project [87], and technicians are responsible for safety and the progress of the works of the construction site. All the professional figures are responsible of the safety of the construction site [87]. An overview of the socio-demographic characteristics is reported in Table 2.

Table 2
Results of the part 1: socio-demographic characteristics (n = 271 respondents; source: Authors' elaboration).

Characteristics	Category	Survey answer (%)
Provenience	a. Lombardy region	84.5
	b. Trentino-Alto Adige Region	10.3
	c. Other	5.2
Age	a. < 20 years	0.0
	b. 20–40 years	27.3
	c. 41–60 years	55.7
	d. > 60 anni	17.0
Profession	a. Architects	14.8
	b. Architectural engineers	69.3
	c. Technicians	15.9

Knowledge and experience with integrated PV

Task 41 showed that lack of knowledge is the second barriers for PV integration in buildings, after economic costs [19]. This section aims at investigating the level of knowledge on integrated PV technologies and the experience with case studies in the reference territory. In general, the respondents declare to be aware of this technology (93 %, whereas 7 % admits not knowing these systems). Positive answers are less when asking if they have ever seen any case study with integrated PV (79 %, whereas 21 % admits not knowing any case study or didn't answer). Table 3 shows the frequency distribution of the knowledge respectively to the provenience and profession.

This knowledge is gathered from internet sites (54.2 % of respondents), television (5.1 %), newspapers or sector magazines (19.2 %), fairs (29.4 %), real examples (81.8 %), scientific publications (0.5 %), or seminars (0.2 %). 7 % of the respondents personally dealt with case studies with integrated PV, as designer, installer or building owner.

Table 3
Results of the part 2: knowledge and experience with integrated PV (Source: Authors' elaboration).

Provenience	Profession	Number of respondents (n)	Question	
			Did you know what integrated PV means before reading the introduction? Answer: Yes (n, (%))	Have you ever seen examples of integrated photovoltaics? Answer: Yes (n, (%))
Lombardy region	a. Architects	33	32 (97)	28 (85)
	b. Architectural engineers	168	158 (94)	131 (78)
	c. Technicians	28	23 (82)	22 (79)
	Total	229	213	181
Trentino-Alto Adige region	a. Architects	2	2 (100)	2 (100)
	b. Architectural engineers	17	16 (94)	14 (82)
	c. Technicians	9	9 (100)	8 (89)
	Total	28	27	24
Other	a. Architects	5	5 (100)	4 (80)
	b. Architectural engineers	3	2 (67)	2 (67)
	c. Technicians	6	6 (100)	3 (50)
	Total	14	13	9

Perception and acceptance of PV systems in historic and traditional buildings

The scope of this section was to investigate the openness to PV technology and willingness to adopt it in historic buildings. The first two questions refer to the social acceptance respectively of PV systems attached and integrated in these buildings. These two types of PV application are both suitable for protected buildings (i.e., PV to be attached to an existing building element and PV to be integrated substituting a damaged building element). Thus, it is particularly interesting to check the different perception by technical stakeholders. The results of the replies to this question are reported below (Fig. 3).

The potential responses include: (i) "yes", indicating feasibility; (ii) "it depends", suggesting conditional feasibility; (iii) "no", denoting infeasibility; and (iv) "I don't know/don't answer", reflecting uncertainty or no response. While the total acceptance ("yes") represents a clear endorsement of the feasibility, the conditional acceptance category ("it depends") highlights the significance of situational context and specific criteria in the decision-making process. This points to the necessity for a case-by-case assessment and tailored solutions to address the challenges associated with the incorporation of PV technologies in historic structures. The integration of PV attached to historic buildings shows a significant acceptance rate of 61.6 %. Concurrently, 22.2 % of respondents find this technology unsuitable, while 16.2 % express uncertainty or choose not to respond. The "it depends" response had an acceptance rate of 0 %. The situation is different for integrated PV, where the percentages of acceptance, non-acceptance, and indecision decrease respectively at 51.3 %, 9.2 %, and 2.6 %. Here, 36.9 % percentage of respondents considers this technology suitable only in specific situations, with an *ad hoc* design and following heritage-compatible criteria. An intriguing observation emerges from the comparison of data from both scenarios. While PV attached to historic buildings exhibits a higher acceptance rate, the introduction of integrated PV reveals a more

