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# Assessing the social perception of agrivoltaic systems in vineyards. A case study of an integrated trellis-based configuration in South-eastern Spain

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ABSTRACT

Sustainable development is a key priority in addressing global challenges such as climate change and land degradation. In South-eastern Spain, the Murcia Region stands out for its agricultural significance and its exceptional potential for solar energy generation, owing to its semi-arid climate and high solar irradiance. However, the rapid deployment of ground-mounted photovoltaic systems has intensified competition for agricultural land, positioning agrivoltaics systems as a promising dual-use solution. This study explores the attitudes of wine tourists towards vertically integrated low-height agrivoltaics systems in vineyards, a sector of major economic and cultural relevance in the region. The methodology consisted of guided visits to pilot low-height vertically integrated agrivoltaics systems installed in vineyard trellises at several wineries, followed by administration of a structured ethically reviewed questionnaire. Statistical analysis reveals a predominantly positive social perception of agrivoltaics systems in vineyards, emphasising support for dual land use and a preference for the low-height system integrated into the trellises, due to its greater harmony with the wine-growing landscape. Differences in perception by gender, educational level and environmental awareness suggests the need for differentiated communication strategies in case actions are taken to further increase the favorable social perception observed. Overall, findings position agrivoltaics as a viable solution for reconciling agricultural and energy production in a context of climate change and resource scarcity.

## 1. Introduction

Sustainable development has become a firmly established concept in the global agenda [1] as a key tool to address major global challenges such as climate change, biodiversity loss and environmental degradation. The exponential growth in global energy demand, coupled with the urgency to mitigate climate change, has fuelled an unprecedented shift toward renewable energy sources [2]. The European Union, under the Green Deal framework, aims for a 55% reduction in greenhouse gas emissions by 2030 and climate neutrality by 2050 [3].

Within this framework, photovoltaic (PV) systems are among the fastest-deploying technologies. However, conventional ground-mounted PV systems (GM-PVS), which maximize energy output per unit of land, increasingly compete with agricultural uses, contributing to land-use conflicts and rural depopulation [4]. To address this, agrivoltaics (AV), or agri-PV, has emerged as a promising solution allowing the simultaneous use of land for solar energy and agricultural production, and therefore reconcile energy needs with sustainable agricultural practices [5].

Agrivoltaics systems (AVS), initially proposed by Goetzberger & Zastrow [6] and later implemented by Nagashima [7] , showed from their initial development stages a potential to enhance land productivity and sustainability [8]. For example, Dupraz et al.[9], and Marrou et al. [10] highlighted their ability to retain soil moisture, reduce heat stress and generate additional income for farmers. Many implementations have been carried out across the globe, featuring considerable

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differences in system design and regulatory approaches, influenced by the types of crops being cultivated [11]. In consequence, a key challenge in AVS research and market development lies in accurately forecasting agricultural and energy outputs before installation. This matter has become more prominent with the recent introduction of new standards, regulations, and guidelines for AVS across different regions [12]. Innovative solutions able to maximize a sustainable dual use of land are needed in the incoming future [13]. Within this framework, regions like the Spanish Mediterranean, where agriculture is a fundamental economic pillar and climate conditions are highly favourable for photovoltaic energy production, constitute a benchmark for AVS assessment [14].

In order to secure AVS viability, the system design must be adapted to crop type, regional climate, and solar geometry. Crop sensitivity to shading shows marked differences: most crops experience growth inhibition under excessive shading, particularly above 50% panel coverage [15], while percentages of shade just above 15% were found to negatively affect quality of tomatoes inside greenhouses of Almería (Spain) [16]. On the other side, certain crops like spinach or strawberries tolerate or even benefit from moderate shading. Therefore, optimal configurations must balance light distribution and energy yield by tailoring panel height, spacing and tilt.

Within this context, vineyards represent a largely unexplored but ideal candidate for AV integration due to their trellised structure, distance between vine lines and tolerance to moderate shade. Different studies 17,18 explored PV deployment in vineyards, but lacked in-depth biological analysis or required elevated, costly structures. In an experimental AVS overhead installation settled in Piolenc (France), it was observed that vines located under the structure were more resistant to heat waves, preventing them from slowdowns in development and favouring less evapotranspiration. This reduced the need for water by 12-34%, and improved grape profile, with an increase of 9-14% in acidity and 13% in anthocyanins [19]. To improve on those previous experiences, vertical PV panels mounted directly on trellises as an alternative low-cost, low-impact strategy has been proposed [20]. This configuration minimizes structural materials, cost, and land disturbance while maintaining crop yield. Simulations carried out in south-eastern Spain, showed that when the row spacing to trellis height ratio is $\geq$1.5, mutual shading was minimized and vertical PV panels up to 0.6 m above vines can be installed with negligible annual irradiation loss. In consequence, this configuration allowed for 40–60% of the installable capacity of a GM-PV system, with a Land Equivalent Ratio (LER) between 1.27 and 1.50. LER is a commonly used indicator in AVS, which is defined as:

$$LER = \frac{Y_{agri-APV}}{Y_{agri}} + \frac{Y_{APV}}{Y_{PV}}$$

where $Y_{agri}$ denotes agricultural yield in a single use of land and $Y_{agri\text{-}APV}$ refers to the yield in an AVS for the same area unit. $Y_{PV}$ indicates energy production under a standard PV system assumption, while $Y_{APV}$ represents the energy production of the AVS.

Social acceptance of AVS is increasingly recognized as a key factor for their large-scale implementation. While technical and environmental aspects are well documented, the social dimension, particularly in rural and protected landscapes, still presents significant challenges. Public opposition tends to be lower for small-scale and rooftop PV projects, while GM-PVS often face resistance due to concerns over landscape transformation, biodiversity loss, and fairness in land use [21]. Compared to GM-PVS, AVS are perceived more positively as they maintain dual land functionality and offer climate adaptation benefits. Surveys and interviews in Germany, Belgium and Denmark highlighted that local stakeholder generally prefers AVS over GM-PVS, particularly when AVS are seen as contributors to food production, biodiversity protection, and equitable economic returns [21]. Nevertheless, concerns persist regarding their visual impact, long-term land viability, and the adequacy of policy frameworks supporting participatory planning.

In summary, while AVS holds substantial potential for reconciling energy and food production, their societal viability depends on thoughtful design, stakeholder inclusion (winegrowers, winemakers, wine tourists and energy producers), and region-specific governance that ensures both environmental integrity and local acceptance. Considering the critical role of public perception in the future AVS deployment, this study seeks to contribute to a better understanding of that perception. Specifically, it explores wine tourists' perceptions of low-height AVS in vineyards of the Murcia Region, where wine production and tourism are significant regional economic contributors. In particular, it investigates how visitors assess the coexistence of photovoltaic panels within the vineyard landscape, and their preferences over low-height integrated trellis-based configuration AVS.

## 2. Literature review

In relation to the general social aspects affecting the implementation of AVS, a recent study conducted in the United States of America [22] stressed the importance of integrating the three dimensions of social acceptance (market, community, and policy). This integration is essential to ensure the successful deployment of AVS projects. In Germany, more specific critical social dimensions, such as territorial justice and citizen participation, have been emphasized [23] underscoring the need to incorporate participatory processes from early stages to reduce resistance to AVS implementation.

