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Incorporating public perception of Renewable Energy Landscapes in local spatial planning tools: A case study in Mediterranean countries

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ABSTRACT

The European energy transition requirements have been posing many questions on the deployment of renewable energy sources. The development of renewable energy infrastructures entails landscape transformations affecting the perceived landscape quality and local acceptance. Sustainable energy spatial planning considers environmental, cultural, ecological needs but often neglect community perception of landscape transformations including both the physical landscape structures and the meanings associated to them. To address this issue, the paper aims to explore public perception and incorporate it in the planning tools. The research draws on a survey of residents of Arcos de la Frontera, Spain, conducted with the visual Q methodology, and on structured interviews with local experts. A selection of 36 different photovoltaic applications in urban and rural areas was evaluated by 21 citizens. The analysis identified four distinct viewpoints on photovoltaic applications in urban and rural landscapes. Local experts provided feedback on the current local spatial planning tools and on their consideration of landscape transformations. Considering both citizens and experts, we provided landscape integration strategies linked to siting and landscape design of solar power plants to be included in urban planning tools.

1. Introduction

In the last decades, climate change and global warming have been causing concerns for the future of our ecosystems. This led to signing intergovernmental agreements and setting national and regional targets to mitigate climate change, including the use of Renewable Energy Sources (RES). In this framework, the European Union defined specific targets for each member country, with the ambitions to reach 32% of energy use from RES and to reduce GHG emissions by 2030 by 55% (European Commission, 2018). In Spain, for example, where the study has been conducted, the first act to facilitate the energy transition was made through the Royal Decree-Act 15/2018, with a set of measures by the central government to increase the involvement of society and guarantee energy security using RES (Roth et al., 2018). A further step in innovative policies supporting decarbonization was achieved through the Strategic Framework for Energy and Climate based on the Integrated National Energy and Climate Plans, the Climate Change and Energy Transition Law and the Just Transition Strategy. The National Integrated Energy and Climate Plan (PNIEC 2021–2030) is the first major strategic energy and climate planning exercise in Spain to achieve a 100% renewable electricity sector and carbon neutrality by 2050 (Miteco, 2020a). In 2020, renewable energy production covered 46.7% (25.7 % power capacity from wind power and 13.7 % from solar photovoltaic) of the overall electricity generation mix. Specifically, solar Photovoltaic (PV) is the technology that grew the most in 2021 (Red eléctrica de España, 2022). The targets for Spain are set to reach 74% of electricity generation from renewables (especially wind and solar) by 2030 (IEA 2021), supported for example by funding for homes and businesses to install solar panels, solar batteries and aerothermal units of €1.3 billion (Real Decreto 477/2021).

In general, the envisioned RES deployment entails a massive transformation of landscapes (Roth et al., 2018; Selman, 2010), becoming a driver of change of landscapes in which people live (Apostol, Palmer, Pasqualetti, Smardon, & Sullivan, 2017; Ioannidis & Koutsoyiannis, 2020; Nadaï & Van der Horst, 2010; Selman, 2010) and potentially increasing local resistance (Pasqualetti, 2011; Dall'Omo, Norese, Galante, & Novello, 2013; Scognamiglio, 2016; Nilson & Stedman, 2022). However, the determinants of acceptance of this transition are various

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and related to aesthetic, environment, economic benefits, project details, or temporal and social aspects of the processes (Roddis et al., 2020; van den Berg & Tempels, 2022). Thus, social acceptance is not only influenced by landscape transformations but also by a range of attitudes towards Renewable Energy Technologies (RETs) including socio-political, market and community factors in different levels and stakeholders (Wüstenhagen, Wolsink, & Bürer, 2007). In this view, sustainable energy planning manages energy transition through several dimensions including technological, environmental, economic and social in local decision-making practices (Tsoutsos, Drandaki, Frantzeskaki, Iosifidis, & Kiosses, 2009). While social issues have been widely addressed in wind power studies (Gaede & Rowlands, 2018; Silva & Delicado, 2017; Smardon & Pasqualetti, 2017; Stober et al., 2021), only recently attention has been paid to solar energy (Delicado, Figueiredo, & Silva, 2016; Roddis et al., 2020; van den Berg & Tempels, 2022). These studies claim that economic benefits, environmental impact, process, procedural justice, landscape quality are factors for success and failure of local projects. However, there is limited knowledge on how Renewable Energy Landscapes (RELs) are perceived by the communities (Bevk & Golobič, 2020; Salak, Lindberg, Kienast, & Hunziker, 2021; Spielhofer, Thrash, et al., 2021). While aesthetic perception has been considered for decades (Daniel, 2001; Lothian, 1999; Ulrich, 1986), it is relatively novel in terms of Solar Power Plants (SPPs) (Botelho, Arezes, Bernardo, Dias, & Pinto, 2017; Chen et al., 2021; Chiabrando, Fabrizio, & Garnero, 2009; Kapetanakis, Kolokotsa, & Maria, 2014; Scognamiglio, 2016; Torres-Sibille, Cloquell-Ballester, Cloquell-Ballester, & Artacho Ramírez, 2009). Moreover, aesthetic perception is relevant not only for acceptance but also for environmental impacts (Sánchez-Pantoja, Vidal, & Pastor, 2018a; Scognamiglio, 2016; Tolli, Recanatesi, Piccinno, & Leone, 2016; Torres-Sibille et al., 2009) and can be influenced by cultural and biological factors such as the experience with the environment, the cognitive process and the structure of eye (Bell, 2012; Sánchez-Pantoja et al., 2018a).

