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Eye-Tracking Experiment on Perception and Acceptance of Agrivoltaics: Pilot Study on the Impact of Grassland Use Visualisations

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Abstract: Agrivoltaics (AV) are expanding worldwide, but knowledge about the perception and acceptance of this approach is far from complete. The aim of the present study was to investigate the visual perception and acceptance of AV systems, focussing on the central research question of whether the type of grassland use influences the visual perception and acceptance of vertical interspace AV. For this purpose, three photo-based pictures of a vertical interspace AV plant were used in a laboratory experiment with 29 participants: the original photo showing the AV plant with grassland only; an edited photo with cattle added and an edited photo with silage bales added. The eye-tracking results showed that additional picture elements (i.e., cattle and silage bales) at least partially attracted visual attention, but did not distract from the technical elements of the depicted AV systems. The analysis of the acceptance ratings indicated relatively stable attitudes towards AV, which could not be easily modulated by depicting different types of grassland use within AV systems. Short-term and limited changes in attitudes towards AV appeared to result from the provision of information and mental engagement with the topic. We recommend carrying out further research based on larger, representative samples and more realistic stimuli of AV systems that would provide a better understanding of visual perception and acceptance than photos alone, such as on-site visits or VR visualisations, to enhance the external validity of the results. We also suggest conducting longitudinal studies to explore possible long-term effects on the public acceptance of AV systems.

Keywords: gaze behaviour; vertical interspace agrivoltaics; overhead agrivoltaics; ground-mounted photovoltaics; solar panels; picture manipulation

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1. Introduction

Human energy requirements and energy policy are important drivers for landscape change [1,2]. The sharp rise in global energy demand in recent decades [3] has resulted in societies being confronted with landscape changes at an accelerated pace due to the expansion of infrastructure for energy generation and distribution [1,2]. In this context, regenerative energies are becoming ever more important as they are increasingly being used to cover energy requirements [2], with solar photovoltaics playing a pivotal role. Forecasting models suggest that solar energy will become the dominant power source worldwide before the mid-century. In the European Union, the share of PV in energy production is expected to increase from its current level of just under 10% to around 50% by 2050 [4].

The anticipated expansion of solar PV will entail considerable land use and landscape changes [5], raising the question of public acceptance of a large-scale roll-out of this technology [6]. While solar PV installations on rooftops and existing infrastructure or on brownfield sites enjoy a high level of general acceptance in the population, large solar parks on greenfield-sites (ground-mounted PV, GM-PV) are less valued [6–9]. The reasons for this are multifaceted and are primarily related to the food–energy–environment trilemma, insufficient participation and impaired landscape experiences [9–12]. As the term "renewable energy landscapes" already suggests, landscape perception is amongst the most important issues in this context. Even if landscape perception refers to all senses and their interaction, visual impacts predominate landscape perception and thus have a decisive influence on the acceptance of regenerative energy infrastructure in general and open-space solar PV in particular [10–14].

Agrivoltaics (AV), referring to various systems enabling the simultaneous land use for agricultural and solar energy production [15], is singular in open-space solar PV insofar as it could relax the food–energy–environment trilemma. The cultivation of food crops or animal husbandry and solar PV energy production on the same site can be a win–win situation. A higher economic efficiency per hectare can be achieved [16] while contributing to food and energy security [17]. Under certain conditions and depending on the design of the system, AV systems can contribute to environmental protection and biodiversity enhancement by providing habitats for native vegetation and pollinator insects [18,19], helping to prevent soil degradation [20] and improving water-use efficiency [21]. Despite the aforementioned advantages of AV that may increase the acceptance of this technology [9], other factors influencing the acceptance of open-space solar PV installations remain unaffected, in particular, the impact on the landscape.

However, while AV is expanding at a global scale, knowledge about the perception and acceptance of this approach is far from being complete [20,22], hampering the strategic planning of socially acceptable forms of future energy and food supply and therefore requiring more detailed research [19]. The present study contributes to the literature by investigating the visual perception and acceptance of AV using photo-based pictures of AV systems (in our study, we refer to the unit of PV installation and agricultural use as the AV system. In the experimental part of the study, we therefore distinguish between three AV systems which are characterised by different agricultural uses, i.e., by different types of grassland use, but that do not differ with regard to background and PV installation) in a laboratory experiment supplemented by eye-tracking. The focus was on vertical interspace AV with bifacial solar modules installed on grassland. The following key research question was derived from the premise that the visual perception and landscape experience is influenced by the interplay between the technical aspects and the agricultural use of AV systems: does the grassland use between the photovoltaic installations influence the visual perception and acceptance of vertical interspace AV systems? We limited the eye-tracking experiment to three pictures with the AV systems depicted differing in the type of grassland use: grassland only, cattle grazing and silage bales. In addition, to better assess the results on the acceptance of the vertical interspace AV in focus, the acceptance ratings of this system were compared with those of overhead AV and GM-PV.

The following section gives an overview of the theoretical framework and the hypotheses that guided the investigations. The material and methods section provides a schematic overview of the study process and describes in detail the approach used, which consisted of a laboratory eye-tracking experiment and a quantitative survey. The results section first looks at the qualitative eye-tracking data before analysing in detail the quantitative eye-tracking and survey data. Finally, the results are discussed. For the sample analysed, our results show that a general open-mindedness towards vertical interspace AV on grassland could be assumed. However, the visualised grassland use type apparently had only minor influence on the visual perception and no influence on the acceptance of the displayed AV systems. The comparison of the displayed GM-PV and AV showed a higher acceptance of AV. This applies to both vertical interspace AV and overhead AV. From this, we conclude that the higher acceptance of the AV systems shown may primarily depend on factors other than the very specific type of grassland use visualised in the photo-based pictures of our study. What these factors are and whether AV is generally considered superior to conventional ground-mounted PV by the public, as the results of our study suggest, should be investigated in detail in further studies, as such knowledge may be pivotal for the strategic planning of socially accepted forms of energy supply.

2. Theoretical Framework

2.1. Introduction to Agrivoltaic Systems

AV systems are characterized by the technical characteristics of the PV installations and the type of agricultural land use. AV systems can be open or closed, whereby closed systems, i.e., basically photovoltaic greenhouses and photovoltaic livestock fences, are not considered in this study [23]. Open AV systems are installed on open land. They can vary with regard to the system structure (interspace/overhead), module type (fixed tilt/solar tracking) and type of agricultural use (grassland/arable farming/perennial crops) [15].

Interspace systems are ground-mounted systems similar to GM-PV in terms of their technical design and mounting structure, with increased spacing between the solar module rows allowing for agricultural activities [24]. An innovative concept with an interspace structure is vertical AV with bifacial solar modules. The bifacial solar modules can generate electricity on both sides and usually face East/West. Unlike conventional ground-mounted photovoltaic systems that usually have their energy production peak in the midday hours, the vertically installed modules produce the most electricity in the morning and afternoon [25]. In this concept, the solar modules are installed at a row-to-row distance of 6–15 metres, and the distance between the module rows enables cultivation, for example, in the form of arable farming, grassland management, or also for grazing with often-standard farm technology [15]. Recent projects in the European Union combine vertical interspace solar PV installations with arable farming (Neudorf an der Mur, Leibnitz, Austria), hay and silage production (Aasen, Donaueschingen, Germany) and grazing (Culemborg, The Netherlands) [26].

Overhead AV systems are elevated installations where the solar modules are mounted on stilts at a height of 2–5 m above the ground, and agricultural activities occur underneath the solar PV modules. For both overhead and vertical AV systems, the dimensions and specific design depend on the intended agricultural use and the dimensions of the agricultural machinery required for the respective use [23].

2.2. Perception and Acceptance of AV

The relationship between the design of open-space solar PV installations and its impact on the perception and acceptance of this technology in general and of local projects in particular is complex [8,11,12]. A major obstacle to the acceptance of GM-PV is a high visibility in the landscape due to the size, regular geometry, colour of the solar modules and highly reflective surfaces, especially if the PV projects are implemented in visually sensitive locations [10,12,27]. In addition to the visual impacts, the ecological impact and issues of participation, such as procedural and distributional justice as well as ownership, also influence the acceptance. In order to ensure a high level of acceptance of PV projects, it seems advisable to keep them local in the sense of comprehensive participation of the local population and low-key in the sense of minimising the ecological and visual impact on the landscape [10].

