ENVIRONMENTAL RESEARCH
ENERGY

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OPEN ACCESS

RECEIVED
27 December 2025

REVISED
26 March 2026

ACCEPTED FOR PUBLICATION
31 March 2026

PUBLISHED
10 April 2026

PAPER

Stakeholder views of land conflicts in utility-scale solar energy: toward a spatial assessment tool

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Keywords: public perception, stakeholder participation, land-use conflict, conflict mapping, spatial assessment, solar PV power plants

Supplementary material for this article is available online

Abstract

Renewable energy sources (RESs) power plants, particularly solar photovoltaic (PV) infrastructure, are being deployed at an unprecedented scale to allow the transition to carbon neutrality. Rapid expansion of PV facilities cannot proceed without careful consideration of spatial planning and environmental impacts. Although social acceptance of RES is generally high, there is little consensus on where such plants should be located, as stakeholders perceive their impacts in diverse and often conflicting ways. This study aimed to (i) assess the spatial distribution of planned utility-scale solar power plants (SPP) in Portugal in relation to environmentally and culturally sensitive areas; (ii) analyse stakeholder perceptions of SPP impacts across different land uses and territorial settings; and (iii) develop an impact index that incorporates stakeholder information to classify PV projects by degree of impact. An online survey was conducted to examine perceived impacts associated with SPP development, and a classification methodology was designed using an additive aggregation method to produce a geographic information system-based index to classify projects. The questionnaire answers reveal substantial heterogeneity in individual preferences but also indicate intragroup convergence and intergroup divergence among stakeholder groups. The impact index provides a framework for classifying land-use conflicts related to large-scale solar projects and enables preliminary assessment of planned developments in relation to stakeholder alignment. These findings contribute to spatial energy planning by demonstrating how stakeholder perceptions of land-related impacts can be operationalised to inform siting decisions for RES plants.

1. Introduction

The energy transition, particularly electricity system decarbonisation, represents a paradigmatic shift with substantial spatial implications. The deployment of renewable energy sources (RES) systems, spanning raw material extraction through the installation of large-scale infrastructures such as photovoltaic (PV) solar power plants (SPP), has been associated with a wide range of impacts. The comparatively lower power density (W m^{-2}) of renewable technologies in relation to fossil fuels implies that a RES-dominated electricity system has a more extensive spatial footprint [1]. While energy system decarbonisation is frequently framed as widely supported within political and policy discourses [2], its spatial implications introduce major challenges [3].

A recurrently identified challenge for spatial energy planning concerns the siting of SPP and the associated spatial conflicts. Siting contexts, referring to the spatial configuration, environmental attributes, and regulatory conditions of project locations, may be evaluated in fundamentally different ways by distinct actors, with implications for project contestation, delay, or reframing. Stakeholder perceptions of

SPP are shaped by multiple characteristics, such as project scale, economic conditions, social dynamics, and the degree of local engagement [4, 5]. Considering that the siting context is a key factor influencing acceptance [6, 7], the assessment of perceived impacts across different locations by different actors remains crucial.

Despite the extensive research on public attitudes towards RES [8–12], comparatively limited attention has been paid to how distinct stakeholder groups attribute different levels of conflict to specific projects and locations, or how these different perceptions can be translated within systematic spatial assessments for informing planning. This gap is consequential, as siting outcomes are not determined solely by biophysical suitability or grid constraints, but also by socio-political processes through which some concerns are amplified while others are marginalised.

To address this gap, the present study incorporates stakeholder and citizen perceptions of utility-scale solar PV impacts across diverse land-use categories and territorial settings. This approach contributes to a better understanding of the spatial conflicts associated with solar energy deployment and enables the classification of planned PV projects according to perceived conflict intensity. Accordingly, the following research question is examined: To what extent do perceptions of utility-scale PV power plant siting vary across land-use and territorial contexts, and how can these perceptions be operationalised to inform a spatial assessment of planned projects?

2. Literature review

The spatial consequences of the energy transition extend beyond questions of technical feasibility to also encompass concerns about how landscapes are transformed, which communities bear costs, and which actors benefit. The siting of large-scale RES infrastructures involves land use changes and several socio-environmental impacts [13–18], while being conditioned by a complex set of spatial, environmental, and socio-political constraints, many of which are not codified within formal regulatory frameworks [19]. The selection of locations for deployment of SPP constitutes a multifactorial decision-making process, influenced by geographical determinants, including slope and solar radiation, technical determinants, such as proximity to the electricity grid, and policy determinants, notably financial incentives and spatial constraints [20–22]. Conventional planning systems may have limitations in adequately addressing the spatial conflicts of the energy transition [23, 24]. Identifying suitable locations for RES infrastructures and embedding spatial considerations into energy planning has increasingly gained prominence in European energy policy [25]. For instance, the RED III directive (Directive (EU) 2023/2413) introduces the concept of renewable acceleration areas (RAAs), intended to streamline permitting procedures and prioritise deployment in pre-designated zones where significant negative environmental impacts are not expected. Nevertheless, research by Kiesecker *et al* [26] suggests that achieving RES targets in several EU member states may necessitate development on high-conflict land cover types, given the limited availability of low-conflict alternatives. At present, no consensus exists regarding operational definitions of low- and high-conflict areas or appropriate spatialisation methodologies, reflecting ongoing tensions between expansion targets and territorial, environmental, and social considerations.

These tensions extend beyond technical and regulatory challenges, encompassing broader concerns regarding how the benefits and burdens of the energy transition are distributed across space. In this context, the siting of SPP has been linked to spatial energy justice concerns, in which distributive, procedural, and recognitional dimensions shape both the acceptability and the outcomes of the transition [27]. Recent scholarship highlights the influence of scale politics and spatial governance on interpretations of just transition pathways, including the privileging of particular stakeholder groups and territorial imaginaries within decision-making arenas [28]. These justice-related dimensions further indicate socially differentiated evaluations of siting contexts, suggesting that spatial outcomes emerge not only from technical and regulatory frameworks but also from how diverse actors perceive, negotiate, and contest the implications of project siting.

Therefore, social acceptance has emerged as a decisive factor in RES siting. Perceived impacts associated with SPP deployment, whether substantiated or not, have generated local resistance and opposition to large-scale projects, constituting a barrier to achieving RES targets. For instance, Susskind *et al* [11] show that numerous utility-scale RES projects in the United States have been delayed or blocked as a result of socially driven forms of opposition. In addition to environmental concerns, contestation has been linked to not-in-my-backyard sentiments and local disamenities, including perceived property value depreciation, landscape aesthetic degradation, limited community benefit distribution, and insufficient engagement processes [11, 29–31]. Understanding the roots of such opposition requires attention to how different stakeholders perceive and evaluate RES projects.

However, how different stakeholders may have divergent perceptions of SPP siting remains insufficiently explored. While existing contributions on siting criteria and public perception highlight the relevance of incorporating social dimensions into the planning and permitting processes [32–34], they tend to focus on general levels of public acceptance. Although studies indicate that attitudes towards solar energy are generally favourable, evidence suggests that large-scale projects are associated with greater resistance, particularly in situations where local impacts are perceived as negative [7, 11, 35]. Moreover, limited analytical attention has been given to understanding how divergent or antagonistic positions emerge in response to site selection and how perceived impacts translate into intensity of land-use conflicts. Some studies suggest that public opposition may lack empirical grounding, and heterogeneous support levels are influenced by the role of the actor and their level of knowledge [9, 36, 37]. This highlights the need for more systematic approaches capable of capturing and operationalising such divergences in the context of land allocation for RES infrastructure.

In this regard, methodological advances in RES land-use planning can be strengthened by integrating stakeholder perspectives through qualitative approaches operationalised within geographic information systems (GISs). Previous research has highlighted the potential of incorporating stakeholder perspectives to identify land-use conflicts and to map stakeholders' values [38, 39]. Within RES planning, such approaches have been applied to capture and spatialise community concerns. For example, Calvert and Jahns [40] employed participatory mapping in combination with survey- and focus-group-based sentiment analysis to examine community perceptions of RES projects, assessing how those concerns are reflected in space. González and Connell [41] have developed a decision-support tool to assess site suitability for RES infrastructure based on stakeholder-driven criteria. Similarly, Rösch & Fakharizadehshirazi [42] demonstrate that the integration of public input through mapping tools can inform decision-making on the siting of RES infrastructure, particularly in contexts characterised by high demand for land for agricultural production and nature conservation. Collectively, these contributions highlight the relevance of stakeholder inclusion; however, they tend to prioritise general public input, with comparatively limited attention to divergences in perception among distinct actors regarding specific siting contexts.