Whereas the role of landscape transformations is highlighted by several scholars, little attention is given on how to include local landscape knowledge and perception in local energy planning tools. Spain currently lacks landscape limitations with regard to the implementation of RES, and as a consequence, the Ministry of Ecological Transition has initiated the implementation of an environmental sensitivity zoning system for large-scale wind and solar installations. (Miteco, 2020b). The concern for landscape is an issue of growing interest that stimulated some autonomous communities (e.g. Murcia and Andalusia) to reformulate land use plans incorporating the renewable challenge (Losa, 2022). Moreover, targets and scenarios are often set without involvement of stakeholders (Prados, 2010) or considerations of the landscape transformations (Sovacool, 2014). Hence, beyond technical and economic aspects, social considerations should be included in the process of energy landscapes creation (Delafield et al., 2021; Sovacool, 2014; Stober et al., 2021). Attempts to include public perception in the selection of optimal sites are developed by Oudes and Stremke (2018), Spyridonidou et al. (2021) and Loukogeorgaki, Vagiona, and Lioliou (2022). However, these studies include perception only as site selection and they do not give insights on the design of energy landscapes.

To address these knowledge gaps, we explore the relationship between landscape planning and design and public perception, focusing on the physical changes derived by the implementation of ground-mounted and on-roof photovoltaic installations. The study is developed through a case study, as the expression of the perception of a landscape is subordinate to the interaction with it. In this complex framework, the present study aims to contribute to the integration of expert and public opinion and values in the local energy spatial planning tools (i.e. practices and policies defining spatial organization such as land use and indicators), by means of land suitability and physical appearance design considerations. With this in mind, two main objectives are set. The first is to explore the experience of the inhabitants on landscape transformations derived by SPPs. The second is to incorporate it into spatial planning and design guidelines. This is achieved by answering the following questions:

1) How do inhabitants perceive different types of solar systems?
2) How is landscape considered in energy spatial planning tools?
3) How to include the considerations and preferences expressed by the observers in energy planning tools?

The first question is answered by analysing the results of a survey to citizens on their perception of photovoltaic applications through visual stimuli (section 4.1). The results indicate topics important to participants that can be considered by practitioners and decision-makers. To address the second question, we combined literature studies with expert interviews from the field of energy planning in Andalucia (section 4.2). The outcomes show limitations and opportunities to include the concept of landscape in local energy plans. Combining interview analysis with a thorough literature review addresses objective three and provides useful information to draft or to improve local energy spatial plans including public perception (section 4.3). This article is structured as follows. First, we summarize relevant theories on landscape perception in relation to RET and illustrate methodologies to assess it. Second, we outline the methodology employed in the study. Third, we present and discuss the results of the research. Finally, we present the main conclusions.

2. Theoretical framework

2.1. Public perception and physical features

The relationship between landscape changes and social acceptance has been explored from various perspectives using concepts that express social values, such as place attachment (Devine-Wright, 2011), ecosystem services (Picchi, van Lierop, Geneletti, & Stremke, 2019; Randle-Boggis et al., 2020), landscape character (Tudor, 2014), landscape-based approaches (Sánchez-Pantoja et al., 2018a), Sánchez-Pantoja, Vidal, & Pastor, 2018bnd ecological impacts (Scognamiglio, 2016). The impacts of SPPs on landscapes depend on two characteristics related to different stages of the perception process – sensation and perception (Antrop & Van Eetvelde, 2017). These are linked to both the appearance and the meaning they incorporate into the landscape. Thus, perceived impacts occur in a dual way: influencing the spaces occupied by these installations and altering the visual conditions of the territory. The intrinsic landscape refers to the first aspect, while the extrinsic landscape pertains to the second (Gomez Orea, 2003). Hence, the idea that the oppositions are related to the NIMBY (Not-In-My-Backyard) syndrome is considered too simplistic (Devine--Wright, 2005; Ioannidis & Koutsoyiannis, 2020), as oppositions often stem from a protective attachment to the landscape. Transformations induced by renewables can cause unfamiliar, immediate and dramatic changes (Selman, 2010), impacting not only physical patterns but also how users interpret and experience the environment (Oudes & Stremke, 2021; Wolsink, 2018). This is in line with the definition of landscape given by the European Landscape Convention as any part of the territory such as it is perceived by its inhabitants, being its character defined by the action of natural and/or human factors and their interrelationship (Council of Europe, 2000). The relation between SPPs' characteristics and perception has been studied by impact studies, which distinguish object-, observer- and context-related impacts (Bishop, 1997). Indeed, Renewable Energy Landscapes (REL) are perceived differently based on values and cultural background of the observers and their subjective experiences encompassing subjective, physiological and behavioural components (Frantál, Van Der Horst, Kunc, & Jaňurová, 2017; Sánchez-Pantoja et al., 2018a). Thus, besides the aesthetics of the systems, a broader understanding of how infrastructure changes landscape character must be considered (Wolsink, 2018). Therefore, spatial configurations not only influence aesthetic quality but also the potential for accommodating other functions (Bridge, 2018). In line with the structure of spatial planning tools, spatial qualities can be expressed as site suitability (e.g. Burke, 2018) or site design requirements (e.g. Lucchi, 2023). For example, location and site, land use changes and scale of the project can determine acceptance (Eichhorn, Tafarte, & Thrän, 2017; Nilson & Stedman, 2022; Scognamiglio, 2016). Moreover, other factors of importance are physical ones, such as density, materiality, design of the components, and reversibility (Lucchi, 2023; Mérida-Rodríguez, Lobón-Martín, & Perles-Roselló, 2015). Sánchez-Pantoja et al. (2018) linked objective factors, such as visibility, colour, glare, and integration degree with public perception and distinguished three categories: land use, solar energy system and glare. However, landscape should not be considered only as a scenery in which visual impact is limited by mitigation strategies. It should rather include an overall consideration of landscape transformation (Bevk & Golobič, 2020; Pasqualetti & Stremke, 2018), especially considering that its perception differs between different users (Antrop & Van Eetvelde, 2017). In this view, multifunctional solar farms have been receiving attention (Oudes & Stremke, 2021) as they can also provide nature development, recreational areas, educational functions, agriculture or livestock (Dupraz et al., 2011; Frolova et al., 2019; Toledo & Scognamiglio, 2021), or re-use of available surfaces. Besides public perception, spatial configurations can determine positive or negative impacts on other dimensions of solar infrastructures including economy and nature (Oudes, van den Brink, & Stremke, 2022).