Due to its similarity to GM-PV, AV could face similar problems in terms of public acceptance in the future, especially at the local level. The different types of AV systems with their specific technical appearances may affect the landscape experience in different ways, e.g., by changing the agricultural use or the openness of the landscape [22]. These changes may raise public concerns and even encounter resistance [28]. Ketzer et al. emphasise that AV generally has considerable visual impacts that can potentially have a negative effect on landscape qualities that are important for recreation and tourism [29]. A study conducted in the US found that the visibility of an AV system is one of the key factors driving opposition to local AV development [30]. As already observed for GM-PV [12], PV systems installed on rooftops or industrial sites are favoured by the public over AV systems [9,29,31]. A recent study investigating the landscape user experience of vertical interspace and overhead AV indicate that the experiential value of landscapes decreases when AV projects are implemented [24]. Nevertheless, AV enjoys a higher level of acceptance than GM-PV and other forms of regenerative energy [9]. Biró-Varga et al. point out that the technical design of AV systems has an impact on acceptance. Their findings suggest that vertical interspace AV systems are favoured over overhead AV systems [24]. Other factors influencing the acceptance of AV systems correspond to those already observed for GM-PV and other regenerative energies, i.e., essentially issues relating to environmental impacts and participation [9].

As observed for GM-PV [12], the landscape impact of AV depends not only on the design of the AV system [24], but also on the characteristics of the environment [9,29]. The question of how sensitively the system is integrated in the landscape will strongly influence visual impact and the level of acceptance [29]. This challenge is also recognised by potential investors. When envisaging AV projects, farmers consider changes to the landscape as a barrier to investing in AV, presumably due to the awareness that these interventions in the agricultural landscape could impair landscape aesthetics and thus provoke resistance from the local community and other landscape users [32].

An important characteristic of the environment that influences the aesthetic perception of agricultural landscapes is the agricultural use [33–35]. Heterogeneous landscapes, i.e., mixed land use, influence scenic beauty positively due to their visual complexity [34]. It has been repeatedly shown that the presence of grazing livestock also has a positive effect on landscape preferences [36,37], possibly because viewing free-range animals can have a positive influence on the emotional state of the beholder [38]. However, for AV systems, the influence of agricultural use on perception and acceptance has not been systematically investigated so far, and the literature dealing with this topic is generally is scarce: Results of Ketzer et al. suggest that AV systems combining PV with energy crops may not be appreciated by the public [29]. Tölgyesi et al. surmise that AV systems with grassland used for hay production, free-range animal husbandry or beekeeping, may have a high biodiversity and a flower-rich appearance, which could increase the aesthetic value of formerly species-poor agricultural land and counterbalance the industrial appearance of the solar modules [19]. Torma and Aschemann-Witzel point out that the combination of animal husbandry and PV on good soils could be perceived as a loss of good arable land for productive arable farming and could therefore be viewed critically, while on poorer soils, it could be seen as a potentially useful application [39].

2.3. Eye-Tracking in Landscape Experience Research

In landscape experience research, in-depth interviews and questionnaire-based surveys are widely used methods [40]. Besides on-site observations, photos of the landscapes in question are frequently used as stimuli [40,41] with photo rating being a basic method for capturing individuals' perceptions of landscapes in a reliable manner [42].

These approaches are well-established and provide valuable insights into landscape users' experiences. However, if researchers want to know on which visual cues the landscape evaluations of a participant are based, they must rely on the participant's statements. By complementing the aforementioned approaches with eye-tracking, objective measurements of participants' gaze behaviour are available. Eye-tracking data reveal which visual information was perceived by the respective participant during stimulus reception, i.e., which parts of the stimulus were visited and which were ignored [43]. They further provide more detailed information about the participants' allocations of visual attention by allowing fixation-related parameters to be calculated. For this purpose, areas of interest (AOIs) are usually defined in advance. AOIs are areas of a stimulus in which the gaze behaviour of the participants is of particular interest for testing the hypotheses or answering the research questions. The time to the first fixation provides information about the activation level of an AOI within a stimulus; if it is short, i.e., an area is quickly visited visually, the activation level of this area is high. The fixation duration, which is considered in this study as the sum of the time of all individual fixations within an AOI, can be interpreted as a measure of the time required for the cognitive processing of the visual information presented in the AOI [44].

A challenge with eye-tracking studies is that they are costly and very time-consuming, and are therefore often based on convenience samples with a small sample size [41,45]. Despite these drawbacks, eye-tracking is a promising technology to investigate the perception of energy landscapes in more detail [41]. If the gaze behaviour is recorded, together with subjective assessments of the landscape, much more data are available to understand people's perceptions of the environment [43], with the gaze data particularly providing information about landscape objects that could influence observers' assessments [46] of energy landscapes.

2.4. Hypotheses

The hypotheses (H) were derived from the literature and from a preliminary study we conducted in spring 2022. From previous landscape research based on eye-tracking, it is known that conspicuous artificial elements in natural or agricultural landscapes attract visual attention [45,47,48]. This visual attention can be distracted by inanimate and animated elements [48,49]. From this, we hypothesised the following for the eye-tracking experiment, in which we compared photo-based pictures of an AV system with grassland only with an AV system with grassland plus cattle and with grassland plus silage bales.

H1: *Visual perception of vertical interspace AV systems is influenced by the type of grassland use.*

H1a: *Animate (grazing cattle) and inanimate elements (silage bales) between the module rows attract faster and more visual attention compared to pure grassland.*

H1b: *Compared to pure grassland, animate (grazing cattle) and inanimate elements (silage bales) distract visual attention from the technical elements (essentially, the solar modules).*

It is generally assumed that there is a relationship between visual perception and acceptance, whereby different levels of visual attention to different features of an object are associated with different levels of acceptance of the object as a whole [50]. An eye-tracking study on landscape perception suggests that an increased visual attention to modern structures in natural landscapes is associated with a lower acceptance of the landscape compared to similar landscapes without artificial elements or to landscapes with traditional structures shaped in harmony with the landscape [47]. Based on the assumption of hypotheses H1b that animate and inanimate elements distract visual attention from the artificial solar elements, this leads us to the following hypothesis:

H2: *Visual perception of vertical interspace AV systems is associated with the acceptance of the systems.*

There is evidence that the provision of information influences the acceptance of renewable energy infrastructure. During our study, the participants received information on the topic of AV and were encouraged to engage with the topic by participating in the survey. Using a question asked in the same way at the beginning and the end of the survey we tested the following hypothesis:

H3: *Information on AV influences acceptance of this technology.*

3. Materials and Methods

A mixed-method approach was chosen to answer the research question. To test the hypotheses related to the visual perception of vertical interspace AV, an eye-tracking experiment with a between-subjects design was conducted. The eye-tracking experiment was integrated into and supplemented by a questionnaire-based online-survey. For investigating the influence of information on the acceptance of AV, a within-subjects approach was chosen.

3.1. Study Procedure

Right at the start of the data collection from each participant, the calibration for the eye-tracking experiment was carried out, even though the eye-tracking experiment was only the second part of the study. This procedure was chosen to avoid disrupting the participants in the survey process. Once the calibration was successfully completed, the participants started the actual survey. Figure 1 gives a schematic overview of the study procedure. The survey started with introductory questions aimed at ascertaining the participants' prior knowledge on AV and by asking them about their acceptance of AV on different types of agricultural land use, e.g., fallow, grassland or specialised crops. This was followed by an information section in which the participants received pictorial and textual information about different types of AV, including vertical interspace AV with bifacial modules. After this information part, the experimental part started with the eye-tracking-experiment.

The eye-tracking experiment aimed to test Hypothesis 1: The participants were shown one of three AV systems which were actually three versions of the same AV site situated in Donaueschingen/Germany, to investigate the participants' visual attention to the solar modules and the grassland between the modules (for a detailed description of the three versions see Section 2.2). Sitting on a chair, the participants viewed the pictures on a 17-inch laptop screen from a distance of around 60 to 80 cm. The pictures were embedded in the LimeSurvey tool and presented against a white background according to the survey tool layout settings used. They were displayed with a length of 23.7 cm and a width of 6.5 cm. A between-subjects design was chosen, as otherwise, sequence effects in visual attention would be expected. The participants were given 10 s to look at the picture. During this time, eye-tracking data were recorded with the help of a remote eye-tracking device (Tobii nano, 60 Hz, Tobii AB, Danderyd, Sweden) and the cloud-based software Eyevido Lab (EYEVIDO GmbH, Koblenz, Germany). Subsequently, the participants were asked about their acceptance of the AV system shown in general and under specific conditions (e.g., if the AV system would be in their neighbourhood, if they could benefit financially from the system, etc.). These questions, together with the eye-tracking data, were intended to test Hypothesis 2. Using an open-ended question, the participants were also invited to share what thoughts came to their mind when looking at the system.

After this, the participants were also shown the other two AV systems they did not receive in the experiment and were asked the same questions they were asked about the system they saw in the experimental part. The display time for each of the pictures was also 10 s. This means that, at the end, all subjects had answered the questions on acceptance for all three systems and received the same information, though in a different sequence.