3. Data and methods

This section outlines the methodological framework adopted for assessing stakeholder perceptions regarding the siting of utility-scale (⩾1 Megawatt or MW) SPP in continental Portugal, as well as the operationalisation of these perceptions within an impact index for spatial conflict assessment. The methodology was structured in three sequential stages.

1. The first involved the design and implementation of an online questionnaire intended to elicit stakeholder perceptions regarding the impacts arising from the development of solar PV facilities;
2. The second stage involved collecting data on planned PV projects in Portugal and assessing their spatial distribution in relation to various spatial constraints, understood here as territorially explicit environmental, land-use, and socio-political factors that may limit, condition, or generate conflict around the siting of solar PV developments, and using the stakeholders' response to calculate an impact index. This assessment used a cumulative weighted approach based on stakeholder perceptions gathered in the first stage;
3. The third and final stage involved the application of the index to the evaluation of planned PV projects, thereby illustrating its potential use as a preliminary screening tool. This stage aimed to assess the potential of the index by testing it with a selection of randomly chosen projects, as well as with projects that have received media attention due to public opposition movements, legal actions, and related controversies.

Figure 1 provides an overview of the methodological workflow, illustrating the questionnaire structure, the impact rating scale, and the transformation of stakeholder responses into the frequency-weighted scores used for impact index construction. The figure summarises the two main questionnaire sections (respondent characterisation and perceived siting impacts), the six-point response scale applied to each spatial constraint, and the subsequent aggregation procedure through which individual ratings are converted into constraint-specific weighted indicators. These indicators are then spatially integrated with planned SPP geometries to derive project-level impact index values. This visual synthesis clarifies the methodological linkage between perception elicitation and spatial conflict assessment.

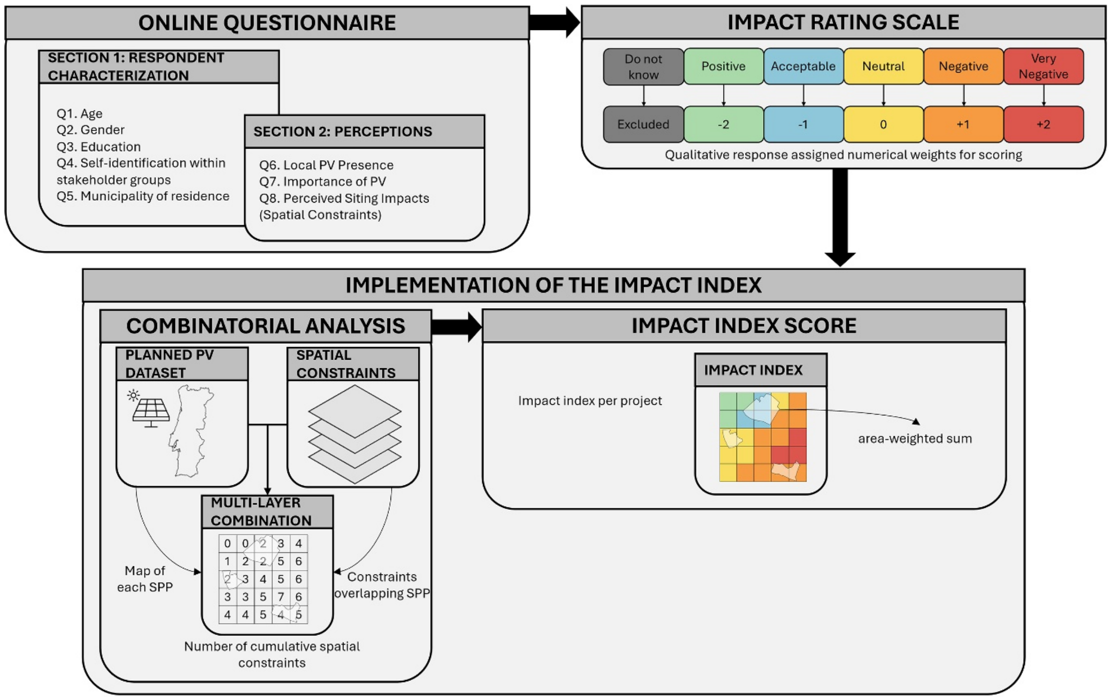

Figure 1. Overview of the methodological framework.

3.1. Case study justification

Portugal provides an illustrative case to study the perceived stakeholder impacts of SPP, owing to the ambitious policy targets for PV deployment and emerging siting conflicts. By the end of this decade, Portugal is expected to reach an installed solar PV capacity of 20.8 GW, of which 15.1 GW are utility-scale projects. The increase in installed capacity reflects efforts to decarbonise the national electricity system and to meet rising demand associated with electrification processes in general and, more particularly, the advancement of green industry in Portugal associated with the development of green hydrogen. In line with the hydrogen production targets set out in the EN-H2 National Hydrogen Strategy, electrolyser capacity of 3 GW is expected to be installed by 2030, with solar PV electricity serving as a key input to the production process. In this sense, SPP development is critical for electricity and green hydrogen production in Portugal.

However, resistance has similarly emerged around large-scale PV projects. Silva [43] demonstrates that, despite the generally high levels of public support for solar electricity, proposals for the construction of these facilities have increasingly provoked opposition from local actors and environmental organisations. The main drivers of contestation include perceived landscape degradation, procedural and distributive injustices, controversial siting decisions, insufficient public participation, and tensions with local economic activities and sociocultural identities [43–47]. Valquaresma *et al* [48] further observe that Portuguese newspaper discourse on the green transition mirrors far-right narratives, emphasising alleged elite capture and presenting transition outcomes as detrimental to taxpayers and rural communities.

Taken together, these dynamics position Portugal as an illustrative case for exploring the spatial and social dimensions of SPP deployment. The combination of ambitious expansion targets and locally contested projects creates a context in which understanding stakeholder perceptions becomes essential for interpreting how SPP siting is evaluated across different territorial settings. Moreover, these perceptions provide the basis for developing a systematic framework to translate local concerns and evaluations into spatial assessments of conflict potential.

3.2. Questionnaire on perceptions of the location of SPP

An online questionnaire disseminated via Google Forms was launched on 9 April 2025 during a debate on PV development in the Alentejo region in Portugal and remained open and disseminated until 30 May 2025. Questionnaire dissemination followed a chain-referral approach combining snowball and convenience sampling, whereby initial respondents were encouraged to circulate the questionnaire within professional and social networks.

The goal of the questionnaire was to assess the respondents' perceptions of SPP ($\geqslant$1 MW) location in continental Portugal. The questionnaire was composed of an introductory part, including a presentation of the objectives, an information sheet and a consent form, and two sections structured as follows: (1) characterisation of respondents; (2) perceptions of PV solar energy in continental Portugal and evaluation of siting impacts.

In the first section, participants were asked to provide information about their age range (Q1), gender (Q2), level of education (Q3), and their self-identification within a range of stakeholder groups (Q4), and the municipality of usual residence (Q5). In the second section, the survey inquired whether respondents' municipality of residence hosts any utility-scale PV SPP plants (Q6), and whether they perceived solar PV as playing a significant role in the national decarbonisation strategy (Q7). The final question asked respondents to evaluate the potential impact of utility-scale solar PV plants deployment across a range of territorial contexts, constraints, and land characteristics, by rating each item on a six-point scale from 'very negative impact' to 'positive impact', including a 'do not know' option (Q8). The Q8 covered a wide range of characteristics, including areas classified for nature conservation, environmentally sensitive areas, forest types, pastures and shrubland, cultural heritage sites, aquifer systems, agricultural and ecological reserves, and proximity to residential areas. For a full list of characteristics and their definitions, see table 1. To conclude, respondents were provided with the opportunity to offer any further observations or remarks.

The characteristics and settings considered were based on the main spatial constraints affecting the deployment of SPP in Portugal. These were identified through a dialogue that took place between 2022 and 2023 involving all national SPP permitting authorities, national RES promoters and main environmental non-governmental organisations (ENGOs) within a work group created to study the development of RAAs in Portugal. To assess the extent to which the various projects are situated within potentially sensitive or contentious areas, input was obtained from a range of stakeholders involved in the planning and permitting of RE developments. This input was used to inform the classification of such areas. Six different stakeholder groups were taken into account: ENGOs; PV developers; interested citizens; representatives of national, regional or municipal entities (public entities); academic or scientific research professionals, and agroforestry professionals. 'Interested citizens' are defined here as respondents without a formal professional or institutional affiliation to the sectors listed above, who participated in the survey in the context of broader public engagement with solar PV development.

