Energy Research & Social Science 109 (2024) 103408

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Landscape user experiences of interspace and overhead agrivoltaics: A comparative analysis of two novel types of solar landscapes in the Netherlands

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ARTICLE INFO

Keywords:
Landscape quality
Social acceptance
Energy transition
Multifunctional
Solar power plants
Agriphotovoltaics

ABSTRACT

As renewable energy adoption accelerates, solar power plants are being installed at a higher-than-ever rate, frequently occupying agricultural lands. Agrivoltaic systems integrate crop cultivation and electricity production on the same land, providing a solution for the otherwise competing land use demands between energy generation and food production. The implementation of agrivoltaic power plants, however, potentially impacts landscape quality, consequently raising concerns among local inhabitants and other landscape users. This study examines the effects of two types of agrivoltaic systems on landscape quality and how people perceive these transformed landscapes. Eleven landscape quality factors are assessed in a survey with residents from Culemborg and Wadenoijen, the Netherlands, to compare their landscape experience before and after the construction of agrivoltaic systems.

The results indicate a decrease in the *experiential value* after the implementation of agrivoltaic systems, while the *future value* shows a slight increase. The *use value* – the third dimension of landscape quality - increases for the interspace agrivoltaics and declines for the overhead system. Environmental impacts, wildlife habitats as well as health and well-being are rated as the most important factors for the design and implementation of agrivoltaic systems by landscape users. Although respondents support farmers' involvement in the energy transition and the multifunctional character of agrivoltaics, they express concerns about the impact on wildlife and the decline in the attractiveness of the landscapes. This study suggests directions for further research on the landscape-energy nexus and provides recommendations for the development of landscape-inclusive agrivoltaic power plants.

1. Introduction

In the efforts to accelerate the transition toward renewable energy (RE) technologies, driven by the growing evidence of climate change, more and more governments are establishing specific targets. Solar energy is the most abundant energy resource available on Earth [1], and electricity production using photovoltaic (PV) cells is one of the fastest-growing technologies [2] due to their modularity, cost-effectiveness, and wide applicability. The number and size of solar power plants (SPP) are expected to continue growing rapidly, as they are suitable for both rural and urban regions [3]. Electricity generation by solar PV increased by 22 % (179 TWh) in 2021 compared to 2020 worldwide [4]. However, to achieve the global goal of Net Zero Emissions by 2050, an average annual growth of 25 % is necessary between 2022 and 2030 [5]. Meeting this capacity expansion is becoming increasingly challenging as suitable locations for SPPs are diminishing [6,7].

Particularly in densely populated countries such as the Netherlands, land for new RE infrastructure is limited. Yet, an increasing amount of agricultural land is being turned into ground-mounted SPPs, inciting land competition between energy and food production [8,9]. The National Climate Agreement of the Netherlands encourages the combination of solar energy production with additional functions and recognises multifunctionality as one of the main spatial principles for the country's energy transition [10]. Slowly, multifunctional SPPs are emerging that

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Abbreviations: AV, Agrivoltaics; AVPP, Agrivoltaic power plant; LQ, Landscape quality; SA, Social Acceptance; PV, Photovoltaic; RE, Renewable energy; SPP, Solar power plant.

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https://doi.org/10.1016/j.erss.2023.103408
Received 29 June 2023; Received in revised form 3 November 2023; Accepted 31 December 2023

enable food production, support biodiversity and reduce visual impact in response to economic, nature- and landscape-related societal considerations [11].

Among the innovative solutions for the multifunctional use of space, agrivoltaics (AV) has gained prominence [9]. AV refers to the combined use of the same area of land for agricultural and electricity production by means of PV technology [12]. It offers a resource-efficient solution to the challenge of land competition by co-producing agricultural crops and solar energy, offering mutual economic, social, and environmental benefits [8,13]. The concept of AV aligns with at least two United Nations' Sustainable Development Goals [14], by addressing hunger (Goal 2) and promoting affordable, clean energy (Goal 7) [15]. Agrivoltaic systems increase land productivity and can potentially strengthen rural economies [16] while protecting crops against hail and excess temperature [17], and increasing plant resilience to drought stress [8]. Further benefits include improved power production efficiency due to the cooling effect of vegetation, reduced greenhouse gas emissions, income for farmers and other entrepreneurs, and community employment [18]. AV system deployment has grown exponentially, surpassing 14 GW_p global installed capacity in 2021 [19], with demonstration projects worldwide and predicted rapid expansion of agrivoltaic power plant (AVPP) implementation [9]. In this research, 'agrivoltaics' and 'AV system' refer to the PV panels and their support structures, while AVPP also includes the land underneath and between the PV arrays.

Large-scale implementation of AVPPs may impact landscape quality (LQ) and influence community acceptance of these systems, a well-explored phenomenon for ground-mounted SPPs [20,21]. AVPPs may elicit various responses linked to social acceptance (SA) from residents and other landscape users. Here, specific focus is placed on community acceptance, which refers to the acceptance of RE projects and their siting, particularly by local residents [22]. In this study, LQ is defined across three dimensions: *use, experiential* and *future value* based on the Vitruvian triplet [23] applied in previous research [24,25] and spatial policies [26–28]. Furthermore, LQ is considered from a subjective school of thought [24], based on individual experiences of the same landscape.

Both landscape quality [25,29] and landscape change [30,31] are increasingly recognised challenges associated with RE infrastructure deployment, particularly with wind energy [32] and electricity infrastructure [33]. Ground-mounted PV systems too have been examined in agricultural landscape contexts [29]. Literature suggests that the height of AV systems, reaching up to 6 m, affects landscapes and their experience by landscape users such as residents, farmers and tourists [9,34]. Studies suggest that taller AVPPs may have a negative effect on visibility, leading to public concerns and potential rejection of agrivoltaic projects [9]. While some argue that such tall structures may be perceived negatively by landscape users [11], empirical evidence is lacking.

It is unknown yet how different AV systems affect LQ, and how people perceive landscape changes induced by the implementation of AVPPs. This research compares the LQ of two different AV systems in the Netherlands through a survey. The two examined systems are (1) an interspace system with vertical PV panels and extended spacing between the arrays and (2) an overhead system with elevated structure and crop cultivation underneath the PV canopy (Fig. 3 and 4). The survey targets residents in the municipalities of the two examined cases, specifically those residing near the AVPPs [35,36]. The central research question is as follows: *What is the landscape quality of vertical interspace and overhead agrivoltaic power plants according to landscape users?*

2. Theoretical framework

This section covers three topics central to this research. Firstly, the different types of agrivoltaic systems are introduced. Secondly, the social acceptance of solar power plants and agrivoltaics is discussed. Lastly, the framework for examining the quality of multifunctional landscapes is presented.

2.1. Introduction to agrivoltaics

Agrivoltaic systems are classified based on technical and agricultural characteristics. The classification by Trommsdorff et al. [37] is the most comprehensive to date and employed in our study. Agrivoltaics are categorised into open and closed systems (Fig. 1). The latter category mainly consists of greenhouse-integrated PV structures and requires special technical design requirements, which are significantly different from open systems. Therefore, they are outside the scope of this study. Open agrivoltaic systems are further categorised according to system structure (interspace and overhead AV), module type (fixed and single- or dual-axis tracking) and agricultural activity (grassland, arable farming, and horticulture).

Interspace AV systems are either fixed (Fig. 2) or single-axis tracking ground-mounted systems with extended spacing between the arrays, enabling agricultural activity between the PV panels [39]. The mounting structure and technical design are similar to ground-mounted SPPs. The vertical PV system (Fig. 3) is a type of interspace system, with bifacial modules and east-west orientation [37]. The space between PV arrays (6–15 m, depending on the PV module height) allows for machinery to access the crops or livestock to graze. Increased land productivity and improved spatial uniformity for sunlight and water distribution are the advantages of this system [40]. The vertical PV system is more cost-effective compared to overhead systems due to its lower support structure.

Within grassland farming, sheep husbandry is commonly practised for interspace systems [41]. However, this PV system is typically optimised for energy yield [37]. Recent projects combine vertically mounted interspace AV with livestock grazing in Germany, e.g., Donaueschingen-Aasen solar park in Baden-Württemberg and Eppelborn-Dirmingen solar park in Saarland [42]. The AVPP in Den Heuvel, Culemborg is the first commercial vertically mounted interspace AVPP in the Netherlands.

Overhead AV systems (Fig. 4–5) are elevated structures (2–6 m), allowing agricultural activities to occur beneath the PV panels. The height of the structure is determined by the type of agricultural machinery and the farming management used [16,37]. Compared to interspace AVs, overhead systems offer higher land use efficiency due to the added value of arable farming and horticulture, which are typically combined with this type of system [37]. However, the taller mounting structure leads to higher financial costs [9]. The elevated installation of inverters and other electrical components can eliminate the need for a security fence around the AVPP [16]. Another key benefit of overhead AVs is the sheltering effect on crops beneath the PV arrays [8]. These advantages are expected to increase the social acceptance of overhead AVs [37].

Overhead AV in horticultural applications offers synergies with various crop types. One of these synergies is the integration of PV arrays in vineyards, known as Enovoltaics, which is being studied for its impact on grape yields under hot and dry climatic conditions [43]. Padilla et al. [44] proposed a cost-effective and visually unobtrusive AV structure in Murcia, Spain, using the existing trellis structure of the vines. Grape production is expected to benefit from the shading effect of PV arrays [43]. Another promising horticultural application of overhead AV is berry cultivation where PV panels can replace plastic foils and hail nets providing protection against hail damage and sunburn on crops [16]. In the Netherlands, AVs have been installed with five different crop types: blueberry (Broekhuizen), blackberry (Sint Oedenrode), redcurrant (Wadenoijen), raspberry (Babberich) and strawberry (Boekel) [45] (Fig. 6).

