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Visual Perception and Acceptance Of Agrivoltaic In An Eye-Tracking Experiment In Germany

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ABSTRACT

The development of photovoltaics as a renewable energy source is associated with apparent changes to the landscape and the countryside. Thus, questions of landscape aesthetics and public acceptance arise. This also applies to agrivoltaic (AV), an approach that refers to different techniques for the simultaneous use of land for agricultural purposes and photovoltaic electricity production. We tested hypotheses on the extent to which varying image content representing different types of grassland use affects the visual perception and acceptance of AV. To test our hypotheses, we conducted a between-subjects experimental study within a mixed methods approach. In our eye-tracking experiment, participants were randomly shown one of the three versions of the AV site. During this time, eye-tracking data was recorded, allowing qualitative analyses with heat maps and attention maps. Quantitative analyses included time to first fixation, fixation duration, and number of fixations in defined areas of interest (AOI) of gaze behaviour. Subsequently, participants were asked about their acceptance of the AV variant. Eye-tracking data from 29 participants were used for data analysis. The results show that additional image elements attract visual attention - statistically significant only according to some of the several quantitative indicators. Although additional image elements modulate some gaze behaviour indicators, we are not able to provide evidence that this leads to an increased acceptance of AV. In the before-and-after comparison, which considers a more comprehensive processing of information by the participants, the acceptance of AV increased significantly only for grasslands and special crops. Our results suggest that attitudes towards AV are rather stable and cannot be easily modulated by additional information. More comprehensive communication and participation strategies may be needed to avoid public conflicts about AV.

Key words: eye-tracking, experiment, agri-photovoltaics, agrivoltaic, grassland, cattle, renewable energy, landscape aesthetic

1 Introduction

The expansion of photovoltaics as renewable energy source is associated with apparent alterations of landscape and countryside. This begs the question of acceptance of energy infrastructure in general (Wissen Hayek et al. 2019) and of photovoltaic installations more specifically by the public. This also applies to agrivoltaics (AV), an approach that refers to various techniques for the simultaneous use of land for agricultural purposes and photovoltaic electricity production (Trommsdorff et al. 2022; Resser et al., 2021).

AV play a special role in ground-mounted photovoltaic systems. AV systems with their dual-land-use can potentially relax the food-energy nexus (Feuerbacher et al. 2021). AV systems thus primarily pursue the goals of generating an increase in land use efficiency, equalising land competition and making the expansion of photovoltaics on open spaces more acceptable to society as a whole for the energy transition and also more acceptable to farmers (Feuerbacher et al., 2021). In addition, AV offers further advantages, synergy effects and opportunities (Jouttijärvi et al. 2022). A study shows the potential of the systems: 10% of farms could cover about 9% of the nationwide electricity demand on 1% of the arable land in Germany (Feuerbacher et al. 2022).

Bifacial AV are an innovative concept with vertically installed solar modules. Bifacial solar modules can generate electricity on both sides. Unlike conventional ground-mounted photovoltaic systems, the vertically installed modules produce the most electricity in the morning and afternoon, rather than in the midday hours. Due to their mostly chosen east-west orientation they produce anticyclical compared to classic, south-facing modules (Jouttijärvi et al. 2022). As a result, higher specific electricity yields can be generated and higher spot prices tend to be generated on the market, thus dampening the "cannibalism effect" on the electricity market (Blume-Werry et al. 2021). In this concept, the module rows are installed at a distance of at least eight to ten metres. This resulting distance between the rows enables cultivation, for example, in the form of arable farming, grassland management or also for grazing with often standard farm technology. 90% of the area is retained for agricultural use in this concept (Trommsdorff et al. 2022).

The impact of agrivoltaics on landscape aesthetics can vary depending on various factors, including the design of the system, the location of the panels, and the type of crops grown (Toledo et al., 2021; Sirnik et al., 2023). Agrivoltaics potentially have both positive and negative impacts on landscape aesthetics. On the positive side, the combination of photovoltaic panels and agricultural crops can create a visually interesting and dynamic landscape that blends modern technology with traditional farming practices (Oudes et al., 2022). The presence of renewable energy infrastructure in the midst of agricultural fields can also convey a sense of innovation and progress. On the negative side, some people may view the installation of photovoltaic panels as a disruption to the natural beauty of the landscape, particularly in rural areas where unobstructed views of the countryside are highly valued (Pascaris et al. 2022). Additionally, the visual impact of agrivoltaics may depend on the design of the system and the placement of the panels. Poorly designed systems that do not integrate the panels with the surrounding landscape may appear unsightly and detract from the overall aesthetics of the area. Overall, the impact of agrivoltaics on landscape aesthetics seems to be complex and context-dependent. The success of the system in terms of both energy and agricultural production, as well as its visual integration with the surrounding landscape, will depend on careful planning and design. Also, a careful assessment on the impacts of ecosystem services from photovoltaics is indicated (Carvalho et al., 2023)

While the potential for landscape preference studies with eye-tracking is increasingly acknowledged (e.g. Schirpke et al. 2022), it is not clear in how far a variation of image content representing different grassland use types impact visual perception and acceptance of AV. To the best of our knowledge, there are no previous studies which have tested these hypotheses. Therefore, our study focuses on perception and acceptance of AV installed on grassland that uses vertically arranged bifacial solar modules to capture solar radiation on both sides of the panels. From a preliminary study conducted in spring 2022, we obtained first indications of how German citizens assess this particular technology and whether different variations of grassland use could influence visual perception of the scenery: Eye-tracking data suggests that inanimate and particularly animate elements that underpin grassland use between rows of solar panels could divert visual attention away from photovoltaic installations and the scenery and in this way increasing acceptance of these AV (Püttschneider et al. 2022). From this preliminary study, we derived the following hypotheses:

(1) Visual perception of bifacial AV is influenced by the type of grassland use
(2) Visual perception influences acceptance of AV
(3) Information on AV influences acceptance of this technology

The objective of the paper is to analyse in how far a variation of image content representing different grassland use types impact visual perception and acceptance of AV. The paper is organized as follows: After this introduction we explain the data and methods used within our experiment. The results section first looks at the qualitative results before analysing in detail the quantitative eye-tracking and the survey data. Finally, the results will be discussed and some conclusions will be drawn

2 Data and methods

Our study aimed to test the above hypotheses using a between-subject experimental design within a mixed-method approach. By combining different research methods, we were able to capture both qualitative and quantitative data, providing a more comprehensive understanding of our research question. Specifically, we conducted an in-person eye-tracking information experiment combined with a survey. The eye-tracking information experiment allowed us to track the participants' gaze behavior while they viewed our stimuli, which included artificially manipulated images randomly assigned to participants. This provided us with objective data on which elements of the stimuli captured the participants' attention and how they visually processed the information. By analyzing the eye-tracking data, we were able to gain insights into the effectiveness of different design elements and identify potential areas for improvement. In addition to the eye-tracking information experiment, we also conducted a survey to capture participants' subjective responses to our stimuli. This included questions about their attitudes, beliefs, and perceptions regarding the information presented in the stimuli. By analyzing the survey data, we were able to gain insights into the participants' emotional and cognitive responses to the stimuli, as well as their overall level of engagement. The mixed-method approach allowed us to triangulate the findings from both the eye-tracking information experiment and the survey, providing a more comprehensive understanding of the research question. For example, the eye-tracking data may reveal that participants fixated more on certain design elements, but the survey data may provide insights into why those elements were effective or ineffective in conveying the intended message. Overall, the use of a mixed-method approach allowed us to gain a deeper understanding of the research question by capturing both qualitative and quantitative data, providing a more complete picture of the participants' responses to the stimuli.

Experimental design

After introductory questions related to previous knowledge on AV, the core part of the questionnaire begins by asking participants about their acceptance of AV sites on different types of agricultural land use (e.g. fallow; grassland; specialised crops, etc.) – this item batterie is repeated at the end of the survey for a before-after-comparison to test hypothesis 3. Then participants are given image and text information about different types of AV, including bifacial solar systems on grassland. In the following eye-tracking experiment, participants are shown one of the three versions of the AV site of Donaueschingen/Germany to investigate the visual attention participants pay to the background, the solar modules, and the grassland between the modules. A between-subject design was chosen as sequence effects in visual attention were expected. This part of the study is used to test hypothesis 1.

Participants had 15 seconds to look at the image. During this time, eye-tracking data was recorded, allowing qualitative analyses (heat maps, gaze diagrams) and quantitative analyses (fixation duration, number of fixations in defined areas of interest, time to first fixation) of gaze behaviour. Subsequently, participants are asked about their acceptance of the AV variant in general and under specific conditions (e.g., if the AV site would be in their neighbourhood; if they could benefit financially from the site, etc.). This part of the study is used to test hypothesis 2.

After this experimental part, participants are also shown the other two versions they did not receive in the experiment, so that in the end all participants are at the same level of information. Finally, all participants were asked again the questions from the beginning of the survey about the acceptance of AV sites on different types of agricultural land use to determine the influence of the information participants received during their participation in the survey on the acceptance of AV.

Stimuli, areas of interest and eye-tracking data

The experiment is based on an image of an AV site with bifacial solar modules situated in Donaueschingen, Germany. The original image shows pure grassland with no further elements between the solar modules (version 1). Using an image editing software, we manipulated the image to show grazing cows (version 2) and silage bales (version 3) between the solar modules (Fig. 1).

Areas of Interest (AOI) are freely definable areas of interest in eye-tracking examinations. An AOI is a clearly defined, delimited part of the stimulus, which is used in the examination image. By defining the AOI, it is therefore possible to analyse gaze behaviour. AOIs can be analysed and evaluated according to various parameters. In this study, the areas of interest inserted into the stimulus are displayed in figure 2. The size and position of all AOIs is the same in all three studies to allow direct comparisons between the treatments. Only the position of the AOIs in the silage bale treatment differ slightly from the other two studies. To record the eye-tracking data, we use a remote eye-tracking device (Tobii nano, 60 Hz) and the cloud-based software Eyevido Lab.