Several studies have identified barriers perceived by farmers for the AVS implementation, including administrative, technical and financial [24]. In USA, such barriers were mainly reported as concerns over long-term land productivity, market potential and fair compensation. They also included the need for predesigned system flexibility to accommodate different scales, farming types and evolving agricultural practices. Administrative barriers were also documented in Turkey, where early-adopting farmers expressed positive attitudes towards AVS but strong distrust in regulatory frameworks and administrative procedures [25]. Moreover, excessive bureaucracy and vague regulations were seen in Germany as greater deterrents than scepticism toward the technology itself [26]. Technical barriers have been noted in Germany, Belgium and Denmark, due to the perceived technical complexity and lack of familiarity with the technology [27]. From a financial perspective, risks of smallholder exclusion in projects dominated by large investors in China have been highlighted, raising structural tensions and instances of social resistance within rural communities [28].

Policy attention to the siting and design of AVS in the landscape is needed to positively influence social acceptance [29]. Therefore, the success of AVS needs a complex equilibrium among agriculture, energy production, ecology and landscape. As concluded for the case of Germany [21] from a conservationist perspective, the agricultural and ecological compatibility of AVS is key to acceptance in rural settings. Then, in regions where agricultural activities are already established, such as vineyards, the design of an AV power plant would be expected to align with the prevailing landscape configurations as [29] deduced from its study in the Netherlands. Hence, low-height AVS allow a better integration in the established landscape minimizing visual impacts and crop disruption. On the contrary, overhead AVS has a spatial configuration that may lead to more lasting transformations in the landscape and, in consequence, more likely to incite local opposition [30]. This aspect was confirmed In Netherlands [31] where it was observed that AVS type (e.g., interspaced vs. suspended) significantly affects aesthetic perception and landscape value.

Regarding the evaluation of the social perception towards AVS implementation in vineyards, a recent study within Alicante wine Protected Designation of Origin (PDO) in Spain reveals that 64.8% of respondents support the integration of grapevines with photovoltaic panels on the same land. However, this support is contingent upon specific limitations in the design and use of such systems, aimed at

preserving the traditional wine-growing landscape as much as possible. Notably, this combined approach is regarded as more environmentally sustainable than either monoculture viticulture or standalone photovoltaic installations [32].

From a broader perspective [33] procedural justice, transparency, and community involvement have been emphasized for increasing AVS acceptance and identified as key factors influencing positive perceptions, the trust in developers, the alignment with regional interests and the visible local benefits. Moreover, the presence of ecological standards and the ability of AVS to support biodiversity—such as providing pollinator habitats—may enhance public approval, especially when integrated with conservation goals. Also, useful perspectives to improve the AVS implementation using media and expert discourses have been proposed [34].

## 3. Methodology

The case study is focused in the Murcia Region, an administrative division of Spain located in the southeast of the country, with a semi-arid climate and abundant solar radiation, making it an ideal setting for the development of both agriculture and photovoltaic initiatives. More than 2700 annual insolation hours place Murcia Region predominantly in a BW (arid-desert) climate according to Köppen-Geiger classification ensuring a global daily average solar radiation over 5 kWh/m$^2$ and a solar annual radiation over 1,826 kWh/m$^2$ [35,36]. Murcia Region has a population of 1,568,492 inhabitants [37] and an area of 11,314 km$^2$, giving a population density of 139 inhabitants/km$^2$. Its economy is based on agriculture, industry, and construction, but tourism has increased its importance, being United Kingdom and France visitors the main ones [38]. Although representing just 2.2% of Spain's total land area, it contributes an impressive 20% of the country's fruit and vegetable exports [39]. Internationally renowned for its high-quality produce, the region benefits from a long-standing agricultural tradition, climatic favourable conditions for farming, and the use of cutting-edge agri-tech innovation. The wine sector plays a pivotal role in the regional economy, not only in terms of agricultural output but also through its significant contribution to employment, rural development and wine tourism [40]. Murcia Region's wine production, supported by its three PDOs of Jumilla, Bullas and Yecla, generates considerable economic value, with wine exports accounting for a substantial portion of the agri-food sector's revenue. Viticulture in Murcia Region comprises 20,918 hectares of vineyard (half of them under PDO [41] producing 64,188 tonnes of grape and 757,484 hectolitres of wine, with annual exporting revenues around 157 million euros [42].

### 3.1. Research objective and application

The main objective of this study is to assess the opinion of wine tourists in Murcia region about AVS in vineyards, focusing on the use of a specific PV system which is integrated in the trellises structure. Four pilot AVS, installed in several locations in Murcia Region, were used in the study (Fig. 1). These AVS represent low-height vertically integrated configurations with PV panels placed above the trellis vineyard from 1.8 to 2.4 m height.

Pilot installations were located in Carchelo and BSI wineries in PDO Jumilla, Evine winery in PDO Yecla and Tomás Ferro agri-food




**Fig. 1.** Pilot installations of low-height trellis-integrated AVS, located in Murcia Region: Carchelo and BSI wineries (PDO Jumilla), Evine winery (PDO Yecla) and Tomás Ferro agri-food experimental station (Cartagena).

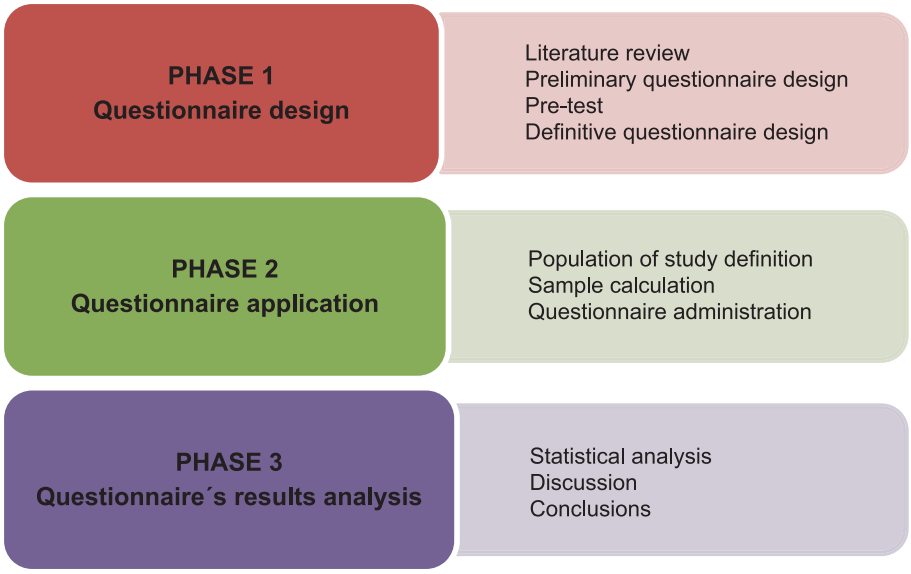



**Fig. 2.** Contextual factors, methodological approach and analytical dimensions considered for the research model to guide the case study.

experimental station at the Technical University of Cartagena (Fig. 1). Wine tourists participated in guided tours through the pilot installations under evaluation. These tours included explanations of AVS along with their potential advantages and drawbacks. Following the visits, participants were invited to complete a survey.

