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Review

The Social Acceptance of Airborne Wind Energy: A Literature Review

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Abstract: Airborne wind energy (AWE) systems use tethered flying devices to harvest higher-altitude winds to produce electricity. For the success of the technology, it is crucial to understand how people perceive and respond to it. If concerns about the technology are not taken seriously, it could delay or prevent implementation, resulting in increased costs for project developers and a lower contribution to renewable energy targets. This literature review assessed the current state of knowledge on the social acceptance of AWE. A systematic literature search led to the identification of 40 relevant publications that were reviewed. The literature expected that the safety, visibility, acoustic emissions, ecological impacts, and the siting of AWE systems impact to which extent the technology will be accepted. The reviewed literature viewed the social acceptance of AWE optimistically but lacked scientific evidence to back up its claims. It seemed to overlook the fact that the impact of AWE's characteristics (e.g., visibility) on people's responses will also depend on a range of situational and psychological factors (e.g., the planning process, the community's trust in project developers). Therefore, empirical social science research is needed to increase the field's understanding of the acceptance of AWE and thereby facilitate development and deployment.

Keywords: airborne wind energy; renewable energy; acceptance; acceptability; perception; opposition

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1. Introduction

Airborne wind energy (AWE) is an emerging wind energy technology. With AWE systems, higher-altitude winds (generally 300–600 m above the ground) can be harvested using tethered flying devices, also called kites [1]. Like conventional wind turbines, AWE systems will impact people and nature once deployed. Direct impacts could relate to the technology's sound emissions, visibility, and ecological effects, as indicated by research on wind turbines [2–9]. Potential acoustic impacts could result from noises emitted by the generator, winch, tether, and the flying kite. The appearance of an AWE system, specifically the ground station, tether, kite, and shadow, could lead to visual impacts. Due to the flying nature of the kites, ecological impacts would mainly concern the technology's influence on birds and bats and disturbance of mammals [10]. This is exacerbated by the fact that developers plan to initially deploy AWE systems in more remote and rural areas [11,12], where avian wildlife can be omnipresent. An additional impact could relate to the perceived and actual safety of the kites. For example, the uncontrolled crash of an AWE system could cause damage to people or property.

People's responses to new and existing energy technologies should be taken seriously, no matter how "irrational" they appear to developers and authorities. Otherwise, resulting opposition can lead to increased implementation costs, decreased political support for the energy technology in question, and ultimately limit the sector's scale and contribution to renewable energy targets [13]. Other low-carbon energy projects, including wind turbines, carbon capture and storage facilities, and biomass power plants have been hindered and canceled in the past due to strong negative responses of the public [13–16]. Therefore, it is important to understand the impacts of AWE and how they influence the social acceptance of the technology.

In keeping with Wüstenhagen, Wolsink, and Bürer's (2007) original conceptualization of social acceptance, the term is used here to refer to a complex and dynamic process involving all relevant actors and their positions across three inter-related dimensions: the socio-political, the community, and the market level [17,18]. However, the focus of this paper is more on the socio-political and community acceptance of AWE than on the market acceptance. Socio-political acceptance refers to the acceptance of the technology and related policies by the general public, policymakers, and other key stakeholders. In contrast, community acceptance describes the degree to which particular siting decisions and energy projects are accepted, especially by residents and local authorities. Importantly, acceptance refers to all positions and actions, not just favorable ones: e.g., active or passive resistance or support, uncertainty, indifference, or tolerance.

1.1. How Airborne Wind Energy Systems Operate

A variety of different AWE systems exist, which can be categorized according to the following three aspects: electricity generation (ground-gen, fly-gen), kite system (soft-wing, fixed-wing, hybrid-wing), and flight operation (crosswind, tether aligned, rotational) [19–21]. Regarding electricity generation, some kites produce electricity through onboard generators and transmit it with a conducting tether to the ground (fly-gen), while others convert the lift forces of the kite into electricity on the ground using either a fixed or a moving (e.g., rotating) ground station (ground-gen) [19]. The kite moves away from the ground station during ground-gen, unwinding the tether from a drum, which then turns a generator. The electrical energy from the generator is transmitted to short-term storage (e.g., battery or supercapacitor) and from there to the grid [22]. Once the kite has reached the maximum prescribed length of the tether, it is depowered and reeled back in, only to be instantly reeled out again, leading to a recurrent pumping cycle, which lasts a couple of minutes each (Figure 1).

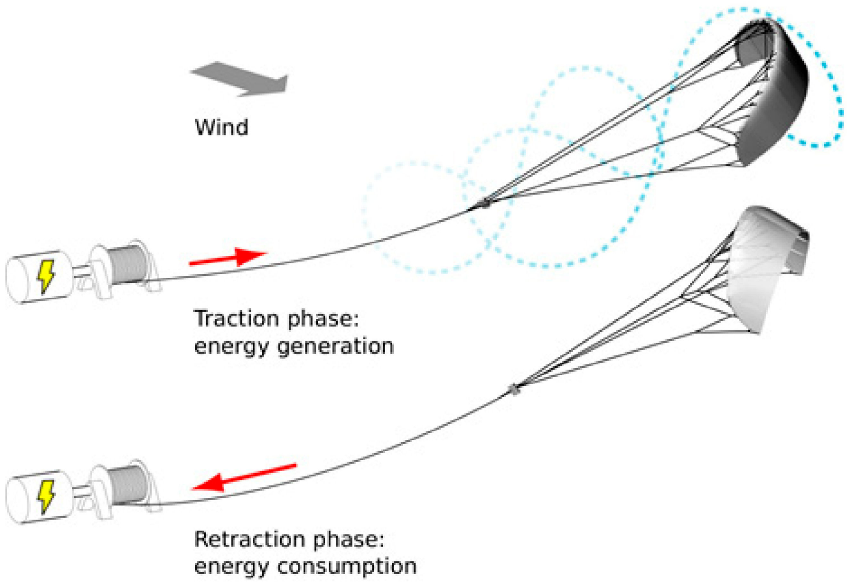

Figure 1. The pumping cycle of an airborne wind energy system consisting of a fixed ground station and a soft-wing kite flying crosswind maneuvers [23].

The reel-in phase (or retraction phase) consumes less energy than is generated during the reel-out phase (or traction phase). The crosswind maneuvers are discontinued in the reel-in phase, and the kite is depowered, resulting in a positive net power outcome across phases [21]. The kite will still be around 200–250 m away from the ground when fully reeled in. Although there are no publicly available quantitative data on the visual impact of AWE systems yet, test flights suggest that the kite appears relatively small in the sky during operation. The ground station is more visible, of course, also during operation. Besides, the kite casts a continuously moving shadow on the ground during flight.

Regarding the kite systems, soft-wing kites consist of inflatable membrane wings and resemble kites used for paragliding or kite surfing (see Figure 2) [19]. In contrast, fixed-wing kites look more like conventional aircraft or drones (see Figure 3). Hybrid-wing kites combine a rigid support structure with a textile membrane canopy.