3.3. Planned SPP database

The analysis employed a SPP database developed by Alves *et al* [49], representing a harmonised inventory of utility-scale PV SPP validated through remote sensing and photointerpretation techniques. The database integrates information from multiple national sources and was constructed through a combination of point-to-polygon conversion, satellite-based photointerpretation, and rule-based geometric correction procedures to delineate the effective land area occupied by each facility. Planned projects ($n = 99$, 7003 ha, $\bar{x} = 71$ ha) were identified as polygons lacking visible panel arrays but holding approved grid capacity reservation titles, indicating developments either pending environmental authorisation or authorised but not yet constructed, with status referenced to December 2024. For this study, only the subset corresponding to planned projects was retained, and the dataset was used primarily to provide spatial footprints for overlay analysis with territorial constraints and for subsequent impact index calculation. No additional project attributes were incorporated into the analytical framework.

3.4. Spatial constraints

Spatial constraints were conceptualised as territorial characteristics or land classifications where the deployment of utility-scale SPP may lead to potential negative environmental, social, or economic impacts. The legal status of the considered constraints varies, with some not constituting formal restrictions; nevertheless, most are considered in the process of environmental permitting of SPP projects within the framework of Environmental Impact Assessment (EIA) in Portugal. Constraint selection aimed to encompass a broad spectrum based on the major conflicts and land use changes reported in the literature on landscape transformations associated with SPP in Portugal [14, 43, 50]. Not all land characteristics asked on the questionnaire were operationalised as spatial constraints (table 1) for calculating the impact index (e.g. eucalyptus forests, pastures, and shrubland). Certain information has a confidential or non-public nature (e.g. protected species distribution maps) and, therefore, cannot be reproduced cartographically.

Table 1. Spatial constraints considered.

Name	Detail	Type of Constraint	Data Source
Areas Classified for Nature Conservation	Natural parks and reserves, protected areas, Natura 2000 sites, and geosites.	Strong constraint on SPP deployment	The Institute for Nature Conservation and Forests
Environmentally Sensitive Areas	Areas relevant for biodiversity conservation outside classified areas, but important for certain species (e.g. bird migratory routes, habitats of wolf or lynx, wetlands)	Not necessarily a legal restriction, although considered within the Environmental Impact Assessment framework	
Priority Areas for Forest Management	Areas subject to forest management plans, such as the Forest Regime and Forest Intervention Zones	Not necessarily a legal restriction, although considered within the Environmental Impact Assessment framework	
Montados and/or Chestnut Groves	Areas of cork oak, holm oak, oak and/or chestnut	Strong constraint on SPP deployment	Directorate-General for Territory
Cultural Heritage	Landscape heritage, Archaeological heritage areas and Classified heritage or sites under classification and respective administrative protection zones	Constraint according to heritage protection legislation	Directorate-General for Cultural Heritage
Proximity to Residential Areas	Residential and mixed-use buildings (including a 100 m buffer)	Not a legal restriction, although it may serve as a proxy for local opposition associated with NIMBY sentiments	Directorate-General for Territory
National Agricultural Reserve	Areas classified under the National Agricultural Reserve—non *aedificandi* zones that exhibit higher suitability for agricultural activity as a result of their agroclimatic, geomorphological, and pedological soil characteristics	Strong constraint on SPP deployment	Directorate-General for Territory
National Ecological Reserve	Areas classified under the National Ecological Reserve—biophysical structure encompassing a set of typologies that, due to their ecological value and sensitivity or their exposure and susceptibility to natural hazards, are subject to a special protection regime	Moderate constraint on SPP deployment	
Areas over groundwater reserves	Areas associated with groundwater recharge and aquifer protection, including karst systems, quartzite formations and granite outcrops	Not necessarily a legal restriction, although considered within the Environmental Impact Assessment framework	Portuguese Environment Agency and National Energy and Geology Laboratory

3.5. Frequency-weighted scoring

To integrate stakeholder perceptions into the spatial assessment, qualitative responses were converted into a quantitative indicator using a frequency-weighted scoring approach. This procedure transforms Likert-scale responses into numerical weights and computes an average impact score for each spatial constraint category.

Table 2. Numerical values assigned to each response category for the computation of the frequency-weighted score.

Response category	Numerical value (v_k)
Very negative impact	2
Negative impact	1
Neutral/No impact	0
Acceptable impact	−1
Positive impact	2
Do not know	No value assigned

Respondents evaluated each impact category using a six-point scale. The 'Do not know' responses were excluded from the calculation. The remaining categories were converted into numerical weights (v_k) as shown in table 2.

This coding scheme assigns positive values to negative perceptions (indicating higher perceived conflict) and negative values to positive perceptions (indicating lower perceived conflict). Neutral responses receive a value of zero.

For each spatial variable in table 1, the impact index score was calculated as:

$$\mathrm{Index}_i = \frac{\sum_{k=1}^{6}\left(n_{ik} x v_k\right)}{N}$$

where n_{ik} denotes the number of responses assigning the score k (ranging from 1 to 6) to variable i, and v_k represents the corresponding numerical value attributed to each response category, and N is the total number of responses for the variable. Higher positive values, therefore, indicate a stronger perceived impact associated with that spatial constraint.

This index aggregates the weighted scores of each response class, dividing by the total number of responses to obtain an average weighted score per respondent. This approach ensures that the indicator reflects both the distribution of responses and the relative importance of each class.

3.6. Implementation of the impact index

The frequency-weighted scoring approach was implemented within a GIS environment. To identify areas of conflict arising from multiple overlaps, a multi-layer intersection analysis was conducted, employing a combinatorial analysis algorithm to evaluate the cumulative intersections between the inventory of planned SPP and the spatial constraints at a 10 m pixel resolution for each project. The algorithm systematically generates all possible combinations of overlapping constraints for each pixel based on Boolean maps of SPP facilities and the spatial constraints. This approach provides a structured method for detecting areas where multiple constraints coincide. This enabled the spatial integration of stakeholder perceptions into a spatial dimension. Then, for each planned SPP polygon, the indicator was spatially overlaid with the relevant project geometries, and a score of the impact index was calculated for the entire project area. This calculation involved multiplying the project area by the sum of the weighted scores corresponding to the different intersection combinations identified within the project boundaries. This procedure enabled the attribution of a single, representative impact index score to each project polygon, thereby facilitating a comparative assessment of the stakeholder-perceived impacts between projects.

4. Results

The section presents the main empirical findings, beginning with sample characterisation. This is followed by an examination of perceptions regarding solar PV siting, both in general terms and with reference to specific land uses and categories of territorial settings across stakeholder groups. The analysis subsequently addresses the weighting of various factors based on the responses provided by participants, and the way these weightings inform the construction of the spatial impact index by testing its application with a number of SPP projects.

The results indicate broad recognition of solar PV's role in decarbonisation, alongside systematic divergence in perceived spatial impacts across stakeholder groups. Higher impact levels are generally attributed to ecologically and culturally protected contexts, whereas production-oriented landscapes, particularly eucalyptus forests, tend to be associated with lower, or even positive, perceived impacts.

Table 3. Summary of respondents' characteristics.

Variable	Category	Percentage (%)
Age	<40	25
	41–60	60
	>60	15
Gender	Female	54.1
	Male	45.4
	Other/prefer not to say	0.4
Education	Secondary	7
	Bachelor	39
	Master	41
	Other	0.5
Stakeholder group	Interested citizens	55
	Representatives of national, regional or municipal entities	16
	Academic or scientific research professionals	12
	Agroforestry professionals	3
	PV developers	5
	ENGOs	2

Stakeholder disaggregation reveals systematic intergroup divergence, with ENGOs and agroforestry professionals assigning higher impact scores, while PV developers consistently report lower values, indicating contrasting assessments of territorial sensitivity. Application of the index to planned projects suggests that impact intensity is more strongly related to constraint type than cumulative count, with greater stakeholder divergence observed for projects linked to documented public opposition. Planned projects were rated as having lower perceived impacts by PV developers, whereas ENGOs and agroforestry professionals assessed them as more impactful across nearly all categories.