Besides the main objective, the investigation aims to find if there are statistically significant differences among groups of people segmented by sociodemographic data: gender, age, educational level, income, residence and environmental awareness.

The research model applied to the case study conducted in the Murcia Region is illustrated in Fig. 2.

### 3.2. Survey design and sampling

A structured and anonymous questionnaire was designed for data collection using Google Forms. This questionnaire was validated by the Experimental Research Ethics Committee of the Responsible Research Office at Miguel Hernández University, the public research body involved in this phase, in compliance with the regulations governing the development of experimental procedures. Authorization code NA. IAN.240309 guarantee that the research activity was carried out within an appropriate ethical, safe and legal framework.

The questionnaire was available in Spanish and English, to accommodate both local and foreign visitors to the Region of Murcia.

The form was divided in four sections using two types of questions: 5-point Likert scale response and one choice between several options. The first section collects the participant's opinion about the application of AVS to vineyards with six questions. The questions are listed in Table 1.

When participants were asked about their preference among different types of PV systems, an image of each type was provided to ensure greater clarity (Fig. 3).

The second section focuses on the importance of potential benefits and drawbacks of vineyard AVS implementation, using 5-points Likert scale (Table 2).

The third section evaluates the environmental awareness of the respondents through their willingness to pay for sustainably certified wine . Previous studies concluded that consumers who have positive attitudes towards environmental protection have higher willingness to pay for eco-certified wines [43–49]. To this end, respondents were classified into two groups (Table 3): those who have a higher level of environmental awareness (i.e. those who answered 'yes') and those who have a lower level of environmental awareness (i.e. those who answered 'no').

The fourth section of the questionnaire was designed to gather participantś personal and sociodemographic data, which enabled further segmentation of the sample and the analyses of potential differences in perceptions across groups (Table 4). The income variable was categorized according to the current Spanish income tax brackets.

A preliminary design of the form was submitted to pre-testing, with a small group of researchers to verify the clarity, adequacy, reliability and applicability of the questionnaire.

The targeted group consisted of wine tourists visiting wineries in Murcia Region. A convenience sample was employed, given the assumption that this non-probabilistic technique is susceptible to selection bias. Nevertheless, this is a technique that is widely used in social research, and the results obtained are similar to those obtained from probability-sampled data [50]. The study was carried out between June

**Table 1**
Questions corresponding to Section 1: Attitudinal items assessing perceptions of the importance and level of agreement with AVS implementation in vineyards

| |
|---|
| **Importance about the generation of photovoltaic energy**(1=Not important; 2=Slightly important; 3=Somewhat important; 4=Important; 5=Very important) |
| **Agreement with the generation of photovoltaic energy on agricultural land**(1=Strongly Disagree; 2=Disagree; 3=Indifferent; 4=Agree; 5=Strongly Agree) |
| **Preference about the use of wine-growing land**(Choose one) |
| Single use for vineyard, grape/wine production |
| Single use for energy generation, dismantling the existing vineyard, and replacing it completely with photovoltaic systems |
| Combined use of vineyard and photovoltaic systems |
| **Agreement with the implementation of an AVS in vineyards**(Agree; Disagree) |
| **Preference of implementing a photovoltaic energy generating system in a vineyard**(Choose one) |
| AVS with photovoltaic modules interspersed with vineyard corridors (Fig. 3A) |
| AVS with solar panels in height above the vineyard (Fig. 3B) |
| AVS with low height integrated into the vineyard structure (Fig. 3C) |
| **Degree of landscape integration of the visited AVS (**Fig. 3**)**(1=Not integrated; 2=Little integrated; 3=Somewhat integrated; 4=Integrated; 5=Fully integrated) |

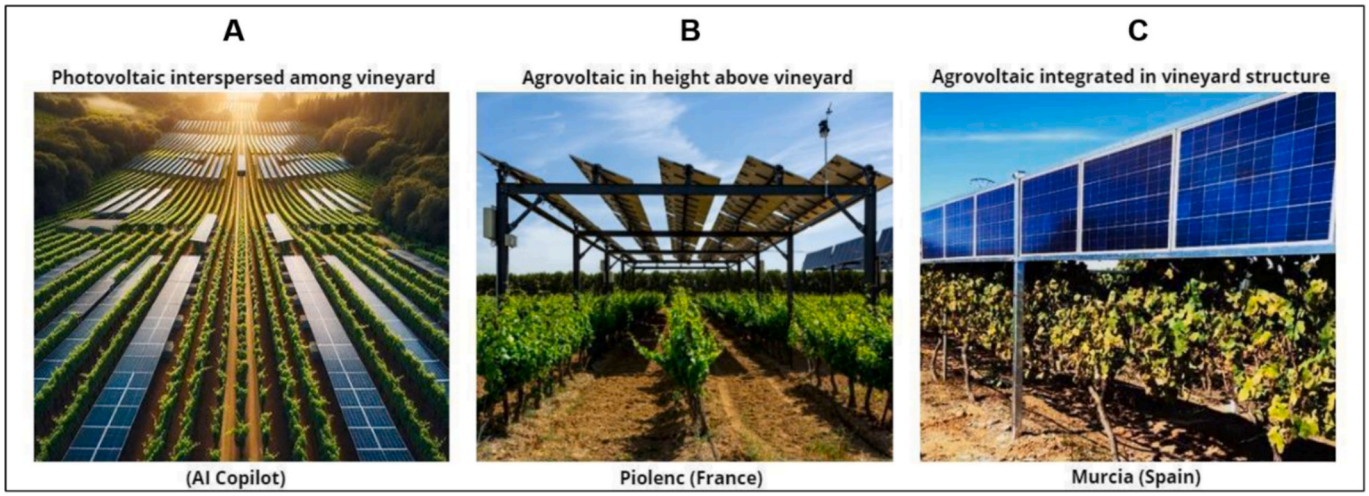



**Fig. 3.** AVS concept images provided in the survey.

and December 2024. The anonymity of respondents was always guaranteed.

The sample comprised a total of 238 responses of participants over 18 years residents of Murcia Region, which met the sample size proposed for studies of this nature, namely 200 interviewers [51] . A comparison with a probability sample size calculated using the formula [52] $n = N \times Z2 \times p \times q / (N-1) \times c2 + Z2 \times p \times q$ for the 1,263,329 inhabitants over 18 years old of Murcia Region in 2025 [38], revealed a margin of error of 5.4% with a confidence level of 95% (p=q=0.5). Cronbach's alpha coefficient value was 0.830 within the acceptable range (0.70-0.95) defined (Nunnally and Bernstein, 1994) confirming the reliability of the survey.

The statistical analysis was carried out by using the free software program R 4.2.0. [53].To ascertain whether there were statistically significant differences in the variables under consideration with respect to gender, age, educational level, income, residence and environmental awareness, a variety of statistical techniques were employed. For qualitative variables, $\chi^2$ test was used, or, in instances where the value of a group was less than 5%, the Fisher Exact Test (FET) was utilised. Occasional missing or incomplete responses were handled using mean imputation, whereby the missing value for a given variable is replaced by the mean of the available responses for that variable [54]. This approach was applied to minimize data loss, maintaining the integrity of the data set.