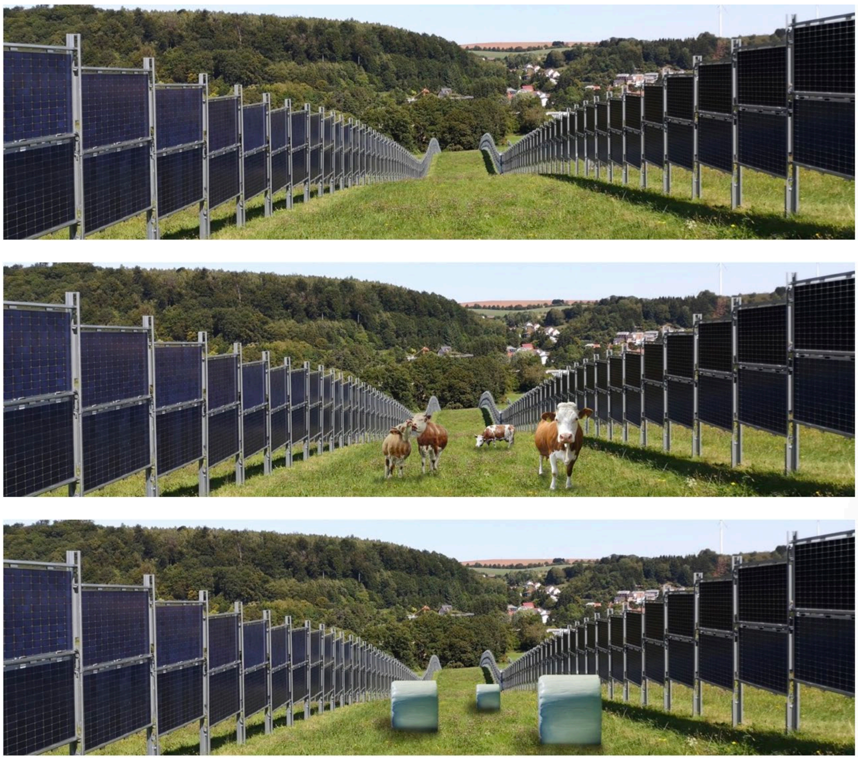


Figure 1: Stimuli used in the eye-tracking experiment

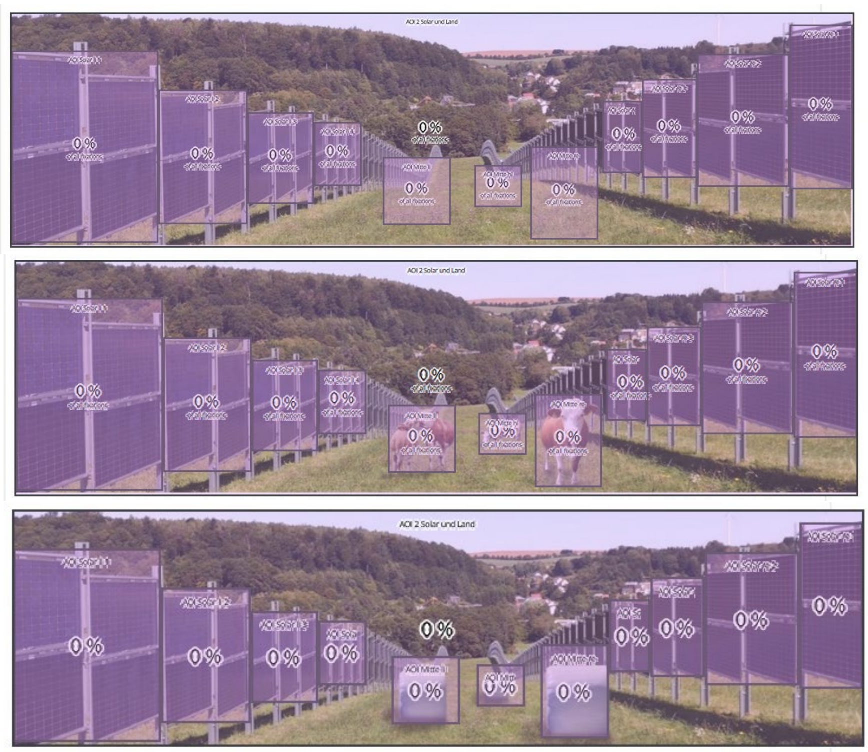


Figure 2: Stimuli with areas of interest (AOI)

Questionnaire and pretest

Item batteries with 5-point-Likert scales were used in the survey. Details are shown in the results sections. We used the LimeSurvey Professional software for questionnaire design and administration. A pretest was conducted prior to data collection. A pretest serves for evaluation and verification of the general experimental design from the participants' point of view (Porst 2013). The understanding of questions and answers was checked and the necessary duration of the study was determined. After the pretest this was set at 10-15. For the pretest, 8 participants (5 male/ 3 female) were recruited. In addition to checking the questioning in "LimeSurvey", a special focus was placed on the handling of the eye-tracking technology by the participants (head stabilised, as little body movement as possible and at the same time completing the online questionnaire).
A twofold person-related calibration appeared to be important. The calibration in "EyeVido" is automatically predefined by the programme before the start of the study, but does not show a direct calibration result. The calibration of each individual participant in the "Eye-Tracker-Manager" was considered reasonable after the pretest, despite the increased time required per participant. The different heights of the participants and the resulting variable recording of the justify this additional step. In addition, this served to ensure the quality of the data collection in changing light conditions. The results of the pretest led to the following changes:

- Reduction of viewing time per image from 25 seconds to 10 seconds.
- Pre-calibration of each participant
- Reduction and correction of free text response options
- Adjustment and correction of different question types
- Randomisation of items in item-batteries to reduce sequence effects