2.2. Assessing public perception

The methods used to evaluate perception are various. Real landscapes can be used as stimulus (Bevk & Golobič, 2020; Jallouli & Moreau, 2012), providing a holistic experience as they address all the senses and allow participant to move through the landscape. Specifically, Bevk and Golobič (2020) used participatory photography in existing REL and post-visit focus groups. This method enables the consideration of both the positive and negative impacts of RES, as well as the alignment of the ideas about REL with the reality of their impacts. Other methods involve visual stimuli (Torres-Sibille et al., 2009), coupled with semantic differential method (weighted sum of individual impacts; the weights are decided according to AHP by experts) (Beer, Rybár, & Gabániová, 2023; Salak et al., 2021; Sánchez-Pantoja et al., 2018b); with self-assessment manikin (Spielhofer, Hunziker, Kienast, Wissen Hayek, & Grêt-Regamey, 2021); a mixed method of choice experiment and virtual reality (Caporale, Sangiorgio, & De Lucia, 2024); or with the visual Q methodology (Lu, Lin, & Sun, 2018; Naspetti, Mandolesi, & Zanoli, 2016). The use of visual stimuli has been frequently used in renewable energy studies, as expressing an opinion about RES based on pictures represents a simplification for non-experts and produces a great emotional reaction for the assessment of a landscape. Besides assessing visual impact of SPPs, Q methodology has also been used to investigate values about hydropower (Venus et al., 2020) and wind farms (Beckham Hooff, Botetzagias, & Kizos, 2017; Ellis, Barry, & Robinson, 2007). Finally, some studies use questionnaires (Oudes & Stremke, 2018; Spyridonidou et al., 2021) or interviews (Delicado et al., 2016). In this study, we apply the visual Q methodology as it is suitable to investigate subjective viewpoints of citizens on landscape assessment through an engaging activity. Moreover, providing visual stimuli may generate greater emotional reactions and facilitate the expression of an opinion (Naspetti et al., 2016).

3. Materials and methods

3.1. The case study in Arcos de la Frontera

In Spain, energy planning is a responsibility of the Central Government, although the regions play a very important role in the decision-making process. Local governments play only a secondary role in the authorisation procedure (Frolova & Pérez, 2011; Iglesias & Carballo, 2011). Spain is an emblematic example of significant development of SPP, favoured by geographic, legal, and economic conditions and subsidies (Mérida-Rodríguez, Reyes-Corredera, Pardo-García, & Zayas-Fernández, 2015). The economic support of the government has a strong role in this expansion, attracting speculative investments. The transformations occurring due to the expansion of SPPs were rapid, spontaneous and not linked to structured territorial planning (Mérida-Rodríguez, Lobón-Martín, & Perles-Roselló, 2015), preventing discussions on the integration in the landscape.

The case study is representative of medium and small cities which generally host large SPPs above 10ha. Arcos de la Frontera is a city of around 30.000 inhabitants, in Andalusia, Spain (Fig. 1). The city is characterized by a peculiar topography: the historic centre and the urban area are located on a sandstone hill 185m a.s.l., while the peri-urban and agricultural areas lie in the surrounding flat areas, along the Guadalete river and the reservoir.

3.2. Procedure

The study used interviews with inhabitants to collect the perception of RELs and expert interviews for data gathering on local energy planning. Moreover, a literature review was conducted to investigate perception methodologies, and to define gaps and approaches for local energy spatial planning.

The procedure is structured in three steps (Fig. 2): (1) pre-interview literature review and design of the interviews; (2) interviews with the inhabitants and experts; (3) post-interview analysis and discussion of the results as potential integration for planning tools.

Firstly, literature was reviewed covering three main topics: landscape integration of SPPs; social perception and acceptance; local energy planning tools. Interviews were designed by choosing an appropriate method, preparing the surveys and selecting the participants. Secondly, the interviews were performed during the months of February and March 2022. The enquiry with the inhabitants was conducted in Arcos de la Frontera with the visual Q methodology, by asking people to evaluate photovoltaic landscapes using photos. Experts' interview data were collected via structured interviews conducted through in-person and online meetings to gather data around local energy planning in Andalusia. Thirdly, the results of the interviews were analysed in the first case with factor analysis and in the second case with AHP and aligned with literature to identify themes for socially-accepted spatial planning and design strategies, and to highlight limitations and possible solutions to improve local energy planning.

3.3. Interviews with the inhabitants: the visual Q methodology

In the present study, Q methodology and visual images were applied to investigate the acceptance of photovoltaic systems by individuals, in relation to their perceived impact on the landscape. Different photovoltaic applications, captured by pictures, were used to collect subjective perception and sort them into similar groups with similar attitudes through statistical analysis combining qualitative and quantitative research. The visual Q methodology has been widely applied to explore landscape preferences (e.g. Fairweather & Swaffield., 2002; Hempel, 2021; Milcu, Sherren, Hanspach, Abson, & Fischer, 2014; Sáenz de Tejada Granados, Santo-Tomás Muro, & Rodríguez Romero, 2021). Moreover, it has been used to identify individual perception of SPPs and determine the impact on the urban and rural landscape (Lu et al., 2018; Naspetti et al., 2016). Using this methodology, pictures of landscapes are evaluated by individuals and ranked in a forced distribution which is then analysed to determine common patterns. The steps of the methodology follow the guidelines of McKeown and Thomas (2013) and include: the collection of a wide sample of images representing photovoltaic applications (concourse), the selection of a restricted number of images that will be evaluated (Q sample), the selection of the participants (P set), the evaluation of the images by each participant (Q

Fig. 1. Location of Arcos de la Frontera in the Mediterranean context; case study: aerial image of the city: (1) view from the city, (2) view to the city. Source: Author's.

sorting) and the analysis of the results. Each step is set out in the following subsections.

