Community Acceptance of Airborne Wind Energy
Is the Sky the Limit?

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COMMUNITY ACCEPTANCE OF AIRBORNE WIND ENERGY

Is the sky the limit?

Helena Schmidt

COMMUNITY ACCEPTANCE OF AIRBORNE WIND ENERGY: IS THE SKY THE LIMIT?

Dissertation

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“In the case of climate, we are not the dinosaurs. We are the meteor. We are not only in danger – we are the danger. But we are also the solution.”

António Guterres,
Secretary-General of the United Nations

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LIST OF ABBREVIATIONS

AWE	–	Airborne wind energy
EPNL	–	Effective Perceived Noise Level
FAA	–	Federal Aviation Administration
IAM	–	Integrated Acceptance Model
ICBEN	–	International Commission on Biological Effects of Noise
PA	–	Psychoacoustic annoyance
PALILA	–	Psychoacoustic Listening Laboratory
SQM	–	Sound quality metric

SUMMARY

Airborne wind energy (AWE) is an emerging renewable technology that generates electricity using tethered flying devices, such as kites. It harvests wind energy at higher altitudes than conventional wind turbines. As the technology nears commercialization, its successful deployment will depend not only on technical and economic feasibility but also on social acceptance. Understanding how communities perceive and are affected by AWE can help ensure smoother deployment, protect community well-being, and enhance contribution to renewable energy goals.

This dissertation is among the first research to systematically investigate the social dimensions of AWE, focusing on community acceptance – residents' approval of local energy projects – and its influencing factors. The research is based on surveys conducted with residents near AWE test sites in Europe and a laboratory listening experiment to assess reactions to AWE-related sound emissions. The findings demonstrate that community acceptance of AWE projects relates to a combination of technical characteristics, subjective perceptions, and the fairness and transparency of project implementation. In line with the applied Integrated Acceptance Model (IAM), stronger perceived impacts – such as sound emissions, landscape impacts, and aviation lights – were associated with lower levels of acceptance. At the same time, fair and transparent project implementation was linked to higher acceptance. Noise annoyance emerged as a critical factor, shaped by both psychoacoustic properties (i.e., sharpness, tonality, and loudness) and individual characteristics (i.e., noise sensitivity, familiarity with AWE, and age).

While most of the results align with research on wind turbine acceptance, some key differences emerge. Unlike for wind turbines, the remaining three IAM factors – perceived local economic benefits, expected community support for the project, and general attitudes toward the energy transition – did not significantly predict acceptance in the case of AWE. This may be due to the fact that the technology is still undergoing development and is not yet commercially available or contributing to renewable energy targets. As a result, economic and social considerations that are typically relevant for commercial energy projects may not yet be salient for communities living near AWE test sites.

The findings highlight the need to incorporate social science insights into AWE development from the outset. By investing in interdisciplinary research, developing targeted mitigation strategies, engaging with local communities meaningfully, and establishing robust regulatory frameworks, the AWE sector can avoid common pitfalls faced by established renewable energy technologies.

The early stage of AWE presents an opportunity to learn from these experiences and take proactive steps to ensure that the technology is developed and deployed in a way that is both technically and socially viable. By anticipating and addressing potential social challenges early on, the sector can help ensure that AWE gains public trust and contributes to a just energy transition.