In the final part of the survey, the participants were asked again the question from the introductory section of the survey about their acceptance of AV on different types of agricultural land use. The reason for repeating this question was to determine the influence of the participants' mental engagement with the topic and the information they received during their participation in the survey on the acceptance of AV. This before–after comparison (within-subjects design) was applied to test Hypothesis 3.

To also explore the acceptance of vertical interspace AV in comparison to other systems, the participants were shown a picture of a conventional open-space photovoltaic system (GM-PV) and an overhead AV system. After each picture, they were asked the same battery of items on the acceptance of the system shown as for the vertical interspace AV system in the experimental part. Here again, one open-ended question was used to encourage the participants to share their thoughts on both systems (GM-PV and overhead-AV).

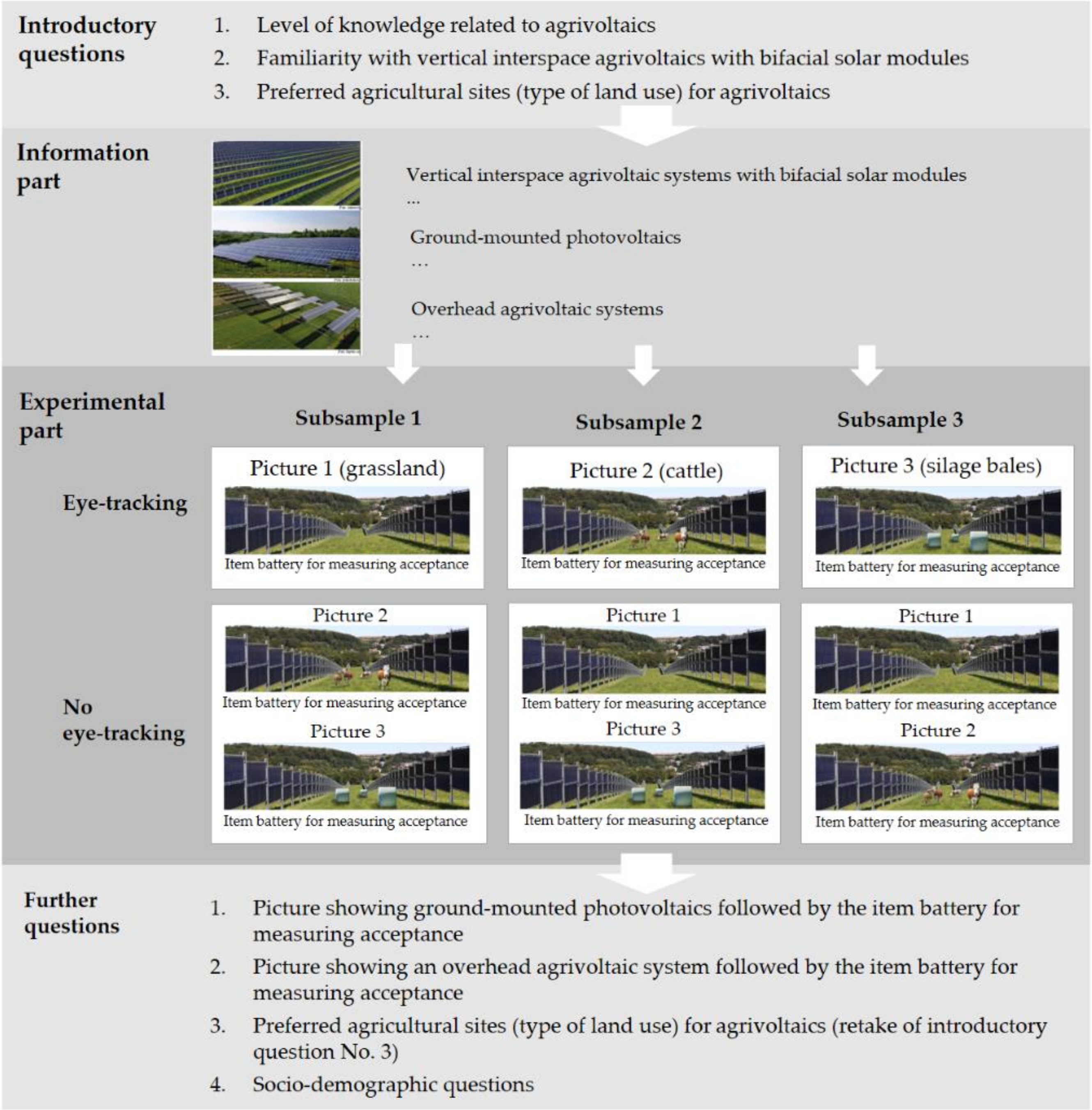

Figure 1. Schematic overview of the study procedure (questionnaire with embedded eye-tracking experiment).

3.2. Stimuli and Definition of Areas of Interest

To create the stimuli for the eye-tracking experiment, a photo-based picture of a vertical interspace AV system with bifacial solar modules, installed on grassland, was used. The AV system is situated in Donaueschingen/Germany. The original photo-based picture showed pure grassland with no further elements between the solar modules (picture 1). Using a picture-editing software, we manipulated the photo to show grazing cattle (picture 2) and silage bales (picture 3) between the solar modules (Figure 1).

Areas of interest (AOI) are a tool for the further processing of eye-tracking data. An AOI is a clearly defined, delimited part of the stimulus of which the researcher is interested in gathering quantitative data about the gaze behaviour. AOIs can be used to analyse various eye-tracking parameters, such as the fixation duration or time to first fixation [51]. The AOIs inserted into the photo-based stimulus in this study are displayed in Figure 2. The eye-tracking software only allowed the definition of rectangular AOIs, meaning that we could not use custom shapes that follow the exact shape of the object of interest. This necessitated the definition of four AOIs each on the right (SR1 to SR4) and left (SL1 to SL4) side for processing the eye movements on the solar panels for quantitative data analysis. To obtain quantitative data for the areas of picture manipulation, three AOIs were defined covering those areas: ML, MM and MR. The abbreviations used for the AOIs were structured as follows: the first letter indicates the item (S = solar panels; M = manipulation area) and the second letter indicates the position (L = left; M = middle, R = right). The size and position of all AOIs were the same in all three versions to allow direct comparisons between the versions (grassland only, grazing cattle and silage bales). Only the position of the AOIs in version 3 (silage bales) differed slightly from the other two versions.

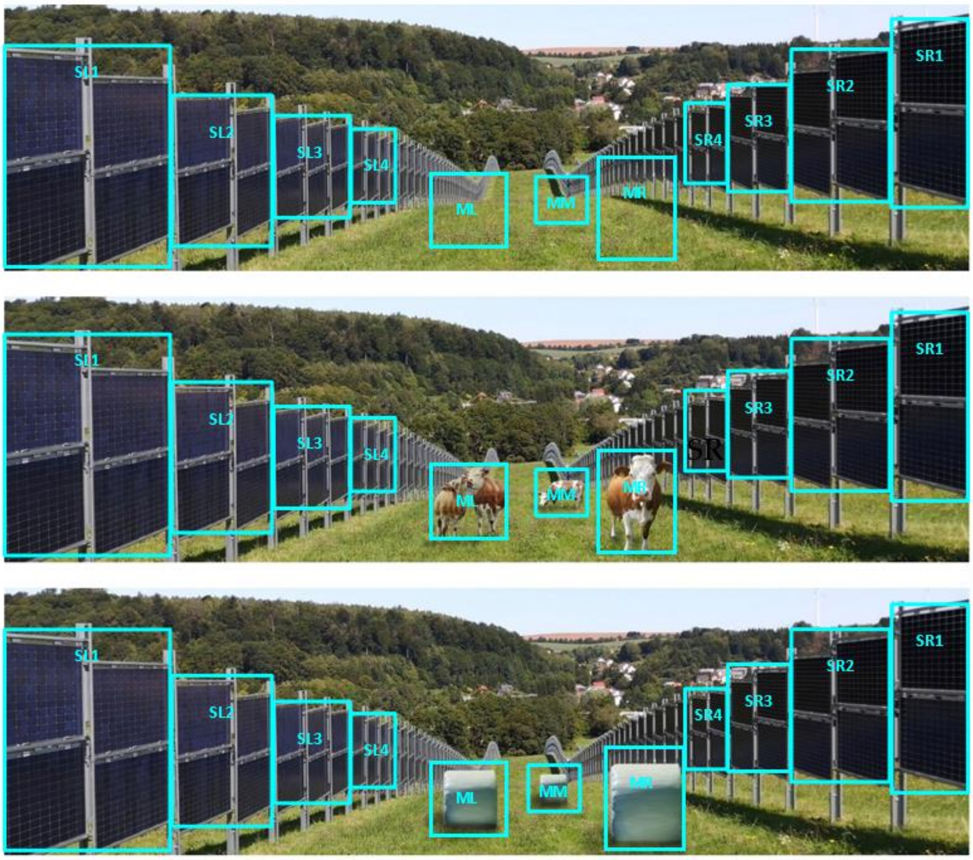

Figure 2. Stimuli used in the eye-tracking experiment with areas of interest marked in turquoise; picture 1 (**top**): grassland only; picture 2 (**centre**): grazing cattle and picture 3 (**bottom**): silage bales.