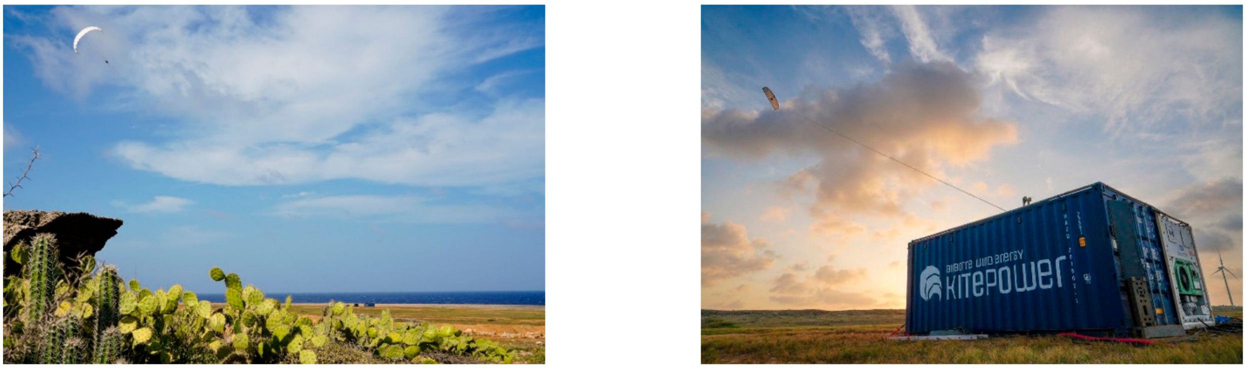

Figure 2. Pilot operation of the 100 kW AWE system of Kitepower on the Caribbean island Aruba in October 2021 (photo courtesy of Kitepower B.V.).

Figure 3. Ampyx Power's AP3 during flight testing on Breda International Airport in May 2021 (photo courtesy of Ampyx Power B.V.).

Concerning flight operation, only the lift forces of the kite are transferred to the ground and converted into electricity there during crosswind and tether-aligned operation. For the rotational operation of the entire kite, on the other hand, the torque of the kite is transferred and converted at the ground [20]. During crosswind operation, the kite flies figures of eight or circles during the reel-out phase, increasing the amount of energy harvested [21]. The combination of a fixed ground station with crosswind operation is most common [21]. Table 1 presents an overview of the technical specifications of the different prototypes currently being tested by AWE developers.

AWE systems are still in the development phase, with only a few systems in operation with launching customers. Tests of these prototypes and theoretical conceptualizations suggest that the emerging technology could have multiple benefits over conventional wind turbines. AWE systems can capture stronger and more constant winds at higher altitudes [36], and the harvesting operation could be continuously adjusted to available wind resources by changing the flight trajectory of the kite [37]. The control system can change the altitude of the flight path, depending on where the higher wind speeds are. The tether reeling speeds and the flight maneuvers can also be adjusted to maximize the energy output. These changes during operation are possible because the length of the tether is adjustable, and the flight trajectory can be varied within certain limits. Taken together, the higher general operational altitude of AWE systems and the greater flexibility in changing the harvesting operation may both result in a higher potential energy yield for AWE systems compared to wind turbines [37]. Besides, AWE systems require fewer materials, potentially leading to a lower carbon footprint [38,39]. Existing and planned prototypes of AWE systems are easier to transport, install, and uninstall than wind turbines. This means that AWE systems can be used in contexts that are not suitable for wind turbines. For example, for mobile applications (e.g., festivals, construction sites), hurricane areas—where systems can be securely stored to avoid damage—remote locations (e.g., islands, such as shown in Figure 2, communities, or mines), repowering of old wind turbine platforms offshore, and floating offshore wind energy systems in deep waters [19,28,40–42]. In some of these contexts, AWE systems could potentially replace electricity produced by diesel generators with cheaper and renewable electricity [40,43]. However, AWE systems are more complex to realize technically than wind turbines [44]. Some technical challenges have not been entirely solved yet, such as continuous automated operation (including take-off, nominal operation, landing), long-term durability of system components, operation under extreme weather conditions, and safe landing in an emergency [11].

Table 1. Overview of the technical specifications of the tested prototypes of AWE developers.

Developer	Prototype Name	Kite System	Electricity Generation	Wing Span (m)	Wing Surface Area (m^2)	Min.–Max. Altitude (m)	Rated Power (kW)	Source [a]
SkySails Power	SKN PN-14	soft-wing	ground-gen	15.6–22 [b]	90 [c], 180 [d]	200–400	200	[24]
Kitepower	Falcon	soft-wing	ground-gen	13.3 [b]	47 [c], 60 [d]	70–400	100	[25]
Kitenergy	KE60 Mark II	soft-wing	ground-gen	12.5 [b]	42 [c], 50 [d]	100–400	60	[26]
EnerKíte	EK30	hybrid-wing	ground-gen	8–14	4–8	50–300	30	[27]
Ampyx Power	AP3	fixed-wing	ground-gen	12	12	200–450	150	[28]
Kitemill	KM1	fixed-wing	ground-gen	7.4	3	200–500	20	[29]
TwingTec	Pilot System	fixed-wing	ground-gen	5.5	2	up to 300	10	[30]
Skypull	SP130	fixed-wing	ground-gen	2 × 1.3	2 × 0.5	up to 75	1.5	[31]
Windswept	Daisy Kite Turbine	fixed-wing [e]	ground-gen [f]	6 × 1 m (rotor ø 4.48 m)	6 × 0.2 m^2	10	1	[32]
someAWE	someAWE rotary kite	fixed-wing [e]	ground-gen [f]	4 × 1 m (rotor ø 3.5 m)	4 × 0.15 m^2	-	500 W	[33]
Kitekraft	SN7	fixed-wing	fly-gen	2.4	1.08	100 [g]	~12	[34]
Windlift	C1	fixed-wing	fly-gen	3.8	0.95	30–100	2	[35]

[a] information that was missing on the websites was provided by the developers, [b] projected wing span, [c] projected wing surface area of the kite, [d] wing surface area when kite is laid-out, [e] rotary kite system, [f] with tensile torque transfer from the kite, [g] tether length.

1.2. The Aim of This Paper and Research Questions

This literature review investigates what has been written about the social acceptance of AWE so far and compares the findings to the acceptance research on wind turbines. As a result, the review reveals gaps in the literature on AWE, leading to research recommendations. The aim of the paper results in the following two research questions:

1. What does the literature say about the social acceptance of AWE?
2. To what extent are conclusions regarding the social acceptance of AWE based on empirical evidence?

The following section explains the research method adopted for this review. Section 3 describes the results from the literature review. Section 4 discusses the findings and provides recommendations for future research and implications for policy and industry.

2. Research Method

2.1. Literature Search

An initial scoping search of the English-speaking AWE literature was conducted between May and August 2021 by searching Web of Science and Google Scholar for relevant publications and scanning two of the most influential publications on AWE [45,46]. In none of the few publications that were identified as relevant was social acceptance of AWE the main focus. Instead, the publications usually only referred to it in a couple of sentences. Besides, these publications used widely different terms to refer to social acceptance and related aspects.

The scoping search demonstrated that it is necessary to search the full text of publications, rather than just the title or abstract, for a wide range of different keywords to conduct an exhaustive literature review on this topic. We chose the database Google Scholar for the systematic identification of literature because it is the largest general database that scans the entire text for keywords [47].

Between August and September 2021 and in January 2022, we searched Google Scholar by combining two sets of keywords with the operator AND. The first set contained synonyms of AWE, such as high-altitude wind energy, kite power, and airborne wind turbine. The second set consisted of words that could be used to refer to the social acceptance of AWE, such as public acceptance, local support, and community concern (see Appendix A for the complete sets of keywords). We selected the keywords based on the initial scoping search and published literature reviews on the social acceptance of wind turbines [48–50]. The selection of AWE keywords was mainly informed by the fourth author's (i.e., RS) knowledge of the AWE literature. His competence in this area can be evidenced by his activities in the field over the last 12 years, which include the supervision of 11 Ph.D. researchers and the assessment of another 11 external Ph.D.s, the co-organization of the bi-annual Airborne Wind Energy Conference from 2015 through 2021, and his (co)editorship of two Springer textbooks on AWE with a total of 65 contributed chapters.