2.2. Social acceptance of solar power plants and agrivoltaics

The social acceptance of RE is strongly related to the perceived impact of energy technologies on LQ [22,29]. For solar energy, it has

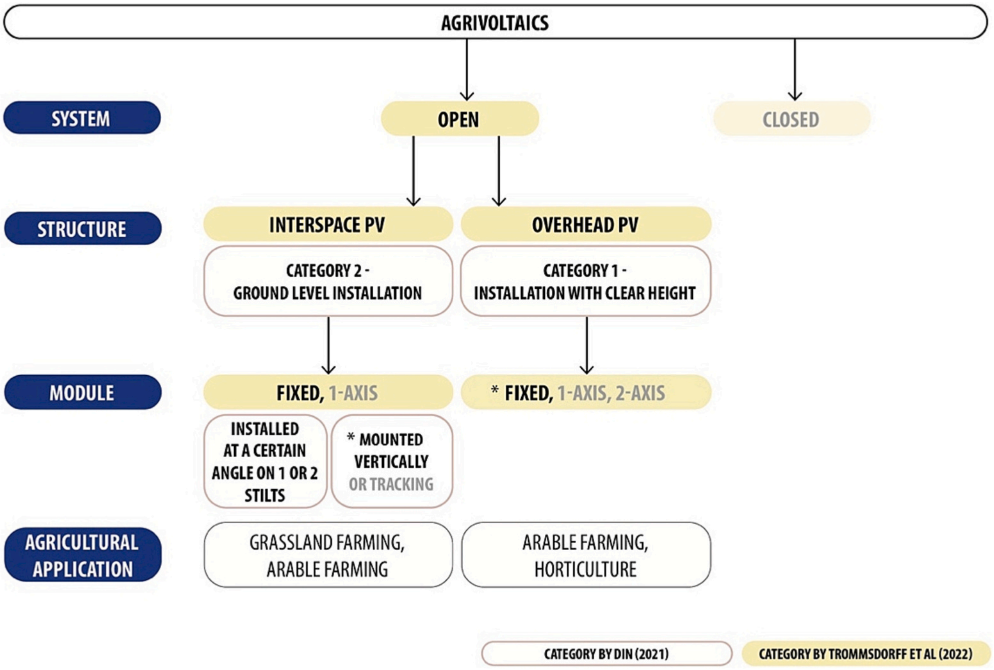


Fig. 1. Classification of agrivoltaic systems based on Trommsdorff et al. [37] and DIN [38]. The type of the examined AVPPs in this paper is indicated with a *.

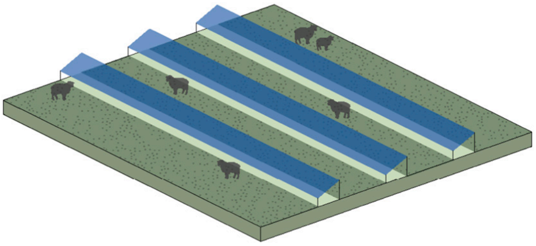


Fig. 2. Interspace AV system with fixed modules.

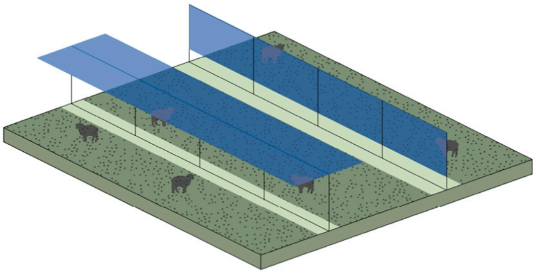


Fig. 3. Interspace AV system, single-axis tracking (left) and fixed vertical bifacial modules (right).

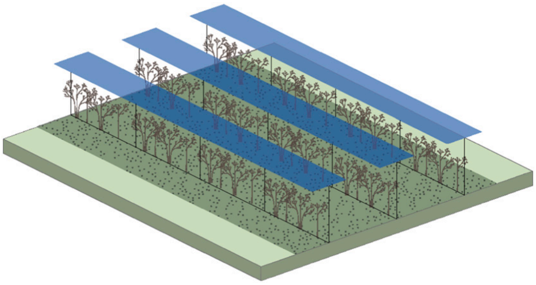


Fig. 4. Overhead AV system with fixed modules.

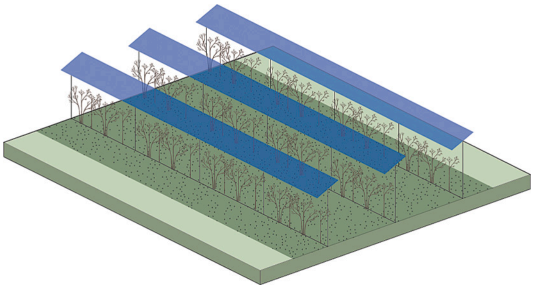


Fig. 5. Overhead AV system with single-axis tracking modules.

been demonstrated that large-scale SPPs transform landscapes [7,30], particularly in rural areas [21]. The experience of SPPs is strongly influenced by their spatial properties, visibility and the characteristics of the host landscape [30]. A survey conducted in Andalusia, Spain revealed that landscape protection was the residents' main reason for opposing the expansion of the number and size of SPPs [21]. Visual impact, aesthetics & scenic quality, and perceptions of landscape change were mentioned most frequently with regards to acceptance and landscape design according to the systematic literature review by Enserink et al. [46]. Wüstenhagen et al. [22] conceptualise SA into three categories: socio-political, market and community acceptance. In this paper, we focus on the latter category - community acceptance – and, more specifically, on acceptance factors related to landscape.

Community acceptance studies on agrivoltaics are scarce. A recent empirical study conducted in the U.S. pointed out that visibility and project siting are key concerns in the opposition to agrivoltaic development [47]. Another study from Japan found that residents were concerned about the impact of AV systems on the rural landscape due to new infrastructure and sunlight reflection [48], although this study did not specifically focus on landscape aspects. Taller AV systems may negatively affect visibility, leading to public concerns and rejections [9]. Based on the APV-RESOLA [49] and the APV Obstbau [50] research projects in Germany, Fraunhofer [51] identified key success factors for the SA of agrivoltaics. Factors included defining minimum distances from residential areas, appropriate site selection and visual shielding.

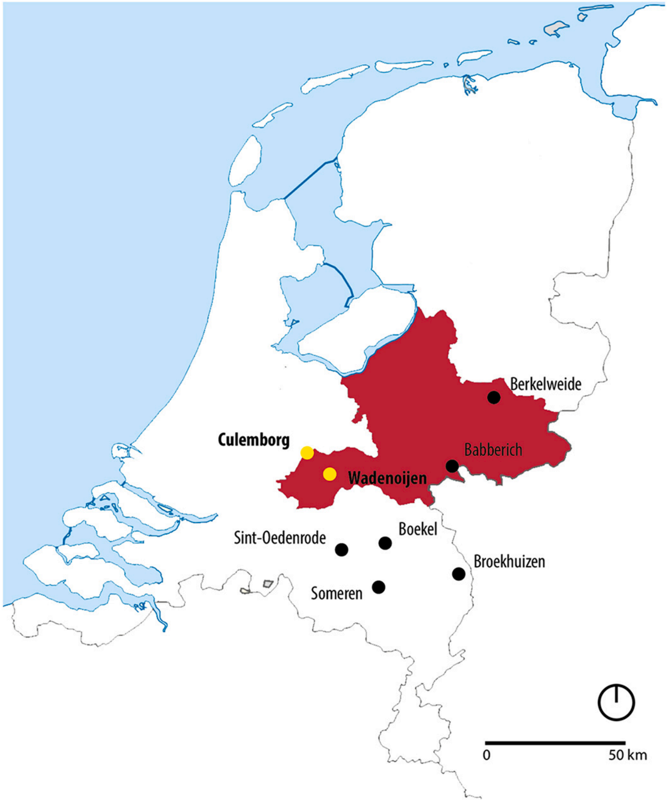


Fig. 6. Location of agrivoltaic cases in the Netherlands. The location of the two embedded cases in the province of Gelderland is indicated with yellow dots and bold text. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Ketzer et al. [12] argue that the (in)sensitive integration of AV into the landscape strongly influences the level of acceptance. Toledo & Scognamiglio [9] call for more attention to landscape in general and the use of design-research to overcome barriers to SA with regards to AV implementation.

2.3. Landscape quality of multifunctional landscapes

The link between landscape impacts and support for RE projects highlights the importance of examining the social acceptance of agrivoltaics from a landscape quality perspective. In defining LQ and developing assessment methods, approaches can be divided into objective, subjective and intersubjective schools of thought [24]. In this research, LQ is considered from a subjective school of thought, examining individual experiences of two landscapes including the meanings ascribed by the landscape users.

Hooimeijer et al. [52] developed a framework to evaluate the LQ of multifunctional landscapes. This framework has been applied by Oudes et al. [25] in the analysis of large-scale landscape transformations, and by Dutch spatial policies in the past two decades [26–28]. Hooimeijer et al. operationalise LQ by translating Vitruvius' triplet utilitas, firmitas and venustas [23] into three design dimensions, namely *use, experiential* and *future value*, respectively, and linking them to four societal interests - *economic, social, ecological* and *cultural* (Table 1). *Use value* refers to functional suitability and efficiency, *experiential value* relates to identity and meaning, and *future value* considers efficiency and sustainability over time. *Economic interest* concerns land use efficiency, *social interest* includes combatting inequality, *ecological interest* relates to sustainable design and *cultural interest* concerns the human experience. Hooimeijer et al. [52] identified aspects that specify LQ within the matrix, e.g., variety and beauty for *cultural interest.*

Table 1
Hooimeijer et al.'s [52] analytical framework for landscape quality.