3.3.1. The definition of the "concourse" of images

A diverse sample of images representing photovoltaic installations applicable in small and medium cities were collected ("concourse"). The images were gathered from online archives and showed SPPs in urban, peri-urban and rural landscapes in Mediterranean countries, mainly Spain. According to the most common typologies of photovoltaic installations in Andalusia, the following types of plants have been selected: photovoltaic system in rural landscapes; photovoltaic installations in urban contexts (residential, administrative, commercial and industrial areas).

3.3.2. The "Q sample" of images

All the images selected for the concourse were reduced to a manageable number of images ("Q sample"). Six categories have been defined with a systematic approach: installations on residential buildings, administrative buildings, commercial and industrial buildings, facilities and leisure areas, rural buildings, and in rural fields. The images were reduced according to their resolution, redundancy, and readability. To select the images, the opinion and suggestions of local experts have been considered. For each category, following a sampling approach, three levels of landscape-integration were considered (i.e. not-integrated, semi-integrated and integrated) in line with the definition of Munari Probst & Roecker (2019). The level of landscape-integration and the category of land use composed the matrix for the final Q sample (Fig. 3), which is composed of two photographs per cell, for a total of 36 images (6 × 3 × 2).

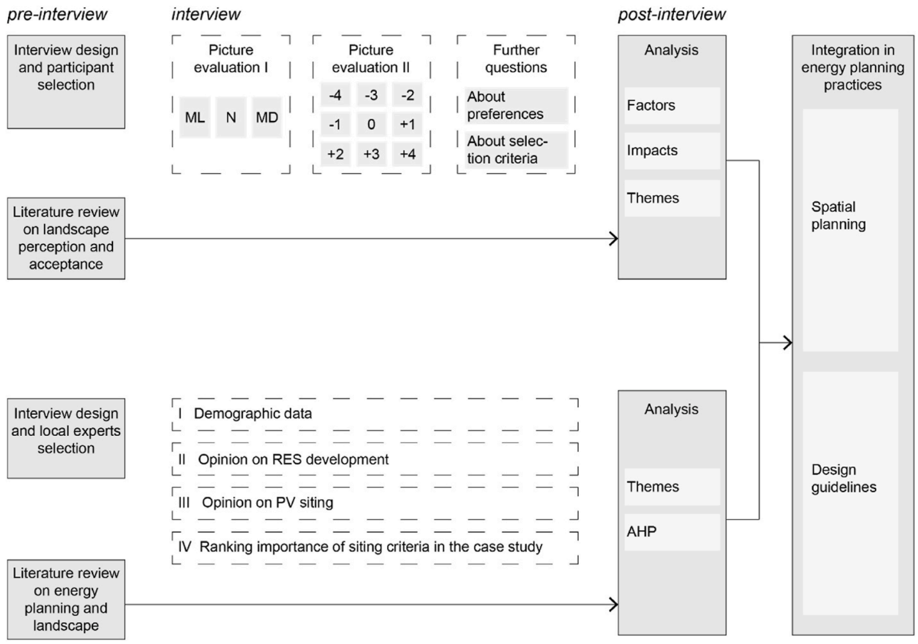

Fig. 2. Scheme of the overall procedure (ML: most liked; N: neutral; MD: Most Disliked).

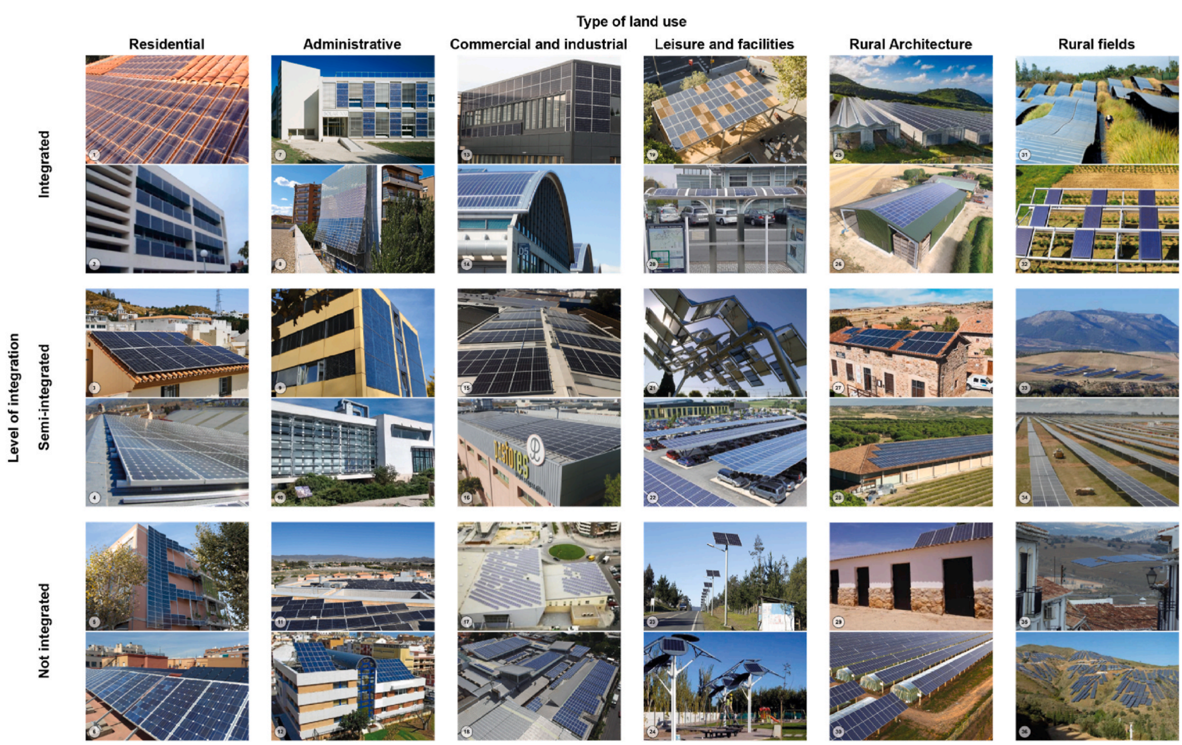

Fig. 3. The factorial design of the Q sample.