4.1. Sample characterisation

This subsection presents the main characteristics of the survey sample, including demographic attributes, education levels, professional affiliations and geographical distribution. A total of 405 responses were obtained. Given that the questionnaire was disseminated via a chain-referral approach combining snowball and convenience sampling, as a non-probability approach, this strategy does not produce a statistically representative sample of the broader stakeholder populations involved in or affected by utility-scale PV development in Portugal. Accordingly, results should therefore be interpreted as perceptions and as group differences within the achieved sample rather than as population prevalence estimates. However, the sample size allows some reference to population-level metrics—for instance, assuming a 5% margin of error and a 95% confidence level with respect to the Portuguese population of 10 421 117 inhabitants (2021 census). However, this does not mitigate the limitations regarding stakeholder representativeness. Therefore, all descriptive statistics reported here provide a profile of the respondents rather than evidence of representativeness across the broader stakeholder population.

As detailed in figure S1 and summarised in table 3, the majority of respondents were aged 41–60. Gender distribution was roughly balanced, with 54.1% identifying as female. Most respondents had completed higher education, including 41% with a master's degree. In terms of stakeholder categorisation, over half were citizens with a personal interest in the topic followed by public entities.

In terms of the geographical distribution of respondents (table S1), a significant proportion reported residing in municipalities such as Lisbon (22%), Coimbra (8%), Almada (6%), Évora (5%), Cascais (5%), Oeiras (4%) and Porto (4%). In total, 83 municipalities were represented in the responses, with 37 municipalities represented by a single respondent. Nine respondents (2%) chose not to disclose their municipality of residence, and one respondent indicated living abroad, without specifying the country. Although responses were obtained from residents in only 83 of the 308 Portuguese municipalities, the distribution of respondents across these municipalities shows a strong correlation ($r = 0.72$) with the municipal population distribution—calculated using only municipalities with responses—which may be regarded as a reasonable approximation.

4.2. Perceptions of PV solar energy in Portugal

This subsection examines the perceptions of solar PV in Portugal, with particular emphasis on respondents' awareness of operating utility-scale facilities within their municipalities of residence, as well as their evaluation of the technology's contribution to the national decarbonisation strategy (figure S2). Awareness of the presence of such facilities was found to be uneven: 31% of respondents indicated that no such facility existed in their municipality, 37% reported uncertainty, and 32% acknowledged the presence of at least one facility.

Evaluation of the role of solar PV within the national decarbonisation agenda revealed a high degree of consensus regarding its significance. Only a small minority (2.5%) attributed low or negligible importance to the technology, whereas a substantial majority (93%) expressed positive evaluations, with 33% considering it important and 60% rating it as very important. A further 4% of respondents adopted a neutral stance.

4.2.1. Perceptions of land conflicts based on impacts

Impact perceptions across spatial constraints indicated that some variables elicited relatively consensual responses, whereas others produced more heterogeneous distributions in which no clear majority position could be identified (figure S3).

In the case of Areas Classified for Nature Conservation, 92% of responses reflected perceptions of very negative or negative impacts. A similar pattern was observed for Environmentally Sensitive Areas outside these classifications, but relevant for the conservation of specific fauna and flora species, with 85% of responses indicating very negative or negative impacts. Additional constraints, such as Priority Areas for Forest Management, Cultural Heritage sites, the National Agricultural Reserve, the National Ecological Reserve, Montados and/or Chestnut Groves, also registered more than two-thirds of responses attributing negative impacts.

By contrast, other spatial constraints did not demonstrate the same degree of consensus, with some even associated with perceived positive impacts. For instance, in the case of eucalyptus forests, although 35% of responses indicated very negative or negative impacts, the majority reflected neutral (21%), acceptable (22%) or positive (19%) evaluations. Further examples of divergence include Pastures and Shrubland areas, where responses revealed substantial dispersion and indicated disagreement among stakeholders regarding the degree of conflict associated with SPP. Similarly, Areas over groundwater reserves and Proximity to Residential Areas displayed some variation in responses, although the majority conveyed negative impact evaluations.

In sum, the consideration of all responses, without disaggregation by stakeholder type, suggests the existence of a broad convergence regarding the perception of high impacts of SPP deployment in Areas Classified for Nature Conservation, Environmentally Sensitive Areas, Montados and/or Chestnut Groves, the National Ecological Reserve, the National Agricultural Reserve, and areas of Cultural Heritage.
By contrast, the areas of Eucalyptus forests were identified as subject to the lowest impact due to the deployment of SPP, meaning the stakeholders perceive it as the least conflictual land use, a perception attributed to the comparatively lower level of impacts associated with them.

4.2.2. Perceptions of impacts according to stakeholder groups

The disaggregation of impact perceptions per stakeholder type reveals both commonalities and substantive differences. The results suggest considerable heterogeneity in individual preferences, while also indicating intragroup convergence and intergroup divergence across stakeholder groups. The six stakeholder groups considered were ENGOs, PV developers, interested citizens, public entities (representatives of national, regional or municipal entities), academic or scientific research professionals, and agroforestry professionals.

No significant variations in perceived impacts were observed across respondents' age groups or educational attainment levels, suggesting that stakeholder evaluations were largely homogeneous with respect to these demographic characteristics. In addition, the potential influence of respondents' municipalities hosting planned or operational PV projects was examined across all stakeholder groups. The analysis revealed no substantial differences in impact perceptions attributable to this factor, indicating that responses were largely consistent regardless of local project presence. In particular, the presence of PV projects within respondents' municipalities did not appear to significantly affect the evaluation of potential impacts across different land types and territorial contexts.

Overall, the analysis of figure 2 suggests that ENGOs perceive the highest proportion of very negative or negative impacts of SPP across most of the land uses and territorial settings. In eight out of twelve categories, ENGOs provided the largest share of responses indicating negative or highly negative impacts. It is also noteworthy that responses from this group indicating acceptable or positive impacts were limited, except for eucalyptus forest areas.

In contrast, PV developers appear to be the group demonstrating the most favourable view of potential impacts, registering the highest proportion of responses associated with acceptable or positive impacts. Within this group, very negative or negative perceptions were relatively infrequent in relation to

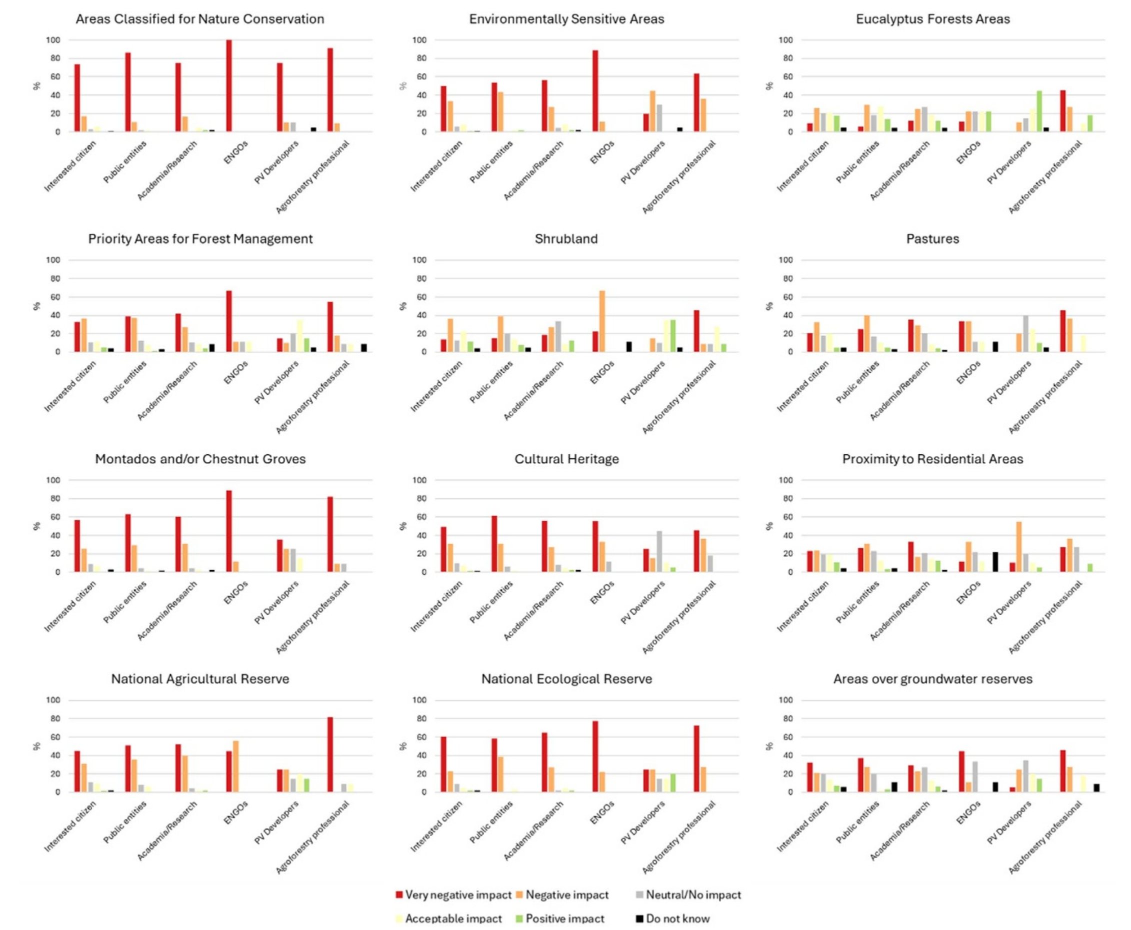

Figure 2. Respondents' evaluations of the potential impact of utility-scale solar photovoltaic developments.

eucalyptus forests, shrublands, and pastures. For example, acceptable or positive impacts accounted for approximately 70% of responses in eucalyptus forest and shrubland categories.