	Economic interest	Social interest	Ecological interest	Cultural interest
Use value	Allocation efficiency Accessibility External effects Multi-purpose	Access Division Participation Choice	Safety, nuisance Pollution Desiccation Fragmentation	Freedom of choice Variety Encounter
Experiential value	Image Attractiveness	Inequality Connectedness Safety	Space, tranquillity Beauty Health	Uniqueness Beauty Contrast
Future value	Stability/ flexibility Agglomeration Cumulative attraction	Inclusion Cultures of poverty	Stocks Ecosystems	Cultural heritage Integration Renewal

3. Methods and materials

This study examines the landscape quality of two different agrivoltaic systems in the Netherlands. The case selection, analysis and short description of the embedded cases are provided in Section 3.1. The survey process is presented in Section 3.2. and the demographic data of the survey respondents is summarized in Section 3.3. The examined factors are described in Section 3.3.

3.1. Introduction of embedded cases

A case study approach is employed to examine two contemporary phenomena – an interspace and an overhead agrivoltaic AVPP - in their context [53]. To identify the main types of AV systems and existing AVPP locations, a list of agrivoltaic cases (Appendix A) in the Netherlands built until September 2022 was compiled based on a recent publication [34] and grey literature (Fig. 6.) The data collection process included analysing satellite imagery, conversations with farm owners and field observations.

The study was conducted in The Netherlands. Most of its area is coastal lowland and reclaimed land (polder), with some hills in the southeast. Notably, around 26 % of the country's land lies below sea level. With a population of 17.5 million people, living within a total area of 41,543 km^2, the Netherlands has a population density of 515 people per km^2 [54]. About 55 % of the land is in agricultural use, primarily arable land and permanent pasture. Most of the population lives in the Randstad region, containing major cities like Amsterdam, Rotterdam, the Hague and Utrecht. The Netherlands has set climate goals, outlined in the 2019 Climate Act [10], such as reducing greenhouse gas emissions by 95 % (compared to 1990 levels) and 100 % renewable electricity generation by 2050. In 2021, 47 % of electricity generation came from natural gas, 15 % from wind and 9 % from solar PV [55].

The two embedded cases were selected from the built agrivoltaic cases according to the following criteria:

- The AVPP should be located in the province of Gelderland, due to available data and resources and the potential of the province to accommodate future agrivoltaic projects.
- The AVPP should be visible from the set of roads or paths closest to the edge of the AVPP [56].
- The system and crop type should be different (e.g., interspace and overhead system; berry and grass) to compare two different types of AV systems.
- The land use of the sites before the installation of the AV system should be different among the embedded cases to examine LQ with and without the AVPP.

Considering these selection criteria, the AVPPs in Wadenoijen and Culemborg were selected (Fig. 7).

This case selection allows the comparison of two AVPPs in Gelderland with different spatial configurations (system type) and different land use. The analytical framework for SPPs by Oudes & Stremke [56] was used to examine the host landscape, solar infrastructure, and landscape features (Table 2).

3.1.1. *Wadenoijen*

The AVPP in Wadenoijen, municipality of Tiel, is one of the five pilot projects of the German RE company BayWa r.e. GmbH [58], and the Dutch subsidiary GroenLeven [59]. It is also one of the first agrivoltaic projects worldwide that cultivates redcurrants [60]. There was already a redcurrant farm prior to the construction of the agrivoltaic system, and the PV panels replaced plastic foils. The farmer's main reason for the development was the protection of plants against extreme weather conditions and the added value provided by RE [61]. By March 2021, the AV system was constructed on 3.7 ha of land, protecting about 4500 redcurrant plants. The farm owner in Wadenoijen is considering expanding the AV system.

3.1.2. *Culemborg*

The vertically mounted interspace agrivoltaic project in Culemborg was developed by Vrijstad Energie [62] together with the German company Next2Sun [63] and started operating in August 2022. Prior to the construction of the 0.7 ha large agrivoltaic system, the area was pasture. The farm owner initiated the project in 2019 to finance the construction of new roofs for the farm buildings [64]. Due to the cost of grid connection and available subsidies, the original solar roof project was supplemented with vertical PV panels on grassland. During the implementation, a small field with herbs and plants for partridges was created, a beehive was placed, as well as trees and shrubs were planted on the parcel.

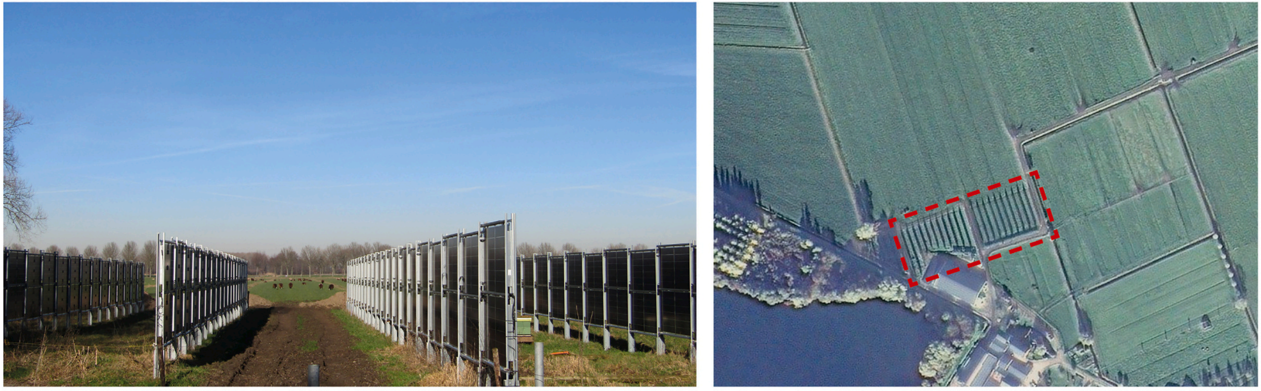
3.2. *Survey with residents*

The aim of the questionnaire was to evaluate the LQ of two different types of AVPPs. This assessment was conducted through in-person surveys with residents of the two municipalities (Tiel and Culemborg) in the vicinity of the AVPPs.

The first step involved establishing a framework of factors to include in the questionnaire (Appendix B). Out of the 36 LQ elements found in Hooimeijer et al.'s framework [52] (Table 1), 14 aspects most relevant for AV were selected. A total of 107 SA aspects were identified from relevant literature [30,46,47]. These were filtered based on their relevance for LQ and AV, resulting in a shortlist of 50. Redundant aspects such as 'multifunctionality' and 'multi-purpose' were simplified and removed. The 50 SA and the selected 14 LQ aspects were grouped per topics, such as environmental impacts, and further clustering yielded a final list of 11 LQ factors. No more than four factors per *use, experiential* and *future value* were selected to ensure a concise questionnaire. The 11 factors were then placed into the LQ framework (Table 1) for the questionnaire development (Fig. 8).

To encourage the participation of local residents, we employed a paper-format questionnaire in Dutch. Before conducting the survey, the questionnaire underwent a pre-test with five Dutch-speaking participants (3rd and 6th February 2023). The final questionnaire consisted of 24 questions divided into three sections: (1) demographic questions, (2) weighting and ranking of factors related to the LQ framework, and (3) a set of questions regarding the 11 LQ factors, supported by images of the

Wadenoijen
Fixed, overhead agrivoltaic system with berry cultivation



Culemborg
Fixed, vertical interspace agrivoltaic system with pasture

Fig. 7. Overhead agrivoltaic system in Wadenoijen (photo by Dirk Oudes, satellite image by [57]) (above) and interspace agrivoltaic system in Culemborg (satellite image by [57]) (below).

Table 2
Analysis of the host landscape, solar infrastructure, and landscape features of the two embedded cases.

	Wadenoijen	Culemborg
Host landscape		
Open/enclosed	Semi-open agricultural landscape	Open agricultural landscape
Parcellation/plot size	Small-scale, irregular allotments	Large-scale, irregular allotments
Existing landscape features	Fruit orchards, arable fields, pastures, hedgerows	Grass and hayfields, farmhouses
Urban settlements	Ribbon settlements, winding roads, scattered buildings and country estates	Scattered buildings with large yards, ribbon settlements, nearby industrial area
Previous land use	Fruit farm (redcurrant)	Pasture
Solar infrastructure		
System layout	2 patches, 3.7 ha	1 patch, 0.7 ha
System's response to parcellation	patch shape is self-referential, there are left-over spaces within the plot	system layout matches the original parcellation, but only a part of the plot is covered with solar infrastructure
Patch configuration	Irresponsive, plot border alignment	Split, plot border alignment
Patch density	High (50–70 %)	Low (25–50 %)
Array orientation	East-west	East-west
Array dimensions	fixed tilt, horizontally mounted total height: 3 m width of arrays: 45 & 164 m 9 rows of 51 m length, 17 rows of 103 m length and 2 rows of 63 m length	fixed tilt, vertically mounted total height: 2.85 m width of arrays: 38 m at the widest point, differing due to irregular plot edges 29 rows of 155 m length, 3 solar fences with different orientation
Concurrence	no	Yes, bifacial modules and solar fence (different size panels)
Materials	Colour of modules: blue Materials used in supporting structure: metal	Colour of modules: blue Materials used in supporting structure: metal
Landscape features		
Ecological	–	Beehive, small field for partridges
Recreational and educational	–	–
Agricultural	Agricultural co-production: redcurrants	Agricultural co-production: grass
Water management	–	–

landscapes with and without the AVPP. Respondents rated the factors regarding the landscapes on a Likert scale of 1 to 5 (1 – strongly disagree, 5 – strongly agree) or marked aspects of the different landscapes by checking boxes. Further information on the questions is provided in Sections 4.1 and 4.3.