SAMENVATTING

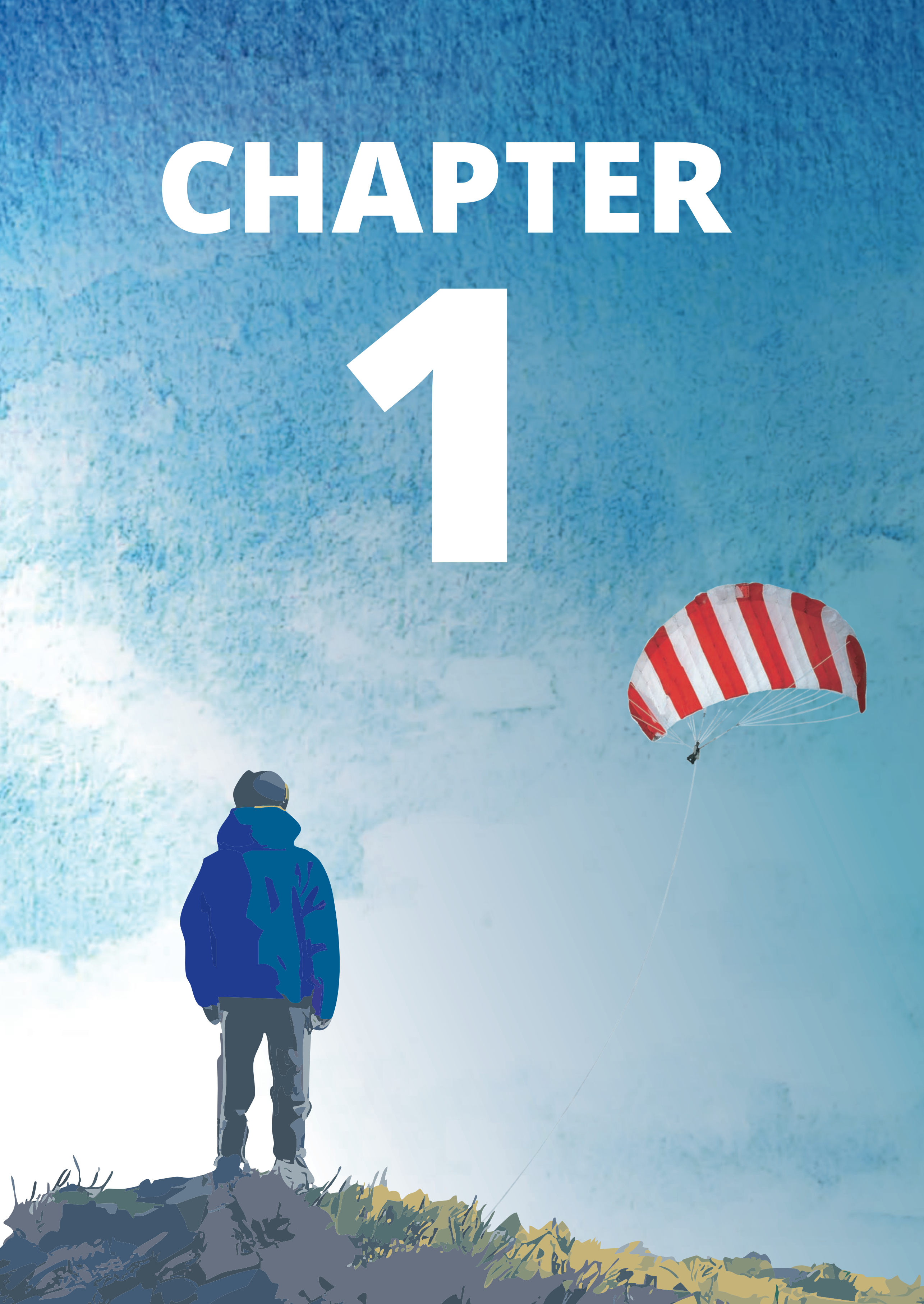
Airborne wind energy (AWE) is een innovatieve duurzame technologie die elektriciteit opwekt door middel van met touw verankerde vliegersystemen. Vergeleken met conventionele windturbines opereren AWE-systemen op grotere hoogte. Nu de commercialisering van deze technologie nadert, zal het succes ervan niet alleen afhangen van de technische en economische haalbaarheid, maar ook van de sociale acceptatie. Inzicht in hoe gemeenschappen AWE ervaren en daardoor beïnvloed worden, kan bijdragen aan een soepelere introductie van AWE, bescherming van het welzijn van omwonenden en versterking van de bijdrage aan duurzame energiedoelen.