A high similarity can be observed in the distribution of responses between academia/research professionals and public entities, whose perceptions appear comparatively aligned. In some categories, agroforestry stakeholders also reported high proportions of very negative or negative impacts. In the case of eucalyptus forests, pastures, proximity to residential areas, and groundwater reserves, this group provided the highest proportion of negative or highly negative responses, higher than two-thirds of the total.

These findings indicate that even in categories where broad consensus was observed, substantial variability across stakeholder groups persists. Furthermore, in categories with more dispersed responses—such as eucalyptus forests, proximity to residential areas, and areas above groundwater reserves—the lack of intragroup consensus suggests internal divisions within stakeholder groups themselves.

4.3. The impact index: perceived impacts of solar energy siting

Resulting from substantial heterogeneity in individual preferences, but also suggesting intragroup convergence, the weighting process yields differing scores for the considered territorial dimensions. Figure 3 illustrates the weighting of the index and depicts the manner in which the differing stakeholder perceptions are reflected. Overall, areas classified for nature conservation and those under the National Ecological and Agricultural Reserves are consistently associated with higher perceived impacts across most stakeholder groups, suggesting these contexts are viewed as particularly sensitive to solar PV deployment. ENGOs and agroforestry professionals exhibit the highest average impact perceptions across nearly all categories, whereas PV developers systematically assign lower impact scores, often close to or below zero, particularly in Eucalyptus forest areas and shrublands.

Eucalyptus forest areas are identified as having the lowest perceived impact across all groups, with scores ranging from—1.1 among PV developers to 0.7 among agroforestry professionals. Conversely, areas classified for nature conservation register the highest perceived impact, reaching an index score of

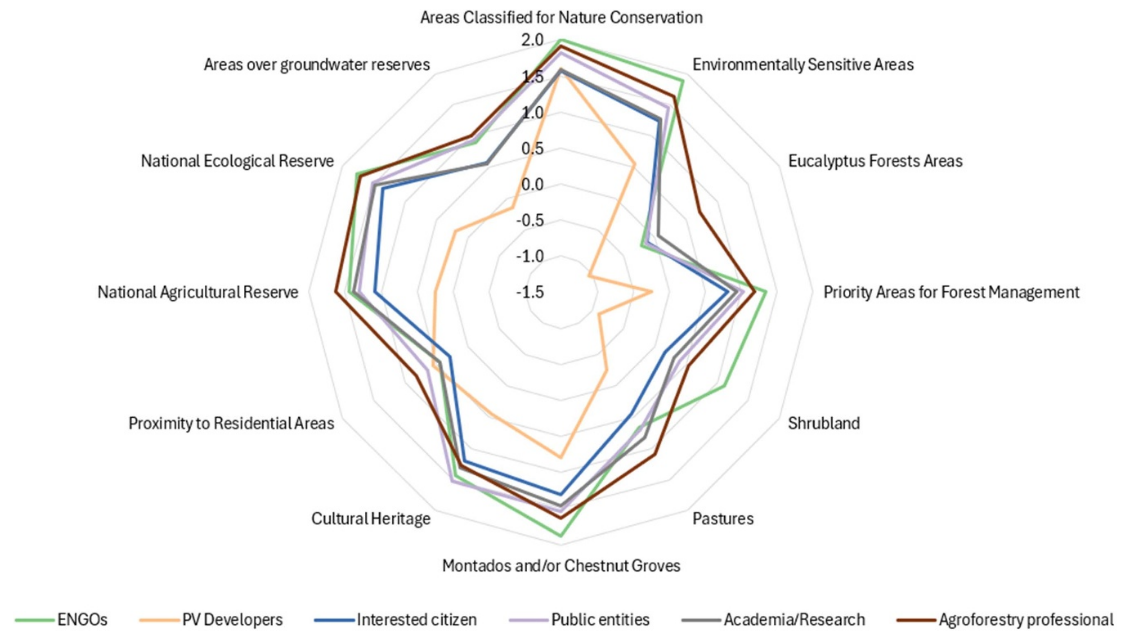

Figure 3. Radar chart illustrating the weighted scores assigned by stakeholder groups. The scores reflect variations in the perceived importance of each category, with higher positive scores indicating greater perceived negative impact and negative scores indicating a potentially positive impact.

2.0 according to ENGOs. Cultural heritage sites, environmentally sensitive areas, and montado or chestnut grove landscapes are also perceived as relatively high-conflict categories, particularly by ENGOs, public entities, and agroforestry representatives.

These results indicate the presence of considerable heterogeneity in perceptions of impact intensity, with evidence of intragroup convergence within ENGOs and agroforestry professionals and intergroup divergence between these and PV developers. The pattern suggests that land categories associated with ecological or cultural protection are more likely to elicit higher perceived impacts, whereas intensively managed or production-oriented landscapes tend to be perceived as less conflictual contexts for solar deployment.

4.3.1. Spatial assessment of planned projects

Combinatorial spatial analysis of multiple intersections (figure 4) indicates that only 7.2% of the 7000 ha included in the planned SPP database in continental Portugal is free from the assessed constraints. On the other hand, 41% intersect with at least one constraint, 39% with two constraints, and 12% with three constraints simultaneously. The area of projects intersecting with four or five constraints is residual, representing 1.3%, of which only 0.005% corresponds to the simultaneous presence of five constraints.

However, more significant than the number of constraints is the nature of the combinations identified. This is attributable to the findings in previous sections that certain areas exhibit a potentially higher level of conflict than others, given that different stakeholders attributed distinct degrees of perceived impacts. The ten most prevalent combinations identified account for approximately 81% of the total area of planned projects. Considering cases involving a single intersection, the predominant intersection in terms of area occurs with environmentally sensitive areas, followed by aquifer systems and classified areas. In relation to cases involving two cumulative intersections, the majority occur between environmentally sensitive areas and priority areas for forest management, which represent the spatial constraints occupying the largest extent within continental Portugal.

By obtaining responses from the different stakeholder groups and their subsequent harmonisation, it was possible to transform the cumulative information of the combinations into stakeholder-weighted scores. Therefore, assessing projects based on the impact index when examining the ten most frequent combinations, as shown in figure 5, becomes apparent that, according to the perceptions of ENGOs and the agroforestry sector, a larger proportion of project areas is associated with a higher degree of conflict, interpreted through their higher perceived impact. In contrast, according to PV developers, approximately 18% of the total SPP planned project area is identified as being associated with a positive impact (index < 0), and the negative index scores recorded are comparatively lower than those identified by

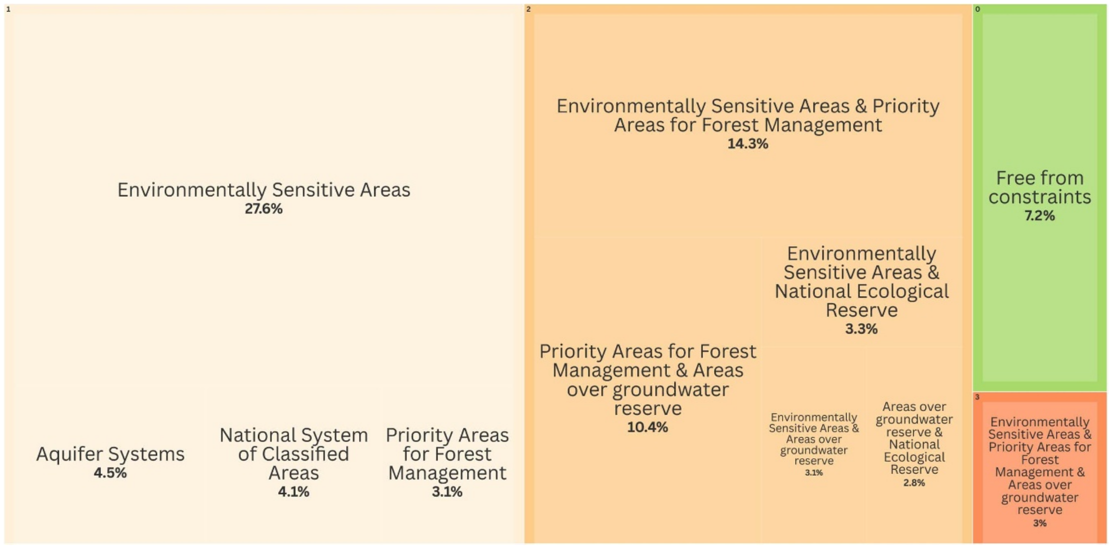

Figure 4. Area (%) of planned projects relative to intersected spatial constraints, considering the top ten combinations, plus area free from constraints (accounting for 83.3% of total planned area).