The survey was conducted over four weekdays (13rd, 21st, 27th and 28th February 2023) in Culemborg and Wadenoijen. We employed convenience sampling [65] by approaching residents encountered near both AVPPs and distributing questionnaires to inhabitants of Culemborg and Wadenoijen in their homes. We estimated a response rate of 60 %. The survey procedure began with explaining the purpose of the research, and respondents who agreed to participate were given 10–20 min to complete the questionnaire. Alternatively, participants were provided with a minimum of 30 min before their responses were collected. Being present while filling out the survey and collecting them personally allowed respondents to seek clarifications regarding any of the questions with the researchers.

3.3. *Demographic data of survey respondents*

The survey was completed by a total of 64 respondents, with 32 responses collected in Culemborg and 30 in Wadenoijen. Two incomplete surveys were excluded from the analysis. The gender distribution of respondents was balanced, and age groups and education levels were diverse (Fig. 9). Comparing the demographic data of the respondents with national statistics reveals that the gender distribution closely aligned. Since individuals under the age of 18 were not the primary target, the survey had relatively more participants in the age groups of 25–34 and 35–44. Regarding educational backgrounds, participants holding HBO, WO and bachelor degrees were more prominently represented compared to the national data. The majority of respondents (87 %) were residents of Wadenoijen or Culemborg, more than half of them (54 %) see the studied AVPP regularly (daily, weekly or monthly) and 60 % knew the location well before the installation of the AV system (Fig. 10).

3.4. *Analytical framework*

In the following, the landscape quality factors selected for the survey are being described.

3.4.1. *Accessibility*

Accessibility refers to the ease of accessing a site, which may be influenced by aspects such as 'geographical location', 'site selection', 'project size', and 'location on agricultural land'. Most AVPPs are inaccessible to landscape users as they are located on privately-owned agricultural lands [34]. However, the presence of fences and other electrical and fire safety elements can affect the perceived accessibility of the landscape when compared to the same landscape without AVPP.

3.4.2. *Multifunctionality*

Multifunctional landscapes serve multiple purposes [68], including agricultural production, electricity generation, improving biodiversity, or recreational opportunities. Multifunctional SPPs can be nature-inclusive (i.e., SPPs that improve the living conditions of flora and fauna), landscape-inclusive (i.e., SPPs that improve the physical landscape elements or patterns), and mixed-production (i.e., SPPs that combine electricity production with other profitable land use functions, such as AVPPs) [11].

3.4.3. *Attractiveness*

The attractiveness of landscapes is influenced by various factors, such as naturalness [69] and scenic beauty [70]. The attractiveness of AVPP refers to the overall appearance and design within the larger host landscape. 'Visual appearance', 'design', and the 'attractiveness of solar technology used' (if applicable) are considered.

3.4.4. *Stability/flexibility*

Stability and flexibility refer to the capacity of a landscape to accommodate innovation and sustainable development, the availability of 'jobs', and 'regional added value' (e.g., independency of energy companies) [71].

3.4.5. *Involving farmers*

Involving farmers in the energy transition relates to various activities, such as encouraging their adoption of RE or engaging them in the planning and decision-making process related to energy transition initiatives. Involving farmers can raise local support for RE [72] and facilitate the just distribution of benefits. Adopting AV systems on farmland may raise the income security of farmers and foster rural development [12].

3.4.6. *Health & well-being*

Health and well-being refer to the physical and mental health and well-being of individuals, encompassing 'safety', 'perception of risks', and the place's 'tranquillity' (calmness). Impacts on health and well-being are strongly intertwined with the acceptance of RE projects

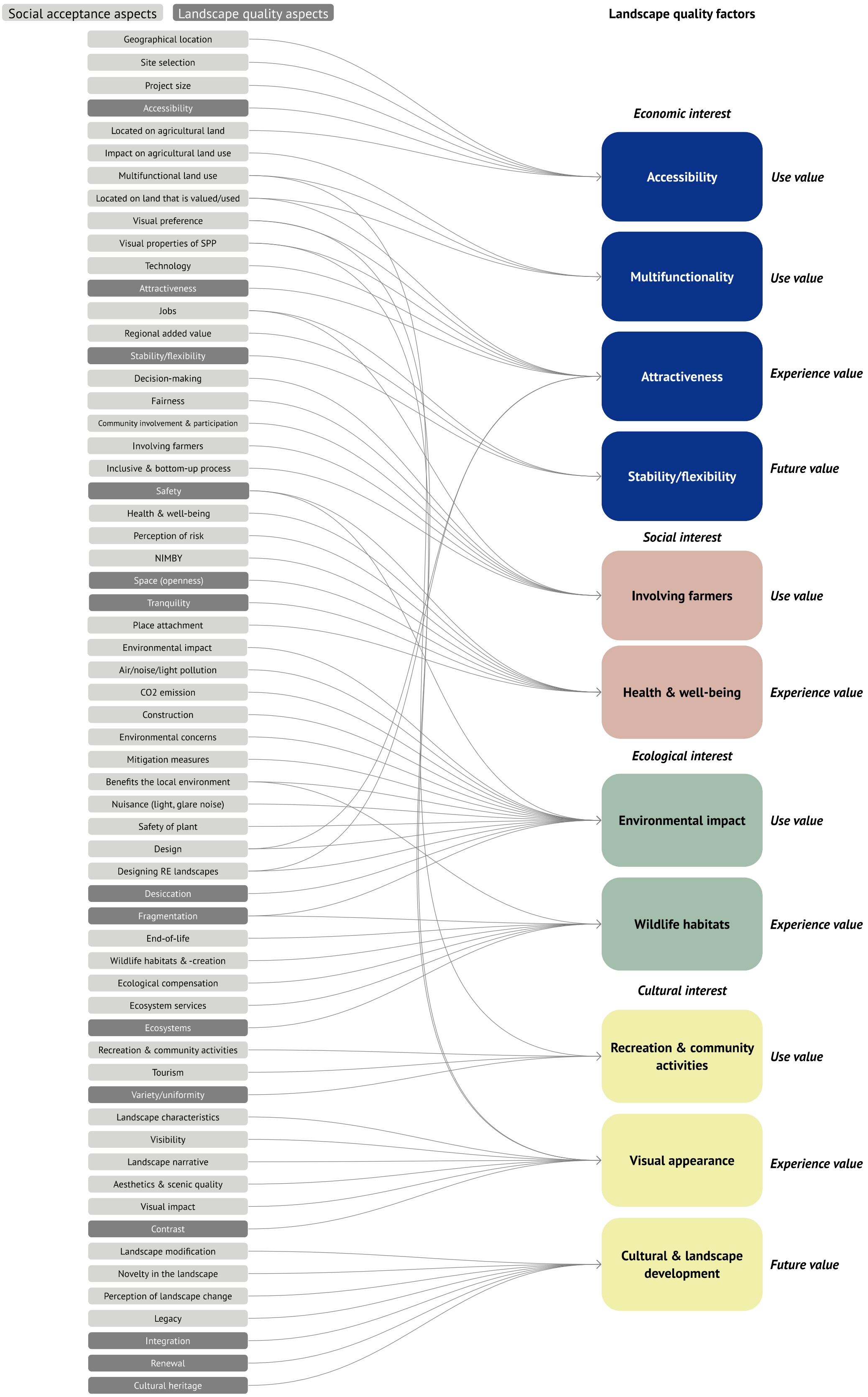


Fig. 8. The filtered list of acceptance and landscape quality aspects (left side) resulted in eleven combined landscape quality factors (right side) that are examined in the survey with residents.

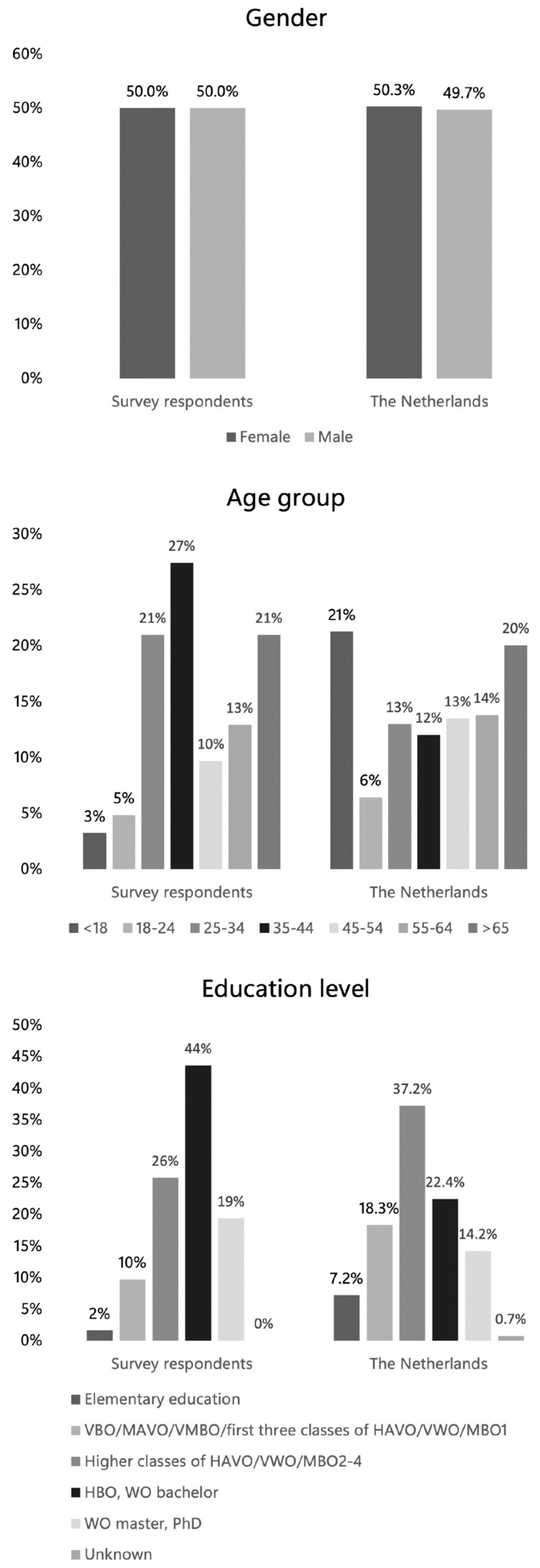


Fig. 9. Gender, age group and education level of the survey respondents and the Dutch population [66,67]. VMBO = pre-vocational education. HAVO = higher general continued education. VWO = preparatory scientific education. MBO = junior college. HBO = college or university of applied sciences. WO = university.