Participants

We aimed for 30 - 45 participants, or 10 - 15 participants per experimental group. Participants were recruited through personal contact or on the social media networks to reach as wide an age range as possible. Data collection took place in autumn 2022. 30 participants participated in this study between 02.10.2022 and 16.10.2022. Due to data quality problems identified in a preliminary data analysis, some individuals with low quality eye-tracking data were excluded. Efforts were made to generate replacements in December 2022 with additional 7 participants taking part between 12.12.2022 to 27.12.2022. Participants in October did not receive any financial compensation while those in December received some. No ethical statement was required from the research institution for this type of study at the time of implementation. Participants were explained possible risks of the study and consent for participation was received from all participants.
Socio-demographic triplets were formed out of the recruited participants in order to ensure similar sample sizes for the three treatments and comparable socio-demographic characteristics. Each participant was then randomly assigned to one of the three treatments. Due to quality problems of the eye-tracking data not all participants could be used for the analyses: In treatment 1 with no additional image element 9 out of 11, in treatment 2 with cattle 10 out of 12 and in treatment 3 with silage bales 10 out of 13 participants could be used for data analyses. The following table 1 shows basic socio-demographic characteristics of the three treatment groups. Our sample is almost balanced with respect to gender. Compared to the German population the sample is younger, with higher education and more rural. Despite the socio-demographic triplet procedure, the treatment groups show some distinct differences with the silage bale group being more male, more urban and lower educated. Treatment group cattle is older compared to the other treatment groups and lives more rural. Treatment group grassland has closer relations to agriculture.

Table 1: Sample description with basic socio-demographic characteristics of the three samples

		Treatment 1 (grassland) n=9		Treatment 2 (cattle) n=10		Treatment 3 (silage bale) n=10	
Gender		n	%	n	%	n	%
	female	5	55.6	5	50.00	4	40.0
	male	4	44.4	5	50.00	6	60.0
Education							
	Low					1	10.0
	Middle	1	11.1	1	10.00	4	40.0
	High	8	88.9	9	90.00	5	50.0
Living environment							
	City	1	11.1				
	Mid-sized town					2	20.0
	Small town	2	22.2	1	10.00	2	20.0
	Village	6	66.7	9	90.00	6	60.0
Relation to agriculture							
I work on a farm		1	11.1				
I work in the upstream or downstream sector of agriculture		1	11.1	1	10		
I have a farmer in my immediate family or circle of friends		4	44.4	5	50	7	70
I have loose contacts in agriculture		1	11.1	1	10		
I have few personal contacts in agriculture		2	22.2	2	20	2	20
I have no personal contacts in agriculture				1	10	1	10
Relation to agriculture [1]							
	mean	2.8		2.3		2.3	
	st.-dev.	1.2		1.2		1.1	
	min	1		0		0	
	max	5		4		3	
Age							
	mean	32.4		41.30		35.2	
	st.-dev.	13.2		16.3		13.2	
	min	20		23		22	
	max	57		66		60	

Notes: [1] ordinal variable with following ranks: I work on a farm (5), I work in the upstream or downstream sector of agriculture (4), I have a farmer in my immediate family or circle of friends (3), I have loose contacts in agriculture (2), I have few personal contacts in agriculture (1), I have no personal contacts in agriculture (0).

Qualitative and statistical analysis

The visual representation for the results of the qualitative eye-tracking data was done using heat-maps and attention-maps. Heat-maps highlight the areas under consideration (to varying degrees depending on the setting). A heat map allows eye-tracking data from several participants to be combined in one visualisation. The viewing intensity changes the longer a participant looks at an area. In this study, red indicates the most intensive viewing. Heat maps do not provide information about the temporal sequence of eye movements. In addition to the heat maps, the collected eye-tracking data was also visualised in attention maps. The attention maps have a black cover colour. The intensity of the colour coverage decreases with increasing fixation intensity, i.e. clearly visible areas of the attention maps indicate intensive observation of these image areas (Brychtova et al. 2012, p.4).

The heat and attention maps have specific parameters that are used to characterize them. Firstly, the scaling of the maps is set at 5%, which determines the size of the colored area displayed on the map. Additionally, the opacity of the colored area is also set, with the heat-map having an opacity of 90% and the attention-map having an opacity of 80%. Moreover, the threshold for the fixation duration on the maps is set at 800 milliseconds. This parameter is crucial as it determines when a point on the map will turn red, indicating that the user has been fixating on that point for the specified duration. This threshold helps in analyzing the user's attention span and can provide insights into which areas of the image attract the most attention. In summary, the heat and attention maps are characterized by their scaling, opacity, and threshold parameters, which are all essential in providing detailed visualizations of user attention and fixation on specific areas of a visual stimulus.

Eye-tracking allows to measure and analyze how individuals interact with visual stimuli on a computer screen. To obtain accurate data from an eye-tracking study, several examination parameters must be evaluated. One of the most fundamental parameters to be evaluated is the duration of all fixations in seconds. This physiological parameter provides valuable information about how long and how intensively an AOI was fixated in seconds. According to Geise (2011), this parameter is essential in understanding an individual's visual attention patterns. Another important parameter that is evaluated in eye-tracking studies is the number of fixations. This parameter refers to the total number of selected fixations within the AOI. By analyzing the number of fixations, researchers can gain insights into an individual's attentional processing and how they allocate their visual attention. Lastly, time until first fixation (TFF) in milliseconds is another parameter that is evaluated in eye-tracking studies. This parameter provides valuable information about the time until the first fixation. Measured in milliseconds, this parameter is crucial in understanding how quickly an individual is drawn to a specific area of interest. The evaluation of these examination parameters is crucial in obtaining accurate and reliable data from eye-tracking. By analyzing the duration of fixations, the number of fixations, and the time until the first fixation, valuable insights into an individual's visual attention patterns can be gained and how they interact with visual stimuli on a computer screen. For the processing of eye-tracking data the specifications in table 2 were considered:

Table 2: Specifications for processing oft he eye-tracking data

AOI AV	Fixation duration/Fixation number: AOI Solar li 1 + AOI Solar li 2….+ AOI Solar re 4
	TFF: separately calculated for the left side and the right side: Minimum of the TFF within the 4 respective “solar”-AOIs
AOI Element	Fixation duration/Fixation number: AOI Mitte li + AOI Mitte hi + AOI Mitte re
	TFF: Minimum of the TFF within the three “element”-AOIs AOI (centre left, center high, center left)
AOI Background	Fixation duration/Fixation number: AOI 2 Solar und Land – the other AOIs (PV and Element)
	TFF can not be computed
Percentage (to determine the proportion within the image)	Fix Dur/Fix numb AOI AV/Element/Background divided by Fix Dur/Fix numb AOI 2 Solar und Land

The use of Analysis of Variance (ANOVA) was essential in testing for significant differences between treatment groups. ANOVA allowed for the comparison of eye-tracking data, including the relative shares of fixation duration and fixation numbers, as well as the time to first fixation (TFF). Additionally, ANOVA was used to compare treatment groups in regards to the Likert-scale measurements in the questionnaire. To further explore group comparisons between images, the full sample repeated measurement analysis of variance (rmANOVA) was utilized due to the repeated measurements within the same participants. This method allowed for a more comprehensive analysis of the data, as it accounted for the variability between the images as well as the within-participant variability. For before-after comparisons, paired t-tests were employed, as they are a powerful statistical tool for assessing the significance of differences between paired observations. This method allowed for the comparison of data collected before and after a particular treatment or intervention. All statistical analyses were conducted using STATA.

3 Results

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

Qualitative eye-tracking results

Heat-maps and attention-maps give first qualitative indications of the gaze behaviour of participants in our experiment (cf. fig. 3). Both the heat-maps and the attention maps display strong gaze behaviour in the central area of the images – regardless of displayed elements. However, while the image with no additional element has the strongest focus in the center, fixations in the image with cattle and the silage bales seem to be slightly more dispersed. There is no obvious effect on gaze behaviour on solar panels and the general background.

Heat-map
Scaling 5%; Opacity 90 %

Attention-map
Scaling 5 %, Opacity 80 %

Treat. 1
grasslan
d
N = 9

Treat. 2
cattle
N = 10

Treat. 3
silage
bales
N = 10

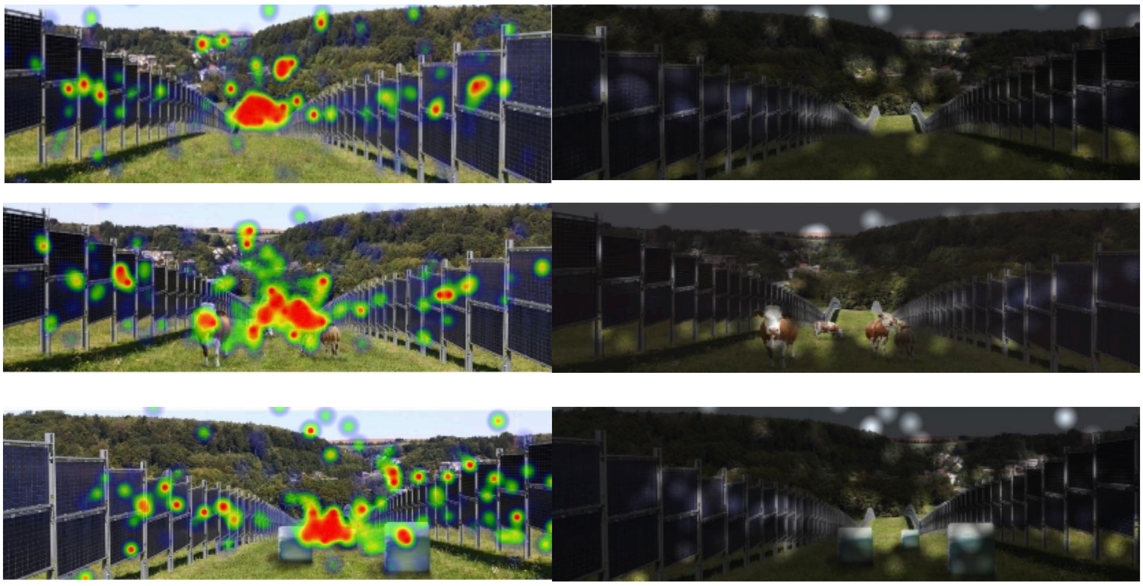


Figure 3: Heat-maps and attention-maps for the three treatments displaying data of those participants with satisfactory eye-tracking results

Quantitative eye-tracking results

Quantitative results are based on the AOI value's displayed in figure 2. Results show that additional image elements attract visual attention away from the solar panels and the background – statistically significant only according to some of the several quantitative indicators. Table 3 displays summary statistics of fixation duration in relative numbers from quantitative eye-tracking data for the first image of the respective treatment.