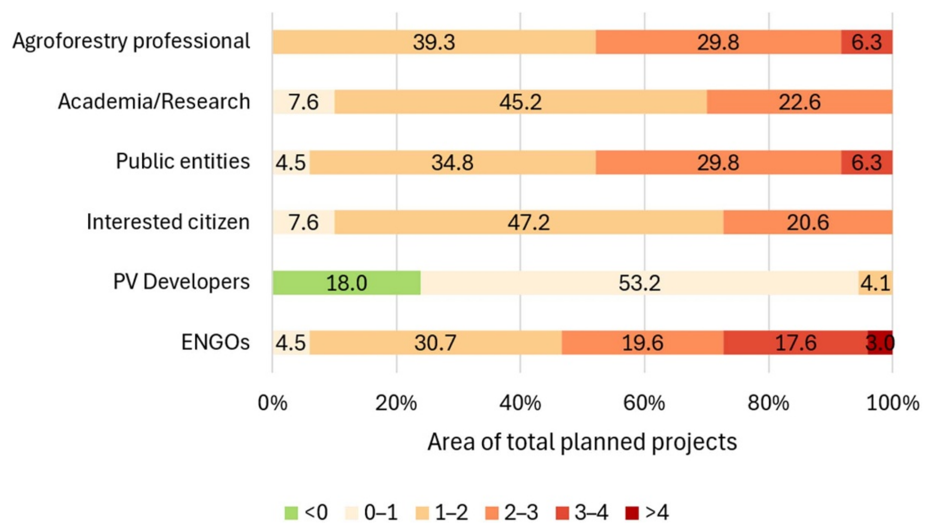

Figure 5. Negative Impact index classified per stakeholder group for planned SPP. Percentages are expressed relative to the combined area of the ten largest combinations, representing 76.1% of the total area of planned projects.

other stakeholder groups. The agroforestry sector is the only group with no scores within the 0–1 range of the impact index, similarly to ENGOs, whose perceptions reflect higher levels of perceived impact. Nevertheless, only ENGOs reported scores above 4, which represent approximately 3% of the total area of planned projects. According to ENGOs, only 4.5% of the project area is associated with low negative impacts (score 0–1). From the perspective of public entities, interested citizens, and academic stakeholders, the projects would receive a similar rating, although among these three groups, public entities appear to adopt the most restrictive stance.

Overall, the comparison across stakeholder groups indicates a considerable divergence in the perceived magnitude of impacts associated with planned SPP. This heterogeneity in perception highlights the need for planning approaches capable of reconciling contrasting stakeholder views in the assessment and siting of large-scale RES infrastructures.

4.3.2. Stakeholder-perceived impacts by projects

The application of the impact index as a spatial assessment tool enabled the attribution of a score to each project, derived from the area intersecting the various constraints relevant to each stakeholder group. The resulting project evaluations are presented in table 4. The findings indicate substantial

Table 4. Classification of PV projects by spatial constraints and stakeholder-derived impact index. The area in hectares corresponds to the layouts provided by the Directorate General for Energy and Geology (DGEG) as of December 2024, which reflect the project boundaries at the stage of the electrical permitting process. These geometries may not precisely represent the current extent of the projects, as subsequent revisions may have occurred. The highest score (greatest perception of negative impacts) in each project is identified in bold, and Δmax–min represents the difference between the highest and lowest stakeholder scores for each project, indicating the degree of divergence in perceived impacts.

Project details				Spatial constraints			Impact index						
Designation	Region	Area (ha)	Public contestation in the media	Total (n. °)	Cumulative (n. °)	Area w/o (%)	ENGOs	PV developers	Interested citizen	Public entities	Academia/ Research	Agroforestry professional	Δ max-min
Felgueiras	Norte	56	Not found	4	3	46	1.0	0.2	0.8	0.9	0.8	0.9	0.8
Mogadouro		270	Not found	3	3	0	**2.1**	1.6	1.6	1.9	1.6	2.0	0.4
Biscaia	Centro	144	Not found	2	1	96	**0.1**	0.03	0.04	0.05	0.04	0.1	0.03
Gavião		230	Yes [51]	5	5	0	**4.5**	0.3	2.9	3.8	3.1	4.2	4.2
Vale do Gaio	Lisbon metro area	101	Not found	4	3	0	**3.2**	0.3	2.1	2.5	2.2	2.8	2.9
Sabugueiro		72	Not found	3	3	0	**2.2**	0.01	1.6	2.1	1.7	2.3	2.2
Cercal/Fernando Pessoa	Alentejo	394	Yes [52]	5	4	0	**3.3**	0.3	2.1	2.6	2.3	2.9	3.0
Mértola		118	Not found	3	3	0	**5.4**	2.3	4.0	4.6	4.1	5.0	3.1
Foral	Algarve	95	Yes [53]	4	3	0	2.6	0.1	1.9	2.4	2.0	**2.7**	2.6
Pedras de Mocho		5	Not found	2	2	0	**3.7**	0.8	2.6	3.0	2.8	3.4	2.9

variation among stakeholders, particularly between ENGOs and PV developers, although certain projects exhibit relative proximity in their scores. Of the ten selected solar PV plants, three—Gavião, Cercal/Fernando Pessoa, and Foral—have been mentioned in national and regional media reports due to public opposition movements in different regions of the country (Centro, Alentejo, and Algarve, respectively).

The case of the Cercal project illustrates a pronounced divergence in stakeholder perceptions. The evaluation conducted by ENGOs yielded a score of 3.3 for potential negative impacts, whereas PV developers assigned a substantially lower score of 0.2. A comparable pattern is observable for the Gavião SPP, where the difference between maximum and minimum scores (Δmax–min) among these groups is even greater. Both projects have been subject to reports of public contestation in the media and litigation processes, either instigated by community organisations or by judicial authorities following the identification of non-compliance with environmental assessment procedures (see references in table 4). Although the Foral project obtained lower scores based on the constraints considered, records of local opposition have also been identified (see reference in table 4). Notably, this project constitutes the only case among those analysed individually in which agroforestry stakeholders attributed higher negative impact scores than other groups. The derived impact index, therefore, appears to reflect the presence of a contentious decision-making environment surrounding these projects, providing a basis for project screening according to the anticipated degree of controversy associated with specific spatial constraints.

Certain projects, however, achieved relatively high impact scores, suggesting potential controversy for some stakeholder groups, without corresponding evidence of public contestation in the media. Conversely, limited variation among stakeholder groups was observed in the Biscaia and Mogadouro SPP, where the intersecting spatial constraints correspond to dimensions perceived more uniformly, such as proximity to residential areas. These cases illustrate a high degree of convergence among stakeholder evaluations, resulting in low perceived negative impact and consistent scoring patterns across groups with Δmax–min values below 0.5.

It is also noteworthy that an increase in the number of intersected spatial constraints does not necessarily correspond to higher impact scores. A comparison between the Felgueiras and Mértola SPP indicates that certain constraint types were perceived as exerting minimal or even positive influence on project siting.

In general terms, the results suggest that PV developers tend to attribute lower impact scores to projects, whereas ENGOs and agroforestry professionals are more likely to associate particular territorial contexts with more significant negative impacts. When the cumulative number of spatial restrictions is also considered, a clearer pattern emerges: projects exhibiting both public opposition movements and the highest Δ among stakeholders—namely Gavião and Cercal/Fernando Pessoa—were also those intersecting the largest number of spatial constraints (five and four, respectively).