3.3. Survey

Item batteries with 5-point Likert scales were used in the survey's questionnaire. The individual items can be found in the results section. We used the LimeSurvey Professional software, version 5.0 (LimeSurvey GmbH, Hamburg, Germany) for the questionnaire design and administration. The questionnaire is provided as Supplementary Material.

3.4. Pretest

A pretest was conducted prior to the data collection. A pretest serves for the evaluation and verification of the general experimental design from the participants' point of view [52]. For the pretest, 8 participants (5 male/3 female) were recruited. The understanding of questions and answers was checked, and the time it took the participants to complete the eye-tracking experiment and questionnaire was determined. Special attention was paid to the participants' behaviour during the eye-tracking section of the study, i.e., whether they were able to follow the instruction to move their head and body as little as possible.

A double person-related calibration appeared to be important as the Eyevido software does not provide information about the results of the calibration process carried out by default at the start of each eye-tracking recording. Thus, pre-calibrating each participant in the eye tracker configuration and setup software Tobii Pro Eye Tracker Manager was considered reasonable to ensure a sufficient quality of eye-tracking data, despite the increased time required per participant. The results of the pre-test also led to the following changes:

- Shortening of the display time per image from 25 s to 10 s;
- Reduction in and correction of the free text response options;
- Adjustment and correction of the different question types;
- Randomisation of items in item batteries to reduce the sequence effects.

3.5. Participants

We aimed for 30–45 participants, or 10–15 participants per experimental group, i.e., per subsample. The participants were recruited in the German federal state of North Rhine-Westphalia through personal contact or on social media networks to reach as wide an age range as possible. The data collection took place in autumn and winter 2022. Between 2 October 2022 and 16 October 2022, 30 individuals participated in the study. The data collection was carried out either at the participants' homes or at locations that were easy for them to reach, in order to make it as convenient as possible for them and avoid travelling costs for them. This approach made it possible to recruit this number of participants outside the university environment, despite the participants not receiving any financial compensation. The preliminary data analysis revealed that the quality of some participants' eye-tracking data was poor, resulting in the exclusion of these data for further analyses. Efforts were made to recruit additional participants to replace those with a poor eye-tracking data quality. Between 12 December 2022 to 27 December 2022, another 7 participants took part in the study. In this case, the data collection was conducted in the university's Behavioural and Neuroeconomics Laboratory, and participants received some financial compensation for their efforts. Again, participants with a poor quality of eye-tracking data had to be excluded.

No ethical statement was required from the research institution for this type of study at the time of implementation. The study was conducted in accordance with the Declaration of Helsinki. Possible risks of the eye-tracking were explained to the participants, which might arise in particular from the pulsating infrared light emitted by the eye-tracker, and the associated (very rare) restrictions on participation. The study did not impose undue stress to the participants, nor did it harm their physical or mental well-being. All the participants provided written informed consent to take part in the study. Before the experiment started, all participants were informed about the aims and content of the study, specifically that the study was intended to get a deeper understanding of the perception and acceptance of solar PV on agricultural land. They received instructions about the study procedure, had the opportunity to ask questions and were informed that they could withdraw from the study at any time without consequences.

Socio-demographic triplets based on gender and age were created from the recruited participants in order to achieve similar sample sizes for the three subsamples and comparable socio-demographic characteristics. Within each triplet, the participants were randomly assigned to the subsamples. As mentioned above, some participants were excluded from the analyses due to the poor quality of the eye-tracking data. The data quality was appropriate for further analyses for a total of 29 participants: in subsample 1 (eye-tracking stimulus: grassland only), 9 out of 11; in subsample 2 (eye-tracking stimulus: cattle), 10 out of 12 and in subsample 3 (eye-tracking stimulus silage bales), 10 out of 13 participants could be used for the data analyses. Table 1 shows basic socio-demographic characteristics of the three subsamples and for the whole sample. Our sample was almost balanced with respect to gender. Compared to the German population, the sample was younger, with a higher education and more rural-based (c.f. [53,54]. Despite the socio-demographic triplet procedure, the subsamples showed some distinct differences, partly due to the fact that some participants had to be excluded as described above. Subsample 3 contained a higher proportion of men, the participants were more urban and lower-educated. Compared to the other groups, the participants of subsample 2 were older and more often lived in rural areas.

Table 1. Sociodemographic characteristics of the sample.

		Subsample 1 Grassland		**Subsample 2 Cattle**		**Subsample 3 Silage Bales**		**Total Sample**	
		n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Gender									
	Female	5	55.6	5	50.0	4	40.0	14	48.3
	Male	4	44.4	5	50.0	6	60.0	15	51.7
Education									
	Low/Middle	1	11.1	1	10.0	5	50.0	7	24.1
	High	8	88.9	9	90.0	5	50.0	22	75.9
Living environment									
	Town	3	33.3	1	10.0	4	40.0	8	27.6
	Village	6	66.7	9	90.0	6	60.0	21	72.4
Relation to agriculture [1]									
	Strong	2	22.2	1	10.0			3	10.3
	Middle	4	44.4	5	50.0	7	70.0	16	55.2
	Loose	3	33.4	4	40.0	3	30.0	10	34.5
Age									
	Mean (SD)	32.4 (13.2)		41.30 (16.3)		35.2 (13.2)		36.4 (14.3)	
	Min–Max	20–57		23–66		22–60		20–66	

Note: [1] Strong: working on a farm or in an agriculture-related sector; middle: having a farmer in the immediate circle of relatives or friends and loose: having loose or no contacts to farmers.

Table 2 provides information on the participants' familiarity with the topic of the study, i.e., AV, at the beginning of the survey. When asked about their level of knowledge of AV on a scale from 1 (no knowledge) to 5 (very comprehensive knowledge); the answers in all subsamples were on average below the scale's median, indicating a rather low level of knowledge regarding the topic. In all subsamples, the majority of the participants were not familiar with vertical interspace AV with bifacial modules.

Table 2. Familiarity with the topic of agrivoltaics (AV).

		Subsample 1 Grassland		**Subsample 2 Cattle**		**Subsample 3 Silage Bales**		**Total Sample**	
		n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Familiarity with vertical interspace AV									
	Familiar	2	22.2	1	10.0	2	20.0	5	17.2
	Not familiar	5	55.6	8	80.0	7	70.0	20	69.0
	Unsure	2	22.2	1	10.0	1	10.0	4	13.8
General knowledge related to AV [1]									
	Mean (SD)	1.9 (0.6)		1.5 (0.7)		1.5 (0.7)		1.6 (0.7)	
	Min–Max	1–3		1–3		1–3		1–3	

Note: [1] Answers provided on a scale from 1 (no knowledge) to 5 (very comprehensive knowledge).

3.6. Qualitative and Statistical Analysis

The eye-tracking data were visualised using heat maps and attention maps. Heat maps are time-aggregated density-based representations of gaze behaviour enabling eye-tracking data from several participants to be combined in one visualisation [55]. In this study, heat maps based on the fixation duration were used. They may serve as an indicator of the level of cognitive effort [56]. The fixation intensity is represented by red (high intensity), yellow, green and blue (low intensity) colouring of the observed areas. Areas without colouring indicate that the participants did not fixate on those parts of the stimulus. In addition to the heat maps, the recorded eye-tracking data were also visualised by attention maps. The attention maps have a black cover colour. The intensity of the colour coverage decreases with an increasing fixation intensity, i.e., clearly visible areas of the attention maps indicate the intensive observation of these image areas [57].

The following AOI-based eye-tracking parameters were used for the quantitative analyses:

- Fixation duration: the sum of the duration of all fixations of an individual occurring within an AOI. If an individual had no fixations within the respective AOI, a fixation duration of zero was considered for further analysis;
- Time to first fixation: the time period from the stimulus onset to the first fixation within an AOI. This parameter could only be calculated for individuals that visually visited the AOI, i.e., had at least one fixation within the AOI.

The fixation duration can serve as an indicator of the cognitive load, with an increasing fixation duration indicating a higher cognitive load. The time to the first fixation provides information about the potential of a particular region of a stimulus to attract visual attention. The shorter the time to the first fixation, the higher the activation potential [44,58].