Due to Google Scholar's limit of 256 characters per search, we had to conduct 64 separate searches to combine the two sets of keywords in all possible ways. We did not use any search filters (e.g., publication year) to prevent missing any relevant literature. To address Google Scholar's limitation of not being a peer-reviewed database, we compared the search results to a topic search in Web of Science using the same AWE keywords as for this review. The comparison with the Web of Science records on AWE suggests that the outcomes of our Google Scholar searches are representative of the existing peer-reviewed AWE literature, which increases the confidence in the findings of this literature review. Using Web of Science only would not have allowed us to identify most publications that mention something related to the social acceptance of AWE because none of these publications contain keywords related to social acceptance in "title", "abstract", or "keywords". Hence, Google Scholar was the database of choice due to its superior full-text search function compared to Web of Science.

We noticed that three relevant publications identified during the scoping search did not surface during the final Google Scholar searches because we had limited the keywords to the most applicable ones, as indicated by the scoping search. These three publications were therefore added manually.

In addition to the Google Scholar searches, we published posts on LinkedIn [51] and in an AWE-focused research forum on ResearchGate [52] to identify any other relevant literature. Both posts received considerable attention: the LinkedIn post had over 4000 views in the feed, 54 reactions, and 13 shares, and forum members read the ResearchGate post 136 times. Nevertheless, neither led to the identification of additional literature.

2.2. Selection Process

After removing duplicates and non-scientific records (e.g., websites, brochures), 362 publications were left. From these, we selected publications that met the following inclusion and exclusion criteria:

1. The publication is written in English;
2. It refers to aspects relating to the social acceptance of AWE;
3. It is a full-text version of a peer-reviewed journal article, a peer-reviewed book chapter, a peer-reviewed conference paper, or a doctoral dissertation;
4. The part regarding the social acceptance of AWE is the respective authors' contribution and not just a paraphrase of another source.

Ph.D. researchers conduct a substantial amount of AWE research, which is why we included doctoral dissertations in the review. After selection, a total of 40 publications remained for the review. See Appendix B for data on the authors, journal, publication type, and the year of publication. The biggest group of excluded articles (*n* = 295) did not mention anything related to the social acceptance of AWE. These articles were identified through our Google Scholar searches because they contained at least one of the AWE keywords and one of the social acceptance keywords (see Appendix A for the exact search string used). However, when reading the publications, it became clear that they do not discuss the social acceptance of AWE, which is why we excluded them. See Figure 4 below for details on the selection process.

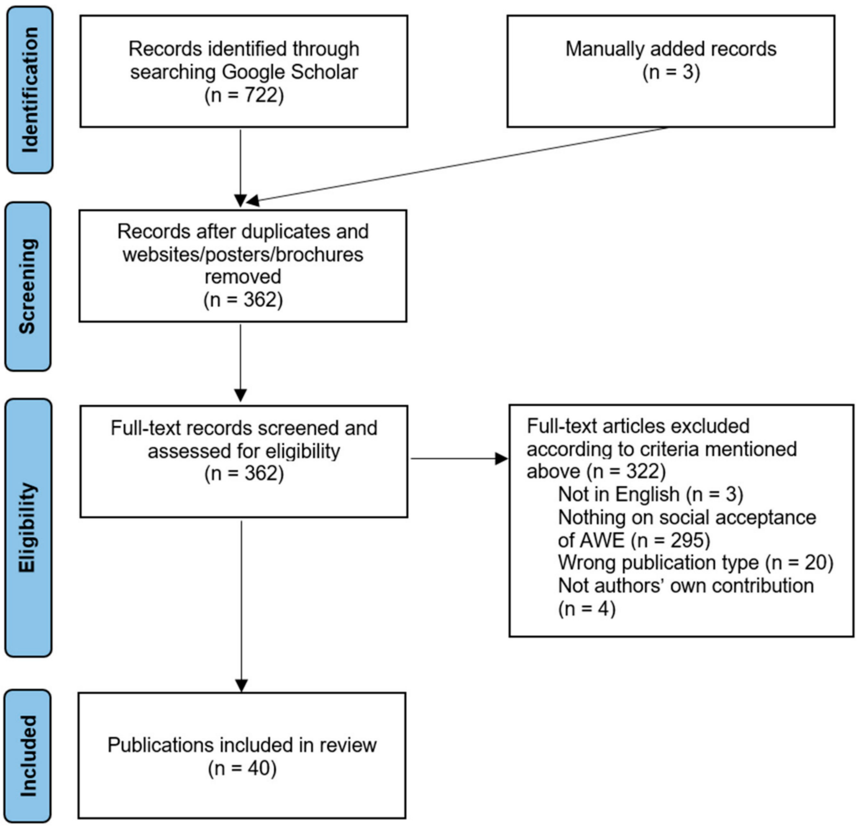

Figure 4. Flow diagram of the selection process for publications on the social acceptance of airborne wind energy.

3. Results

The 40 reviewed publications discussed five major impacts of AWE on social acceptance: safety and related aspects, visibility, sound emissions, ecological impact, and the siting of AWE systems. Strikingly, all the claims made in the publications about AWE impacts appear to be based on authors' assumptions and not on empirical evidence. Therefore, as we illustrate each impact below, starting with the most commonly mentioned ones, we contrast them to recent empirical work from social science energy research on wind turbines, and we examine the validity of the claims made in the AWE literature.

3.1. Safety and Related Aspects

The reviewed literature assumed that people might worry about the safety of AWE and that safety concerns could vary depending on the specific type of AWE system. For example, one publication speculated that people might perceive soft-wing kites as safer than fixed-wing or hybrid-wing kites due to the lighter materials [53]. However, even if laypersons believe that soft-wing kites are safer, an uncontrolled crash of a soft-wing kite could still cause harm because of the impact of the mechatronic control unit suspended from the wing, or the wing itself, which is a large and heavy structure. Therefore, it is possible that the distinct perception and knowledge of experts and non-experts differently influence how acceptable they find various AWE systems.

Another reviewed publication mentioned that the mode of electricity generation might impact safety perceptions. Specifically, the authors hypothesized that the use of fly-gen systems might raise concerns about electric tethers moving through the air [54]. While it is possible that people might worry about that, future admission regulations for AWE sites will likely minimize related safety risks to the public. A third publication presumed that people, especially pilots and regulators in the aviation industry, might see AWE systems as posing a risk to regular aviation [55].

In the expectation of public safety concerns, there was a consensus in the reviewed literature that the industry has to prove reliable operation to increase the support for the technology from investors, regulators, and the general public [22,44,56,57]. Proving reliable operation includes establishing safety regulations [58–60], having AWE systems with high fault tolerance [56,61], and minimizing the risk of accidents to an acceptable level [62]. Furthermore, the reviewed literature argued that AWE test sites should be far away from populated areas until the systems are proven to be safe to avoid concerns among nearby residents [12,63,64].

Safety concerns might currently influence the social acceptance of AWE more critically than for wind turbines. In contrast to wind turbines, there is a lack of research on the risks of continuous, long-term operation because AWE systems have not been operated over extended periods yet, and universal, effective regulation is still lacking [60]. Moreover, a wind turbine is a stationary construction on the ground, which means that operation can be instantly stopped when there is a problem, typically without causing an accident [65]. On the other hand, an AWE system cannot be stopped in mid-air. Whenever a part of the system is no longer working correctly, the system can at best be brought to a controlled landing. However, for a controlled landing, it must still be in a flyable state, which is often not the case when something is broken, leading to a complete crash in the worst scenario [65]. For this reason, a flying AWE system might be perceived as more hazardous and thus less acceptable than a ground-based wind turbine. It would be relevant for future research to test this assumption when empirically examining the impact of actual and perceived safety risks on the acceptance of AWE.