**Table 2**
Questions corresponding to Section 2: Assessment items regarding the importance of potential benefits and drawbacks of vineyard AVS implementation (5-point Likert scale).

| |
|---|
| Importance given to the potential benefits from a vineyard AVS implementation (1=Not at all important 2=Slightly important 3=Somewhat important 4=Important 5=Very important) |
| Solar energy generation |
| Economic profitability land increase |
| Economic and social development of the region |
| Maintaining the wine-growing landscape |
| Benefits to vineyard cultivation |
| Importance given to the potential drawbacks from a vineyard AVS implementation (1=Not at all important 2=Slightly important 3=Somewhat important 4=Important 5=Very important) |
| Landscape environmental impact |
| Grape production decrease |
| Initial installation costs increase |
| Environmental impact on local fauna |
| Higher vineyard maintenance costs |

With regard to questions formulated on a 5-point Likert scale, U-Mann-Whitney test (for two groups) or Kruskal-Wallis test (for three or more groups) was performed. In order to ascertain whether there were statistically significant differences, a p-value of less than 0.05 was considered when comparing two groups. However, when evaluating the differences among three or more groups, Bonferroni correction was performed (Table 5).

## 4. Results

### 4.1. Demographic statistics

The socio-demographic results (Fig. 4) served as a basis for carrying out later segmentations with the objective of analysing the influence of certain characteristics of the population on the responses. The first segmentation, by age, divides the population into four groups (18–35 years, 36–50 years, 51–65 years and over 65 years), with the first group, participants among 18–35 years, constituting the higher percentage (31%). The second segmentation, by gender (female and male) showed a predominating 58% for women. The third segmentation, educational level, comprises four groups (university, bachelor, secondary and primary). Among them, the university group predominates with 75% of responses. The fourth segmentation, regarding monthly income comprises 6 groups. 20% remains in the range 1.684–2.933 €/month, while 26% of the surveyed prefers not to answer. The high response rate (19%) of 25.000 € monthly individual income suggests a misinterpretation of the question, where respondents considered annual income rather than monthly income. In terms of residence area, a fifth segmentation divided the answers in two groups (urban and rural), the majority of the surveyed (78%) corresponding to the first one. Finally, the sixth segmentation considered country of origin, resulting in 95% of the studied population from Spain. Among them, 66% were from Murcia Region.

### 4.2. Descriptive statistical analysis

The first stage of the study focused on the assessment of AVS perception among the respondents. In a preliminary step, the

**Table 3**
Section 3 assessment item of environmental awareness via willingness to pay for sustainably certified wine.

| |
|---|
| Willingness to pay for sustainably certified wine |
| (Yes; No) |

**Table 4**
Questions corresponding to Section 4: Assessment items for personal and socio-demographic profile of the participants

| |
|---|
| Gender (Female; Male; Prefer not to answer) |
| **Age** (18–35: Young; 36-50: Middle; 51-65: Adult); >65: Senior; Prefer not to answer) |
| **Education level** (Primary; Secondary; High School; University; Prefer not to answer) |
| **Income** (<1,037 €; 1,038 - 1,683 €; 1,684 - 2,933 €; 2,934 - 4,999 €; 5,000 - 24,999 €; >25,000 €; Prefer not to answer) |
| **Residence** (Rural; Urban; Prefer not to answer) |
| **Country of origin** |
| **Region of origin (only for Spain)** |

**Table 5**
Segmentation variables and significant levels applied in group comparison depending on the number of groups per category

| Segmentation variable | Definition of the groups | N° of groups | SSD (p<…) |
|---|---|---|---|
| Gender | Female; Male | 2 | 0.05 |
| Age | 18–35 years; 36-50 years; 51-65 years; >65 years | 4 | 0.0083 |
| Educational level | Primary; Secondary; High school; University | 4 | 0.0083 |
| Income | <1,037€; <1,683€; <2,933€; <4,999€; <24,999; >25,000 | 6 | 0.0033 |
| Residence | Rural; Urban | 2 | 0.05 |
| Environmentalawareness | Willingness to pay for sustainably certified wine (yes; no) | 2 | 0.05 |

investigation evaluated the value assigned by the surveyed to the generation of renewable energy and its development in rural lands currently dedicated to agriculture. With regards to the importance of PV energy generation, 99% of the surveyed valued it over 3, and the resulting average in Likert scale was 4.6. The most frequent response (71 %) was "very important", 5-point in Likert scale (Fig. 5a). A similar appreciation is observed in terms of acceptance of PV energy generation on agricultural land. Despite of the higher number of 4-point ratings on the Likert scale and a wider dispersion of responses with lower values, most of the responses considered the use of agricultural land as very important for PV energy generation, with an average of 4.3 on the Likert scale (Fig. 5b).

In a second stage, the study addressed preferences of use for wine-growing lands. A high percentage of the surveyed (87%) preferred a combination of agricultural and energy uses in the same plot, taking a stand in favour of AVS, while 11% supported a single agricultural use and only a 2% a single energy use (Fig. 5c). Consequently, the acceptance towards the implementation of AVS systems in vineyards is highly supported by 94% of the surveyed (Fig. 5d).

Regarding the importance that surveyed gave to the possible benefits derived from AVS in vineyards, all of the proposed were rated over 4 in Likert scale, considering all in between "important" and "very important". Among them, the generation of solar energy is the highest rated with an average of 4.6 (Fig. 6).

Otherwise, possible drawbacks derived from AVS in vineyards are given less importance, with an average of 3.8 (Fig. 7). Landscape environmental impact was the lowest rated drawback and higher maintenance costs in vineyards was the highest.

In a third stage, the investigation looked for the surveyed preferences to implement the AVS in the vineyard. A vineyard-integrated low height system was the AVS preferred by 60% of the surveyed, rather than an overhead AVS above the vineyard (23%) and PV solar panels interspaced among vines (16 %) (Fig. 8).

Finally, the low height AVS installed above the trellises of the vineyard, corresponding to the actual configuration visited in Murcia Region vineyards, is considered the one with higher landscape integration, with an average 3.7 on Likert scale, despite a wide dispersion of the responses (Fig. 9).




**Fig. 4.** Socio-demographic profile of the respondents by gender, age, educational level, income, residence and region/country of origin.