5. Discussion

This research article examined the perception of different stakeholders regarding the impacts associated with the deployment of utility-scale PV SPP across diverse land-use types and territorial contexts. Based on questionnaire responses, an impact index was developed through a weighting procedure to assess a set of planned projects in Portugal. Key contributions of this study include the systematic comparison of stakeholder-based impact perceptions and the development of a participatory indicator with potential relevance for spatial energy planning. This indicator may assist in the spatial assessment of planned projects at an early stage and appears to corroborate elevated perceived impacts in projects subject to legal disputes.

5.1. Stakeholder perceptions: patterns and divergences

The analysis indicated widespread recognition of the contribution of solar PV to Portugal's decarbonisation strategy, accompanied by evidence of heterogeneous perceptions of its impacts across different contexts. While positive evaluations were predominant, the results also demonstrated the persistence of perceived conflicts in relation to specific land uses and territorial categories.

A salient outcome concerned the association of conservation areas, montados and chestnut groves, cultural heritage sites, and the national agricultural and ecological reserves with negative evaluations of solar PV deployment. This tendency corresponds with previous research emphasising the relevance of biodiversity protection, cultural heritage preservation, and agricultural land safeguarding in RES siting processes [44, 54]. The identification of these areas as highly controversial suggests that opposition potential may be linked to the attribution of ecological, cultural, and productive scores to the landscape. In contrast, eucalyptus forests were perceived as comparatively less conflictual, which may reflect their characterisation as intensively managed and environmentally contested landscapes. In recent years, eucalyptus has been among the fastest-expanding tree species nationwide, frequently replacing traditional forest systems as documented by Alves *et al* [55]. This expansion has been largely driven by industrial forestry demand [56], and eucalyptus plantations are commonly associated with low biodiversity, reduced habitat heterogeneity, and increased wildfire exposure [57]. The variation in responses across land use categories thus demonstrates the differentiated valuation of landscapes, with implications for the anticipation and mitigation of spatial conflict in planning practices.

The disaggregation of results by stakeholder group highlighted marked differences in perceptions. ENGOs reported the highest proportion of negative evaluations, particularly concerning conservation and agroforestry areas. Developers of solar projects expressed more favourable positions, especially in relation to eucalyptus forests and shrublands, where management intensity and lower symbolic value may contribute to perceptions of reduced conflict. Public authorities and research professionals exhibited relatively similar distributions of responses, possibly reflecting the influence of regulatory frameworks and technical assessments. Agroforestry stakeholders provided particularly negative evaluations of solar deployment in productive landscapes, underscoring the importance of land-based economic activities in the formation of perceptions of conflict. Such intergroup divergence emphasises the role of institutional mandates, professional interests, and environmental commitments in shaping framings of RES expansion.

The explanation of these divergences may be related to differentiated prioritisation of objectives. The emphasis placed by ENGOs on nature biodiversity conservation and its recognition of natural values unknown to other stakeholders may have contributed to restrictive evaluations. Similarly, the agroforestry sector's attachment to the territory, especially its integration with the land's productive context, is likely to have produced a comparable effect. In opposition, the pursuit of economic feasibility and project implementation by developers may have shaped more permissive positions. The comparatively aligned responses of public authorities and academic professionals may reflect reliance on formal assessment criteria and governance frameworks. Internal divisions within certain groups, particularly in relation to eucalyptus forests, groundwater reserves, and proximity to residential areas, suggest the coexistence of competing priorities even within stakeholder categories, or in some cases result from insufficient knowledge or from the existence of inconclusive and sometimes conflicting scientific evidence on specific issues.

The more restrictive position demonstrated by ENGOs aligns with their publicly stated views on certain projects, as evidenced by their public communications [58–60]. Conversely, the comparatively less restrictive stance of PV developers does not necessarily imply insensitivity towards natural values and biodiversity conservation, as there are documented examples of SPP in Portugal that have incorporated nature-inclusive approaches [61].

Although the sample is biased towards highly educated and predominantly urban respondents, who may be more inclined to prioritise conservation and biodiversity over rural economic activities, sectoral variation indicates that livelihood-related perspectives are nevertheless partially represented. In particular, respondents from the agroforestry sector reported substantially higher perceived impacts for eucalyptus plantations and National Agricultural Reserve areas than other stakeholder groups, including environmental NGOs. Overall, these patterns suggest that, despite the educational skew, the inclusion of sector-specific viewpoints helps to attenuate this limitation and offers meaningful insight into divergent impact perceptions across stakeholder groups.

Taken together, these findings highlight that perceptions of solar PV deployment in Portugal are characterised by substantial heterogeneity both across and within stakeholder groups. While a broad consensus exists regarding the unsuitability of conservation and agroforestry areas for large-scale SPP, other contexts—such as eucalyptus forests, areas above groundwater reserves, and proximity to residential zones—reveal divergent views and limited intragroup agreement. Such divisions suggest that conflict perceptions may not solely derive from stakeholder position or institutional affiliation, but also from differing interpretations of available evidence and varying degrees of familiarity with the environmental and technical implications of solar infrastructure. The coexistence of contrasting views within individual stakeholder categories points to the need for further clarification and dissemination of scientific knowledge on the local environmental effects of solar energy development, particularly in domains where empirical research remains inconclusive or contested.

5.2. Relevance and practical applications of the impact index

The findings suggest that the proposed impact index could support the systematic assessment of project conflict potential, thereby informing decision-making processes. In the context of territory-based energy planning in Portugal, the constructed spatial index contributes to ongoing discussions regarding areas perceived as less sensitive to the deployment of solar projects. The results underscore the inherent difficulty of achieving consensus on which land types may be considered more or less suitable for such developments. The found divergence in stakeholder perceptions, particularly regarding agroforestry areas, eucalyptus forests, and sites above groundwater reserves, illustrates the challenge of establishing a shared understanding of what constitutes a controversial or acceptable location. This is consistent with previous literature highlighting the coexistence of competing expectations and value framings in renewable energy siting, where conflicts frequently emerge from the intersection of environmental protection, local development aspirations, and national decarbonisation objectives [11, 62–64].

The heterogeneity of perceptions revealed in this study suggests that identifying low-conflict zones cannot rely solely on technical or regulatory criteria, but must also account for social acceptability and context-specific sensitivities. In this regard, the proposed index may serve as a decision-support tool for public authorities and project developers in preliminary site assessments. By integrating stakeholder-based perceptions of conflict, the index provides an additional layer of information that can assist in anticipating potential social or environmental opposition before the formal EIA stage. Such anticipatory use could improve transparency in project planning and support the alignment of renewable energy deployment with spatial planning objectives, and assist both public authorities and project developers in preliminary evaluations of project locations, particularly by identifying sites where perceived impacts may be higher among certain segments of the population.

The findings also raise questions regarding the drivers underlying the current geography of solar development in Portugal. Few projects were located within the areas identified as low-conflict or acceleration zones. This pattern may indicate that siting decisions are predominantly influenced by techno-economic considerations—such as grid proximity, land cost, or solar resource potential—rather than by environmental or social sensitivity. Such interpretation aligns with prior research evidencing the dominance of techno-economic rationales in large-scale renewable infrastructure deployment [65]. Nevertheless, a lack of awareness among developers regarding environmental or regulatory constraints cannot be excluded, a limitation that may be exacerbated by restricted access to biodiversity data or by incomplete fieldwork during EIAs. Under such conditions, proposed projects may initially overlap with protected or sensitive areas, with subsequent compliance adjustments negotiated throughout the EIA process.

The methodology constitutes a participatory approach, and its application should be viewed as complementary rather than substitutive of existing assessment tools, given that perceptions are inherently context-dependent and may evolve as public awareness and regulatory frameworks change. Yet it is also noteworthy that the two projects in table 4 exhibiting the highest levels of perceived conflict (i.e. those with the largest Δ max–min scores) correspond to cases currently under judicial dispute. In particular, the SPP proposed for Cercal do Alentejo has been legally challenged by the civic movement 'Juntos pelo Cercal do Alentejo', which has contested its environmental approval and planning procedures [45]. These cases provide empirical confirmation that the index effectively captures significantly negative perceptions associated with contested projects, thereby demonstrating its capacity to reflect perceived conflict intensity in a meaningful way.