3.2. Visual Aspects

Almost half of the reviewed publications (17 out of 40) mentioned the visibility of AWE systems in relation to social acceptance. There seems to be an agreement in the field that these systems are less noticeable than wind turbines, which the literature mainly explained with the high operating altitude of AWE systems [55,58,66–70]. Two publications claimed that the low visibility of AWE systems reduces public concerns [64,71], from which one paper concluded that it makes them suitable for installations in ecologically sensitive areas or at tourist destinations [72]. The rationale behind these claims seemed to be an expectation that AWE systems "ensure unobstructed views of the local environment", as one author put it (p. 738) [55]. However, these assumptions do not take into account the fact that the ground station, which currently often has the size of a standard shipping container, will be visible, nor do they consider any subjective factors that influence the visual impact of infrastructures as will be explained below.

The reviewed literature further suggested that the replacement of the tower with a relatively thin tether [62], the option to land the kite when there is little wind [57,69], and the reduction in shadow flicker [73] reduce the visibility of AWE systems compared to wind turbines. Shadow flicker refers to the flickering effect caused when a moving energy plant periodically casts a shadow on the ground. Most AWE systems can be expected to produce only a weak and sporadic shadow flicker at a given location on the ground because the kite operates at altitudes between 300 and 600 m and constantly changes its position during the pumping cycles. It should be noted that recent cross-country research anyway found that only a very small percentage of residents are greatly annoyed by the shadow flicker of nearby wind turbines (0.2% in both the U.S. and Europe) [3]. Residents were defined as strongly annoyed when they perceived shadow flicker, rated it at least "somewhat" annoying (based on a five-level annoyance scale from (1) "not at all", (2) "slightly", (3) "somewhat", and (4) "moderately" to (5) "very"), and reported a minimum of one physical or psychological symptom that recurs at least once per month and that they attribute to the impact [3]. It is essential to consider symptoms when examining the impact of nearby energy projects on residents because symptoms indicate the experienced stress level [74]. In contrast, reported annoyance, by itself, is more a generic assessment (good–bad) of the specific impact [3]. Thus, the low prevalence of annoyance from shadow flicker indicates that it is not as great of a problem as it is often made out to be. This is not to say that wind turbines, or AWE systems for that matter, create no visual impact on people at all.

The visibility of a wind farm (i.e., seeing it) depends on a range of aspects, such as distance, number of turbines, and landscape features [8]. However, research on the relevance of visibility for the acceptance of wind developments is mixed [2,4,75]. More recent research indicated that the visibility of a turbine might be less critical than individuals' evaluation of a wind farm's appearance and fit within the landscape [75,76].

In any case, Batel and Devine-Wright recently emphasized that research has to consider individuals' preferences for the physical appearance of specific energy infrastructures in relation to the community/local and socio-historical/cultural dimensions to gain a meaningful understanding of the visual–spatial impacts [77] In other words, research has to look beyond visual impact as only materialized in physical characteristics (e.g., size, color, shape) of energy developments. Instead, research should recognize that "people's emotional and symbolic relations with the place where they live will impact on their acceptance, rejection or ambivalence towards RET [renewable energy technologies] in their locality depending on how these RET are seen as fitting or not that place" (p. 45) [77]. This is also referred to as project–place fit [78,79]. Furthermore, Batel and Devine-Wright posited that research should examine how landscape traditions in the sense of cultural, institutional, and ideological representations of landscape impact communities' responses to a proposed or existing development (e.g., the conception of the countryside as an idyll that needs to be preserved vs. the representation of countryside as a place for farming and making a living).

Future studies on the visual–spatial impacts of AWE should apply and learn from the research on wind turbines but also consider the innovativeness of AWE. There are other optical features of AWE systems not discussed in the reviewed literature that might influence people's responses; for example, certain colors of kite systems, specific flight patterns (e.g., circles vs. figures of eight), the kite's fast movements, or the lights attached to the kite and tether for aviation safety. Regarding the latter, recent research across three European countries has found that a small percentage of residents (3–6.1%) are strongly annoyed by the obstruction lights of nearby wind turbines [80]. This suggests that some residents might also perceive safety lights of AWE systems as disturbing, especially as the AWE systems become larger and fly higher, and thus the need for strong lighting to warn pilots increases.

3.3. Acoustic Aspects

Similar to the visibility of AWE systems, the reviewed literature also commonly expected sound emissions to be lower for AWE than conventional wind energy [12,62,71,72,81–84]. The anticipated lower acoustic emissions were typically explained by the high operating altitude of AWE systems [55,58,73] and were assumed to make the systems more suitable for installations in ecologically sensitive areas or at tourist destinations [72]. For ground-gen systems, one publication suggested making the ground station soundproof to reduce acoustic emissions further [62].

Three publications directly concluded that the expected low sound emissions of AWE would positively influence social acceptance [64,71,84]. However, research on wind turbines demonstrates that sound pressure levels and the distance to the wind development rather play a minor role in how residents experience the noise [2,3]. The noise quality seems more important, with amplitude-modulated noise appearing to be a major reason for noise complaints [2]. This could be explained by the fact that short-term amplitude changes are attention-grabbing. Consequently, this shift in attention towards the source of the noise disrupts residents in their activity and is thus perceived as annoying [2].

Next to noise quality, various subjective factors influence how annoyed and stressed people are by wind turbine noise. For example, residents are more likely to be annoyed by the noise and to show stress reactions when they perceive a negative visual impact of the wind turbine on the landscape [2,5,9], or when they are annoyed by a perceived lack of fairness in the planning process [2,3]. Reported stress effects include experiencing bad mood, anger, lack of concentration, difficulty falling asleep, or otherwise not sleeping well [2]. Moreover, residents' attitudes toward wind energy in general and the local wind project specifically are also negatively correlated with their level of noise annoyance [2]. Attitudes refer to individuals' subjective evaluations that can range from positive to negative. Interestingly, financial participation in the local wind project has been related to lower noise annoyance and stress effects for residents [9,85].

In general, the prevalence of strong noise annoyance (i.e., at least somewhat annoyed by sound with a minimum of one stress symptom occurring at least monthly) is relatively low, with statistics varying between 1.1% and 9.9% across European and U.S. wind farms [2,3]. The reported levels were, in fact, comparable to respondents' annoyance with traffic noise [2,3]. Nevertheless, the small subgroup of residents that are strongly annoyed by wind turbine noise should not be disregarded.

The findings from wind turbine research should be considered when assessing the acoustic impact of AWE systems. Multiple developers reported that the sound emissions of their AWE systems comply with local noise limits [86,87]. However, as research on wind turbines indicates, there might still be some residents that are annoyed by the sound that AWE systems emit, and implementing stricter immission regulations or setback distances may not completely resolve this annoyance. Therefore, future noise assessments should not be limited to sound height but also include the long-term monitoring of residents close to AWE sites with analyses of sound parameters, amplitude modulation, stress effects, and situational conditions to untangle various sources of annoyance and symptoms [3]. Besides, such assessments should consider subjective factors, such as the perceived fairness of the participation process and residents' attitudes towards the local AWE site.

3.4. Ecological Aspects

Collisions with birds and bats and the disturbance of mammals and avian wildlife are expected to be the most prominent ecological effects of AWE [10]. Regarding impacts on birds, the reviewed literature assumed that an AWE system would cause fewer bird strikes than a wind turbine [55,64,82,84]. A recurring argument was that the kite operates above the range of avian wildlife except for the short take-off and landing phases. However, the tether can also pose a risk because it moves at a higher speed than birds and is therefore difficult to anticipate for them (see Figure 5) [10].