3.3.3. The "P set"

The "P set" (the group of participants) should be designed to reflect particular interesting points of view rather than having a large number of participants (Watts & Stenner, 2014). In this study, participants were recruited according to two main groups: experts and non-experts. To ensure representativeness of viewpoints, the P-set was composed of 21 participants, of which 12 experts and 9 non-experts. The group of experts included architects, urban planners, engineers, municipal architects, municipal engineers and photovoltaic technicians. The number of participants is not crucial in this methodology as the aim is not to generalize the opinion of the citizens but to establish particular viewpoints (Watts & Stenner, 2014).

3.3.4. The Q sorting

Before the interview, each participant received instructions on the completion of the enquiry, on the framework and objectives of the study. First, participants were asked to divide the photographs in three groups with almost the same number of images, according to their feelings ("most liked", "most disliked", and "neutral or indifferent"). Then, participants were asked to sort the photographs in nine groups ("Q sorting”) according to what they would prefer to see in their municipality: from “most dislike” (−4) to “most like” (+4). Each group was scored with a number between −4 and +4. Finally, after the scoring, participants were asked to justify their choices and explain the criteria for which they assigned scores, especially for the extremes. The average time for each interview was 20–30 min. The total number of accepted answers was 21.

3.3.5. Data analysis

The 21 Q sorts (i.e. forced distribution of each participant) were used as input for the analysis. We applied a factor analysis with PQMethod software (Schmolck & Atkinson, 2002), to investigate patterns in the answers of the participants. According to the input, the program generated the correlation matrix between the q-sorts, showing a couple-by-couple comparison between answers. After the generation of the correlation matrix, the program created unrotated factors (i.e. clusters of similar q sorts). To perform the factor analysis, factors were extracted with the centroid method and rotated with varimax. The number of factors to extract were defined according to Watts and Stenner (2014), considering factors with eigenvalues above 10%, total explanation variance above 50%, and factors with at least two relevant factor loadings. The interpretation of the factors was based on the factor arrays, on the comparison between factors and on the content of the interview during and after q-sorting.

3.4. Experts’ interviews on local energy planning

Interviews with experts were performed to gather insights relating to constraints and opportunities for the future development of local energy planning tools. This was particularly important due to the lack of implementation strategies of SPP in the study area (Krog, 2019). Interviews involved five experts in the field of energy planning, selected according to their experience on siting SPPs and their local expertise. The selected experts belong to different working fields: two academics, one consultant, and two local policy makers. The survey was distributed prior to the interview and was structured into four main sections: demographic information; opinion of the expert about the deployment of RES; opinion of the experts about spatial planning and siting of SPPs; and prioritization of Assessment Criteria (AC) for site selection. Each interview lasted between 30 and 60 min. The analysis of the results did not involve the participants. The results of the second and third section were transcribed and subjected to thematic analysis, organized in framework matrices, summarized and conceptualized (Clarke & Braun, 2018). The results of the fourth section were analysed in accordance with the Analytic Hierarchy Process (AHP) principles (Saaty, 1986, 1987), to obtain relative weights of the compared criteria and form a priority vector.

3.5. Integration of the results in planning tools

Interview analysis was coupled with themes identified from the literature review to propose methodological solutions for the inclusion of landscape attitudes in the energy transition. The suggestions are structured through a landscape-based approach (Bevk & Golobič, 2020; Sánchez-Pantoja et al., 2018a) and include indications for site selection or for site design. Specifically, the landscape integration strategies entail specific parameters at the spatial planning level, such as frequency of views, land cover, and at the design level, such as size, composition, density and colour of the infrastructure to address key societal considerations. Key strategies were identified from literature and selected when in line with the observations of the survey respondents and suitable for the case study.

4. Results

4.1. Public perception of solar landscapes

The factor analysis performed with PQ Method identified seven factors representative of different viewpoints. Statistically significant at the 0.01 level factors loadings were selected: above ±0.43 (2.58*(1/SE; SE = standard error; SE = $1/\sqrt{\text{NI}}$; NI = number of items), so the number of factors extracted was four. The four factor loadings were statistically significant with a p-value <0.01 and accounted for 57% of the variance. The factors represent clusters of participants who sorted the pictures in a similar way. Each participant was part of a factor, and some participants significantly share the view of more than one factor (Table 1).

The images that received the highest scores by factor 1 show integrated solutions in urban components (Fig. 4). Images showing ground-mounted PV in rural land received negative evaluations. As explained by the participants during the post-sort interviews, the visual impact and the preservation of traditional rural landscape are important elements of acceptance. Participants that belong to this factor showed consent towards REL but expressed their preference towards “hidden” solutions.

The participants of factor 2 value positively solutions in the roofs of different type of structures: residential buildings, parking lots, rural architecture. This group dislikes solutions that are not integrated with the surroundings: visible solutions in buildings’ facades, ground-mounted PV in the landscape as well as small PV in urban facilities. The group showed strong preference towards the use of roofs with large areas of photovoltaic panels. According to the post sorting interviews, a recurrent theme for selecting preferences was the efficiency of the panels (e.g. dimension, avoidance of shadow) and their maintenance.

People of factor 3 prefer innovative design solutions integrating PV panels in buildings’ components (double façade, shading systems) or urban elements (Fig. 5). Images showing PV in rural landscapes were negatively evaluated, even if compatible with agricultural functions. Factor 3 showed interest towards Building Integrated Photovoltaics (BIPV) rather than panels applied to the roofs. They highlighted the importance of using available surfaces and allowing multifunctionality, integrating the PV panels (e.g. in terms of colour and slope) with the urban components.