Table 3: Fixation number and fixation duration in relative numbers from quantitative eye-tracking data for the first image of the respective treatment

Variable		Treat. 1 grassland N = 9 Mean	Std. Dev.	Treat. 2 cattle N = 10 Mean	Std. Dev.	Treat. 3 silage N = 10 Mean	Std. Dev.	**ANOVA (p-value)**
Percentage fixation number	AV	**40.4%**	15.6%	**32.4%**	14.6%	**34.6%**	8.9%	0.4187
	Element	**6.9%**	4.8%	**26.5%**	19.4%	**25.1%**	10.8%	0.0061
	Background	**52.7%**	13.6%	**41.1%**	21.8%	**40.3%**	14.5%	0.2371
Percentage fixation duration	AV	**35.5%**	15.4%	**30.4%**	18.1%	**35.4%**	10.8%	0.6989
	Element	**5.5%**	4.7%	**30.0%**	22.3%	**23.8%**	11.9%	0.0045
	Background	**59.0%**	14.2%	**39.5%**	24.7%	**40.8%**	16.3%	0.0657

In addition to table 2 percentages of mean values are also display in figure 4. The diagrams indicate the higher shares of visual attention for the AOIs of elements of those images with elements (cattle, silage bales) between the solar panels – both for duration of fixations as well as number of fixations.

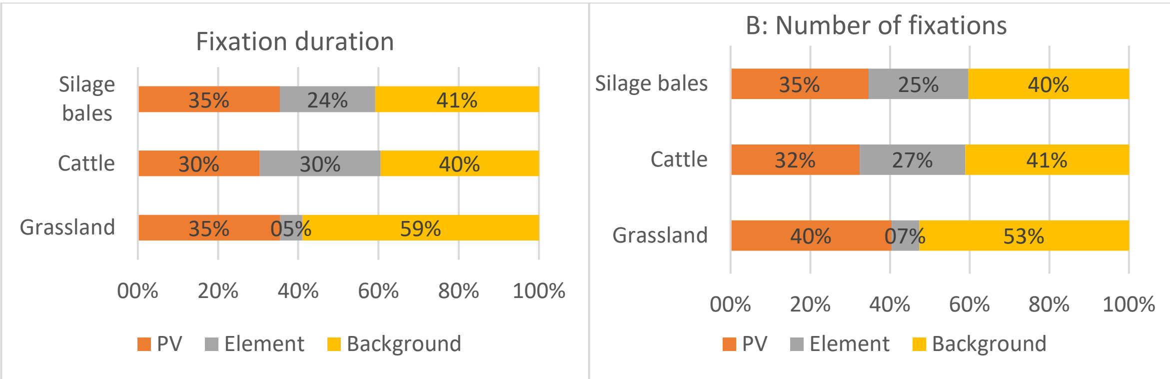
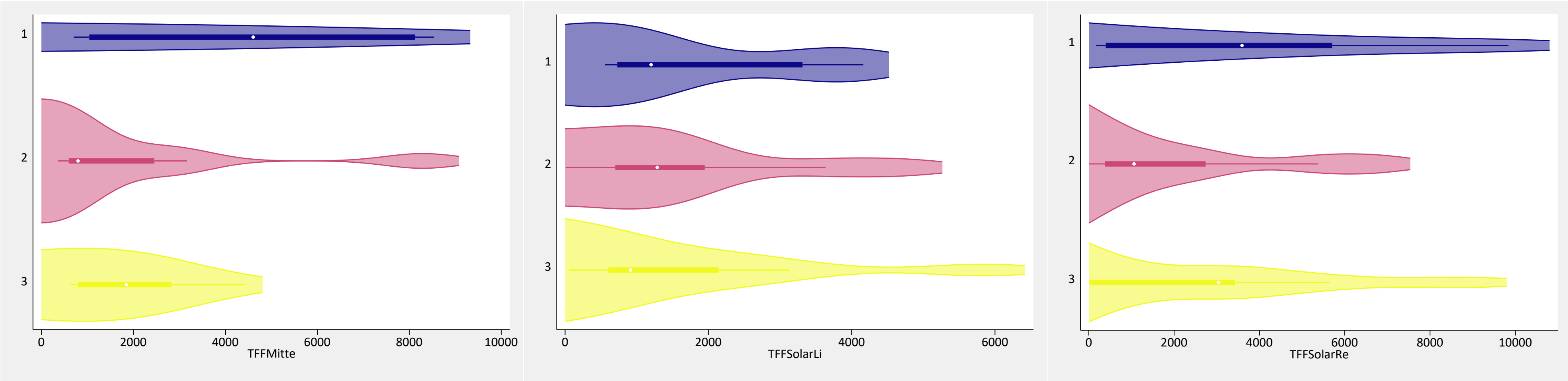


Figure 4: Share of duration of fixation (panel A) and share of number of fixations (panel B) differentiated for the three treatments

Time to first fixation (TFF) was analysed as indicator for activation potential of image elements (cf. figure 5). Although median TFF for cattle is much shorter compared to silage bales and grassland, this difference is not significant at common threshold levels. Considerably faster first fixation is in the AOI of cattle as compared to the AOIs of silage bales and the image with only grassland. There are no significant differences in the times to first fixations of the solar panels on the left nor on the right side.