Figure 5. Pilot operation of the 20 kW kite power system of TU Delft [88] before (**left**) and after a bird collided with the tether (**right**). The bird continued the flight seemingly unaffected, which suggests that bird collisions with a tether are possible but do not necessarily have to be fatal. Max Dereta took the photos on 28 June 2011 at Valkenburg airfield, The Netherlands.

The only peer-reviewed study on the ecological impact of AWE estimated that between 2 and 13 birds would collide with the kite, and around 11 would come into contact with the tether per year, resulting in an annual total of 13 to 24 bird fatalities [10]. The estimates were based on predictions for year-round 24/7-operation of Ampyx Power's planned 2 MW fixed-wing kite, with a tether length of 1 km and an operating altitude of 200–450 m. The bird activity level at the site was assumed to be "moderate". The authors reported that the estimated bird fatalities for AWE fall within the range of bird fatalities that have been recorded for wind turbines (0.6 to 63 fatalities per year, with a median of 7). They considered the number of bat strikes for AWE to be negligible [10]. The results were not based on field data of AWE but rather on comparisons with bird mortality statistics for glider aircraft and power lines and should therefore be interpreted with caution.

AWE developers commissioned a few, albeit not peer-reviewed, reports to receive permits for (continued) prototype testing, which contain actual field data on the ecological impact of AWE, such as surveys of bat/bird flight and breeding activity. Two of these reports directly observed how an operating AWE system affects local bird or bat populations [89,90]. All assessments concluded that the impact of the AWE system on local avian wildlife is negligible [89–91]. However, that does not mean that AWE, in general, is harmless to birds and bats, as some engineers claim [67,70]. Results from an environmental impact assessment at one test site are only transferrable to other test sites to a limited extent because of wildly varying environmental conditions [10,89,90].

Therefore, more longitudinal empirical research is needed across different ecosystems because the occurrence and types of species differ across habitats, time of day, and seasons (e.g., breeding season, migratory season) [10,86]. Moreover, birds' habitat use and flight behavior changes in the different phases of the year and weather conditions (e.g., little wind vs. strong wind). Knowing how a given AWE system or test site affects birds is essential for mitigating measures that counteract potential adverse effects. Mitigation measures could range from changes to the design of AWE systems [92] to regulations that apply to the construction, operation, and maintenance of AWE sites. The latter could, for example, include establishing disturbance buffer zones for sensitive species during the breeding season and constant monitoring and regular inspection of site and equipment [86,91].

Taken together, the claim that AWE systems cause fewer bird strikes than wind turbines is not sufficiently backed up with empirical data yet. Besides, it is unknown how AWE's perceived or actual ecological impacts would influence the social acceptance of the technology. Research suggests that up to around a third of people, especially environmentally conscious individuals, are somewhat concerned about the wildlife impacts of wind turbines [6,7,93]. However, it remains unclear how these concerns influence the acceptance of specific wind projects. Therefore, it would be interesting to investigate how wildlife concerns shape people's views on AWE.

Finally, one publication mentioned that "without towers, the ecological impact of airborne wind energy [. . .] can be reduced to a fraction compared to conventional wind turbines" (p. 623) [94]. The authors did not specify if they mean by ecological impact the effect on living organisms, or if they refer more globally to the environmental footprint of the technology. The latter might too influence people's responses to AWE, as was also suggested by another reviewed publication [95]. The materials used for AWE systems are more critical in terms of their environmental impact compared to wind turbines. For example, the carbon-fiber-reinforced polymers used for fixed-wing kites have been estimated to be 21 times as polluting as the glass-fiber-reinforced polymers in wind turbine blades [38]. Nonetheless, initial research suggests that AWE systems have an overall lower environmental impact because they use notably fewer materials and are more independent of local environmental conditions (e.g., in locations with lower average wind speeds, turbines need to be larger and are thus requiring more materials) [38]. This difference might become more pronounced if the AWE industry finds ways to lower the environmental impact further; for example, through recycling, which is still uncommon for the blades of wind turbines and partially explains the high environmental impact of turbines [96]. The sustainability issues attached to either energy technology might be relevant for how people respond to AWE compared to conventional wind energy.

3.5. Siting of AWE Systems

The reviewed AWE literature expected that the siting of AWE systems influences people's responses to AWE and vice versa. For example, one group of authors assumed that the available area and thus the density of systems in one location depends, among other things, on the social acceptance of the technology [69,97]. However, this perspective seems to disregard the fact that despite generally high public acceptance of wind energy, a local community might oppose the siting of a specific wind development [98]. For example, this might be the case if the community perceives the public participation during the decision-making process for a local site as unfair. In general, a fair public participation process appears crucially important for higher acceptance of a local wind farm and reduced annoyance from wind turbine impacts [3,4,99]. The fairness of the process seems to mainly depend on the transparency and openness of the developer and whether residents have trust in the developer but also on residents' ability to participate in the planning process and influence the outcome [76,99,100].

The reviewed literature further expected that acceptance would be higher for offshore AWE systems because visual and acoustic impacts are thought to be less disturbing to people than onshore [57,101–103]. While there is some evidence that offshore wind turbines are favored, preferences depend on additional factors, such as the distance of dwellings and offshore sites to the coast [104]. Offshore wind development has been related to some of the same topics of discussion as onshore development (e.g., visual and acoustic impacts, economic or employment benefits, procedural justice concerns, climate change mitigation) [50]. However, offshore wind farms also raise different issues, partially because offshore wind farms affect other stakeholders, such as beach users and owners of coastal tourism companies [50,105]. For example, potential negative or positive impacts on tourism, marine wildlife, the fishing industry, and the recreational activity sector (i.e., boating, yachting, surfing, fishing) are often discussed [50,106–108]. It should be noted that the AWE industry is planning to develop floating offshore plants, which have less of an impact on marine wildlife [43,101,109]. Therefore, it remains to be seen whether people's responses differ between on- and offshore AWE developments and why.

Finally, as mentioned before, safety issues also play a role in siting decisions. The reviewed literature mentioned that AWE test sites should be located in remote areas to minimize public safety concerns and that the aviation sector will likely perceive AWE systems as a risk. However, the literature did not elaborate on the disputes that might arise over the allocation of airspace for AWE, nor did it recognize it as a siting issue. Airspace is a finite resource, and the needs of the AWE industry for airspace will likely conflict with the interests of the military and civilian users (e.g., airlines, first responder helicopters, leisure aviation sectors). Indeed, there is some evidence of tensions between the aviation and AWE sectors. In 2011, the Federal Aviation Administration (FAA; U.S. governmental agency) received a request from Makani Power, a former U.S. AWE developer, to include AWE systems into the National Airspace System. Before revising their policies, the FAA invited comments from the public on the subject [110]. A total of 20 comments were submitted, of which around two-thirds were from developers or proponents of AWE who assured that AWE does not pose a risk to aviation safety (e.g., by having sufficient lighting and marking of the systems, constant monitoring of operating systems, registering systems in air traffic navigation charts). There were also six comments by pilots and aviation associations who were afraid that AWE compromises the interests of the aviation sector. The most prominent criticism related to safety risks for the aviation sector, such as collisions of low-level airspace users like agricultural or recreational pilots with AWE systems. The critics also questioned whether sufficient marking and lighting could even be achieved to prevent such accidents (e.g., brightly colored tethers might not be seen from a distance because the tether is too thin, lights may not be feasible to install on the tether because it has to be wound around a drum). One comment clearly reflected the looming dispute over airspace resources. It suggested that AWE systems should only be tested in *existing* prohibited areas—areas on the surface of the Earth within which the flight of aircraft is prohibited—because creating additional prohibited areas for AWE would restrict the "already crowded" airspace even more. However, if AWE systems were only allowed in existing prohibited areas, it would significantly limit the scale of technology deployment. The discussion that arose in response to the FAA's invitation for comments suggests that assessments of the social acceptance of AWE should also consider conflicts regarding airspace resources.