The images receiving highest evaluation by factor four show PV panels in roofs, both in isolated rural areas and in urban context. The pictures receiving lowest points represent ground-mounted PV panels changing the existing land-use. Participants in this group expressed preference towards modern and technological solutions, also in the rural or natural areas if they follow the shape of the surroundings.

4.2. Landscape in spatial planning: learning from experts’ feedback

The main aspect emerging from the experts’ interviews is the need to adopt local spatial planning tools. Such tools are missing at the local, autonomous regions and state levels and are important to define the location of future SPPs. This results in a lack of relation between landscape (e.g. landscape type) and the types of energy systems, as well as a lack of implementation strategies (e.g. interplays between national,

Table 1
Attribution of Q sorts to the factors.

	Factor 1 *“Away from the fields!”*	Factor 2 *“Efficiency first!”*	Factor 3 *“Innovative design”*	Factor 4 *“R-urban integration”*
Participants	5, 9, 11, 12, 14, 16, 21	1, 4, 7, 10, 18, 19, 20	3, 4, 6, 8, 10, 19	2, 13, 15, 17
Non-experts	6	1	1	2
Experts	1	6	5	2
Total variance	17%	17%	14%	9%

Fig. 4. Distinguishing images for factor 1.

Fig. 5. Distinguishing images for factor 3.

regional and local targets; integration with other sustainability concerns). Indeed, "*the responsibility for the evaluation [of a possible solar farm] lies exclusively in the absence of management and planning on a person of the administration*" (EX2). Moreover, implementing SPPs in a "*disordered*" and "*at the discretion of the companies*" way, may harm landscapes and territories. According to the experts, this issue could be addressed by articulating precise requirements in urban planning tools or in landscape impact assessment practices regarding land use instructions or building- or landscape-integration design strategies.

The new law (Directive EU, 2018) sets "*the soil as a limited resource that must be protected and at the same time has included the photovoltaic use as an ordinary use, such as agriculture and livestock. […] The installation of a lot of SPPs on irrigated land will have an impact not only for the citizens but also for the tourism, especially in Andalusia in which the landscape represents an important value*" (EX5).

Spatial planning tools could facilitate integration with other aspects (e.g. attention to the landscape, soil productivity, social structure). The Autonomous community level with the territorial planning (lit. Plan de Ordenación del Territorio) "*tried to develop an initiative of management and indication of suitable areas*" but the methodology proposed was withdrawn due to inaccuracies (EX2). Subregional and local planning tools are absent: at the subregional level some plans were made in 2004 and 2011 mentioning the commitment to renewables, but they do not regulate zones. Spatial planning tools could define suitable areas, according to important factors, such as the location of substations, biodiversity areas, landscape protection. Moreover, landscape pressure may be reduced by limiting the concentration of plants around a single substation. For this purpose, allowing multifunctionality (e.g. agrivoltaics) and limiting "*a maximum amount of soil that can be used*" could guarantee facilitate processes. However, this aspect would certainly bring some issues related to the share of energy between Autonomous Communities and the availability of resources, which would require national and regional discussion prior planning. Finally, all the respondents claimed for more self-consumption and re-use of underused areas, for example roofs of residential and industrial buildings, brownfields, infrastructures, parking lots.

4.3. Landscape integration strategies for spatial planning and design

The insights emerged from the interviews with citizens and experts can be further systematised to suggest planning and design strategies to be included in spatial planning tools as conditional quality requirements. Based on the q-sorts and on the expert interviews, recurring themes related to acceptable solar landscapes: low visual impact, multifunctionality, acceptable land use, mitigated visibility, harmony with the landscape. The issues exposed by the participants are also well aligned with the topics considered by the experts. Suggested strategies in line with the values and perceptions emerged from the surveys are shown in Table 2. They are structured in two scales of application: siting and design. A distinction has been made between strategies valid for ground-mounted and building integrated PV panels, since the difference of scale generates complexities to take into account through design.

Table 2
Suggested spatial planning and design strategies based on the experts' and inhabitants' opinion. BI: building integrated; GM: ground mounted.

	Spatial configuration parameter	Scale	Suggested integration strategy	Reference
Siting	Area and quality of covered land	BI; GM	Re-use of degraded sites and contaminated land	Bevk & Golobič, 2020; Scognamiglio, 2016
		GM	Multifunctionality (e.valuaciónsaic, permeability)	Scognamiglio (2016)
		GM	Preserve prime cultivable land	Bevk and Golobič (2020)
		GM	Reduce fragmentation of the countryside	Scognamiglio (2016)
		GM	Limit to land use occupation	Poggi et al., 2018
	Frequency of views from viewpoints	BI; GM	Frame views from walking paths	Bevk & Golobič, 2020; Chiabrando et al., 2009
		BI; GM	SPP in less visible areas	Bevk & Golobič, 2020; Florio et al., 2018
	Fit with landscape character	BI; GM	Avoid historically sensitive areas centres and naturally well-preserved areas	Bevk & Golobič, 2020; Scognamiglio, 2016
		BI	Priority to residential areas	Clarke, McGhee, and Svehla (2020)
		BI	Priority to industrial areas	Clarke et al. (2020)
Design	Size	GM; BI	SPP size similar to landscape elements/coherent with architectural composition	Bevk & Golobič, 2020; Horvat et al., 2012; Scognamiglio, 2016
	Composition	BI; GM	Follow dominant directions of the surrounding landscape	Scognamiglio (2016)
		BI; GM	Use of only one type of panel	Scognamiglio (2016)
		GM	Minimize the area of SPP	Scognamiglio (2016)
		BI; GM	Inclination of the modules	Scognamiglio (2016)
		BI	Compatible with building composition grid and dimensions of façade elements	Farkas et al., 2012
	Density	GM	The density similar to other landscape features	Scognamiglio (2016)
		GM	Crop production between or beneath solar infrastructure	Scognamiglio (2016)
	Colour	BI; GM	Colour in harmony with the background	Horvat et al., 2012; Sánchez-Pantoja et al., 2018b; Scognamiglio, 2016
	Texture	BI	Texture in harmony with the background	Horvat et al., 2012; Sánchez-Pantoja et al., 2018b
	Multifunctionality	BI; GM	Attention to land cover underneath the modules	Scognamiglio (2016)
		GM; BI	Ecological features beneath or between solar infrastructure	Oudes et al. (2022)
		GM; BI	Educational, recreational or commercial facilities	Oudes et al. (2022)
		GM; BI	Vegetable garden	Oudes et al. (2022)
		GM	Livestock	Oudes et al. (2022)
		GM; BI	Water storage capacity	Oudes et al. (2022)
		GM	Retaining existing vegetation	Macknick, Beatty, and Hill (2013)
	Boundaries	GM	Ecological features adjacent to solar infrastructure	Scognamiglio, 2016; Oudes et al., 2022
		GM	Adjusted fence permeability	Oudes et al. (2022)
		GM	(Close) Access to SPP	Oudes et al. (2022)
	Temporality	GM	Reversibility	Oudes et al. (2022)