As already described above in Section 2.2, it was only possible to define rectangular AOIs due to technical limitations of the software. This necessitated working with several individual AOIs and grouping them into regions of interest (ROI) to obtain information on which parts of the picture (solar panels; picture manipulation illustrating grassland use) the participants allocated their visual attention to. For the quantitative data analyses, the eye-tracking data were pre-processed by summarising the following AOIs into the following ROIs:

Fixations on the solar panels (ROI SO):

- Fixation duration: AOI SL1 + AOI SL2 + . . . + AOI SR4;
- Time to first fixation: calculated as the shortest time to the first fixation within the eight respective solar panel AOIs (AOI SL1, AOI SL2, AOI SL3, AOI SL4, AOI SR1, AOI SR2, AOI SR3, AOI SR4).

Fixations within the areas of image manipulation (ROI IM):

- Fixation duration: AOI ML + AOI MM + AOI MR;
- Time to first fixation: shortest time to the first fixation within the three respective image manipulation AOIs (AOI ML, AOI MM, AOI MR).

An analysis of variance (ANOVA) was used to test for significant differences between the subsamples with respect to the eye-tracking parameters. ANOVA was also used for subsample comparison of Likert-scale measurements in the questionnaire. Pearson correlation coefficients were calculated to test for a relationship between the gaze behaviour and acceptance. For comparisons between pictures using the full sample, a repeated measurement analysis of variance (rmANOVA) was used because of repeated measurements within the same participants. Paired t-tests were employed for the before–after comparisons. If analyses comparing more than two treatments (ANOVA, rmANOVA) revealed statistically significant differences ($p < 0.05$), post-hoc tests were performed and significant differences between the treatments were indicated by different letters. All the statistical analyses were done with Stata IC version 16.1 (StataCorp LLC, College Station, TX, USA) and IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, NY, USA).

4. Results

Before going into the details of the quantitative analyses of the eye-tracking and the survey data, the qualitative eye-tracking results are displayed.

4.1. Comparison of the Qualitative Eye-Tracking Results of the Subsamples

Heat maps and attention maps give first qualitative indications of the gaze behaviour of the participants in our experiment (cf. Figure 3). Both the heat maps and the attention maps indicate a high fixation intensity in the central area of the pictures—regardless of the displayed elements.

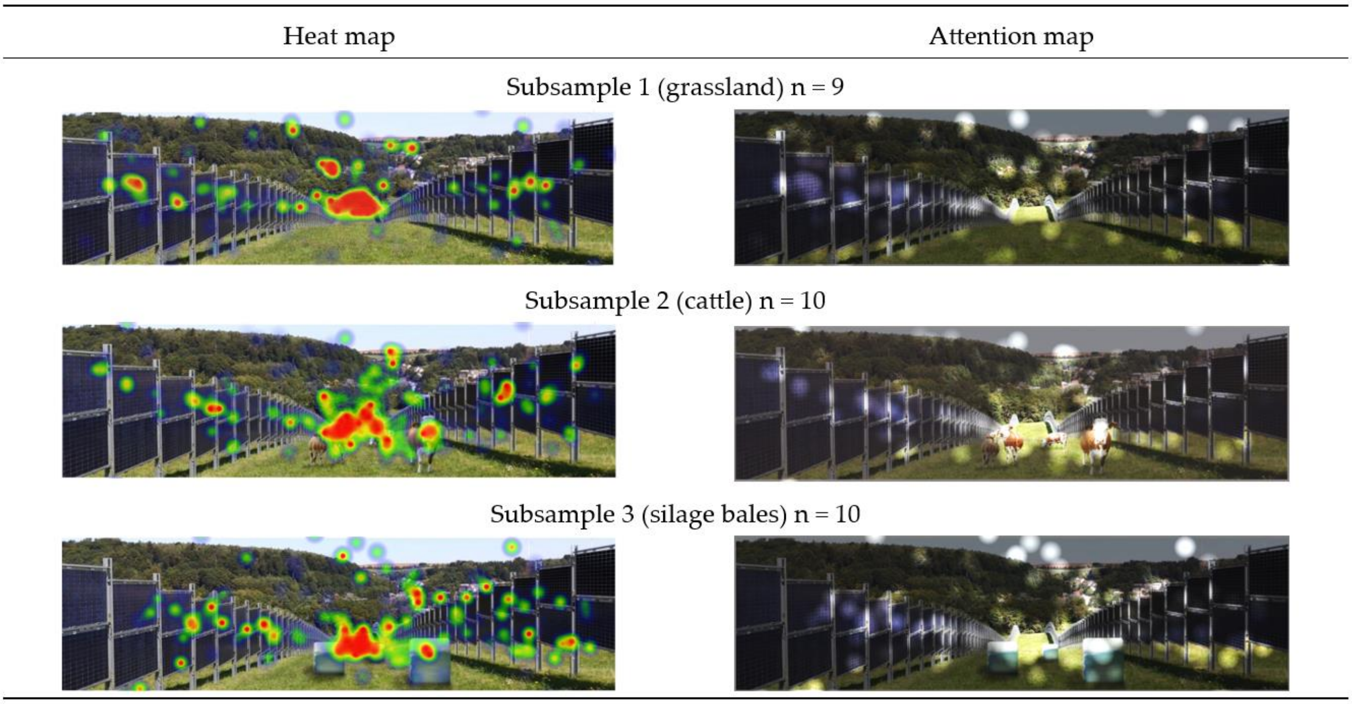

Figure 3. Heat maps and attention maps for the three treatments.

However, while in the picture without manipulation, i.e., without additional elements, the fixations accumulate clearly in the centre, the fixations seem to be slightly more dispersed in both the picture with cattle and the picture with silage bales. There was no obvious effect on the gaze behaviour on the solar panels.

4.2. Comparison of the Quantitative Eye-Tracking Results of the Subsamples

The quantitative results are based on pre-processed eye-tracking data as described in Section 3.6. The results show that the additional picture elements inserted with the help of a picture-editing software attracted visual attention (Table 3). The fixation duration on ROI IM was significantly longer in subsample 2 (cattle) compared to subsample 1 (grassland only). However, the fixation duration on the solar panels (ROI SO) did not differ between the subsamples, indicating that the additional picture elements in subsamples 2 and 3 did not distract visual attention from the solar panels.

The time to the first fixation could only be calculated for those participants who had visually visited at least one of the AOIs of the respective ROI. In subsample 1 (grassland), only 78% of the participants visited ROI IM; ROI SO was visited by all the participants. In subsample 2 (cattle), 90% of the participants visited ROI IM and all participants visited ROI SO. In subsample 3 (silage bales), all the participants visited ROI IM and ROI SO.

For those who visually visited the respective ROI, no significant differences in the time to the first fixation were found between the subsamples for the regions with the solar panels (ROI SO). For the region of picture manipulation (ROI IM), differences in the time to the first fixation tended to be significant ($p < 0.1$), with participants in subsample 2 (cattle) and 3 (silage bales) having their first fixation within this region considerably faster than those in subsample 1 (grassland only).

Table 3. Comparison of the eye-tracking parameters of the regions-of-interest solar panels (ROI SO) and image manipulation (ROI IM) between the subsamples. The eye-tracking parameters refer to the first stimulus shown to the respective subsample in the experimental part of the study.

	Time to First Fixation in Seconds Mean (SD)		**Fixation Duration in Seconds Mean (SD)**	
	ROI SO	**ROI IM**	**ROI SO**	**ROI IM**
Subsample 1 Grassland	1.10 (1.04)	4.43 (3.10)	2.79 (1.45)	0.42 (0.37) ^{a}
Subsample 2 Cattle	0.83 (1.08)	2.00 (2.55)	2.30 (1.42)	2.26 (1.73) ^{b}
Subsample 3 Silage bales	0.60 (0.93)	1.99 (1.22)	2.68 (1.08)	1.77 (0.91) ^{ab}
ANOVA	F (2, 26) = 0.57 $p = 0.570$	F (2, 23) = 2.85 $p = 0.079$	F (2, 26) = 0.36 $p = 0.704$	F (2, 26) = 6.24 $p = 0.006$

Note: Significant differences ($p < 0.05$) between the subsamples were determined by post-hoc tests with Bonferroni correction and are indicated by different letters.

4.3. Comparison of the Acceptance Ratings Between the Subsamples

After completing the eye-tracking task, each participant was asked to answer a battery of items designed to measure the acceptance of the AV system shown in the experiment in several dimensions (Table 4). Most mean values were above the scale's median of 3, indicating a general favourable attitude towards the displayed AV system. The highest values were observed in subsample 1 (grassland only). The lowest mean values were found in subsample 3 (silage bales)—especially for the item containing the aspect of financial participation. Both the participants of subsample 2 (cattle) and subsample 3 (silage bales) rated the compatibility with the scenery lower. However, the differences between the subsamples were not significant.