1 = grassland (n = 9); 2 = cattle (n = 10); 3 = silage bales (n = 10)
Anova TFF element (n = 26) p = 0.0785; influence of treatment on TFF only tendentiously significant)
Anova TFF AOI Solar left side by Treatment (n = 29) p = 0.9484; influence of treatment not significant)
Anova TFF AOI Solar right side by Treatment (n = 27) p = 0.4707; influence of treatment not significant)

Figure 5: Time to first fixation (TFF) of the AOI “Element” (panel A), “PV left side” (Panel B) and “PV right sind” (Panel C) differentiated by treatment

Survey results

After the eye-tracking exercise each participant was asked to rate acceptance of the AV displayed in several dimensions on 5-point-Likert scales as shown in table 4. All values are above the theoretical median of 2.5 indicating a general favourable attitude towards the displayed AV. Highest values are found for the grassland treatment without additional elements. Lowest values are found for the silage bales – especially for financial participation. For compatibility with the scenery both the cattle image and the silage bales image are rated lower. However, difference between the treatments are not significant.

Table 4: Acceptance of bifacial AV after the first image seen evaluated by different items on 5-point-Likert scales

	Treat. 1 Grassland N = 9		Treat. 2 Cattle N = 10		Treat. 3 Silage bales N = 10		ANOVA
Item	Mean	SD.	Mean	SD	Mean	SD	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: question wording: Please answer on a scale from 1 (fully disagree) to (5) fully agree

After the eye-tracking experiment all participants also watched those images not seen in the eye-tracking. After each display the same questions were asked for each image. Therefore, in the end all 29 participants evaluate all three images (grassland, cattle, silage bales) – though in different sequences. Comparing answers to the three images for all participants does not reveal any significant differences, i.e. taken together the displayed bifacial AV was evaluated in the same way regardless of whether only grassland was displayed, cattle on grassland were shown or silage bales on grasslands were presented (cf. tab. 5).

Table 5: Acceptance of bifacial AV for all images for all participants (n=29) by different items on 5-point-Likert scales

	Grassland		Cattle		Silage bales		*rmANOVA P-value*
	Mean	SD	Mean	SD	Mean	SD	
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*

Notes: question wording: Please answer on a scale from 1 (fully disagree) to (5) fully agree

The questions for suitable locations for AVP was asked at the beginning and the end to each participant. Whereas the question at the beginning of the survey is based on participants previous, heterogenous knowledge, involvement in the survey might have led to more equal knowledge levels at the end of the survey – slightly indicated in decreasing standard deviations. All mean values are above the theoretical median value of 2.5. Highest values are achieved for fallow land – lowest values for arable land. Pasture are the only locations for which approval is significantly higher at the end of the survey. For special crops there is a slight tendency of higher acceptance at the end of the experiment (table 6).

Table 6: Before-after responses for suitable locations for AV in general

	Mean before	SD	Mean after	SD	*p-value*
Arable land	**2.86**	1.30	**3.07**	1.19	*0.36*
Grassland for fodder production	**3.14**	1.19	**3.34**	1.08	*0.26*
Pasture	**3.14**	1.19	**3.69**	1.11	*0.05*
Fallow land (agricultural)	**3.97**	1.24	**4.00**	1.10	*0.90*
Special crops	**3.55**	0.99	**3.93**	0.92	*0.09*

Notes: t-test for paired samples; 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 Discussion

Results show that additional image elements attract visual attention – statistically significant only according to some of the several quantitative indicators. Although additional image elements modulate some gaze behaviour indicators, we are not able to provide evidence that this leads to increased acceptance of AV. In the before-after comparison considering more comprehensive information processing by participants, acceptance for AV increased for grasslands significantly – in tendency for special crops – but not for the other land use types.

A centrality-effect of gaze behaviour at the center irrespective of additional image elements may mask a specific element-effect of the two treatments cattle and silage bales. The centrality-effect of gaze behavior refers to the phenomenon that people tend to fixate more on objects or regions that are located near the center of their visual field. This effect has been observed in eye-tracking studies, where people look when performing a task or viewing a scene (e.g. Atalay et al., 2012). The centrality-effect is thought to be related to the fact that the human visual system has a higher resolution and sensitivity in the central region of the visual field, which is known as the fovea. The fovea contains a high density of photoreceptor cells, which enable us to perceive fine details and colors with great clarity (Caves et al., 2018). In contrast, the peripheral regions of the visual field have a lower resolution and sensitivity, and are better suited for detecting movement and changes in the environment. The centrality-effect of gaze behavior is more pronounced for complex stimuli that require more attention and cognitive processing as might be the case in our study. Overall, the centrality-effect of gaze behavior is an important factor to consider when designing visual stimuli for research or practical applications. By understanding how people's gaze behavior is influenced by the location and complexity of visual stimuli, researchers and landscape designers can optimize their materials to better capture and hold people's attention. In order to differentiate these mere physiological effects from more cognitive information processing, in future studies image creation should consider to position additional elements not in the center of the image.