It seems that the influence of siting decisions on people's responses is heavily intertwined with the visual, ecological, acoustic, and safety aspects of the technology, which the reviewed literature expects will also influence the social acceptance of AWE, as previously explained (see Table 2 for an overview).

Table 2. Overview of the technical aspects that the reviewed literature speculates will shape the social acceptance of airborne wind energy (AWE).

Main Technology Aspect	Impact on Social Acceptance
Safety	− Public safety concerns (e.g., regarding fixed-wing kites, fly-gen, aviation) + Establishing safety regulations in the industry + Increasing the fault tolerance of systems + Minimizing accident risks
Visibility	+ Low visual impact due to high operational altitude, absence of a tower, low shadow flicker, and possibility to retrieve the kite in low wind
Sound emissions	+ Low acoustic impact due to high operational altitude
Ecological impacts	+ Few bird- and bat strikes due to high operational altitude
Siting	+ Offshore AWE sites + Operating in remote areas

Note. "−" indicates an assumed negative impact on social acceptance, and "+" indicates a hypothesized positive effect on social acceptance.

4. Discussion and Conclusions

Airborne wind energy (AWE) is an emerging renewable energy technology that harvests higher-altitude winds (300–600 m above the ground) with automatically controlled kites. Like other renewables, AWE will impact people and nature. These impacts will shape the social acceptance of the technology and influence its large-scale deployment. If the industry ignores people's concerns about the technology and the public starts showing resistance to AWE, it could increase implementation costs, decrease political support for AWE, and minimize AWE's contribution to meeting renewable energy targets [13]. Therefore, it is essential to understand which aspects of the technology and its deployment (e.g., visual–spatial impacts, safety, project planning process, benefits schemes for hosting communities) will impact people's responses and how. This review assesses what has been written about the social acceptance of AWE and identifies knowledge gaps in the literature.

Two main conclusions can be drawn from the literature review, which also answer the research questions. First, there is a lack of empirical research on people's responses to AWE. Only a few AWE publications (i.e., this review identified 40) discuss how the technology might impact people and nature. The vast majority of these publications were authored by engineers (83% of authors), and none of the papers were written from a social science perspective. In total, 34 out of the 40 publications had mainly a technical and/or economic focus and mentioned the social acceptance of AWE only in passing. As a result, the literature's claims about how the technology will influence people's responses were only based on authors' assumptions and not on scientific evidence, such as interviews, surveys, or experiments.

Second, most researchers in the field seem to be quite optimistic about how the emerging technology will be perceived, especially given the lack of scientific proof. Specifically, the reviewed literature assumed that the expected low visual impact of AWE due to the high operational altitude, absence of a tower, low shadow flicker, and possibility to retrieve the kite in low wind, and the expected low acoustic and ecological impacts would influence the social acceptance of AWE positively. The only anticipated acceptance issues were certain siting decisions (e.g., onshore rather than offshore developments, sites in densely populated regions) and possible safety concerns about the technology (e.g., regarding fixed-wing kites, fly-gen, aviation, currently lacking regulation and proof of reliability).

In general, the field seems to expect people to process information about AWE (e.g., costs and benefits) in an entirely rational and objective manner. In contrast, existing research has shown that subjective factors, such as political orientation and emotional reactions to energy technologies or specific projects, affect which information people seek about energy-related topics, how they evaluate it, and how they respond to a local energy development [111–114]. Thus, the assumption that the processing of provided information and that responses to AWE systems will be entirely rational appears to have contributed to an optimistic perspective on the social acceptance of the technology. Furthermore, the literature currently overlooks the fact that with the deployment of AWE systems, not only characteristics of the technology will shape responses to AWE but also the deployment context and process; for example, locals' evaluation of the decision-making process and distribution of benefits as (un)fair, their trust in the developers, and their identification with the place [13,76,78,100].

It is undisputed that the optimism of the engineers is needed to realize such technically challenging innovations as AWE. However, an overly positive view on how people will perceive the technology could lead developers and authorities to overlook potential social issues and thereby hinder the deployment of AWE [115]. Some authors already recognize that AWE could trigger opposition [101,102] and that understanding social acceptability issues is therefore key for developing and deploying the technology [57,116–119]. It has even been suggested that the commercialization of AWE depends on creating a positive public vision of the technology [120]. More specifically, it was assumed that if the general public and key stakeholders perceive AWE negatively (e.g., have worries about lacking reliability and safety), it could reduce support for and investment in the technology and hinder its large-scale deployment. Although some literature already acknowledges that an acceptance of AWE is crucial for the success of the technology, one study found that concerns about people's responses are still much less common in the field (7% of all mentioned concerns) than other concerns, such as economic viability (25%) and lacking regulations (24%) [11]. This was especially the case among public and academic stakeholders, although they were also underrepresented in the study compared to business stakeholders, which may have distorted the findings.

In summary, the field should become more aware that gaining a meaningful understanding of the social acceptance of AWE at an early stage of technology development is crucial to the long-term success of the industry and offers the opportunity to adapt the (deployment of the) technology to fit with people's needs.

4.1. Further Research Recommendations

The present review demonstrates the need for *empirical* social science research on the acceptance of AWE, such as through surveys, interviews, focus groups, and lab or field experiments. As discussed in Section 3, the literature on AWE has identified five important issues, namely visual, acoustic, safety, ecological, and siting aspects, that might, to some extent, impact people's responses to the technology, as also indicated by research on other energy developments. However, the literature's claims are so far not backed up by empirical evidence and are limited to technological characteristics. At the same time, research on other renewable energies has shown that other relevant issues, such as situational and psychological factors, are also important to the acceptability of a development. Hence, future studies should learn from the large body of literature on other renewable energy technologies, as repeatedly illustrated in Section 3.

When studying AWE, it is critical to consider the broader social, cultural, and environmental context because the social acceptance of energy technologies is not only determined by individual perceptions [13,121]. Instead of only focusing on individuals' beliefs, values, and attitudes regarding AWE, it should be taken into account that situational factors such as policy contexts, the characteristics and local meanings of deployment sites, communities, and cultures, and the project planning process shape people's responses [122]. In addition, research should consider how other key stakeholders, such as developers, policymakers, and the media, view the deployment of AWE and, specifically, how their interactions with the general public and hosting communities influence responses to the technology [123]. Furthermore, responses to energy technologies and the acceptance of specific projects change over time and should be understood as a dynamic process [122,123]. Therefore, research on AWE should consider the dynamics of the relationships between the different stakeholders.

Some results have been shown to apply across a wide spectrum of renewables, such as the importance of a fair planning process to people's responses. Future research on AWE will likely observe that these findings also generalize to AWE because the nature of the technology is not that relevant in that regard. Nevertheless, there are apparent differences between AWE and other renewable energy technologies that research should consider because they might inform people's responses in some ways. For example, AWE applies the familiar concept of transforming wind into energy, but it does so using a flying rather than a stationary system and operates at much higher altitudes (300–600 m) than wind turbines (the hub height of multi-megawatt onshore turbines varies from around 80 to 165 m) [124]. It means that AWE systems, unlike wind turbines, cannot be stopped in mid-air when a problem arises but can, at best, be brought to a controlled landing. This might raise concerns about the technology's safety, especially as long as the industry is mainly in the testing phase and universal regulations are lacking. There might be other innovative and distinct characteristics of AWE that could influence the social acceptance of AWE and that should be investigated in the future.