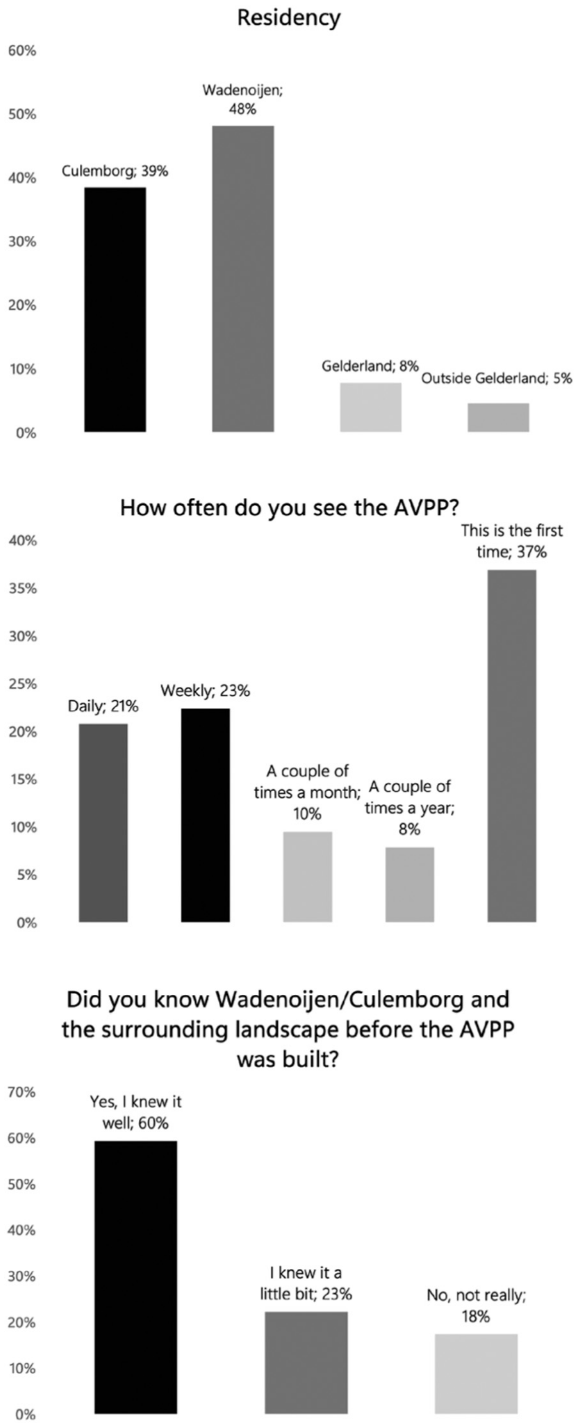


Fig. 10. Respondents' location of residence, frequency of seeing the AVPP and familiarity with the landscape before the construction of the AVPP.

[73,74].

3.4.7. *Environmental impacts*

The negative environmental impacts of SPPs have been thoroughly studied: 'air/noise/light pollution', 'nuisance', and 'landscape fragmentation' [75]. However, nature-inclusive SPPs, as well as AVPPs, can offer positive environmental impacts, such as biodiversity conservation, water conservation, and water use efficiency [14]. AVs may also benefit plant performance [8,17]. Moreover, the replacement of plastic foils with durable PV arrays may be considered a positive environmental impact [43].

3.4.8. *Wildlife habitats*

Wildlife habitats are areas that provide food, shelter, and breeding opportunities for various wild animals, including birds, insects, and small mammals. These habitats can be integrated into AVPPs by, for example, incorporating native and pollinator-friendly vegetation [14,76], creating surface water bodies, and using design elements that mimic natural habitats.

3.4.9. *Recreation and community activities*

Recreation and community activities refer to, for example, tourism opportunities (e.g., for educational purposes, or ecotourism) and the ability of the landscape to provide spaces for social interaction, encounters, and recreation [52].

3.4.10. *Visual appearance*

The visual appearance of AVPPs pertains to their visual properties and their integration into the larger environment, taking into account 'landscape characteristics', 'aesthetics and scenic quality'. Visual appearance is influenced by a variety of decisions, such as the system layout and its response to the host landscape, the solar infrastructure, and the use of landscape features (e.g., ecological, or recreational features) [56]. Elevated agricultural support structures, the elements that support both the crops and the PV panels, are examined as part of the AVPP's visual appearance.

3.4.11. *Cultural and landscape development*

Cultural and landscape development entails aspects such as 'preserving and creating cultural heritage', 'landscape change', and 'renewal'. These aspects may vary across different types of SPPs and AVPPs, as well as across different host landscapes.

4. Results and discussion

The results are presented and discussed as follows. Firstly, the weighting of societal interests and design dimensions for LQ by the respondents is presented. Secondly, the differences in the overall perception of the two agrivoltaic systems are summarized. Thirdly, the results per factor are reported. Finally, possible limitations of the study are discussed.

4.1. *Weighting of societal interests and design dimensions for landscape quality*

When asked to weigh the four societal interests (*economic, social, ecological and cultural*), the respondents from the two embedded cases showed little variations. However, there were larger differences in the weighting of the design dimensions (*use, experiential and future value*). For Culemborg (vertical interspace AV), the *use value* was given the most weight (47 %), whereas, for Wadenoijen (overhead AV), the three dimensions were somewhat more balanced (Appendix C, D).

The ranking of the 11 landscape quality factors revealed the importance of 'environmental impacts' (13 %), 'health and well-being' (12 %), and 'wildlife habitats' (12 %) for the participants with regards to agrivoltaics (Fig. 11). The three factors 'recreation and community activities' (7 %), 'attractiveness' (6 %) and 'accessibility' (5 %) were the least relevant to the respondents.

The weighting of the societal interest and the design dimensions as well as the factor ranking were included in the survey to evaluate the responses given per LQ factor in the third part of the questionnaire. This allowed the assessment of each factor's importance to the participants and, consequently the extent of landscape change due to the AVPP.

4.2. *Differences in the landscape quality of interspace and overhead AV systems*

To evaluate how the LQ changed due to the implementation of the AV systems, the percentage of change by each factor was weighted according to the respondents ranking. The factors were then aggregated on the level of design dimensions. The results reveal that respondents favoured vertical interspace AV over overhead AV (Table 3–4). Even for the factors that scored less after the implementation of the AV in Culemborg, Wadenoijen received an even lower score ('attractiveness', 'health & well-being', 'wildlife habitats' and 'visual appearance').

The *use value* increased in the case of vertical interspace AV (12 %) but decreased in the case of overhead AV (−11 %). The *experiential value* was reduced in both cases (−11 % for the interspace AV and − 16 % for the overhead AV). The *future value* increased slightly for both AV systems (2 %).

In the case of overhead AV, the factor 'environmental impacts' was most pivotal in the decrease of the *use value*. In the case of interspace AV, 'wildlife habitats' showed the largest decline and was perceived as the

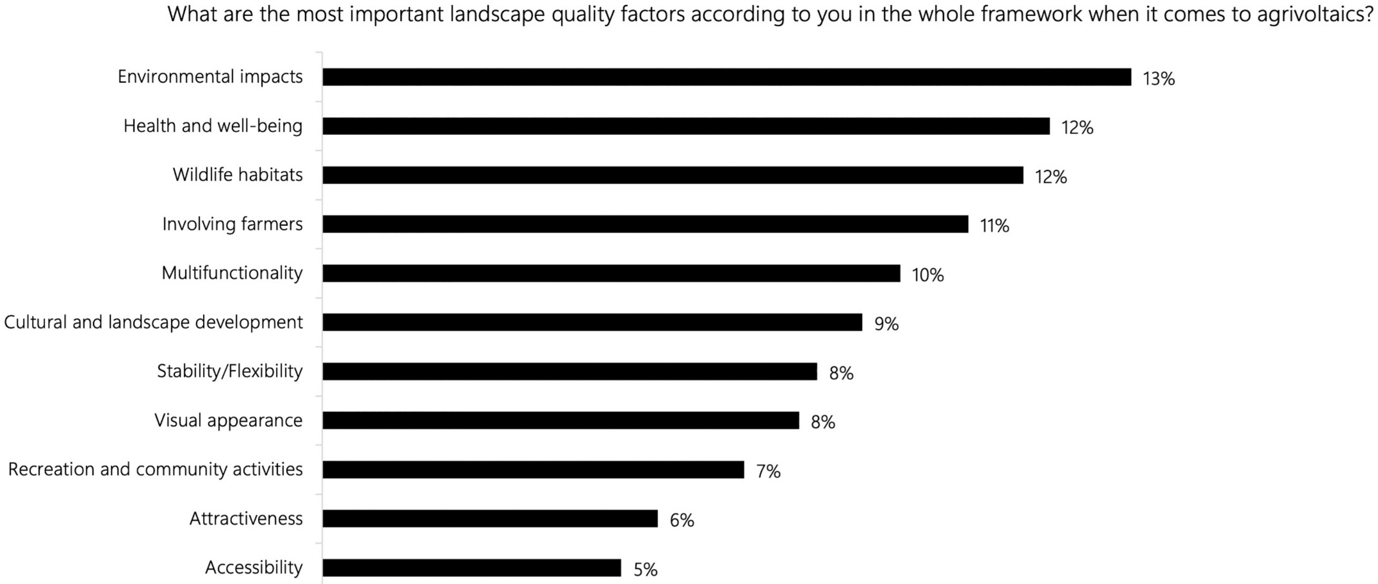


Fig. 11. Ranking the importance of the 11 factors combined for Culemborg and Wadenoijen (*n* = 62).