Table 4. Acceptance ratings of vertical interspace AV after the first picture seen, i.e., after the picture seen in the eye-tracking experiment, evaluated by different items on a 5-point Likert scale.

	Subsample 1 Grassland Mean (SD)	**Subsample 2 Cattle Mean (SD)**	**Subsample 3 Silage Bales Mean (SD)**	**ANOVA *p*-Value**
I support this kind of AV in general	4.11 (0.78)	3.60 (0.84)	3.40 (0.84)	0.177
I support this kind of AV in my municipality	4.11 (0.93)	3.60 (0.84)	3.20 (1.14)	0.148
I support this kind of AV in my municipality if it is possible to participate financially	3.78 (0.83)	3.40 (1.26)	2.80 (1.23)	0.185
I support this kind of AV if it contributes to the energy self-sufficiency of my municipality	3.89 (0.93)	3.90 (0.99)	3.70 (1.06)	0.883
The system shown is environmentally compatible	4.00 (0.87)	3.60 (0.97)	3.00 (1.25)	0.129
The system shown is compatible with the scenery	3.44 (0.73)	2.90 (1.45)	2.90 (1.29)	0.541
Overall	3.89 (0.55)	3.50 (0.86)	3.17 (0.83)	0.144

Note: Response scale: 1 (fully disagree)–5 (fully agree). Overall: mean across all items.

4.4. Associations Between the Gaze Behaviour and Acceptance

To test for possible associations between the gaze behaviour and acceptance of the AV system shown in the experiment, Pearson correlation coefficients were calculated between eye-tracking parameters (time to first fixation and fixation duration) of each ROI and the overall acceptance of the AV system. Table 5 illustrates that there was no significant correlation between the participants' gaze behaviour and their acceptance of the AV system shown in the eye-tracking experiment.

Table 5. Pearson correlations between eye-tracking parameters time to first fixation (TFF) and fixation duration (FD) for the regions-of-interest solar panels (ROI SO) and image manipulation (ROI IM) and overall acceptance of the agrivoltaic systems shown in the eye-tracking experiment, separated by subsamples.

	TFF ROI SO		TFF ROI IM		FD ROI SO		FD ROI IM	
	r	*p*-Value	r	*p*-Value	R	*p*-Value	r	*p*-Value
Subsample 1 Grassland	−0.29	0.450	0.43	0.339	0.21	0.579	0.09	0.811
Subsample 2 Cattle	−0.10	0.779	0.38	0.320	0.20	0.574	0.09	0.807
Subsample 3 Silage bales	−0.38	0.281	0.28	0.426	−0.54	0.109	0.49	0.150

4.5. Comparison of the Acceptance Ratings Considering the Whole Sample

As described in the methods section, after the eye-tracking part, all participants also watched those images not shown in the eye-tracking experiment and answered the same questions about acceptance for each image. Thus, in the end, all 29 participants evaluated all three pictures (grassland, cattle, silage bales)—but in a different order. Comparing the answers of all the participants for the three pictures reveals no significant differences, i.e., taken together, the displayed vertical interspace AV systems were evaluated in the same way regardless of whether grassland, cattle or silage bales had been presented (Table 6). Regardless of the picture, i.e., the type of grassland use between solar panels, a high agreement was found for the item involving the aspect of energy self-sufficiency of the municipality. However, while this item received the highest value among all items for both the grassland and silage bale pictures, it received only the second highest value for the cattle picture. Regardless of the type of grassland use, the participants agreed least with the statement that the AV system is compatible with the landscape.

Table 6. Acceptance of vertical interspace AV for all pictures and all participants (n = 29).

Picture	Grassland Mean (SD)	Cattle Mean (SD)	Silage Bales Mean (SD)	rmANOVA *p*-Value
I support this kind of AV in general	3.52 (1.02)	3.66 (0.97)	3.69 (0.89)	0.528
I support this kind of AV in my municipality	3.34 (1.17)	3.48 (1.09)	3.62 (0.98)	0.294
I support this kind of AV in my municipality if it is possible to participate financially	3.28 (1.22)	3.31 (1.26)	3.52 (1.15)	0.312
I support this kind of AV if it contributes to the energy self-sufficiency of my municipality	3.62 (1.15)	3.62 (1.08)	3.83 (0.93)	0.373
The system shown is environmentally compatible	3.38 (1.11)	3.45 (1.05)	3.34 (1.04)	0.863
The system shown is compatible with the scenery	3.00 (1.00)	3.07 (1.19)	3.10 (1.14)	0.857
Overall	3.36 (0.96)	3.43 (0.96)	3.52 (0.84)	0.491

Note: Response scale 1 (fully disagree)–5 (fully agree). Overall: mean across all items.

4.6. Before and After Assessment of Site Suitability for AV

The question for suitable locations for AV was asked at the beginning and the end of the survey to each participant. This repetition of the question was intended to gauge the influence of information uptake and engagement with the topic during the survey on the acceptance of AV. Whereas the responses to the question at the beginning of the survey were based on the participants' previous, heterogeneous knowledge, their involvement in the survey might have led to more equal knowledge levels at the end of the survey—slightly indicated in the decreasing standard deviations. All mean values at the end of the survey were above the theoretical mean value of 3. The highest values were achieved for fallow land, and lowest values for arable land. Pasture and special crops are the only locations for which the approval tended to be significantly ($p < 0.1$) higher at the end of the survey. The difference between the overall mean values was significant (Table 7).

Table 7. Before–after responses for suitable locations for AV in general (all participants, n = 29).

	Mean (SD) Before	Mean (SD) After	p-Value
Arable land	2.86 (1.30)	3.07 (1.19)	0.364
Grassland for fodder production	3.14 (1.19)	3.34 (1.08)	0.264
Pasture	3.14 (1.19)	3.69 (1.11)	0.050
Fallow land (agricultural)	3.97 (1.24)	4.00 (1.10)	0.896
Special crops	3.55 (0.99)	3.93 (0.92)	0.086
Overall	3.33 (0.68)	3.61 (0.75)	0.048

Notes: *t*-test for paired samples; question wording: "On which locations do you think agrivoltaic systems are most likely appropriate? Please answer on a scale from 1 (not at all appropriate) to 5 (very appropriate)".

4.7. Comparison of the Acceptance of Vertical Interspace AV to Overhead AV and GM-PV

A secondary objective of the study was to explore how vertical interspace AV is assessed compared to overhead AV and GM-PV. For this, the participants responded to the same items as for the vertical interspace AV systems after being shown pictures of an overhead AV system and a GM-PV park. To determine the values for the acceptance of the vertical interspace AV, the mean values of the participants' responses to all three picture versions (i.e., the three grassland use types) were calculated. As can be derived from Table 8, the acceptance of both AV systems, i.e., the vertical interspace and overhead AV, was considerably higher than for the GM-PV. For the GM-PV, the overall acceptance was slightly below the scale's median, indicating a slightly negative attitude towards this kind of solar energy generation. The overall acceptance for both AV systems was above the scale's median. In line with the previous analyses, the statement that the respective system is compatible with the scenery received the least approval. The agreement with this statement was lowest for the GM-PV.

Table 8. Comparison of the acceptance of GM-PV and agrivoltaics (all participants, n = 29).

	GM-PV Mean (SD)	Overhead AV Mean (SD)	Vertical AV Mean (SD)	rmANOVA p-Value
I support this kind of AV in general	3.07 (1.00) ^{a}	3.66 (0.94) ^{b}	3.62 (0.81) ^{a,b}	0.006
I support this kind of AV in my municipality	2.86 (1.09) ^{a}	3.55 (0.99) ^{b}	3.48 (0.93) ^{b}	0.001
I support this kind of AV in my municipality if it is possible to participate financially	2.83 (1.07) ^{a}	3.48 (1.06) ^{b}	3.37 (1.09) ^{b}	0.001
I support this kind of AV if it contributes to the energy self-sufficiency of my municipality	3.14 (1.09) ^{a}	3.66 (0.97) ^{b}	3.69 (0.91) ^{b}	0.001
The system shown is environmentally compatible	3.03 (1.09) ^{a}	3.59 (0.91) ^{b}	3.39 (0.89) ^{a,b}	0.014
The system shown is compatible with the scenery	2.48 (1.18) ^{a}	3.28 (1.00) ^{b}	3.06 (0.95) ^{a,b}	0.001
Overall	2.90 (0.98) ^{a}	3.53 (0.84) ^{b}	3.43 (0.80) ^{b}	<0.001

Note: Response scale: 1 (fully disagree)–5 (fully agree). Overall: mean across all items. Significant differences (post-hoc tests with Bonferroni correction) are indicated by different letters.