Certain projects classified by the impact index as exhibiting high impact scores do not appear to have generated public contestation in the media. It should be noted that contestation regarding specific projects may be influenced by factors such as the project size, the structure of public participation, proximity of the infrastructure to population centres and perceived inequitable power relations and injustice [4, 45, 66, 67]. Furthermore, there exists the possibility that some projects remain largely unknown to the public or have not attracted media attention due to the challenges associated with community organisation. Media reporting constitutes an imperfect proxy for conflict, and projects may be situated at different procedural stages, with contestation often emerging at specific decision-making moments. In other cases, public opposition may be insufficiently substantiated [9] or the translation of perceptual divergence into overt opposition is likely mediated by contextual factors such as the structure and perceived fairness of participation procedures, negotiated compensation mechanisms, community benefit arrangements, landowner support, and local political alignments. In this sense, a high Δ score should be interpreted as an indicator of potential contestability, rather than as a direct predictor of observed mobilisation or media visibility.

While the present study focuses on utility-scale solar PV deployment in Portugal, the methodology underpinning the Impact Index is potentially transferable to other national or regional contexts. The specific spatial constraints and environmental considerations used here reflect Portuguese legislation and landscape characteristics. However, the core approach of integrating planned project footprints with spatial indicators and stakeholder-weighted impact scores can be adapted by selecting locally relevant constraints and context-specific data sources. Consequently, the key contribution lies in the methodological framework rather than the particular variables applied or the projects analysed, offering a template for early-stage assessment of potential social and environmental conflicts associated with renewable energy projects beyond the Portuguese case.

5.3. Limitations and directions for future research

This research is subject to several limitations concerning sampling, data sources, and methodological design. Although the survey produced a statistically significant sample size in relation to the Portuguese population, the recruitment strategy—based on a chain-referral approach combining snowball and convenience sampling—introduces the possibility of bias. More than 90% of respondents reported having completed higher education, a figure considerably above the national average, which suggests a bias towards more highly educated groups and limited representation of rural or marginalised communities, where the impacts of large-scale infrastructures are often more acutely experienced. Furthermore, the municipal distribution of responses, although positively correlated with population distribution, did not cover all regions of the country, which may have constrained the capacity of the survey to reflect territorial diversity.

The reliance on self-reported perceptions represents an additional limitation, as responses may not always reflect detailed knowledge of specific environmental impacts or planning constraints. For example, issues such as SPP impacts on aquifer systems or the importance of unclassified biodiversity areas may not be fully understood by all stakeholders, thereby introducing subjectivity into the evaluation of impact levels. Moreover, the assignment of weights to conflict criteria was based on perceived relevance, which implies a judgement of 'expertise' that not all respondents necessarily possessed. As argued in the literature, perceptions are shaped by a combination of emotional and rational factors rather than by technical expertise alone [4, 32, 68]. This characteristic should be considered when interpreting the robustness of the weighting process and its translation into impact indices. It is also important to note that the present findings refer exclusively to centralised, utility-scale systems, and therefore do not address perceived impacts associated with small-scale or microgeneration installations, typically occupying areas below one hectare.

Another important limitation concerns the correspondence between the polygons of solar projects as provided by the Directorate-General for Energy and Geology (DGEG) and their actual on-site implementation. Throughout the various stages of the permitting process—whether under the scope of EIA or municipal planning procedures—project designs may undergo modifications to ensure compliance with land management regulations and environmental legislation. Consequently, the spatial configurations and locations identified in the available datasets may not fully represent the final characteristics of the installations (e.g. [69]). The detection of high-impact areas within planned projects, therefore, does not necessarily imply that such configurations will materialise as currently delineated. Moreover, it should be acknowledged that some projects may not ultimately be implemented, either due to permitting constraints or environmental incompatibilities.

Future research could address these limitations through several strategies. Comparative case studies across regions and countries may provide insights into the extent to which identified patterns are specific to the Portuguese context or more widely applicable. Longitudinal studies could investigate the evolution of perceptions over time as solar deployment progresses and as planning frameworks adapt. The refinement of the conflict index through the integration of additional geospatial modelling approaches could enhance its role as a decision-support instrument, and its integration with formal spatial planning instruments should be investigated. Furthermore, the investigation of non-environmental drivers—such as economic incentives, grid constraints, and land ownership patterns—could contribute to a more comprehensive understanding of solar siting dynamics. The recognition that site selection represents only one dimension of socially acceptable solar development [32] also indicates the need for broader research agendas encompassing governance arrangements, benefit-sharing mechanisms, and landscape integration strategies.

Another direction for developing further research, expanding the application of the impact index, would be experimenting with variable weights within the index to reflect power dynamics felt among different stakeholder groups. Power asymmetries, media visibility, and/or policy influence shape SPP location decisions and determine spatial injustices and procedural inequities. On the other hand, prior community negotiations, compensation mechanisms, or procedural transparency (all of which are not captured by the impact index) can substantially shape public acceptance and lower public opposition. An interesting further avenue of research would entail exploring to what extent these 'real-world' power dynamics could be reflected in the impact index for the different stakeholder groups, since they do not always have the same negotiation power.

6. Conclusions

The study highlights the coexistence that, despite the broad consensus among respondents regarding the strategic importance of solar PV for decarbonisation, disagreement persisted on the issue of siting, particularly across stakeholder groups. While areas such as nature conservation zones or cultural heritage sites were consistently identified as 'no-go areas' due to perceived negative impacts by stakeholders, other categories, including shrublands or groundwater reserves, revealed dispersed responses and the absence of intragroup consensus. Such divergence underscores the complexity of stakeholder heterogeneity and the challenge of developing universally accepted planning frameworks.

A key contribution of this research is the development of a participatory impact index, which systematically integrates stakeholder perceptions and captures both intergroup divergence and intragroup variability, providing a more nuanced understanding of potential social and ecological tensions associated with solar PV projects. This method enables the translation of qualitative survey responses into a quantifiable metric, thereby complementing the spatial analysis by incorporating perceived impacts. The indicator shows both the intensity and relative importance of the impacts as expressed by respondents, forming a crucial component in the estimation of a comprehensive spatial conflict index. Conceptually, the findings illustrate that perceived conflict arises not solely from the physical characteristics of sites but from value-laden interpretations of landscapes shaped by institutional mandates, professional interests, and local attachments. This has important implications for the literature on social acceptance of RE, highlighting the need to consider the heterogeneity of stakeholder framings in planning decisions.

The application of the impact index highlights that perceived impact intensity relates more strongly to the type of constraint than to its cumulative count. Notably, stakeholder divergence is greatest in projects associated with public opposition, with PV developers assigning lower impact scores and ENGOs and agroforestry professionals rating them as significantly more impactful across nearly all categories. The results hold implications for both theory and practice. Theoretically, the findings contribute to the literature on social acceptance of RES by illustrating the importance of landscape-specific perceptions and the heterogeneity of stakeholder framings. From a practical perspective, the impact index offers a tool for anticipatory planning, enabling decision-makers to identify high-conflict zones at an early stage of project siting. By incorporating social perceptions alongside technical and environmental criteria, the index can inform site selection, enhance transparency, and contribute to more participatory and legitimate planning processes. In addition, the integration of social perceptions into decision-making frameworks may enhance the legitimacy and durability of planning outcomes, as it acknowledges local values and concerns in parallel with technical and economic considerations.

The incorporation of these findings into spatial energy planning policies could improve the capacity of planning the spatial dimension of decarbonisation to account for social and ecological sensitivities. Explicit recognition of stakeholder perceptions in siting procedures may reduce land-use conflicts and improve social acceptance, contributing to more balanced trade-offs between RES deployment and land-use management. Such an approach requires the articulation of planning instruments with mechanisms for public participation, ensuring that the diversity of stakeholder perspectives is not only recorded but also meaningfully integrated into energy planning decision-making.

Acknowledgments

The authors gratefully acknowledge Paula Oliveira and Juliana Barbosa for their support in preparing the data on spatial constraints, and Elaine Santos for her valuable contribution to the design of the questionnaire. André Alves acknowledges the Portuguese Foundation for Science and Technology (FCT I.P.) for funding his doctoral scholarship through the MIT Portugal Programme (PRT/BD/154418/2023), and the support from the MOPT Research Group of the Centre of Geographical Studies, University of Lisbon, funded by FCT (UID/00295/2025, https://doi.org/10.54499/UID/00295/2025).

Data availability statement

The data cannot be made publicly available upon publication due to legal restrictions preventing unrestricted public distribution. The data that support the findings of this study are available upon reasonable request from the authors.

Supplementary data available at https://doi.org/10.1088/2753-3751/ae5969/data1.

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