Furthermore, higher shares of visual attention to cattle and silage bales might be a salience effect (cf. Dupont et al. 2016) or a mere exposure effect depending if gaze behavior is rather driven bottom-up by the stimuli (salience effect) or top-down by the familiarity of the participants with the objects shown (mere exposure effect). The salience effect and mere exposure effect are both phenomena that can influence gaze behaviour, but they operate in different ways. The salience effect is the tendency for people to focus their attention on information that is most noticeable or striking, rather than on information that may be more relevant or important. This effect can occur when people are presented with a wide range of information and are forced to make decisions based on limited time or resources. In our study, where most participants were not familiar with the type of AV shown in the images this might have been the case for the center of the image. On the other hand, the mere exposure effect refers to the fact that people tend to develop a preference for things simply because they are familiar with them. Over time, people tend to develop a more positive attitude towards that stimulus, even if they cannot recall the specific instances in which they were exposed to it. This might be the case for the simple grassland, the cattle on the grassland and the silage bales on the grassland in a rather rural sample of participants. In summary, the salience effect is driven by the attentional biases that people have towards striking or prominent information, whereas the mere exposure effect is based on the familiarity of a stimulus. In addition, participants

may not quickly distinguish between living objects (cattle) and material objects (silage bales) at a first glance. In future studies, larger and singular animal images should be used in image manipulation in order to make living objects easier to recognize and make them intuitively and quickly distinguishable from material objects. Landscapes with more heterogeneous structures and elements attract per se higher visual attention (Schirpke et al. 2022). This might well explain the very similar visual perception patterns of the cattle and the silage bales treatment – which in consequence correlates with very similar acceptance scores for these two treatments.
The non-significant results for treatments directly after the eye-tracking suggest that the pre-existing knowledge and attitudes of participants towards AV may have been stronger than any new information provided within the experiment. This implies that participants may have had a preconceived notion about AV and its impacts on ecosystem services. Hence, it is essential to consider participants' previous knowledge and attitudes towards the topic when designing experiments on attitudes towards AV or other complex issues. While slight differences in gaze behaviour can provide valuable insights into participants' visual attention and cognitive processes, they may not necessarily indicate profound information processing that might lead to changes in attitudes towards a topic. It is essential to combine this data with other measures such as self-reported knowledge and behavioural intentions to draw more comprehensive conclusions. As the practice of AV gains momentum and becomes more widespread, future studies are likely to have access to a stronger previous knowledge base on participants' attitudes towards AV's impacts on ecosystem services. This may lead to a more nuanced understanding of the trade-offs between the benefits and drawbacks of AV, and how these can be effectively communicated to the public. For instance, a study by Carvalho et al. (2023) emphasize photovoltaics' impacts on ecosystem services to be considered in policy design to combine sustainable agricultural practices with energy production. In summary, the non-significant results for treatments directly after the eye-tracking highlight the importance of considering participants' pre-existing knowledge and attitudes towards complex issues like AV. Combining eye-tracking data with other measures, such as self-reported knowledge and behavioural intentions, can provide a more comprehensive understanding of how participants process information and evaluate complex topics. As the practice of AV continues to expand, future studies may build on a stronger previous knowledge base to improve our understanding of attitudes towards the practice and how best to communicate its impacts on ecosystem services to the public
Our study is not without several limitations and requires further attention in future research. While we did not have evidence that manipulated images influenced gaze behavior and acceptance rating, it is possible that subliminal manipulation may have occurred. For example, the use of specific lighting, color contrasts or image placement may have subconsciously impacted the participants' response to the images. Therefore, to avoid these potential biases, future studies could work with real photos without manipulation or employ more realistic manipulations to ensure that any effects observed are valid and not artificially induced. Another limitation is the potential impact of socio-demographic characteristics on visual perception and acceptance evaluations. Socio-demographic differences in treatment groups may have worked as confounding factors. Therefore, future studies should focus on targeted recruitment to ensure that the sample is more representative of the population and includes individuals with varying socio-demographic characteristics. Improved randomization of participants within larger samples would also help to reduce the likelihood of such confounding influences. Furthermore, a larger sample size would allow us to consider socio-demographic influences explicitly in the statistical analyses. This would enable us to identify potential differences in visual perception and acceptance evaluations among different sub-groups of the population. For example, differences in age, gender, connection to agriculture, and socioeconomic status may play a significant role in visual perception and acceptance of AV. Thus, future research should aim to increase sample size and consider socio-demographic variables in the statistical analyses to provide a more accurate understanding of the effects observed. (cf. Schirpke et al. 2022).

5 Conclusion

Our results suggest that people's attitudes towards AV, the practice of combining agriculture and solar energy production, are rather stable and not easily influenced by additional information. This finding has implications for how AV are communicated to the public in order to avoid conflicts. A more comprehensive communication and participation strategy may be needed to explain the benefits and drawbacks of AV, and to address concerns about potential impacts on the environment and local communities. For example, if AV is being proposed in a rural community, it may be important to communicate how AV can increase the land-use efficiency, generate additional income for farmers, and reduce greenhouse gas emissions. At the same time, it may be necessary to address concerns about potential soil degradation, changes in water availability, and impacts on local wildlife. Using more heterogeneous landscape elements within AV-images, such as animals or material objects, may be a useful communication tool to engage the public and make the concept of AV more relatable. However, this approach may not be sufficient to replace more substantial information campaigns that provide a detailed and comprehensive understanding of the potential benefits and drawbacks of AV. In summary, the study suggests that a more comprehensive and nuanced communication strategy is needed to address the complexities of public attitudes towards AV, and to ensure that stakeholders are properly informed and engaged in decision-making processes. This may involve providing clear and transparent information about the potential impacts of AV, involving stakeholders in decision-making, and tailoring communication strategies to specific local contexts.

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