4.8. Participants' Comments on the AV Systems Shown

The participants were invited to share their thoughts on the vertical interspace AV system shown in the eye-tracking experiment, as well as on the GM-PV and the overhead AV shown in the explorative part of the survey. The opportunity to share their thoughts about the vertical interspace AV system shown in the eye-tracking experiment was used by two participants in subsample 1 (grassland only), four participants in subsample 2 (cattle) and three participants in subsample 3 (silage bales). In subsample 1, one participant listed elements of the landscape including PV and described the landscape as appealing. The other participant appreciated that it would still be possible to use the meadow. In subsample 2, all the responses related to livestock farming. Two participants assessed the parallel use for solar energy production and grazing positively. The other two referred to fenced-in cattle, with one participant describing the animals as 'penned in'. The opinions of the participants in subsample 3 also diverged. While one participant described the space between the solar panels as 'cramped', another described it as 'quite large'. The comment of the third participant referred to the picture manipulation: 'Edited with Photoshop? Don't the silage bales roll off?'.

The open question in the exploratory part of the survey, which focused on the GM-PV and overhead AV system shown, was answered by 11 participants. However, not all the answers could be clearly assigned to one of the two systems, as some participants did not clearly state to which system their answer referred. Although the open question was aimed at learning more about the participants' thoughts on GM-PV and overhead AV, two participants compared these two systems with the vertical interspace AV and considered the latter to be superior. The majority of participants expressed indirectly or directly that they were in favour of the dual or multiple use of agricultural land. As one participant put it: 'In my opinion, the solar panels should be installed in such a way that additional uses are possible. I don't think it's a good idea to use up land just for that, unless it's contaminated, like landfill sites or something like that'. One participant felt that the overhead AV shown was the system that was most compatible with the environment, and another stated that this system would fit into the landscape better than GM-PV.

4.9. Compilation of the Results with Reference to the Hypotheses

The main objective of the study was to experimentally test the visual perception and acceptance of vertical interspace AV systems. The hypotheses could only be partially confirmed.

H1: *Visual perception of vertical interspace AV systems is influenced by the type of grassland use.*

H1a: *Animate (grazing cattle) and inanimate elements (silage bales) between the module rows attract faster and more visual attention compared to pure grassland.*

H1b: *Compared to pure grassland, animate (grazing cattle) and inanimate elements (silage bales) distract visual attention from the technical elements (essentially the solar modules).*

When considering the whole vertical interspace AV system, consisting of the technical installations and agricultural use, Hypothesis H1 was confirmed. The participants in subsample 2 (cattle) paid more visual attention (longer fixation durations) to the ROI IM, which contained cattle as animate elements, compared to subsample 1 (pure grassland). The differences in the time to the first fixation between the subsamples were only marginally significant ($p < 0.1$). Thus, H1a could partly be confirmed with regard to the assumption that animate elements attract more visual attention compared to pure grassland and in the tendency that elements visualising grassland use attract visual attention faster. However, H1b was not supported by the results. Even if the elements illustrating grassland use attracted visual attention, they did not divert visual attention away from the solar modules (c.f. Section 4.2).

H2: *Visual perception of the vertical interspace AV systems influences the acceptance of the systems.*

Hypothesis H2 was not supported. Even if the visual perception of the vertical interspace AV systems was influenced by the type of grassland use, i.e., differed between the subsamples, this was not the case for the acceptance ratings (cf. Section 4.3). Even within the subsamples, a correlation between the participants' gaze behaviour and the acceptance ratings could not be confirmed. (cf. Section 4.4).

H3: *Information on AV influences acceptance of this technology.*

Hypothesis H3 was partially confirmed. In the before–after comparison, which took into account more comprehensive information processing by the participants, a significant increase in acceptance was observed when all values (i.e., the mean values across all AV sites) were considered. However, if the acceptance values are analysed separately for the individual AV sites, only grassland and special crops were marginally significant ($p < 0.1$) towards an increase in acceptance (c.f. Section 4.6).

5. Discussion

5.1. Discussion of the Results

The objective of the study was to better understand how AV systems, especially vertical interspace AV systems, are perceived, and which factors could influence the acceptance of these systems. A central question was whether different types of grassland use visualised using photo-based pictures could have an impact on the visual perception and acceptance of AV.

The results indicate that the participants in this study were rather positive towards AV. These results are in line with the findings of other studies analysing German and European citizens' perceptions of AV, which describe an open-mindedness towards AV, provided certain preconditions are met [15,39]. In particular, it seems important that AV projects provide economic benefits to the local community and ensure a fair distribution of these benefits [30]. This is consistent with the observation from our study that participants would be most likely to support AV if it contributes to the energy self-sufficiency of their community. The possibility of financial participation, on the other hand, was considered less attractive by the participants, presumably because it bears the risk of economic benefits being unfairly distributed. The comparison of AV systems with GM-PV in our study showed, in line with various previous studies [9], that the acceptance of GM-PV is always lower than that of overhead AV and for most of the items measuring acceptance also lower than that of vertical AV. This preference for AV could be due to the dual use of the land for energy and agricultural production, which was repeatedly mentioned positively by the participants, while the exclusive use for solar energy production was considered problematic.

Investigations on the acceptance of AV repeatedly point to the fact that perceived visual effects on the landscape are of great importance for the evaluation of AV systems and that sites with natural screening or flat locations should be preferred to ensure the best possible integration of the systems into the landscape and make them less visible [12,15,30]. This sensitivity to visual aspects of AV projects was also apparent in our study. Regardless of the technical design, i.e., vertical interspace or overhead AV, the participants were rather undecided about the compatibility of AV with the landscape. This can be concluded from the responses to the question on the assessment of compatibility with the scenery, which were each around the median of the response scale for the AV systems (overhead and vertical interspace AV). This result was not altered by the type of grassland use between the solar modules in the vertical interspace AV system, even though the eye-tracking data revealed that additional picture elements, particularly the cattle, modulated the gaze behaviour. The modulation of the gaze behaviour could be a consequence of the greater heterogeneity of the landscape resulting from the additional picture elements. Eye-tracking studies show that heterogeneous landscapes are more visually 'entertaining' and thus lead to changes in gaze behaviour [41]. The shorter time to the first fixation on the ROI IM in the stimuli with the additional elements (cattle/silage bales) indicate that these additional elements could have exogenously influenced the participants' gaze behaviour due to visual salience [59]. However, the high standard deviations in this eye-tracking parameter indicate that the hierarchical distribution of visual attention deviated considerably for some participants. This may be contributed to the fact that visual attention is not only controlled exogenously, but also endogenously, e.g., by the motivations, interest, task or existing knowledge [44,60]. For example, it could be that for some of the participants the exogenous influence of the additional picture elements on the gaze behaviour was superimposed by endogenous factors, such as their existing knowledge about or interest in grassland farming, animal husbandry or regenerative energies, which could have guided the gaze behaviour.

However, visual attention was not distracted from the solar panels by the additional visual elements, supporting findings by Guo et al. that modern artificial elements in the landscape automatically attract attention and substantially influence the landscape experience [47]. The analysis of the gaze behaviour within the subsamples also revealed no clear relationship between the visual attention and acceptance ratings, i.e., no effect on the acceptance ratings was found based on how quickly or how long the solar modules or the area between the modules were observed by the respective participant. This is consistent with the observations of Moczek et al., who describe that wind turbines attract visual attention, but that there is no relationship between the level of visual attention to wind turbines and the landscape experience [45]. Another reason for the almost undiminished visual interest in the solar modules despite the additional picture elements could have been the information that was given to the participants about the objectives of the study for reasons of transparency prior to the start of the survey. The information that the study's focus was on investigating the perception and acceptance of AV might have been interpreted by the participants as a task. This might have led to a more endogenously driven gaze behaviour [61], which might have had the effect that special visual attention was paid to the solar modules. The participants might have had the impression that they had to visually inspect the solar modules closely to develop an informed opinion on AV.

The results of our study also provided no evidence for a positive influence of the depicted grazing cows on the acceptance of AV. Even though previous studies suggest that grazing animals positively influence landscape preferences [36] and animals in outdoor or extensive husbandry systems can also lead to positive emotions [38,62], this may not have been sufficient to have an influence on the evaluation of AV, at least in our study. However, it could also be that some participants had doubts about whether grazing between solar panels offers sufficient animal welfare and that these concerns had an impact on the acceptance ratings of the AV system. This is at least indicated by the participants' comments about penned or fenced-in cows. Whether this perceived confinement of the animals is primarily caused by the stimulus shown (i.e., picture perspective/shown section of the AV system or the landscape), or by a basic attitude of the participants with regard to livestock farming, cannot be answered with the data collected.