Table 3

Change of landscape quality experienced by respondents in Culemborg. Note: The negative percentage values mean decline and the positive percentage values mean improvement. Change = degree of improvement (+) or decline (−) of the landscapes with AV systems. Ranking impact = the share of the importance of the factors according to the respondents from Culemborg.

	Design dimensions	Factors	Ranking impact	Change	Share of factor change in overall LQ change	Overall LQ change
Culemborg (interspace AV)	Use value	Accessibility	6 %	12 %	1 %	+12 %
		Multifunctionality	10 %	28 %	3 %	
		Involving farmers	11 %	90 %	10 %	
		Environmental impacts	14 %	−8 %	−1 %	
		Recreation & community activities	7 %	3 %	0.2 %	
	Experiential value	Attractiveness	6 %	−35 %	−2 %	−11 %
		Health & well-being	12 %	−28 %	−3 %	
		Wildlife habitats	11 %	−48 %	−5 %	
		Visual appearance	7 %	−3 %	−0.2 %	
	Future value	Stability/Flexibility	9 %	13 %	1 %	+2 %
		Cultural and landscape development	8 %	5 %	0.4 %	

Table 4

Change of landscape quality experienced by respondents in Wadenoijen. Note: The negative percentage values mean decline and the positive percentage values mean improvement. Change = degree of improvement (+) or decline (−) of the landscapes with AV systems. Ranking impact = the share of the importance of the factors according to the respondents from Wadenoijen.

	Design dimensions	Factors	Ranking impact	Change	Share of factor change in overall LQ change	Overall LQ change
Wadenoijen (overhead AV)	Use value	Accessibility	4 %	−30 %	−1 %	−11 %
		Multifunctionality	9 %	30 %	3 %	
		Involving farmers	11 %	80 %	9 %	
		Environmental impacts	13 %	−147 %	−19 %	
		Recreation & community activities	7 %	−30 %	−2 %	
	Experiential value	Attractiveness	5 %	−49 %	−3 %	−16 %
		Health & well-being	12 %	−33 %	−4 %	
		Wildlife habitats	13 %	−60 %	−8 %	
		Visual appearance	9 %	−24 %	−2 %	
	Future value	Stability/Flexibility	7 %	26 %	2 %	+2 %
		Cultural and landscape development	10 %	5 %	0.5 %	

third most important factor in the ranking of both cases (Fig. 11). For the *experiential value*, all factors showed a decline in both cases.

These results may guide further research on the acceptance of agrivoltaics from a LQ perspective. Such research also may deepen the understanding of how the local population perceives landscape changes due to RE deployment. In Section 4.3. we explain further results and comparisons per LQ factor.

4.3. *Results per factor*

Respondents were asked to rate 7 out of the 11 LQ factors before and after the installation of the AV system on a Likert scale [77] of 1 to 5 (1 – strongly disagree, 5 – strongly agree) (Fig. 12–13). A summary of the results for the two embedded cases can be found in Appendix E. The factor ‘involving farmers’ was only rated after the implementation of the AV system. Regarding ‘environmental impacts’, respondents were asked to indicate any positive and negative impacts of the landscape without and with AV. Similarly, for ‘cultural and landscape development’, any influence could be marked in the landscapes without and with AV. The ‘visual appearance’ was rated on a Likert scale of 1 to 5 (1 – negative impact, 5 – positive impact). Respondents could specify the reasons for negative impact and the effect of the vertical support structure and the PV panels on LQ.

4.3.1. *Accessibility*

Results reveal that 49 % of all participants perceived the landscape with agrivoltaics as accessible, which is only 7 % less compared to the landscape without the AV. More specifically, 59 % of the participants experienced the vertical interspace AV landscape as accessible (12 % increase), while only 37 % perceived overhead AV landscape as accessible (30 % decrease).

This large difference in the perception of the two systems may be due to the different types of farms and the larger landscape context: the Culemborg AVPP may be perceived as more open without conventional fences around the AV, while the Wadenoijen AVPP is largely surrounded by hedges and fences when observed from the residential area. Another explanation could be that respondents find grassland more accessible than a fruit farm. It has been reported earlier that fences and security elements affect the perceived accessibility of landscapes [56]. In Wadenoijen, one respondent expressed a strong opinion about the presence of these physical elements, suggesting that they also influence the perception of landscape accessibility.

4.3.2. *Multifunctionality*

The multifunctionality of the landscape with AV was recognised by 77 % of the respondents, an increase of 28 % compared to the pre-AV situation.

Given the growing international interest in multifunctional SPPs [11,78] and the increased number of policies promoting the multiple use of landscapes [10], this finding is particularly relevant for making recommendations to decision-makers. In line with previous research on the perception of medium- to large-scale SPPs in Long Island, USA [79], the multifunctional character of agrivoltaics contributes positively to both landscape quality and public acceptance.

4.3.3. *Attractiveness*

Altogether, the attractiveness of the landscape decreased by 42 % after the arrival of AV; only 32 % of the respondents considered landscapes with AV attractive. Regarding the different systems, 47 % perceived vertical interspace AV as attractive (35 % decrease), while as

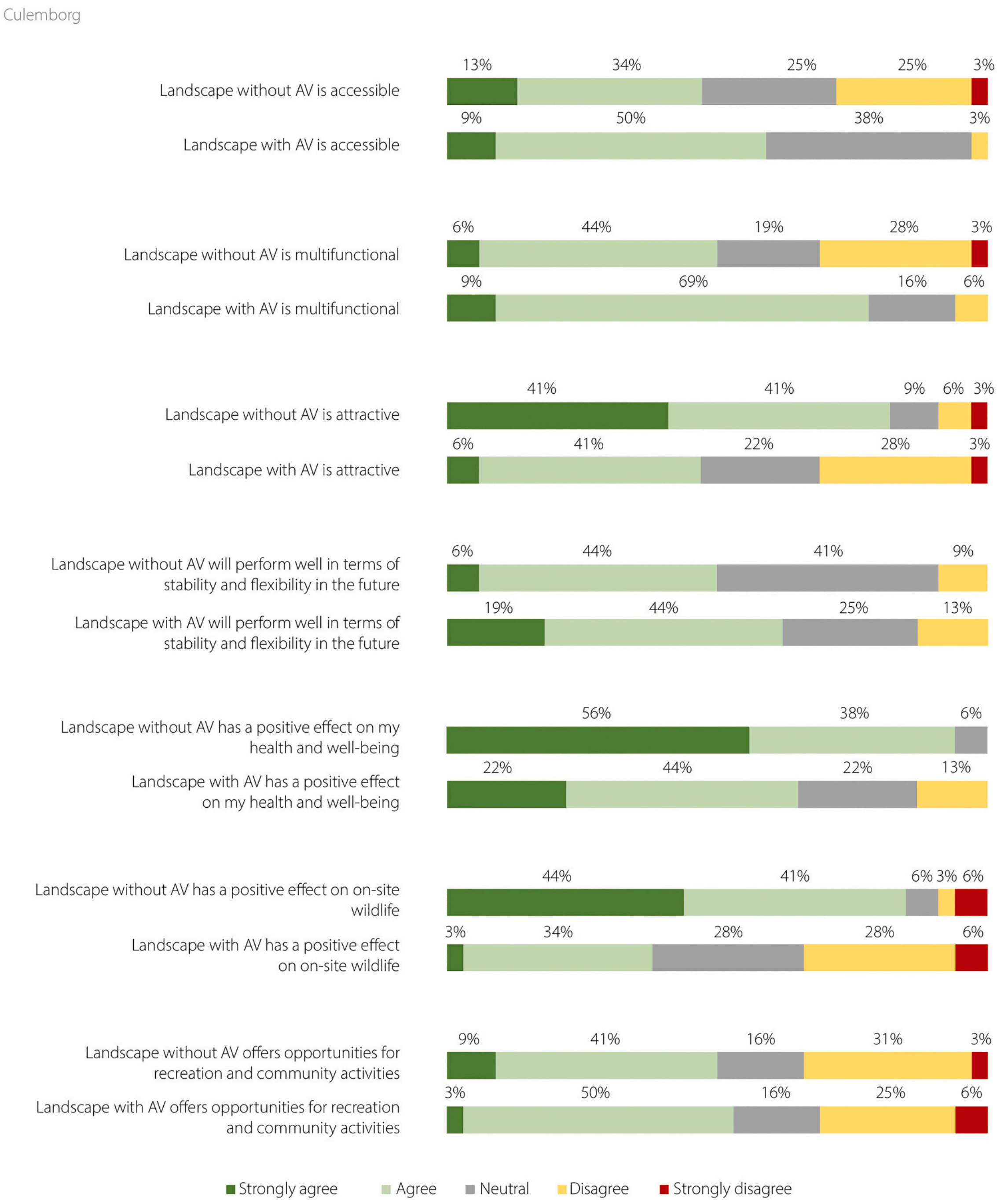


Fig. 12. Responses to statements about seven landscape quality factors for Culemborg without and with agrivoltaics ($n = 32$).

little as 17 % perceived overhead AV as attractive (49 % decrease).