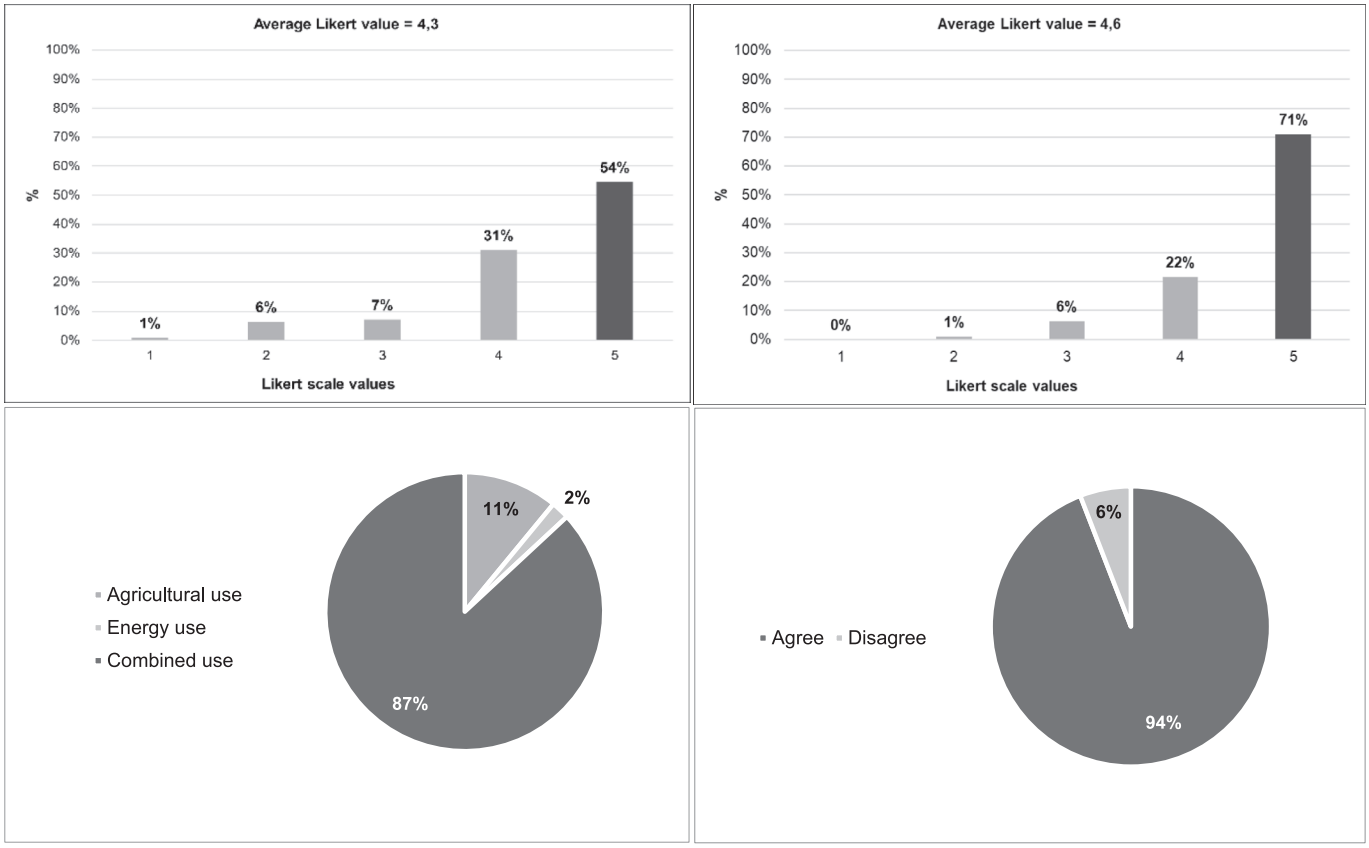



**Fig. 5.** Assessment of AVS perception among the respondents: (a-top left) distribution of responses on the perceived importance of PV energy generation in agricultural land (5-point Likert scale), with a mean score of 4.6; (b-top right) distribution of responses on the the level of acceptance of PV energy generation in agricultural land (5-point Likert scale), with a mean score of 4.3.; (c-bottom left) respondents' preferences regarding land use in vineyards; (d-bottom right) overall acceptance of AVS implementation in vineyards

### *4.3. Segmentation analysis of participants by sociodemographic and environmental awareness variables*

A subsequent segmentation analysis was conducted with the objective of identifying disparities amongst population groups based on age, gender, education level, income, residence and environmental awareness.

In the segmentation analysis carried out with the variables age, income and residence, no statistically significant differences in the groups formed were observed.

When segmenting by gender (Table 6), a statistically significant difference was found in the potential benefits of implementing an AVS in vineyards. In that set of responses, women were more sensitive to the maintenance of the vineyard landscape than men (4.44 vs. 3.89).

In the segmentation by educational level (Table 7), statistically significant differences were observed only in the question regarding the preference for implementing an AVS in a vineyard. On one hand, respondents with university and high school studies were mostly in favour

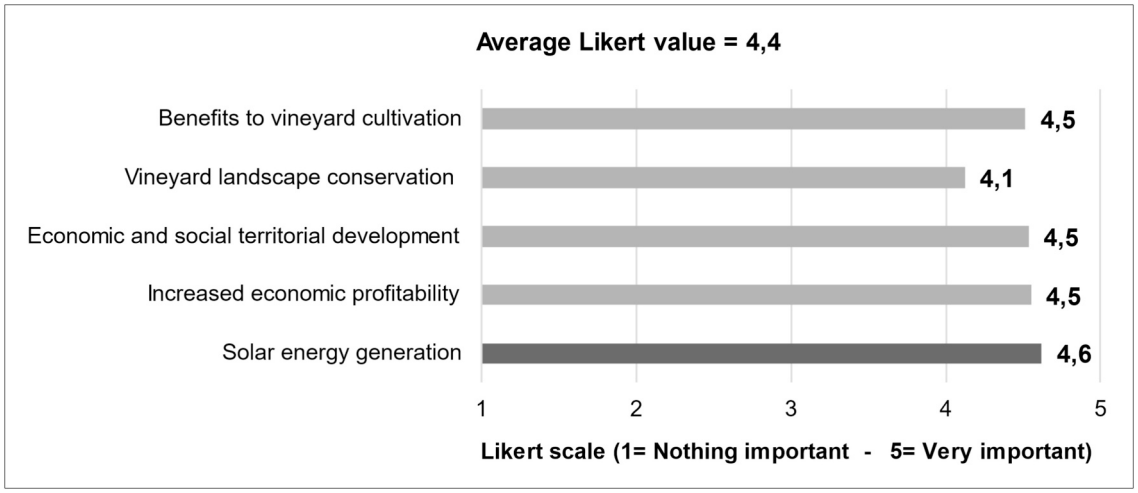



**Fig. 6.** Respondentś evaluation of potential benefits of AVS implementation in vineyards (5-point Likert scale), with a mean score of 4.4.