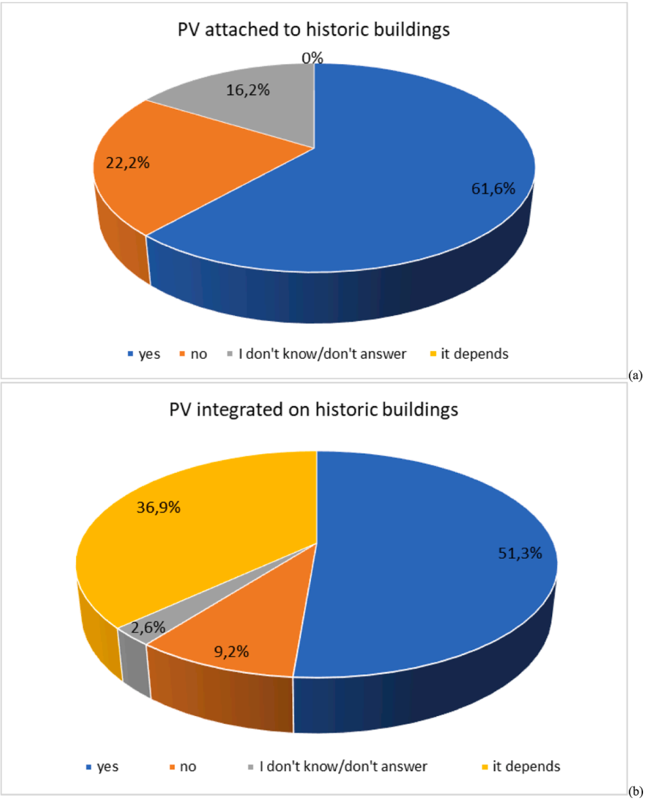

Fig. 3. Acceptance of (a) PV systems attached and (b) PV systems integrated in historic and traditional buildings (Source: Authors' elaboration).

nuanced perspective, distinguishing between total and conditional acceptance. It's worth noting that there is an association between acceptance of PV systems attached and acceptance of PV systems integrated in historic and traditional buildings (Chi-squere Test (2) = 89.51, p-value = 0.001). 75.2 % of people who agree to install PV systems attached to historic building agree also to install PV systems integrated. 23.5 % people of this respondent group express that it depends and 1.2 % are not agree.

Consumers' willingness to adopt PV technology is considered the crucial factor to determine their social acceptance [86]. Thus, a question is dedicated to the potential drivers relating to PV installations in these buildings. This question is addressed only to respondents who declared to accept or accept only in specific situations the PV integration. Literature considers various benefits for PV systems, such as energy savings [14], cost reduction [15], enhancement of economic values, functionalities, and human comfort [27,34,88], and heritage conservation [7,50]. All these theoretical drivers are considered in the possible replies. The main driver identified by the survey is related to the energy retrofit of historic buildings, that can improve their economic and aesthetical value thanks the innovative PV appealing (61 %). Low PV visibility and camouflage favour their integration (55 %). Also, economic aspects are a PV driver thanks the reduction of the energy costs (55 %), the improvement of the economic value of buildings (30 %), and the payback lower than 25 years (7 %). Finally, the sustainable approach related to RES production is considered a quite important driver (23 %). The results are showed below (Fig. 4).