5. Discussion

5.1. Landscape and solar power plants

In general, photovoltaic systems in rural and urban settings are positively seen as tools for sustainable energy transition. The results increased our understanding of what physical features affect acceptance of solar landscapes. Visual Q methodology facilitates the connection of values and themes affecting public perception to landscape-integration strategies. The outputs gathered from the participatory method are in line with other studies using participatory methods, such as by Naspetti et al. (2016) assessing SPPs in Italy and by Bevk and Golobič (2020) in Slovenia. Indeed, photovoltaic applications are considered important by all the participants, but ground-mounted SPPs in farmland are consistently disliked both by experts and non-experts. This is in line with Bevk and Golobič (2020) finding that the most evoked issue is aesthetics and with Naspetti et al. (2016) claiming that rural landscapes are expected to provide both aesthetics and food production. Social, environmental and economic benefits of REL are recognized, especially by Factor 2 which considers power generation and maintenance a priority. In this case, visual appearance is assessed based on their energy production and economic advantages. The respondents of Factor 1 seem to embrace an idyllic view of rural areas, considering SPPs a misfit. In this case, their position would not change with different spatial composition of the energy infrastructure.

The results of the q-sorts illustrate that differences in urban land use types may influence the perceived impact of photovoltaic applications on the landscape. Our results show that in most cases the level of integration is secondary to the land use. In general, participants prefer power plants integrated in buildings rather than ground-mounted, as also found in Bevk and Golobič (2020). Indeed, ground-mounted SPPs with dense panels placed in rural areas are disliked by experts and non-experts, as also found by Naspetti et al. (2016). The conflict with biodiversity, ecology and cultural aspects emerges as relevant, as in other similar studies (Lu et al., 2018; Naspetti et al., 2016). This aspect is aligned with some impacts highlighted in literature for ground-mounted panels: reduction of cultivable land and fragmentation of the countryside (Chiabrando et al., 2009; Scognamiglio, 2016). These impacts could be addressed by multifunctional SPPs designed with attention to land cover and presence of vegetation or by agrivoltaics (Oudes et al., 2022). However, in this study these types of SPPs were not appreciated. This topic could deserve further development and research, as in other studies multifunctionality seem to have a positive influence on acceptance (van den Berg & Tempels, 2022; Enserink, Van Etteger, Van den Brink, & Stremke, 2022). Rural landscapes, providing aesthetic and cultural ecological services, are connected to food production (Ives & Kendal, 2013) and to leisure (Scognamiglio, 2016). Therefore, radical transformations by photovoltaic installations received negative feedback by all factors. Only one factor (R-urban integration) seems more open to mixed use between agriculture and PV systems, expressing positive feedback to agrivoltaics (Toledo & Scognamiglio, 2021) solutions.

While there is homogeneity among factors in rejecting photovoltaic plants substituting crops or pastures, acceptable solutions in the built environment seem to be dependent also on the professional background of the participants: non experts like hidden solutions on the roofs, some experts prefer efficient and functional solutions, others BIPV. This general opinion may be attributed to the profile of the consumer and the level of societal maturity in favour of RES. The preference of PV on envelopes than ground-mounted could hinder the perception of a higher amount of benefits, as the latter is devoted to big companies, while the former is mainly for self-consumption. The results suggest that Factor 3 favours technological and innovative solutions integrated in the envelopes of buildings which, despite being not optimal in terms of energy production, reduce land use and reinforce community perception. BIPVs are expected to grow in the next years and seem an appropriate solution to technically and aesthetically integrated PV in the built environment (IEA, 2019). While design of photovoltaic solutions in the buildings' envelopes seem to be recognized and appreciated, the role of design in ground-mounted SPPs appears not well known by experts and non-experts. Indeed, only few participants commented on panels following the shapes of landscapes or density of the panels. As literature studies suggest, more attention should be given to the design of solar power plants (Kapetanakis et al., 2014; Mérida-Rodríguez, Lobón-Martín, & Perles-Roselló, 2015) and planning, to achieve social acceptance.

5.2. Setting quality criteria in the energy policies

Given European Climate and Energy plans and the shift towards decentralised energy production, local authorities have an important role in siting local energy infrastructure (Delafield et al., 2024; Ko, 2023; Krog, 2019) and in defining criteria for the design of RELs (Oudes et al., 2018). The concerns expressed by the consulted experts in relation to the absence of local energy planning tools are aligned with those highlighted in literature studies, specifically lack of implementation strategies and local resistance (Krog, 2019), low community benefits (van den Berg & Tempels, 2022), and lack of integration with other concerns (Osorio-Aravena, Frolova, Terrados-Cepeda, & Muñoz-Cerón, 2020; Poggi, Firmino, & Amado, 2020). Indeed, local energy planning tools could facilitate the integration with other sustainability issues such as water or public health (Osorio-Aravena et al., 2020). Reasons behind these issues are explained in literature by the lack of simple modelling tools at the municipal level, requiring minimum experience and technological skills (Bouw, Noorman, Wiekens, & Faaij, 2021) as well as of a clear definition of priorities and procedures to coordinate energy policies (Osorio-Aravena et al., 2020) and lack of budget and competent staff working on such sectors (Krog, 2019).