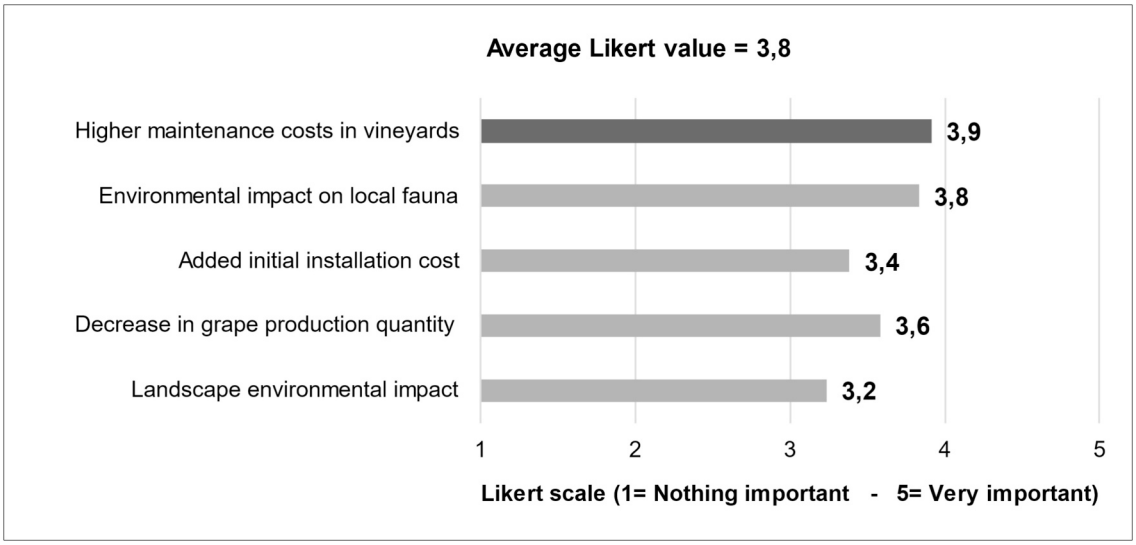



**Fig. 7.** Respondentś evaluation of potential drawbacks of AVS implementation in vineyards (5-point Likert scale), with a mean score of 3,8.

(60% and 50%) of the implementation of AVS installations with low height integrated into the vineyard structure. On the other hand, respondents with secondary and primary education preferably opted for AVS with solar panels in height above the vineyard (45.5% and 25.0% respectively). In addition, all four groups showed a similar opposite preference for AVS with PV modules interspersed with vineyard corridors (less than 17% of respondents).

Finally, with regard to segmentation based on environmental awareness (see Table 8), which has been assessed using the 'willingness to pay for certified sustainable wine' as outlined in Table 3, several differences were observed. In terms of opinion on the AVS applied to vineyards, respondents with greater environmental awareness gave more importance to photovoltaic energy generation (4.65 vs. 4.32) and were more in favour of photovoltaic energy generation on agricultural land (4.46 vs. 3.99). In terms of the importance attributed to the potential benefits of implementing AVS in vineyards, the group with greater environmental awareness also assigned higher ratings to items in which there were statistically significant differences between the two groups: solar energy generation (4.69 vs. 4.42), increased economic profitability of the land (4.64 vs. 4.35) and economic and social development of the region (4.66 vs. 4.28). In contrast, as anticipated, the group with a lower environmental awareness assigned a higher degree of relevance to three potential disadvantages of implementing an AVS in a vineyard, with statistically significant differences observed between the two groups: decrease in grape production (3.82 vs. 3.48), increased initial installation costs (3.77 vs. 3.21), and higher vineyard maintenance costs (3.85 vs. 3.43).

## 5. Discussion

This article explores the social perception of AVS in vineyards. Social acceptance of AVS is increasingly recognized as a key factor for their large-scale implementation [4]. Consequently, this research is associated with studies on the social acceptance of AVS adoption, a novel and underdeveloped research topic [25]. While the technical and environmental aspects have been thoroughly documented, the social dimension, particularly in rural and protected landscapes, still poses significant challenges. Furthermore, it has been demonstrated that public perceptions are of crucial importance in achieving improved acceptance rates of AVS projects among all the relevant stakeholder groups [27]. Most social studies focus on AVS perceptions of various stakeholders from different sectors, including academia, energy, policy, farming, residents and community organisations. However, these studies employ non-representative samples, which limits the generalisability of their findings. In this sense, the present investigation differs from previous studies in that it examines, for a representative sample, the opinion of wine

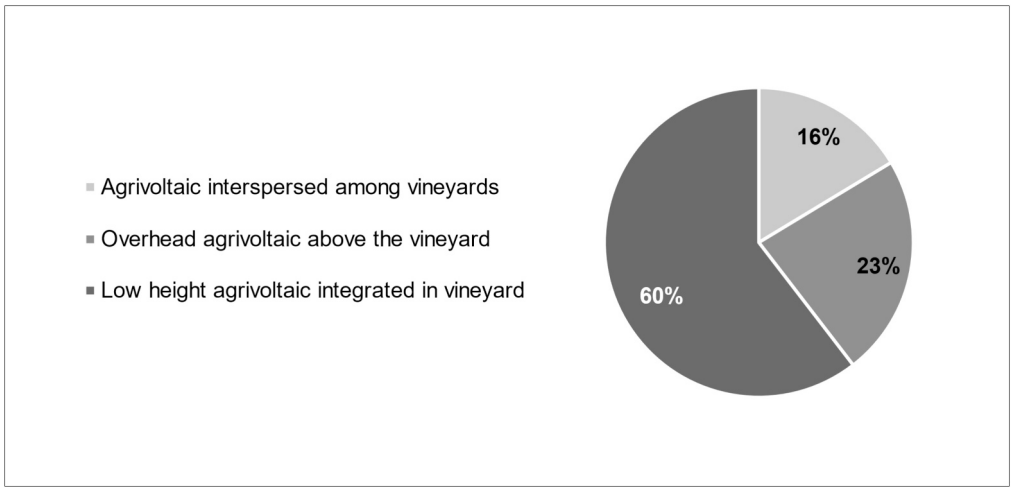



**Fig. 8.** Respondents' preferences for vineyard AVS configurations: trellis integrated, overhead and interspaced PV systems.

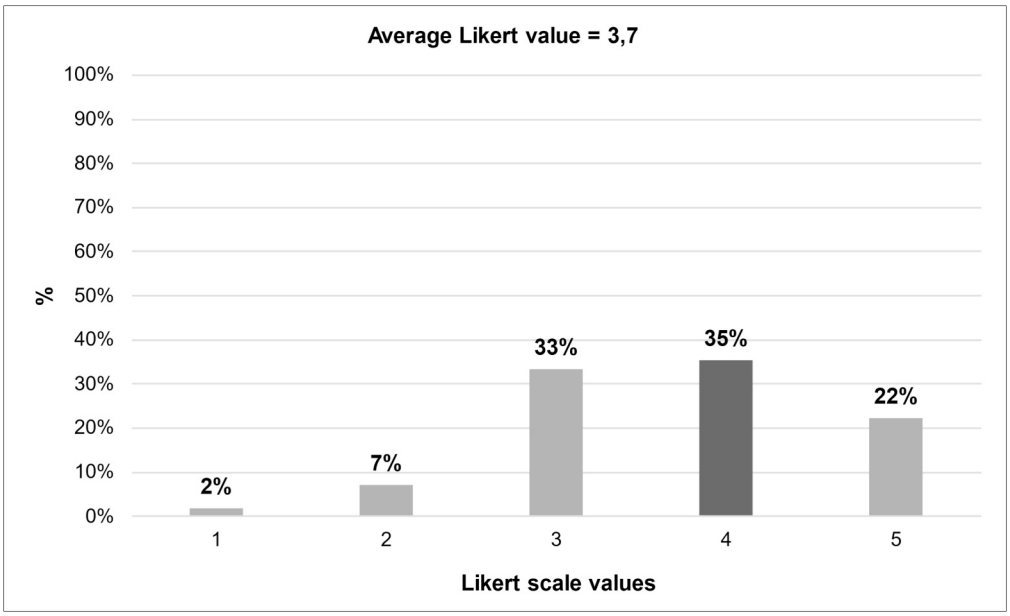



**Fig. 9.** Distribution of responses on the perceived landscape integration of low-height AVS (5-point Likert scale), with a mean score of 3,7

**Table 6**
Gender segmentation results about the perceived benefits of vineyards AVS

| Gender | Female | Male | | |
|---|---|---|---|---|
| Quantitative variables (Likert scale 1 to 5) | Average | Average | U Mann–Whitney | *p*-value * |
| Potential benefits or disadvantages of AVS importance | | | | |
| Importance given to potential benefits from vineyards AVS implementation. | | | | |
| Maintaining the wine-growing landscape | 4.44 | 3.89 | 4379 | 0.002 |

*$p$ value $< 0.05$ statistically significant differences

tourists in Murcia Region (south-eastern Spain).