Otherwise, a question is dedicated to the potential risks of integrating PV systems in these buildings. Literature considers the following risks: higher costs of electricity [32], capital costs [30,31], impact on amenities [7,27,34,50,13], visibility and material impact on conservation [7,27,34,50,13], complex decision-making and authorization processes [34,33], technology maturity [19,89], and lack of confidence and knowledge on the technology [27]. All these theoretical risks are inserted in the possible replies. The main risk identified by the survey concern the PV impact on the heritage values, both in terms of material (88 %) and aesthetic (68 %) impact. In the first case, PV systems affect heritage significances, and cause losses of original materials, building elements, and construction techniques. In the second case, PV systems change original visual appearances. This second result confirms the low aesthetic appeal of PV modules identified by PVACCEPT [24], updating the result according to the visual appearance of innovative PV technologies that have different colours, patterns, reflectivity, shapes, and dimensions of traditional building technologies. Besides, another barrier concerns the priority given to other retrofit intervention (e.g., on building envelope, or on HVAC) (28 %). Economic risks (20 %) are lower perceived than PV ACCEPT [24] where resulted the main barrier, or Task 41 [19] where resulted the second one. This results probably is due to the changes both of PV panels and energy costs during the last 20 years. Long and complex legislative and authorizative process is another barrier (12 %). This outcome differs from the result obtained from designers, Public and Heritage Authorities of the Lombardy region [7] where it was the main barrier for fostering the PV systems in protected buildings, and sites. Besides, doubt on PV performance (8 %), and maintenance needs (4 %) are less perceived as risk. Finally, lack of technical knowledge is not considered as barrier (0 %), differently from Task 41 where resulted the main risk for PV implementation. Thus, the knowledge (or its perception) increases significantly in the last 10 years. Similarly, lack of interest on PV, and of knowledge on incentives are not considered barriers (0 % each). The results are showed below (Fig. 5).

Perception and acceptance of PV systems in protected landscapes

The shift from buildings to landscapes PV integration improve the degree of design complexity, involving urban planning, architecture design, energy planning, heritage conservation, and natural protection. Thus, the scope of this section was to investigate the openness to PV technology and willingness to their adoption in landscapes protected for their heritage and natural values. The first question refers to the acceptance of PV integrated in protected landscapes. The results are summarized below (Fig. 6).

The acceptance of integrated PV systems in protected landscapes is high 90 %, composed by complete (46.5 %), and partial (43.5 %) acceptance. As previously for integrated PV, partial acceptance refers to the need of a tailored PV design. Only few respondents consider this technology not suitable (7.0 %) or have some doubts for its application (3.0 %). The results are in line with the previous analysis about PV systems integrated in historic buildings, with small differences on the ranges of total and partial acceptance.

The contrasting acceptance rates between PV integrated into historic buildings and those integrated into protected landscapes present intriguing implications. While the former exhibits a moderately favourable reception, a significant portion of respondents voice concerns or uncertainties regarding its implementation. A synthetical overview is reported below (Table 4).

Then, a question is dedicated to the benefits of PV systems integrated in protected landscapes. Literature show several benefits for PV integration in protected landscapes, such as their reduced visibility [7,13,27,34,50], the economic return of the investment [15], the energy production [14,90], and the reuse of unsecured areas [7,27,34]. All these theoretical drivers are considered in the possible replies. The main driver identified by the survey is low PV visibility or camouflage (54.7 %), that has the same importance at building level (58.2 %, Fig. 4). Also, the sustainable approach related to RES production is considered a quite important driver (44.5 %). Economic aspects consider the payback lower than 25 years (15.9 %). These two values double the results obtained on PV installation in historic buildings (respectively 22.6 % and

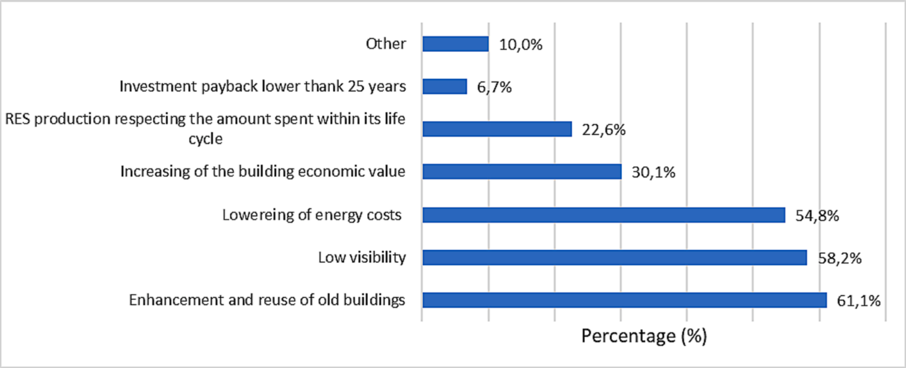

Fig. 4. Potential drivers of installing PV systems in historic and traditional buildings (n = 239 respondents who declared to accept or accept only in specific situations the PV integration; Source: Authors' elaboration).