In general, research should take into account that AWE is an emerging technology that will still change over time. Current prototypes are still on the smaller side in terms of size and capacity (see Table 1 for details). As the industry is working towards higher capacity, it can be expected that the size and design of AWE systems will change as a result. Furthermore, while currently only one system is flown at a time, future installations might combine multiple AWE systems [125]. People might respond differently to the technology at the various stages of development.

The infancy of the technological development of AWE should not be seen as a limitation to research but rather as an opportunity. Research can help identify people's needs and values regarding the technology and involve the public in the technological development and not just at the deployment stage, which will be further explained in the following section.

4.2. Implications for Policy and Industry

The implementation of low-carbon technologies has often been seen as benefiting the regional or (inter)national public (e.g., mitigating climate change) while disproportionately burdening local populations (e.g., impacting local landscapes) [4,126]. It is becoming increasingly common to offer benefits to host communities, such as creating local jobs, rental payments to landowners, community ownership models, lower local electricity prices, and landscape and ecological enhancement measures, to balance out local negative impacts [13]. AWE systems will also affect place and people at deployment sites, and project planners will likely consider compensation measures for the siting of the systems. However, they should be aware that community benefits do not necessarily increase project support [75]. A recent review concluded that compensation schemes for renewable energy projects are more likely to be acceptable, not perceived as bribery, and beneficial for project support when the compensations fit with local needs and concerns [127]. Thus, developers should identify the relevant community (e.g., individuals living close to the proposed infrastructure vs. individuals negatively affected by the project), their needs and concerns, and what type of compensation would best match those.

Compensation alone is usually not that effective and should be combined with wider public engagement strategies. In particular, a fair planning process is essential. The fairness of such a process highly depends on the developer's transparency, residents' trust in the developer, and residents' ability to participate in the planning process and influence the outcome [4,76,99,100]. For trust to be meaningful in planning processes, it should not simply be utilized to reduce opposition [128]. Instead, the trust should also be extended to acknowledging that residents have valid views and knowledge and that open participation can lead to positive outcomes independent of whether these support a given project proposal. As a result, residents might sometimes deem a given project proposal inappropriate or unacceptable, but that would help create a dialogue between developers, planners, local communities, and scientists and thereby lead to opportunities for improving future developments of AWE.

That being said, it would be beneficial to the industry if public engagement does not only occur during the planning stage but also during the development of the technology, the implementation, and throughout the entire operation of AWE plants and include more members of the public than only residents of hosting communities. This type of public engagement is also referred to as co-production. It offers multiple benefits over legislated, invited public participation at the deployment stage only [129], for an overview of co-production in the wind energy sector. First, early participation allows the democratization of decisions about the design, implementation, and use of local energy infrastructures by giving decision-making power to locals. Second, locals' knowledge can help to improve a given energy project. Third, co-production helps in taking people's concerns more seriously and finding improvements together instead of simply compensating them for experienced impacts. The fact that AWE is still in its infancy allows for the pursuit of new and effective ways of engaging the public in developing and deploying the technology.

In conclusion, how AWE's characteristics influence people's responses to it will likely depend on a range of situational (e.g., policy context, characteristics of landscape) and psychological factors (e.g., the public's trust in project developers, perceived fairness of decision making). Collaborative efforts of engineers and social scientists and lessons learnt from research on other renewable energies can facilitate a more successful development and implementation of AWE in the future.

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Appendix A

Table A1. Keywords selected for the literature search in Google Scholar.

	Airborne Wind Energy Keyword Set (Individual Keywords Were Combined with Operator OR)	Social Acceptance Keyword Set (Individual Keywords Were Combined with Operator OR)
Included in Google Scholar search	"airborne wind energy", "airborne wind power", "high altitude wind energy", "high altitude wind power", "crosswind kite", "kite model", "kite wind generator", "kite wind energy", "airborne wind turbine", "flying electric generator", "kite power", "kite energy", "pumping kite", "lighter-than-air wind energy system", "kite-based wind energy", "kite wind power", "kite-powered system", (parawing AND energy), ("wind power" AND "flying kite"), (kite AND "tracking control"), (kite AND "flight control"), "kite generator", (laddermill AND kite), ("kite system" AND "power generating"), ("power kite" AND "wind energy"), ("tethered airfoil" AND "wind energy"), ("kite system" AND wind), ("kite system" and "wind energy")	"social acceptance", "societal acceptance", "environmental acceptance", "public acceptance", "acceptance by the public", "accepted by the public", "accepted by people", "social acceptability", "public acceptability", "environmental acceptability", "socially accepted", "publicly accepted", "social support", "public support", "community support", "local support", "social perception", "public perception", "public opinion", "public attitude", "public involvement", "community involvement", "public participation", "community participation", "community engagement", "social impact", "public resistance", "public opposition", "local opposition", "community concern", "societal impact", "social dimension", "NIMBY", "not in my backyard", "visual impact", "visual intrusion", "visual disturbance", "visual effect", "auditory impact", "auditory intrusion", "auditory disturbance", "auditory effect", "acoustic impact", "acoustic intrusion", "acoustic disturbance", "acoustic effect", "noise impact", "noise intrusion", "noise disturbance", "noise effect", "ecological impact"
Excluded from Google Scholar search because keywords did not yield any results in combination with keywords from the other set		"community acceptance", "local acceptance", "acceptance by the people", "acceptance by the community", "acceptance by locals", "accepted by the community", "accepted by locals", "societal acceptability", "community acceptability", "local acceptability", "acceptability by the public", "acceptability by people", "acceptability by the community", "acceptability by locals", "support by the public", "support by the community", "support by locals", "socially supported", "locally supported", "social resistance", "community resistance", "social opposition", "community opposition", "positive perception", "negative perception", "perception by people", "perception by the community", "perception by locals", "public preference", "social preference", "concerns by the community", "public engagement", "social implication"

Appendix B

Table A2. Publication details of the papers selected for the review on the social acceptance of AWE.

Author(s)	Year	Title	Publication Type	Publication Medium	Professional Background Author(s) [a]	Identification
Abbate & Saraceno	2019	What else is emerging from the horizon?	Book chapter	Lecture Notes in Energy	1 physicist, 1 engineer	Google Scholar
Ahmed, Hably & Bacha	2012	High altitude wind power systems: A survey on flexible power kites	Conference paper	In 2012 XXth International Conference on ElectricalMa-chines	3 engineers	Google Scholar
Alonso-Pardo & Sanchez-Arringa	2015	Kite model with bridle control for wind-power generation	Journal article	Journal of Aircraft	2 engineers	Google Scholar
Archer, Delle Monache, & Rife	2014	Airborne wind energy: Optimal locations and variability	Journal article	Renewable Energy	1 engineer, 2 atmospheric scientists	Manually
Bauer	2018	Multidisciplinary Optimization of Drag Power Kites	Doctoral dissertation	Technical University of Munich repository	1 engineer	Google Scholar
Bosch, Schmehl, Tiso, & Rixen	2014	Dynamic nonlinear aeroelastic model of a kite for power generation	Journal article	Journal of Guidance, Control, and Dynamics,	4 engineers	Google Scholar
Bronstein	2011	Harnessing rivers of wind: A technology and policy assessment of altitude wind power in the U.S.	Journal article	Technological Forecasting & Social Change	1 public policy major	Manually
Bruinzeel, Klop, Brenninkmeijer & Bosch	2018	Ecological impact of airborne wind energy technology: current state of knowledge and future research agenda	Book chapter	In R. Schmehl (Ed.) Airborne Wind Energy	3 ecologists, 1 innovation management major	Google Scholar
Cahoon & Harmon	2008	Airborne wind energy: Implementation and design for the U.S. air force	Conference paper	In 9th Annual International Energy Conver-sionEngineering Conference	2 engineers	Google Scholar
Cherubini	2017	Advances in airborne wind energy and wind drones	Doctoral dissertation	University Sant'Anna School of Advanced Studies repository	1 engineer	Google Scholar
Cherubini, Moretti & Fontana	2018	Dynamic modeling of floating offshore airborne wind energy converters	Book chapter	In R. Schmehl (Ed.) Airborne Wind Energy	3 engineers	Google Scholar
Cherubini, Vertechy & Fontana	2016	Simplified model of offshore airborne windenergy converters	Journal article	Renewable Energy	3 engineers	Google Scholar
Chihaia, Nicolaie, Cîrciumaru, El-Leathey, & Constantin	2019	Market Potential Of Unconventional WindTurbines. A Technology Review	Conference paper	Proceedings of 2019 International Conference onHydraulics and Pneumatics	5 engineers	Google Scholar
de Lellis	2016	Airborne wind energy with tethered wings: Modeling, analysis and control	Doctoral dissertation	Universidade Federal de Santa Catarina repository	1 engineer	Google Scholar