In the context of AVS implementation in vineyards, some scientists and engineers advocate for the mitigation of conflicts and drawbacks associated with agricultural land conversion through the integration of farming practices and solar energy generation [55]. This assertion is corroborated by the overwhelming majority of respondents (94%) who expressed a favourable attitude towards AVS integrated into existing agricultural structures, emphasising their potential to mitigate climate impacts and enhance agricultural resilience. This finding aligns with the results of previous studies [24], which reported 81.8% acceptance rate among USA participants for AVS, or 64.8% of respondents in favour of AVS implementation in vineyards within the PDO Alicante region in Spain [32].

Ketzer et al. [4] conducted a study in Germany, which revealed the necessity of integrating AVS into the existing infrastructure in a manner that is compatible with the natural environment. This approach was deemed essential to mitigate potential adverse effects on recreation and tourism. In a similar vein, Biró-Varga et al. [31] observed in the Netherlands that the nature of AVS has a substantial impact on the aesthetic perception and the value of the landscape in areas dedicated to wine tourism. In Germany, Belgium and Denmark, Hilker et al. [21] found that public opposition tends to be lower for small-scale PV projects. These results are consistent with the preference expressed by 60% of Murcia Region participants for visually integrated configurations of low-height AVS integrated into the vineyard structure and compatible with the vineyard landscape.

The potential benefits in agricultural, environmental and socio-economic aspects from vineyard AVS implementation evaluated in this study were considered important or very important for the respondents, while the drawbacks were qualified below important. The findings of this study corroborate the conclusions of the research conducted by Hilker et al. [21] in Germany, Belgium and Denmark. The aforementioned researchers emphasised that local stakeholders predominantly favour AVS, which is regarded as a means of contributing to food production, biodiversity conservation and the equitable distribution of economic returns. Conversely, De Falco et al. [34] discovered that in Italy, experts and the media regarded the AVS as a “compromise” between energy and agriculture, rather than a mutually beneficial solution for both sectors.

In terms of agricultural aspects, respondents consider that AVS is beneficial for vineyard cultivation (average Likert value 4.5), although some authors, such as De Falco et al. [34], warn of the possible agronomic risks of AVS concerning its potential impact on certified crops such as PDO. However, in the case of Germany [21], it was considered, from a conservationist perspective, that the agricultural and ecological compatibility of AVS is key to its acceptance in rural settings.

**Table 7**
Educational level segmentation results on AVS configuration preferences

| Educational level | Primary | Secondary | HighSchool | University | | | |
|---|---|---|---|---|---|---|---|
| Qualitative variables | %** | %** | %** | %** | $\chi^2$ | df | *p*-value * |
| AVS applied to vineyards | | | | | | | |
| Preference for implementing a photovoltaic energy generating system in a vineyard | | | | | | | |
| Agrivoltaic with photovoltaic modules interspersed with vineyard corridors | 0.0 % | 9.1 % | 12.5 % | 16.7 % | 55.018 | 12 | |
| Agrivoltaic with solar panels in height above the vineyard | 25.0 % | 45.5 % | 21.3 % | 20.5 % | | | 0.000 |
| Agrivoltaic with low height integrated into the vineyard structure | 12.5 % | 16.7 % | 50.0 % | 60.0 % | | | |

*$p$ value $< 0.0083$ statistically significant differences
**The rest of the respondents up to 100% in each group did not answer

**Table 8**
Environmental awareness segmentation results on perception of vineyard AVS

| Willingness to pay for sustainably certified wine | Yes | No | | |
|---|---|---|---|---|
| Quantitative variables (Likert scale 1 to 5) | Average | Average | U Mann–Whitney | *p*-value * |
| AVS applied to vineyards | | | | |
| Importance about generation of photovoltaic energy | 4.65 | 4.32 | 4182 | 0.001 |
| Agreement with the generation of photovoltaic energy on agricultural land | 4.46 | 3.99 | 3891 | 0.000 |
| Potential benefits or disadvantages of AVS importance | | | | |
| Importance given to potential benefits from vineyards AVS implementation | | | | |
| Solar energy generation | 4.69 | 4.42 | 4210 | 0.010 |
| Economic profitability land increase | 4.64 | 4.35 | 4142 | 0.004 |
| Economic and social development of the region | 4.66 | 4.28 | 4055 | 0.003 |
| Importance given to potential drawbacks from vineyards AVS implementation | | | | |
| Grape production decrease | 3.48 | 3.82 | 4394 | 0.031 |
| Initial installation costs addition | 3.21 | 3.77 | 3625 | 0.000 |
| Higher vineyard maintenance costs | 3.43 | 3.85 | 4080 | 0.007 |

*$p$ value $< 0.05$ statistically significant differences

The environmental aspects of AVS are also beneficial, as solar energy generation avoids $CO_2$ emissions (average Likert value 4.6) and is key to maintaining the wine-growing landscape (average Likert value 4.1). Conversely, the drawbacks of the AVS regarding landscape environmental impact (average Likert value 3.2) and environmental impact on local fauna (average Likert value 3.8) are of lesser importance. The present findings are in alignment with the conclusions drawn by Sirnik et al. [29] in the Netherlands, which demonstrated that landscape alterations frequently result in minimal acceptance of solar power installations. This is because the proposed AVS in vineyards tends to result in only minor changes to the landscape. The findings of Torma et al. [27] are corroborated, as they concur that AVS in their sample of stakeholders in Germany, Belgium and Denmark are perceived positively as a satisfactory compromise to resolve land-use conflicts and a method to contribute to the green transition, and negatively as generators of a visually unacceptable impact. Finally, the findings of this study demonstrate the efficacy of AVS in promoting biodiversity, particularly in conjunction with conservation objectives. This observation aligns with the findings reported by De Falco et al. [34] in Italy, who reported a similar outcome.

From a socio-economic perspective, the potential benefits of supporting AVS can be attributed to the capacity to enhance the economic productivity of land (average Likert value 4.5), the advantages associated with vineyard cultivation (average Likert value 4.5), and its role in promoting the socio-economic development of the region (average Likert value 4.5). The respondents identified several drawbacks to the implementation of the technology. These included increased initial installation costs (average Likert value 3.4), higher maintenance costs for the vineyard (average Likert value 3.6), and the potential for a decrease in grape production, which could lead to a reduction in wine production and, consequently, in socio-economic income (average Likert value 3.6). This aspect also aligns with the findings of respondents surveyed by Torma et al. [27], who considered AVS to be expensive and a misallocation of money and time.