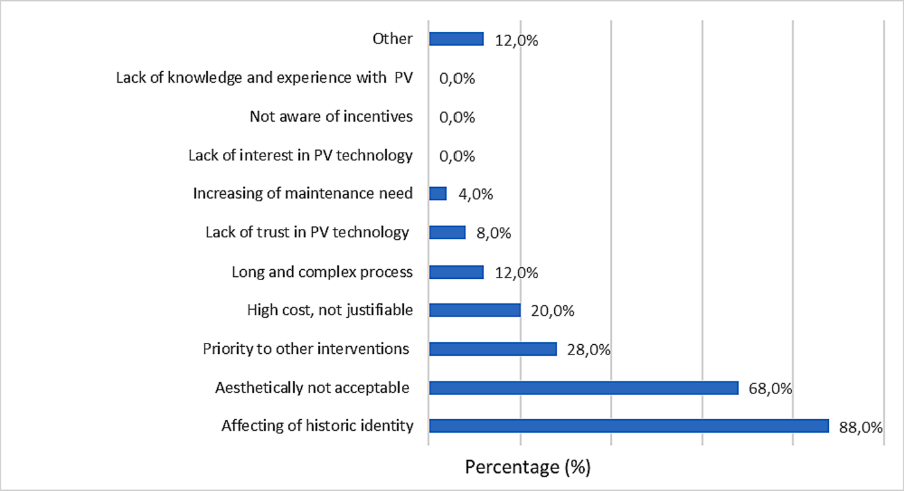

Fig. 5. Potential risks of installing PV systems in historic and traditional buildings (n = 25 respondents who declared not to accept the PV integration; Source: Authors' elaboration).

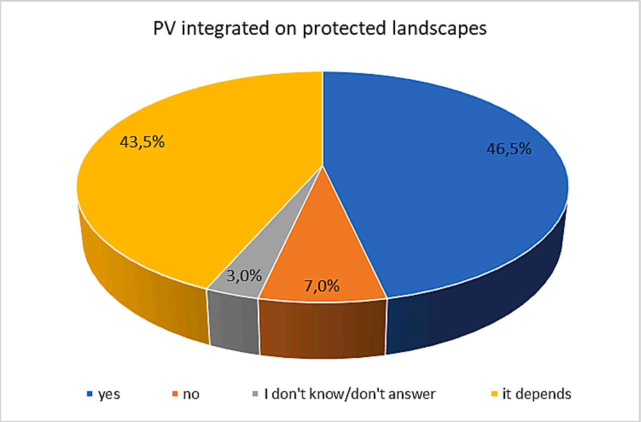

Fig. 6. Acceptance of PV systems integrated in protected landscapes.

Table 4
Comparison of PV acceptance in historic buildings and protected landscapes (n = 271 respondents; source: Authors' elaboration).

Context	System	Total or partial acceptance (n, (%))	Non-acceptance (n, (%))	Uncertainties (n, (%))
Historic and traditional buildings	attached PV	167 (61.6)	60 (22.2)	44 (16.2)
	integrated PV	239 (88.2)	25 (9.2)	7 (2.6)
Protected landscape	integrated PV	244 (90.0)	19 (7.0)	8 (3.0)

6.7 % as showed in Fig. 4). The results are showed below (Fig. 7).