Table A2. *Cont.*

Author(s)	Year	Title	Publication Type	Publication Medium	Professional Background Author(s) [a]	Identification
de Lellis, Mendonça, Saraiva, Trofino, & Lezana	2016	Electric power generation in wind farms withpumping kites: An economical analysis	Journal article	Renewable Energy	5 engineers	Google Scholar
Fagiano & Milanese	2012	Airborne wind energy: An overview	Conference paper	In 2012 American Control Conference	2 engineers	Google Scholar
Fagiano, Milanese & Piga	2010	High-altitude wind power generation	Journal article	IEEE Transactions on Energy Conversion	3 engineers	Google Scholar
Girrbach, Hol, Bellusci & Diehl	2017	Towards robust sensor fusion for state estimation in airborne applications using GNSS and IMU	Journal article	IFAC-PapersOnLine	4 engineers	Google Scholar
Gulabani, Karim, Radhakrishnan, Shenoy, & Zuber	2020	Review on unconventional wind energy	Journal article	Journal of Engineering & Technological Sciences	1 engineer, 4 unknown	Google Scholar
Jehle & Schmehl	2014	Applied tracking control for kite power systems	Journal article	Journal of Guidance, Control, and Dynamics	2 engineers	Google Scholar
Kamp, Ortt & Doe	2018	Niche strategies to introduce kite-based airborne wind energy	Book chapter	In R. Schmehl (Ed.) Airborne wind energy	1 engineer, 1 economist, 1 innovation studies major	Google Scholar
Key de Souza Mendonça, Braga, & Bornia	2020	Airborne wind energy systems: Current state andchallenges to reach the market	Conference paper	International Joint Conference on Industrial Engineering and Operations Management	3 engineers	Google Scholar
Khan & Rehan	2016	Harnessing airborne wind energy: Prospects and challenges	Journal article	Journal of Control, Automation and ElectricalSystems	2 engineers	Google Scholar
Luetsch	2011	High altitude wind power plants: Dealing with the risks	Conference paper	11th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference	1 manager	Google Scholar
Lunney, Ban, Duic, & Foley	2017	A state-of-the-art review and feasibility analysis of high altitude wind power in Northern Ireland	Journal article	Renewable and Sustainable Energy Reviews	4 engineers	Google Scholar
Malz	2020	Airborne wind energy—to fly or not to fly?	Doctoral dissertation	Chalmers University of Technology repository	1 engineer	Google Scholar
Malz, Walter, Göransson, & Gros	2021	The value of airborne wind energy to theelectricity system	Journal article	Wind Energy	4 engineers	Google Scholar

Table A2. *Cont.*

Author(s)	Year	Title	Publication Type	Publication Medium	Professional Background Author(s) [a]	Identification
Paulig, Bungart & Specht	2013	Conceptual design of textile kites considering overall system performance	Book chapter	In U. Ahrens, M. Diehl & R. Schmehl (Ed.) Airborne wind energy	3 engineers	Google Scholar
Piancasatelli & Cassani	2020	Energy transfer from airborne high altitude turbines: Part III. Performance evaluation of small, mass-produced, fixed wing generators	Journal article	Journal of Engineering and Applied Sciences	2 engineers	Google Scholar
Ranneberg, Wölfle, Bormann, Rohde, Breipohl, &Bastigkeit	2018	Fast power curve and yield estimation of pumping airborne wind energy systems	Book chapter	In R. Schmehl (Ed.) Airborne wind energy	1 mathematician, 2 engineers, 1 architect/designer, 1 meteorologist, 1 unknown	Google Scholar
Roberts	2018	Quad-rotorcraft to harness high-altitude wind energy	Book chapter	In R. Schmehl (Ed.) Airborne wind energy	1 engineer	Manually
Roberts, Shepard, Caldeira, Cannon, Eccles, Grenier & Freidin	2007	Harnessing high-altitude wind power	Journal article	IEEE Transactions on Energy Conversion	6 engineers, 1 atmospheric scientist	Google Scholar
Salma & Schmehl	2020	Flight anomaly detection for airborne wind energy systems	Conference paper	Journal of Physics: Conference Series	2 engineers	Google Scholar
Salma, Friedl & Schmehl	2020	Improving reliability and safety of airbornewind energy systems	Journal article	Wind Energy	3 engineers	Google Scholar
Salma, Ruiterkamp, Kruijff, van Paassen & Schmehl	2018	Current and expected airspace regulations for airborne wind energy system	Book chapter	In R. Schmehl (Ed.) Airborne wind energy	5 engineers	Google Scholar
Sommerfeld	2020	Optimal performance of airborne wind energy systems subject to realistic wind profiles	Doctoral dissertation	University of Victoria repository	1 engineer	Google Scholar
Tulloch	2021	Modelling and analysis of rotary airborne wind energy systems - a tensile rotary power transmission design	Doctoral dissertation	University of Strathclyde Glasgow	1 engineer	Google Scholar
Watson et al.	2019	Future emerging technologies in the wind power sector: A European perspective	Journal article	Renewable and Sustainable Energy Reviews	5 engineers	Google Scholar
Yan, Yee, & Huang	2017	Preliminary research on modelling and control oftwo line kites for power generation	Conference paper	2017 4th Asia-Pacific World Congress on ComputerScience and Engineering (APWC on CSE)	3 engineers	Google Scholar
Ye, Chaer, Lawner, & Ross	2020	Viability of airborne wind energy in the United Kingdom	Journal article	Journal of Thermal Science and Engineering Applications	4 engineers	Google Scholar

Table A2. *Cont.*

Author(s)	Year	Title	Publication Type	Publication Medium	Professional Background Author(s) [a]	Identification
Total	2007–2021	-	18 journal articles; 8 conference papers; 8 book chapters; 6 doctoral dissertations	-	Engineering: 96, atmospheric science: 3, ecology: 3, physics: 1, innovation studies: 2, mathematics: 1, design/architecture: 1, public policy management: 1, economy: 1, management: 1, unknown: 4	Google Scholar: 37, manually: 3

[a] The professional background of the authors of each paper was included in the count, so some authors that contributed to more than one paper were included multiple times. The Watson et al. paper discussed various technologies, so only the authors who wrote the part on AWE were included here.

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