Regarding the disparities among population segments, it is relevant to note that no prior studies considering these segmentations can be found. The findings revealed that there were no statistically significant differences in the variables of age, income and residence. However, there were statistically significant differences in the variables of gender, educational level and environmental awareness. To mitigate these disparities among the groups, a series of communication initiatives should be implemented, targeting those groups with the most unfavourable opinions in an effort to enhance their perceptions. Consequently, it is recommendable that men are made aware of the significance of preserving the landscape dedicated to viticulture. In a similar vein, the significance of integrating solar panels into the landscape should be accentuated, particularly among individuals with a primary and secondary education who exhibit a minimal inclination towards low-height integrated AVS. Finally, emphasis should be placed on improving communication about the importance of AVS and its advantages among the group of people with lower environmental awareness.

This research has demonstrated that there is a broad social acceptance for the implementation of AVS in vineyards, among wine tourists in Murcia Region (South-eastern Spain), thus confirming the research to date that found an overall positive evaluation of AVS 56,4,22.

However, future actions towards a successful AVS deployment should consider and adequate promotion of its potential benefits while reducing its potential harms (whether in agronomic, environmental, and socio-economic aspects) in order to avoid the high perceived uncertainty regarding the usefulness and feasibility of agrivoltaics, suggested by some authors such as [4].

Consequently, this research validates the recommendations proposed by various authors concerning the necessity for social acceptance of AVS for their advancement. In the extant literature, Pascaris et al. [22] suggest that the growth of AVS is contingent on market adoption of the technology through community acceptance. In addition, Ketzer et al. [4] indicate that the success of renewable technologies largely depends on local acceptance. Finally, Chopdar et al. [33] highlight the importance of community involvement for increasing AVS acceptance.

## 6. Conclusions

The results of this study indicate a broadly positive social perception of the implementation of AVS, particularly within vineyard settings in the Murcia Region of southern Spain. Notwithstanding the limitations in terms of demographics resulting from the questionnaire distribution method, such as an overrepresentation of university-educated and urban residents from the Murcia Region, the data provides significant insights into public attitudes towards renewable energy use in agricultural contexts. This research proffers a novel perspective on the subject, obtained from the analysis of the divergent opinions held by different demographic groups regarding the implementation of AVS.

A substantial consensus has been identified among the surveyed population regarding the significance of solar energy generation on agricultural land. In addition, a clear majority of respondents expressed support for integrating energy and agricultural uses on the same plot, thereby confirming a high level of acceptance of AVS as a dual-use land model. The respondents identified numerous perceived benefits of AVS, particularly the generation of solar energy, while potential disadvantages, such as environmental or visual impact, were generally regarded as less significant.

Evaluation of AVS configurations revealed that the low-height system integrated into the vineyard was found to be the most favoured option, due to its greater compatibility with the traditional wine-growing landscapes. This lends further support to the notion that AVS design plays a critical role in social acceptance, and that landscape integration should be given priority in implementation strategies.

It has been established that there is an absence of discrepancy in opinion based on factors such as age, income and place of residence. However, when the sample is divided according to gender, educational level and environmental awareness, variations in opinion become manifest.

In the broader context of climate change and optimised land use, respondents consider the AVS to be a viable solution for balancing energy production with agricultural productivity. This standpoint is consistent with previous findings showing that the AVS enhances the sustainability and equity of both processes. This is of particular

importance in regions where water scarcity, radiation stress and climate extremes are prevalent, as is the case in the Murcia Region in southern Spain. The AVS has the capacity to enhance resource efficiency, ensure the preservation of yield, and foster economic resilience in such regions. Consequently, the potential of AVS to evolve into pivotal components in the advancement of both sustainable energy systems and contemporary agriculture is anticipated.

Beyond the specific context of the Murcia Region, these findings hold potential relevance for other Mediterranean wine-growing areas with similar climatic conditions and viticultural landscapes. Such regions are characterized by semi-arid or Mediterranean climates, a strong wine culture, consolidated traditions of PDO wine production, and significant wine tourism activity. Examples include Mediterranean and southern viticultural regions of Spain (e.g., Priorat, Penedés Utiel-Requena and Montilla-Moriles PDOs), Italy (Tuscany, Sicily, Puglia, Sardinia), Mediterranean viticultural regions in France (Provence, Languedoc-Rosellón, South Rhône Valley), Portugal (Alentejo, Douro), as well as wine-growing regions in Greece and Cyprus. Consequently, the high level of acceptance for trellis-integrated low height AVS observed in Murcia suggests that this model may represent a socially viable option in these contexts, where the preservation of viticultural landscapes alongside the integration of renewable energy constitutes a common challenge.

In order to enhance the favourable social perception revealed by this study, efforts could be made by public administrations to communicate more effectively the potential benefits of AVS to society and, consequently, improve the public's opinion and acceptance of AVS. It is asserted that such endeavours will contribute to AVS deployment. The successful implementation of renewable technologies is contingent upon social acceptance, a notion that has been demonstrated in this article and previously postulated by several studies.

## 7. Limitations of the study

This study presents some methodological considerations that should be acknowledged. Firstly, the use of a convenience sample of wine tourists visiting specific wineries in the Murcia Region may have influenced the representativeness of the sample, as university educational level was predominant among respondents. Secondly, the study focused on participants who had been exposed to AVS education during guided visits, which does not allow for direct comparison with unexposed groups. Thirdly, some inconsistencies were detected in self-reported income data, which may have introduced distortions in the segmentation analysis. Lastly, although missing responses were very rare, the use of simple mean imputation, while minimizing data loss, may slightly underestimate variance.

## 8. Future research directions

Future studies should incorporate the perception of additional stakeholders such as winemakers and winegrowers in an economic frame derived from pilot experiences. In addition, research should analyse the AVS perceptions of wine tourists with no prior exposure to the topic, enabling comparisons with those already exposed to AVS education, and thereby evaluate the influence of guided visits. This would provide a more robust assessment of how awareness and understanding of AVS influence public acceptance. Finally, future research should examine the transferability of these results to other contexts, reinforcing the role of AVS as a sustainable land-use strategy in Mediterranean agriculture.

## Declaration of generative AI and AI-assisted technologies in the manuscript preparation process.

During the preparation of this work the author(s) used ChatGPT in order to help to correct the English grammar of this work. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

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## CRediT authorship contribution statement

**Irene Arias-Navarro:** Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Baltasar Miras-Cabrera:** Writing – original draft, Visualization, Validation, Resources, Project administration, Investigation, Conceptualization. **Carlos Toledo:** Visualization, Validation, Resources, Project administration, Investigation, Conceptualization. **Asunción María Agulló-Torres:** . **Javier Padilla:** Validation, Supervision, Resources, Project administration, Conceptualization. **África Martínez-Poveda:** Validation, Supervision, Project administration, Methodology, Conceptualization. **Francisco J. Del Campo-Gomis:** Writing – original draft, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

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

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## Data availability

Data will be made available on request.

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