The experts identify three main roles of the planning tools: definition of potential siting locations, consideration of other existing RE infrastructures in the area and definition of a limit of landscape pressure. In addition to these aspects, literature evidences the role of spatial planning tools to provide system costs and benefits and drive public acceptance (Bouw et al., 2021), visualize scenario and cluster composition (Poggi et al., 2020), highlight the local context characteristics, such resource potential, available infrastructures (Bouw et al., 2021; Mirza, Anderson, Seadon, & Brent, 2024), and define a clear role for the Municipalities in the energy planning processes (Geissler, Arevalo-Arizaga, Radlbauer, & Wallisch, 2022).

According to the experts, spatial planning tools should consider landscape transformations associated with the implementation of REI. They suggest going beyond a-posteriori methods, such as Visual Impact Assessment (VIA) (Cilliers et al., 2023), Landscape Impact Assessment (LIA), Social Impact Assessment (SIA) (Vanclay, 2003), and Territorial Impact Assessment (TIA) (Kruse, Marot, Bottarelli, & Centeri, 2018), which evaluate stand-alone projects by setting a priori requirements. In this view, Florio, Munari Probst, Schüler, Roecker, and Scartezzini (2018) assigns different landscape and architecture integration design requirements to municipal areas according to the combination between visibility of roofs and landscape sensitivity. However, the process of designing RELs is not often considered in spatial planning tools, as also highlighted by Enserink et al. (2022). Another aspect observed by both the interviewed experts and literature relates to the mitigation of land consumption and land use changes to control landscape transformation due to RES, as soil is a limited resource by multiple land uses, by re-using available surfaces (Geissler et al., 2022). Furthermore, social aspects currently are not fully included in landscape considerations in planning tools. Bouw et al. (2021) justifies this aspect due to difficulties to include in spatial plans qualitative and non-numerical data. This indicates a general alignment between the limitations derived by literature review and the concerns expressed by the experts. However, future research could go into detail in understanding the obstacles to adapt or create new policies to select specific sites and to define quality requirements.

5.3. Limitations

Despite the importance to drive the scope of the academic debate on the acceptance of renewable energy landscapes and to provide practical solutions that could be employed by public administrations, some limitations can be highlighted in the proposed methods and results. In particular, the research was limited by the selection of a restricted number of involved experts with a background of solar landscapes, in academia, environmental impact procedures and regional governance and by the small sample of interviewed inhabitants. Hence, future studies should include companies implementing solar farms and local decision-makers. Moreover, considering the explorative nature of the research, interviewees were chosen to cover many possible viewpoints and to provide an initial expert opinion to establish a primary discussion on the field of local energy planning in Andalusia.

In this study, citizens have been asked to express their opinion on landscape perception related to photovoltaic applications in their municipality. However, to assess social acceptance trade-offs and consequences entailed with the proposed solutions (e.g. higher energy bills) should be considered. Indeed, in Southern European Countries economic benefits appear to be the most important attributes to meet local acceptance (Delicado et al., 2016; Rodriguez-Segura et al., 2023; Caporale & De Lucia, 2024). This issue could be addressed by associating application choices with repercussions to see whether the repercussion might affect the first choices.

The use of Q method has some advantages and drawbacks. For example, the qualitative and quantitative divide of the method makes it difficult to interpret the results. For the purpose of the study, it was a valid tool to engage citizens in the streets and to facilitate the expression of an opinion by non-experts. Indeed, the method has been extensively used in fields related to territorial transformations (e.g. Sáenz de Tejada Granados et al., 2021; Sudau, Celio, & Grêt-Regamey, 2023).

As the research involves landscape, it can only provide generalizable knowledge for contexts under similar conditions. Thus, the results might also serve as a reference for siting and designing socially acceptable SPPs in the Mediterranean areas. The presented approach can be relevant to other contexts attempting to include the opinion of the inhabitants through a landscape approach in the planning tools.

6. Conclusion

This study on public perception of energy landscapes shows that landscape transformations due to SPPs are a concern for inhabitants and experts. This study contributes to incorporating qualitative considerations in local policies as a means to enhance social acceptance. The main findings are as follows:

1) A general positive understanding on energy transition and the required transformations has been observed through the interviews. Roof or facade applications are preferred to ground-mounted SPPs. Important topics according to the citizens are the relation with landscape character, land-use, economic and technological aspects, visual properties and relations with other issues such as ecology. However, the role of landscape design seems to be not clear or considered to address the issues.
2) Local experts expressed concerns on the model of RES deployments and on the lack of planning tools failing to define suitable locations, to manage transformations as a globality and to control landscape change dynamics. The interviews with the experts offered a view on the context of the study and provided results in line with the ones pointed out by literature studies. However, a more in-depth understanding would be useful to determine the obstacles to adopt these tools.
3) Literature studies stress the role of landscape design in the energy transition. The concerns expressed on the energy planning tools can be addressed by including both spatial planning and design strategies, and by linking the energy targets with the landscape fragilities. According to the results of the public enquiry and the interviews with the experts, it seems that using a landscape-based approach in the planning tools could provide accepted landscape transformations. This paper provides a procedure to integrate such considerations into local energy spatial planning tools, considering strategies for selection of suitable sites and for improving the SPP design.

The findings of this study indicate that landscape considerations might be useful to include public perception in the energy transition processes, by informing site selection and SPP's architecture. Such insights can activate decision-makers to update and adapt planning tools for energy landscapes. The study draws from international studies, but its scope is framed by the context of the Spanish energy transition.

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CRediT authorship contribution statement

Anna Codemo: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Michela Ghislanzoni:** Writing – review & editing, Validation, Supervision, Methodology. **María-José Prados:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition. **Rossano Albatici:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition.

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