Otherwise, a question is dedicated to the risks of PV systems integrated in protected landscapes. The aspects considered are the same of the protected buildings (section 4.3): higher cost of electricity [32], economic investments [30,31], visual disturbance [36], complexity of legislative framework [33,34], lack of confidence and knowledge on the technology [27], technology maturity [19]. All these theoretical risks are inserted in the possible replies. The main risk identified by the survey concern the PV impact on the heritage and natural values, both in terms of material (84.2 %) and aesthetic (68.4 %) impact, like to building level (value respectively of 88 % and 68 % as shoved in Fig. 5). PV systems affect respectively heritage and natural identity and visual appearance, changing the image of traditional landscape. As the previous case, the visual appearance of PV technologies has different colours, patterns, reflectivity, orientations, shapes, and dimensions of heritage landscapes. Besides, another barrier concerns the priority given to other safety or maintenance interventions (10.5 %) as well as the lack of trust in PV technology (10.5 %). High costs (5.3 %), maintenance needs (5.3 %), and lack of knowledge on PV (5.3 %) are less perceived as risks. Finally, people declare interest in PV technology at landscape level. The results are showed below (Table 5).

Keywords to identify the PV systems integrated in heritage contexts

The aim of this section was to obtain information on people's emotional attitude on the integration of PV systems in historic buildings and protected landscapes. At this purpose, a dichotomous semantic differential scale is used for identifying positive (e.g., good, beautiful, contemporary style, useful) and negative aspects (e.g., bad, ugly, old style, useless). PV systems identify both positive and negative words. Positive elements refer to their contemporary lifestyle. Otherwise, in some cases positive and words are both considered, such as flexible and rigid, exuberant and shy, dark and bright, cold and hot, pacific and aggressive. This refers also to the aesthetic aspects, where PV are considered both beautiful and ugly, pleasant and unpleasant. The same appears on cost, where are considered both cheap and expansive. Finally, these systems are considered useless (Fig. 8).

Discussion of the results

The study identifies several benefits and drivers related to PV installation in heritage buildings and landscapes, based on the survey results:

- Among respondents who partially or totally accept PV integration in historic buildings (239 respondents, accounting for 88 % of the total respondents), the main benefits are primarily energy-economic and aesthetic in nature. The key advantages identified are:
o Enhancement and reuse of old buildings (61.1 %).
o PV integration that doesn't stand out (58.2 %).
o Lowering costs for energy use (54.8 %).
- Similar feedback was received from respondents who partially or totally accept PV integration in protected landscapes (244 respondents, comprising 90 % of the total respondents). The main benefits perceived in this case are:
o Enhancement and reuse of unsecured and disused areas (63.7 %).

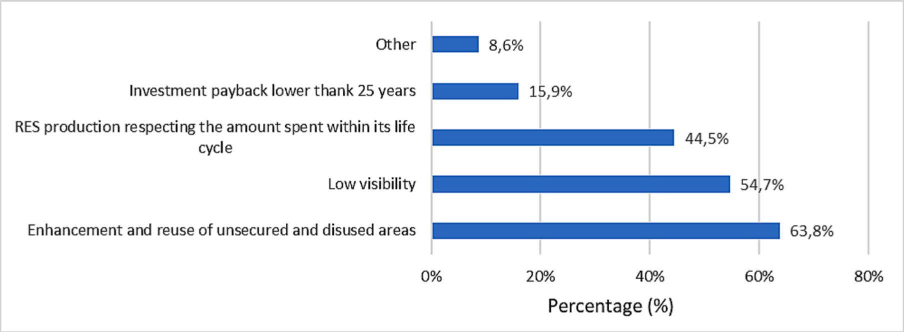

Fig. 7. Potential drivers of installing PV systems in protected landscapes (n = 244 respondents who declared to accept or accept only in specific situations the PV integration; source: Authors' elaboration).

Table 5
Potential risks of installing PV systems in protected landscapes (n = 19 respondents who declared not to accept the PV integration; Source: Authors' elaboration).

Possible answers	Survey results (n, (%))
It can affect the historic and naturalistic identity	16 (84.2)
Aesthetically not acceptable	13 (68.4)
Other	4 (21.1)
Lack of trust in the PV technology	2 (10.5)
Other safety or maintenance interventions are prioritised	2 10.5
Increased maintenance need	1 (5.3)
High cost, not justifiable	1 (5.3)
Lack of knowledge and experience with the PV technology	1 (5.3)
Lack of interest in the PV technology	(0.0)

- PV integration that doesn't stand out (54.7 %).
- Production of more renewable energy compared to the amount spent within its life cycle (45 %).