The survey result regarding the Wadenoijen overhead AVPP is contradictory to the findings of Sirnik et al. [34] who reported that some interviewees found that AV system more attractive and believed it had a positive impact on the landscape experience compared to the plastic foils used to protect crops before the installation of overhead PV panels.

4.3.4. *Stability/flexibility*

About 59 % of the respondents expressed that AV landscapes will perform well in terms of stability/flexibility in the coming 10–20 years, showing a 19 % increase compared to landscapes without AV. For vertical interspace AV, 63 % expressed positive views, indicating a 13 % increase. For overhead AV, 56 % of respondents were positive, showing a 26 % increase.

When examining international agrivoltaic cases, Sirnik et al. [34] found that the regional economy benefited through improved quality and reliability of crop yields in Wadenoijen, among other cases. Additionally, studies have shown the benefits of AV in protecting crops and livestock [8,17] and in a broader economic and environmental context [13,14]. These publications suggest that agrivoltaics hold the potential to contribute, among others, to more robust future food production. Our results on stability/flexibility are in line with the literature stressing the positive influence of this AV characteristic on the local acceptance of solar energy.

4.3.5. *Involving farmers*

Altogether, 86 % of the respondents appreciated that local farmers were involved in RE projects. Culemborg, 90 % agreed with the

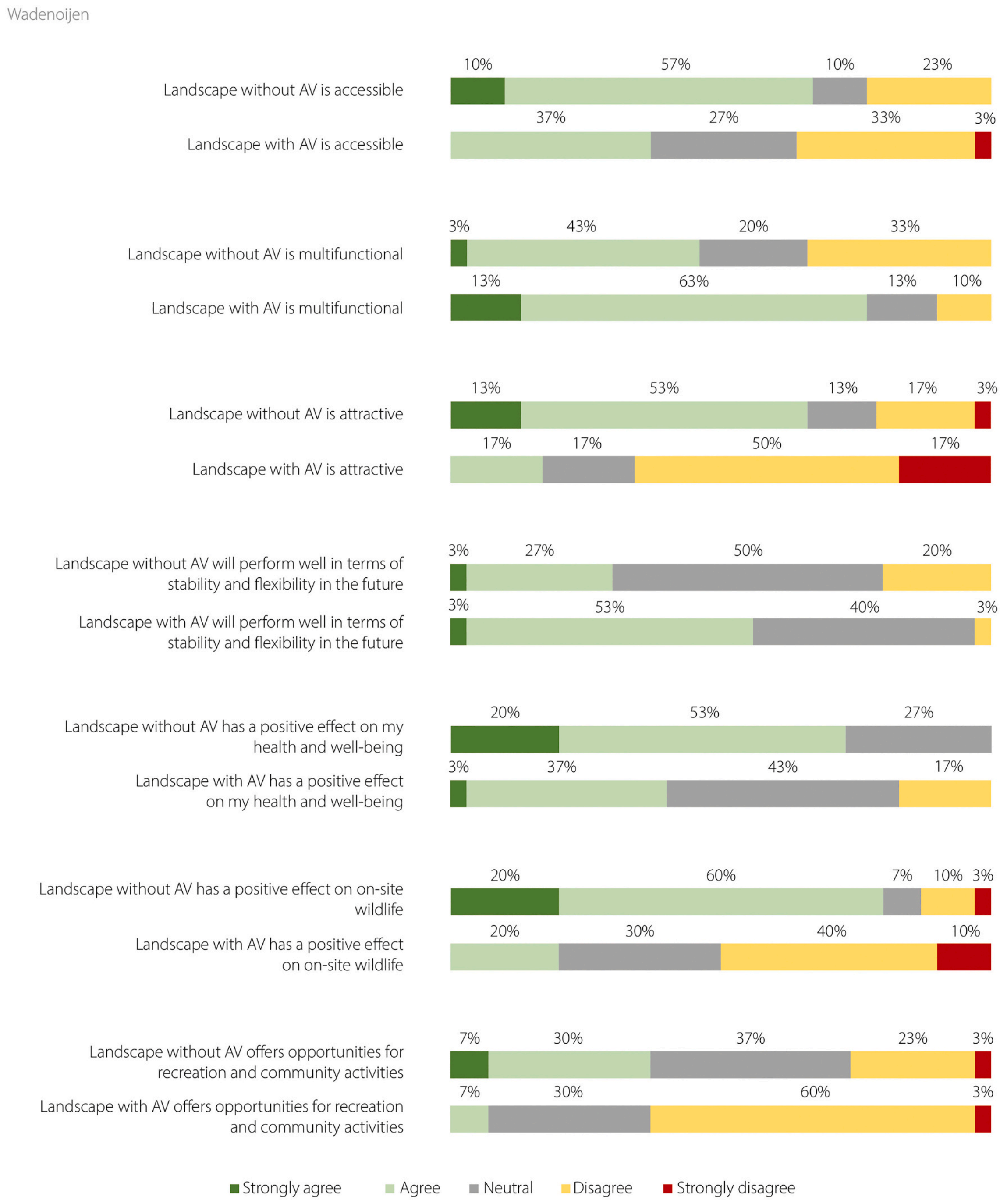


Fig. 13. Responses to statements about seven landscape quality factors for Wadenoijen without and with agrivoltaics ($n = 30$).

involvement of farmers (Appendix E), while for Wadenoijen 83 % of the respondents were supportive (Appendix F).

Recent research and policy guidelines point toward the need to involve farmers in the energy transition and the design of the AV systems [80,81] and our results suggest that this may play a role in the local acceptance of AVPPs. However, as our survey only included a broad statement on this topic, further research should examine the specific possibilities of farmers' involvement in AV projects and their influence on the social acceptance of agrivoltaics [80].

4.3.6. Health & well-being

The landscapes without AV were perceived to have a positive impact on health and well-being by 84 % of the respondents. Only 53 % expressed that the landscapes with AV systems had the same positive impact, representing a decrease of 31 %. For Culemborg, 66 % of the participants agreed with the AV's positive impact on health and well-being (28 % decrease). For Wadenoijen, only 40 % agreed that the AV had a positive impact on health and well-being (23 % decrease).

Enserink et al. [46] argue that health and well-being should be considered as key factor for the acceptance of RE projects, and the evidence of our study supports this claim. The potential of AV systems to reduce greenhouse gas emissions and other air pollutants is in line with the Sustainable Development Goal of 'Good health and well-being' [14,15]. This and similar benefits of AV for human health may not be apparent to everyone yet. However, the importance of this factor in the social acceptance of solar projects is beyond question and according to Roddis et al. [73] interconnected with other factors such as place attachment, landscape character, recreation, and visual impact.

4.3.7. *Environmental impacts*

Overall, respondents indicated that landscapes with AV have 11 % more positive environmental impacts compared to the landscapes before the AV installation (Table 5). The most frequently marked impacts were 'mitigation measures' (22 %), 'reduced CO_2 emissions' (20 %), and 'design' (14 %). For landscapes with AV, 65 % more negative environmental impacts were marked, the most frequently marked impacts being 'nuisance' (25 %) and 'landscape fragmentation' (22 %). For Wadenoijen, 'less use of plastic foils' (20 %) was also marked as a positive impact, in addition to the frequently marked 'mitigation measures' (25 %).

Previous studies on the acceptance of RE projects have emphasized the importance of environmental impacts [46,73,82]. Our results reveal that respondents recognize both the positive and negative impacts of AVPPs. The finding that 'nuisance' and 'landscape fragmentation' were the most commonly voiced negative impacts highlights the need for better integration of AVPPs into the landscape while promoting their environmental benefits. However, concerns regarding the most frequently marked negative factors of landscapes without AV, 'nitrogen pollution' (22 %), 'CO_2 emission' (20 %), and 'desiccation' (18 %), diminished when respondents rated the landscapes with AV. This suggests that respondents perceive landscapes with AV as having a less negative influence on these environmental stressors when compared to landscapes without AV.

4.3.8. *Wildlife habitats*

A positive effect of AV on on-site wildlife was considered by only 29 % of the respondents. The vertical interspace AV was considered to have a positive impact by 37 % (48 % decrease), whereas only 20 % believed that the overhead AV had a positive effect (60 % decrease). This factor ranked third in importance overall (Fig. 11) and showed a notable difference (−53 %) between the landscapes without and with AV.

Similarly, Roddis et al. [73] identified wildlife and habitat impact as the main concern in a case study involving a large-scale SPP in the United Kingdom. Nonetheless, it is important to note the differences between the research of Roddis et al. and our study in terms of project scale and pre-existing land use. In our study, both cases involved agricultural fields, and specific measures were implemented to enhance on-site biodiversity and habitats in the Culemborg case. Scientific evidence on the biodiversity impacts of SPPs and AVPPs is limited [14], meaning that perceptions of impact are of particular importance [73].