Dit proefschrift is één van de eerste onderzoeken waarin de sociale dimensies van AWE systematisch worden onderzocht, met de nadruk op de goedkeuring van lokale energieprojecten door bewoners – oftewel community acceptance – en de factoren die hierop van invloed zijn. Het onderzoek is gebaseerd op enquêtes onder omwonenden van AWE-testlocaties in Europa en een luisterexperiment in het laboratorium om de reacties op AWE-gerelateerde geluidsemissies te analyseren. De resultaten laten zien dat de community acceptance van AWE-projecten samenhangt met een combinatie van technische kenmerken, subjectieve percepties en de eerlijkheid en transparantie van de projectuitvoering. In overeenstemming met het toegepaste Integrated Acceptance Model (IAM) gingen sterker waargenomen effecten – zoals geluidsemissies, landschapsimpact en luchtvaartlichting – gepaard met lagere acceptatie. Tegelijkertijd hing een eerlijke en transparante projectuitvoering samen met hogere acceptatie. Geluidshinder bleek daarbij een cruciale factor, die bepaald werd door zowel psychoakoestische eigenschappen (zoals scherpte, tonaliteit en luidheid) als individuele kenmerken (zoals geluidsgevoeligheid, bekendheid met AWE en leeftijd).

Hoewel de meeste resultaten overeenkomen met onderzoek naar de acceptatie van windturbines, komen er enkele belangrijke verschillen naar voren. In tegenstelling tot windturbines voorspelden de overige drie IAM-factoren – waargenomen lokale economische voordelen, verwachte steun van de gemeenschap voor het project en algemene houding ten opzichte van de energietransitie – de acceptatie in het geval van AWE niet significant. Mogelijk komt dit doordat de technologie zich nog in de ontwikkelingsfase bevindt, nog niet commercieel beschikbaar is en nog niet direct bijdraagt aan duurzame energiedoelen. Hierdoor spelen economische en sociale overwegingen – normaal gesproken relevant bij commerciële energieprojecten – wellicht nog geen grote rol voor omwonenden van AWE-testlocaties.

De bevindingen benadrukken de noodzaak om sociaalwetenschappelijke inzichten vanaf het begin te integreren in de ontwikkeling van AWE. Door te investeren in interdisciplinair onderzoek, gerichte mitigatiestrategieën te ontwikkelen, op een zinvolle manier samen te werken met lokale gemeenschappen en robuuste regelgeving op te zetten, kan de AWE-sector veelvoorkomende valkuilen vermijden die gevestigde hernieuwbare energietechnologieën hebben ervaren. Het vroege stadium van AWE biedt een kans om van deze ervaringen te leren en proactieve stappen te zetten zodat de technologie zowel technisch als maatschappelijk haalbaar wordt ontwikkeld en geïmplementeerd. Door sociale uitdagingen tijdig aan te pakken, kan de sector ervoor zorgen dat AWE het vertrouwen van het publiek wint en bijdraagt aan een rechtvaardige energietransitie.

CHAPTER 1



INTRODUCTION

Humanity is facing an unprecedented challenge: the climate crisis. The combustion of fossil fuels and other human activities that release greenhouse gases have led to a 1.1–1.3°C increase in global surface temperature since pre-industrial times (IPCC, 2023; WMO, 2025). The last ten years were the warmest on record, and climate data suggests that the following years will be even hotter (WMO, 2024, 2025). The rise in global temperatures has caused rapid and extensive changes in the Earth's atmosphere, oceans, biosphere, and cryosphere – containing the frozen parts of the planet (IPCC, 2023). Due to these changes, biodiversity is decreasing, and severe weather and climate extremes are becoming more frequent across the globe, leading to increased poverty, displacement, diseases, deaths, and food and water insecurity (ibid).