The study also confirms certain barriers previously identified in past studies on PV installation at the building level:

Lack of basic knowledge about integrated PV and real applications is not a significant barrier. Among the 271 respondents, 93 % claimed to know what integrated PV is, and 79 % reported having seen at least one application example. Their knowledge and experience mainly derived from real examples (81.8 %), internet sites (54.2 %), and fairs (29.4 %).

Among respondents who do not accept PV integration in historic buildings (25 respondents, representing 9 % of the total respondents), the main reasons are cultural aspects, including the risk of affecting the historic identity (88 %) and integrating a not-aesthetically acceptable component (68 %). These cultural considerations outweighed economic issues (e.g., perception of PV high cost, lack of incentives), policy barriers (e.g., long and complex authorization processes), and knowledge of PV technology.

Similarly, in the case of protected landscapes, the main reasons why respondents do not accept PV integration (19 respondents, comprising 7 % of the total respondents) are also related to cultural aspects, including the risk of affecting the historic and naturalistic identity (84.2 %) and integrating a not-aesthetically acceptable component (68 %). Less perceived concerns included lack of trust in the technology (10.5 %), costs (5.3 %), maintenance needs (5.3 %), and lack of knowledge (5.3 %).

Conclusions

This study aims to investigate the social acceptance of photovoltaic systems in heritage buildings, towns, and landscapes among technical stakeholders in the northern part of Italy (Lombardy and Trentino-Alto Adige Regions). Italy was chosen for its abundance of UNESCO and protected sites, the strict legislative framework on heritage conservation, and the low willingness in photovoltaic acceptance demonstrated in previous studies [24]. The cross-border area between Lombardy and Trentino-Alto Adige Regions was selected due to similarities in heritage values, building characteristics, and natural landscapes, as well as significant differences in energy and conservation legislation and policies. The study is conducted through a survey consisting of six parts: (i) socio-demographic characteristics of the respondents; (ii) knowledge and experience with the photovoltaic technology; (iii) perception and acceptance of photovoltaic systems in historic and traditional buildings; (iv) perception and acceptance of photovoltaic systems in protected landscapes; (v) importance of photovoltaic solutions in the energy retrofit of these buildings; (vi) keywords for identify photovoltaic systems in heritage contexts. The survey aims to identify barriers, benefits, drivers, and challenges to promote the market penetration of

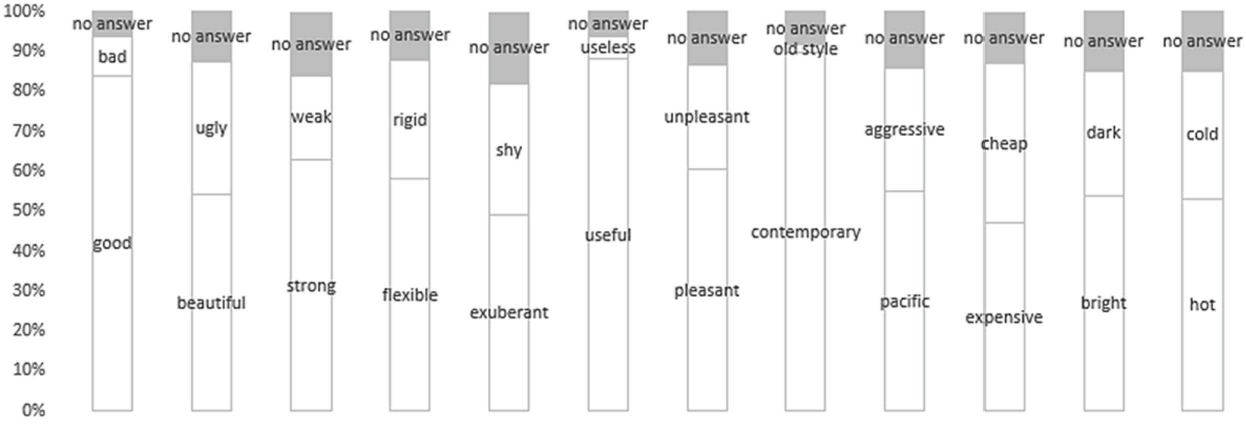

Fig. 8. Dichotomous semantic differential scale results showing the respondents' perception of integrated PV (Source: Authors' elaboration).

photovoltaic systems while balancing heritage/land preservation, energy production, and climate mitigation.