Concerns regarding on-site wildlife of agrivoltaics may also stem from negative impacts associated with agriculture and energy infrastructure, the technology's novelty, and the unfamiliarity of the local community with AV systems. It seems that respondents associated the pre-AV agricultural landscapes with better wildlife habitats, expressing concerns about the addition of technical infrastructure (PV) and its perceived negative impact on biodiversity. According to Walston et al. [14], AV systems with solar-pollinator habitats can have positive impacts on biodiversity conservation, depending on previous land use and project scale. While further evidence is needed in this field, it is important to consider the benefits for wildlife in future AV projects and to effectively communicate these with residents and other landscape users. This can be achieved, among others, by employing participatory design methods [12,83], through educational functions [9] and informative signs.

Table 5

The measured positive and negative environmental factors in both landscapes without and with AV systems. *20 % of all respondents.

	Without AV	With AV
Positive environmental factors		
Mitigation measures	24 (19 %)	31 (22 %)
Benefits to the local environment	19 (15 %)	14 (10 %)
Design	11 (9 %)	20 (14 %)
Reduced CO_2 emissions	23 (18 %)	28 (20 %)
Noise buffer	16 (13 %)	15 (11 %)
Beneficial to plant growth	32 (26 %)	15 (11 %)
Less use of plastic foils	–	16 (20 %)*
Total number of marked factors	**125**	**139**
Negative environmental factors		
Air/noise/light pollution	5 (8 %)	12 (12 %)
Nitrogen pollution	13 (22 %)	5 (5 %)
CO_2 emission	12 (20 %)	9 (9 %)
Construction	2 (3 %)	11 (11 %)
Nuisance	4 (7 %)	25 (25 %)
Safety of AVPP	–	3 (3 %)
Desiccation	13 (22 %)	12 (12 %)
Landscape fragmentation	11 (18 %)	22 (22 %)
Total number of marked factors	**60**	**99**

4.3.9. *Recreation and community activities*

Landscapes with AV offer opportunities for recreation and community activities according to 31 % of the respondents (12 % decrease). In the case of vertical interspace AV, 53 % agreed with this statement (3 % decrease), while only 7 % agreed that the landscapes with overhead AV offered recreation opportunities (30 % decrease). Similar to accessibility – discussed above -, this large difference may be attributed to the different farm types and contexts.

4.3.10. *Visual appearance*

Regarding the visual appearance of the landscapes with AVPP, 40 % of the respondents perceived a negative impact. The most common reasons were that the AVPP did not fit into the landscape (32 %), the tall structure affected the openness of the landscape (28 %), and the screening of the AVPP was insufficient (27 %). For Culemborg, 33 % of the respondents expressed that the vertical structure of the AV system had a negative impact on LQ (Appendix G).

For Wadenoijen, 53 % disagreed that the agricultural support structure (without the AV system) affected LQ negatively, indicating that most of the participants are accustomed to the presence of agricultural support structures in this landscape. However, 32 % agreed that the agricultural elevated support structure of the AV system negatively affected LQ, which is in line with previous studies [9,12]. Furthermore, 53 % agreed that the PV panels on top of the elevated support structure negatively affected LQ (Appendix H). According to one of the respondents, the AV system is 'very reflective', which was also expressed during conversations with other residents.

One participant also mentioned that 'more fences or cameras for control and security' contributed to the negative visual appearance of the overhead AV. Another respondent in Wadenoijen was concerned about the permanent impact of AV systems on the landscape compared to temporary plastic foils.

4.3.11. *Cultural and landscape development*

The most frequently mentioned cultural and landscape development factors for landscapes with AV were 'renewal' (23 %) and 'landscape modification' (21 %) (Table 6). However, respondents attributed 'preserving cultural heritage' (39 %) and 'legacy' (25 %) to the landscapes without AV. These two factors decreased by 30 % and 11 %, respectively, after the implementation of AV.

Table 6

The measured cultural and landscape development factors in both landscapes without and with AV systems.

Cultural and landscape development factors	Without AV	With AV
Preserving cultural heritage	43 (39 %)	12 (9 %)
Creating new cultural heritage	10 (9 %)	13 (10 %)
Landscape modification	14 (13 %)	28 (21 %)
Novelty in the landscape	4 (4 %)	21 (16 %)
Legacy	28 (25 %)	19 (14 %)
Integration	7 (6 %)	9 (7 %)
Renewal	4 (4 %)	31 (23 %)
Total number of marked factors	**110**	**133**

Given this decrease for 'preserving cultural heritage' and 'legacy', it is suggested that more attention should be paid to designing AVPPs that integrate cultural heritage [56,84] and include functions such as recreation to realise societal values [85].

4.4. Limitations of the study

The research reported here encountered several methodological and procedural limitations. Firstly, the scarcity of literature on LQ in relation to SA complicated the development of the analytical framework. The systematic literature review by Enserink et al. [46] on SA factors for RE, for example, was not specific about AVPP. Therefore, two additional studies [30,47] focusing on the perception of SPPs, and acceptance of AV had to be included. Secondly, certain factors from Hooimeijer et al. [52] were less applicable in the context of agrivoltaics and some aspects could have been classified under other design dimensions or societal interests which would have affected the aggregated outcomes. Thirdly, the limited number of respondents (n = 62) might be considered as statistically insufficient to extrapolate results to a national level. However, participants were carefully selected, with a preference for individuals residing within walking distance of the AVPPs. Fourthly, and much in line with other studies on LQ, a few respondents found certain factors complicated to grasp or claimed to have insufficient knowledge about the framework to answer the questions, even with explanations provided. Lastly, constrained by time and resources, this study encompassed only one case per type of AV. Comparing more cases in different landscape types and socio-economic contexts could have yielded more detailed insights into the effect of different types of AV on the LQ experienced by residents.

Despite these limitations, the LQ framework proved valuable in developing the questionnaire. In-person surveys and conversations with residents helped address many of their questions. This approach also enabled the inclusion of those locals who may not have otherwise participated (e.g., in an online questionnaire) or may not have responded if not approached face to face.

5. Conclusions

This study represents the first research on the effects of two different types of agrivoltaic (AV) systems on landscape quality and the experience of those agrivoltaic power plants (AVPP) by landscape users. Through extensive surveys with local residents – who represent key users of the landscape - the research compared two AV landscapes in the province of Gelderland, the Netherlands. In line with previous research, landscape quality is determined by *use*, *experiential* and *future values* [23,25,52]. The research was guided by the following question: *What is the landscape quality of vertical interspace and overhead agrivoltaic power plants according to landscape users?*

The findings reveal a decline in the *experiential value* of landscapes with agrivoltaic systems, while the *use value* increases for the vertical interspace AV and declines for the overhead AV. The *future value* shows a slight increase for both AV systems. While landscape users recognize at least the potential of AV to enhance landscape quality in terms of functionality (*use value*) and robustness (*future value*), they affiliate AV systems with a reduced *experiential value*. To address this critical trade-off of AVPP – common to many types of ground-mounted solar power plants - decision-makers should consider factors such as 'attractiveness', 'visual appearance' and 'health and well-being'.

The findings suggest that respondents prefer the vertical interspace AV system over the overhead AV, which may encourage further exploration of interspace (and vertically mounted) AVPPs elsewhere in the Netherlands and abroad. However, landscape quality and social acceptance should always be considered while assessing the suitability of AV systems. This can be achieved, among others, through the participatory evaluation of landscape quality in particular sites, conducting surveys with landscape users, and involving residents in the participatory development of AV projects.

The study also reveals that 'environmental impact' and 'wildlife habitats' are among the most influential factors for the evaluation of landscape quality. Further (design) research should explore the possibilities to improve the performance of AVPP concerning these factors. For example, by creating educational trails, informative signs, as well as biodiverse and accessible edges, landscape users may become more familiar with agrivoltaics and their benefits. Dutch AVPPs are typically inaccessible due to agricultural production underneath and between the arrays but making the immediate surroundings accessible and minimising security measures can contribute to increasing landscape quality.

While this study examined two recently constructed AVPPs, the introduced analytical framework may help to investigate the landscape quality of agrivoltaics in the design phase of future projects, to improve social acceptance. One could, for example, evaluate different design alternatives for specific AVPPs with a representative selection of landscape users. Further research should explore design guidelines for implementing interspace and overhead AVPPs in different landscape types with particular attention to that dimension of LQ that was affected most negatively in the presented cases: *experiential value*.

In conclusion, while agrivoltaics represent a potential solution for land allocation challenges of solar energy infrastructure, the *experiential value* of landscapes – as evidenced in this research - warrants more attention. This is particularly important in densely populated countries where the deployment of new AVPPs cannot go unnoticed. The need for more attention to landscape experience in AVPP development is further increased through ever-larger applications and the rapid growth of agrivoltaics. Although this study examined two particular types of AV in the Netherlands, the findings also provide directions for agrivoltaic developments elsewhere. The analytical framework and findings may aid the development of landscape-inclusive agrivoltaics, promoting an environmentally and socially just energy transition.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used OpenAI in order to improve the grammar and readability of the paper. After using this service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

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

Data availability

Data will be made available on request.

Acknowledgements

This study is the outcome of a research in Landscape Architecture and Planning at Wageningen University & Research. The authors would like to express their sincere gratitude for Dirk Oudes and Merel Enserink who provided useful feedback and critique in the development of this study. The authors are grateful for the help of the master students in the conducting of the survey, namely Vincent Klaaskate and Karel van Dompseler (both Wageningen University).

Appendices. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2023.103408.

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