The missing association between the gaze behaviour and the acceptance of the participants could also indicate that attitudes towards AV systems cannot be changed by inserting cattle or other elements such as silage bales into a picture showing an AV system. Prejudices, (dis)trust in solar energy in general or open-space PV or AV in particular, or even (dis)trust in the main actors of such projects might have been decisive for the participants' acceptance ratings [63].

An in-depth engagement with the topic of AV, which was more or less inevitable in the context of the study due to the information provided and questions asked, appeared to increase the acceptance of this type of energy generation. This applies at least to short-term acceptance, and is consistent with the results of a recent study that analysed perceptions of and preferences for green infrastructure. The authors describe that in-depth engagement with the topic influenced the participants' evaluation of the infrastructure in question and their decisions [64].

5.2. Limitations

Our study is not without several limitations. Although we do not have more than slight tentative evidence, the artificial character of the manipulated pictures might have influenced the gaze behaviour and acceptance ratings. Even if the manipulations may not have been consciously recognised as artificial, they might have subconsciously influenced the gaze behaviour. And at least for the participant in subsample 3, who expressed the suspicion that the picture could have been edited, an influence on their gaze behaviour could be assumed. A similar assumption was made by Gauly et al. who also worked with manipulated photos. They consider it conceivable that the gaze behaviour in their study was influenced by the imperfect picture editing and the quality of the pictures used [65].

When interpreting the eye-tracking data, the following influences that could have biased the results should also be noted. The first thing to mention is that the comparison of the time to the first fixation in ROI IM is based on a smaller sample size, as only those participants who had at least one visit within this ROI during the picture display time of 10 s could be included in this analysis. If the picture display time had been longer, it is likely that all the participants in all the subsamples would have visited this ROI, which would have increased the time to the first fixation especially in the grassland-only subsample with the lowest numbers of participants that had visited the ROI IM. This might have led to significant differences in the time to the first fixation between the subsamples. Longer display times might have also influenced the Pearson correlations between the acceptance and the time to the first fixation. Secondly, the qualitative analysis of the eye-tracking data revealed strong attention to the centre of all images. This could be at least partly due to a fixation bias towards the centre of the screen, a phenomenon already described for stationary eye-tracking [66]. In addition, the two rows of solar panels may have directed the participants' gaze. This centre fixation bias irrespective of additional picture elements may partly mask a specific element-effect of the two subsamples: cattle and silage bales.

Although photo rating is considered a well-established method to reliably capture individuals' perceptions of landscapes, there are concerns within landscape preference and perception research about the validity of photographs to represent actual landscapes [42,67]. Comparisons of landscape perception and evaluation between on-site observations, panoramic photographs and normal standard photographs show that the validity of photographs depends on various factors, such as the viewing angle, the preference variable to be measured and also the landscape depicted [67].

Our experiment focused on a very specific research question. We investigated the influence of inanimate and animate elements (cattle and silage bales) on the perception and acceptance of AV. For this purpose, only one picture was used, showing a vertical interspace AV plant located in Germany at a specific point in time, i.e., all stimulus features were kept the same, except for the targeted manipulation of the picture. We chose this methodological approach in order to exclude the possible influence of confounding variables that could result from the stimuli used. Although this approach increases the internal validity of our results, it limits their external validity. Thus, our results do not allow any conclusions to be drawn about how other conditions, such as different picture properties (e.g., viewing angle and lighting conditions [68]), different technical properties of an AV system (e.g., solar modules' colour [69]) and environmental or seasonal/weather- related variations [70,71], might affect the visual perception and acceptance of AV. In addition, the AV system is displayed in a close-up perspective. This perspective may not correspond to the natural perspective of a potential viewer, who usually looks at these AV systems from a greater distance.

Research shows that attitudes towards regenerative energy projects can change over time, as can the visual assessment of the landscape affected by the project [72]. Furthermore, visual attention to landscape areas already seen appears to decrease and shift to areas not previously visually inspected when repeatedly confronted with the same landscape stimulus [73]. However, the experimental approach we chose only investigated short-term influences at one point in time and does not allow any conclusions to be drawn about the long-term influence of the type of grassland use on the visual perception and acceptance of AV.

A major limitation concerns the sample size and recruitment of the participants. The sample was a convenience sample and rather small, raising questions regarding the generalisability of the results. Even though the sample contained almost the same number of women as men and therefore almost reflected the German population, the sample is not representative of the latter, as the participants were recruited only in one specific region of Germany, were on average younger, a higher proportion lived in rural areas and had higher levels of education. Furthermore, we cannot exclude the impact of socio-demographic characteristics on visual perception and acceptance evaluations. Socio-demographic differences between the subsamples, which occurred despite the triplet procedure (see Section 3.5), might have worked as confounding factors.

5.3. Implications and Suggestions for Further Research

From the limitations mentioned above, various implications and suggestions for future, in-depth research can be derived. An important aspect here concerns the characteristics and the presentation mode (laboratory/on-site) of the stimuli used for studies on the visual perception and acceptance of AV or for open-space PV in general, as follows:

(1) If picture manipulations are to be made in future studies, care should be taken to position additional elements outside the centre of the picture. When selecting pictures, a possible gaze-directing effect of the rows of solar panels should also be taken into account;

(2) It might be recommendable to make real-world manipulations and work only with real photos without artificial manipulation to avoid these potential biases. However, for visualisations such as those in our study, real cattle and real silage bales would have had to be brought to the real location, and the photos would ideally have had to be taken at the same time of day and under the same weather conditions. It remains open to what extent such an approach could be realised in practice, as it would involve disproportionately high effort and costs. It is also advisable to select photos in such a way that they reflect the natural perspective a landscape observer would normally have on AV systems;

(3) On-site visits could increase the external validity of the results. In this context, eye-tracking glasses could be used to record the gaze behaviour of participants in the real environment. On-site evaluations would also prevent biases that occur when stimuli are presented on a screen, such as a fixation bias towards the centre of the screen;

(4) A promising approach to visualise landscapes for landscape perception research is VR applications, which could also be supplemented with an eye-tracking function. Taking advantage of laboratory conditions, the use of VR tools enables a realistic simulation of landscapes. In contrast to photos or videos, this type of landscape representation is not limited to visualisations with a fixed viewing angle, but enables a virtual ‘walk’ through landscapes [74]. As with on-site visits, immersive VR applications help to prevent visual biases that can occur when static stimuli are presented on a screen. However, even if VR is a reliable tool for landscape assessment, the observer’s assessment of some landscape features may differ between VR and on-site visits, so the pros and cons of both methods should be carefully considered [75];

(5) Future research should put a higher importance on more targeted recruitment and improved randomisation within larger samples. Even if larger representative samples result in considerably greater temporal and financial effort, especially in eye-tracking studies, they would also allow one to consider socio-demographic influences explicitly in the statistical analyses [41]. Larger samples would also allow one to investigate more scenarios (e.g., different technical designs of the AV plant, different types of surrounding landscapes and different weather conditions/seasons) in a between-subjects design;

(6) To investigate long-term effects on the visual perception and acceptance of AV in general and/or of specific AV systems (e.g., vertical interspace AV with grazing), other research methods, such as panel studies [76], need to be applied.

6. Conclusions

The present study aimed to extend the knowledge on people’s visual perception and acceptance of AV systems, focussing on vertical interspace AV on grassland. A key research question to be answered by using photo-based pictures in a survey, supplemented by eye-tracking, was whether the type of grassland use between the solar module rows could influence the visual perception and acceptance of the depicted AV systems. The sample we used was a convenience sample and rather small, which should be kept in mind when interpreting the results. The eye-tracking results revealed that additional picture elements visualising grazing (cattle) and meadow mowing (silage bales) at least partly attracted visual attention, but did not distract visual attention from the technical elements of the depicted AV systems. The analysis of the acceptance ratings suggested relatively stable attitudes towards AV that cannot be simply modulated by illustrating different grassland use types within an AV system. Short-term and limited changes in attitudes towards AV appeared to result from the provision of information and mental engagement with the topic. Whether these changes could be transferred to long-term perspectives remains open. Even if vertical interspace AV as well as overhead AV was evaluated more favourably than GM-PV, AV may also require more comprehensive communication and participation strategies to avoid conflicts with the public and local population. The use of more heterogeneous landscape elements in AV pictures—independent of whether these are animals as animate objects or silage bales as inanimate objects—may not be a sufficient communication tool to replace the provision of more extensive information or participatory processes. We recommend carrying out further research based on larger, representative samples and more realistic stimuli of AV systems that would provide a better understanding of visual perception and acceptance than photos alone, such as on-site visits or VR visualisations, to enhance the external validity of the results. We also suggest conducting longitudinal studies to explore possible long-term effects on the public acceptance of AV.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/grasses3040027/s1, Interview guide.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author; the data collected will be used confidentially and exclusively for scientific purposes.

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