The novelty of the study lies in several aspects:

- It addresses the original topic of PV integration on heritage buildings, towns, and landscapes, which was previously only analysed in 2001 [24].
- It targets technical groups for the survey (designers, Public and Heritage authorities) instead of focusing solely on citizens as in past studies.
- The survey is conducted at both the building and urban level, with a new focus on landscape integration.
- The research group is interdisciplinary, comprising conservators, photovoltaic experts, and mathematicians to maintain a rigorous approach across all fields.
- The study captures the situation during Covid-19 and before the energy crisis, allowing a comparison with the current situation.

The research results will provide valuable insights for the future development of integrated photovoltaic systems in these contexts. Some barriers and drivers can be considered in policy development to enhance perceived benefits, such as:

- National and local policies on the integration of photovoltaic systems play an important role in facilitating sustainable energy transitions.
- Policy barriers can hinder PV applications, so legislation, policies, and guidelines should contain clear and specific criteria, rules, and authorization processes.
- Economic barriers are not considered fundamental, thanks to the increasing cost of energy.
- Conservation of original features and biodiversity is considered the most important barrier.
- Economic incentives must be tailored for specific interventions in natural and heritage-sensitive contexts, considering the aesthetic, technological, and energy integration of photovoltaic systems, as well as the preservation of heritage values, biodiversity, and original features.
- Economic incentives can be awarded at national (e.g., for positive examples of photovoltaic integration on public and private historic buildings), but where there is regional (guidelines), or local (urban planning and building rules) legislation can be inserted as cost cutting, or deduction for well-integrated interventions, especially if on unsecured and disused areas/buildings.
- Technical barriers mainly refer to the sustainability rather than energy performance and durability of the photovoltaic system.
- Sustainability of the intervention can be a driver for the energy market, but it requires a detailed analysis of the life cycle of heritage buildings and photovoltaic systems.

Although the majority of respondents declare acceptance of the technology and have a mostly positive perception, as shown in the dichotomous semantic differential scale results, some actions could help overcome information and knowledge barriers confirmed in the survey and to exploit the potentials, such as:

- Improving education programs starting at the school/university level to instil information and awareness of the photovoltaic integration potential from different perspectives (energy, economic, environmental, aesthetic, etc.).
- Enhancing training and information for designers and conservation/regulatory bodies about the flexibility of photovoltaic solutions. Current developments in technologies (e.g., photovoltaic modules of different colours, shapes, finishing, etc.) could make them aesthetically acceptable for integration in heritage contexts, reducing the risk of affecting cultural, historical, or naturalistic value.
- Providing instruments, such as digital supports for designers and guidelines for conservation/regulatory bodies, could also be helpful.
- Spreading reference examples among citizens, realizing demonstration projects (e.g., the main source of knowledge according to the survey results), exploiting internet sites and public events (e.g., fairs and expositions), showing available products, integration strategies, real applications
- Further research and development to improve the robustness of photovoltaic system integration could strengthen general confidence in the technology.

Limitations of the study include the specificity of the territory area, which provides results for a specific territory. Therefore, further research will expand this study to other territories, thanks to the replicability of the methodological approach and the design of the survey based on a comprehensive literature review of photovoltaic drivers and barriers at the international level. Another limitation concerns the small target group of respondents. In this case, all possible methods of people engagement were experimented, including sending emails and direct letters to users, placing announcements on technical platforms and social media, and Continuous updating of the project’s website [50].

CRediT authorship contribution statement

Elena Lucchi: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Visualization, Supervision, Funding acquisition, Project administration, Validation, Writing – original draft, Writing – review & editing. **Jennifer Adami:** Data curation, Writing – review & editing. **Agnieszka E. Stawinoga:** Data curation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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