1.1 THE NEED FOR A RENEWABLE ENERGY TRANSITION

In 2024, the UN's annual emissions gap report concluded that member states' current emissions pledges would put the world on track to warm by nearly 3 degrees over the course of the century (United Nations Environment Programme, 2024). The report is an unequivocal call to action: Countries need to step up their emission reduction efforts to align with the Paris Agreement on limiting the temperature increase to well below 2°C and, ideally, 1.5°C (UNFCCC, 2016). Meeting the Paris climate goals requires society to reach net zero emissions by the early 2050s (IPCC, 2023). Achieving net zero means balancing any human-caused greenhouse gas emissions with their removal from the atmosphere to ensure no net increase in emissions, such as through afforestation, soil-based carbon sequestration, direct air capture, and ocean-based carbon dioxide removal (Low et al., 2022).

To align with the net zero trajectory, global emissions must first be significantly and swiftly reduced, necessitating a shift from fossil fuels to renewable energy sources (IPCC, 2023). According to the International Energy Agency, global renewables capacity has to triple by 2030 to keep the 1.5°C goal achievable (IEA, 2023). Wind energy is next to solar energy one of the cheapest sources of low-carbon electricity in many markets, is widely available, can be scaled up quickly, and has policy support in over 140 countries (ibid). To meet the net zero targets, 320 Gigawatts of wind capacity would have to be added by 2030, with offshore wind accounting for around a third (ibid).

1.2 THE SOCIO-TECHNICAL NATURE OF THE ENERGY TRANSITION

However, it is not only the technical, economic, and political feasibility that influences the deployment of renewable energy. The adoption of renewables hinges on wider social factors, making the energy transition a socio-technical transition (Geels et al., 2017; Kirkegaard et al., 2023). Wind turbines, for example, are a decentralized energy source, and they are increasingly encroaching upon people's direct living environments (e.g., see Department for Energy Security and Net Zero, n.d.; Hoen et al., 2024). Due to the proximity to dwellings in many areas, people can be directly affected by wind energy infrastructure. For example, through sound emissions, landscape impacts, shadow flicker, obstruction lights, and less tangible project impacts like the disruption of place attachment and feelings of injustice (Aaen et al., 2022; Devine-Wright & Howes, 2010; Devine-Wright & Peacock, 2024; Elmallah & Rand, 2022; Firestone et al., 2018; Gölz & Wedderhoff, 2018; Hoen et al., 2019; Hübner et al., 2019; Mueller & Brooks, 2020; Pohl et al., 2018; C. Walker & Baxter, 2017). Public discontentment with existing wind projects and worries about proposed developments can lead to low social acceptance and opposition, hindering the expansion of renewables and thereby jeopardizing the energy transition at large (Iuga et al., 2016; Susskind et al., 2022; Temper et al., 2020). Opposition against wind projects commonly manifests as physical protests, official complaints, lawsuits, and legislative efforts to introduce laws, policies, or regulations to block projects (Iuga et al., 2016; Stokes et al., 2023; Töller et al., 2024). Conversely, local communities can perceive wind energy projects positively, and they can be of added value for a region (Fast & Mabee, 2015; Mang-Benza & Baxter, 2021; Warren & McFadyen, 2010). Positive experiences usually occur when project impacts are effectively avoided, mitigated, or compensated and when the planning process and the responsible parties are fair and transparent, and the local community benefits from the project (Dwyer & Bidwell, 2019; Hoen et al., 2019; Hogan et al., 2022; Hübner et al., 2023).

1.3 PERSISTING SOCIAL CHALLENGES IN WIND ENERGY DEPLOYMENT

While there are more than three decades of social science research into wind energy development that offer clear recommendations for deploying projects (for reviews, see Ellis & Ferraro, 2016; Hübner et al., 2023; Rand & Hoen, 2017), the widespread integration of social insights into practice and technical wind energy research is still lacking (Kirkegaard et al., 2023). Some of the most pertinent social issues of wind energy development that partially persist to this day include:

- Not taking resident complaints seriously (Landeta-Manzano et al., 2018) or explaining them away with inadequate and pejorative NIMBY (i.e., not-in-my-backyard) arguments that blame residents as being selfish or uninformed rather than holding responsible parties accountable for negative project impacts (Burningham et al., 2015; Devine-Wright, 2011; Wolsink, 2007a);
- Seeking purely technological or regulatory fixes for inherently socio-technical problems like introducing universal sound limits to deal with noise annoyance but not further tackling the root problem (Kirkegaard et al., 2024; Rudolph et al., 2019; Taylor & Klenk, 2019). Noise annoyance could be holistically dealt with by addressing residents' frustrations with the project or proposed solutions and tailoring a wind farm's design and operation to the local geographical, meteorological, and social conditions (Müller et al., 2023; Solman et al., 2023);
- Not involving residents and other relevant societal stakeholders sufficiently in the decision-making process or limiting participation to objecting but not allowing them to help shape renewable energy development positively (Clausen et al., 2021; Elmallah & Rand, 2022; Jami & Walsh, 2017). Excluding key stakeholders from the planning process can lead to feelings of unfairness and aggravation, referred to as procedural injustice (Elmallah & Rand, 2022; Mills et al., 2019; Walker & Baxter, 2017);
- Distributing costs and benefits of wind projects unfairly by not sharing monetary or in-kind profits with local stakeholders or only giving them to certain groups, such as landowners, leading to a lack of distributive justice (Baxter et al., 2013; Brannstrom et al., 2022; Leer Jørgensen et al., 2020).

1.4 AIRBORNE WIND ENERGY: A COMPLEMENT TO WIND TURBINES

Insights into the social dynamics of wind energy deployment can inform emerging renewable technologies like airborne wind energy (AWE). AWE is intended to complement wind turbines by tapping into wind resources above 200-meter altitude with tethered flying devices known as kites (Vermillion et al., 2021). Winds generally get stronger and more consistent with increasing altitude (Stull, 1988). The hub height of wind turbines and, thereby, the energy-generation capacity has consistently grown over the years (Enevoldsen & Xydis, 2019). Nevertheless, turbine size will not expand endlessly due to constraints of design and materials, logistics, transportation, residents' acceptance, and permitting regulations (Beiter et al., 2022). With AWE, an abundant, currently unexploited renewable energy potential can be accessed that helps toward decarbonization (Archer et al., 2014; Bechtle et al., 2019). AWE might offer additional benefits over wind turbines, particularly a lower carbon footprint due to material savings, adjustment of the operating altitude to fluctuating wind conditions, and easier transportation, installation, and decommissioning (Bechtle et al., 2019; BVG Associates, 2022; van Hagen et al., 2023; Wilhelm, 2018). AWE systems could be deployed in various settings, especially for mobile applications (e.g., festivals or construction sites), hurricane-prone areas – where the systems can be securely stored to prevent damage – and remote locations like islands, isolated communities, or mines (Cherubini et al., 2015; Kitepower, n.d.-b; Luchsinger et al., 2018). In the future, AWE systems could also be used to repower old offshore wind turbine platforms or to install floating systems in deep waters (Cherubini et al., 2016; IRENA, 2021). In some of these scenarios, AWE systems offer the potential to replace diesel generators, providing a more cost-effective and renewable energy source. However, AWE technology presents greater technical challenges than wind turbines. The sector still has to completely resolve key issues, such as the long-term durability of components, reliable performance in extreme weather, safe emergency landings, and fully automated operation, which covers take-off, normal operation, and landing (Directorate-General for Research and Innovation & ECORYS, 2018; Salma & Schmehl, 2020; Weber et al., 2021).

1.5 WORKING PRINCIPLES OF AIRBORNE WIND ENERGY

A multitude of AWE concepts exist that can be broadly divided into two working principles, as shown in **Figure 1.1**: ground-generation and fly-generation (Cherubini et al., 2015; Fagiano et al., 2022). Ground-gen systems convert a kite's lift forces into electricity by automatically flying the kite at increasing altitudes along a predetermined path, specifically figure-of-eights or loops. The ascending kite pulls the tether from a drum, which sets the drum in motion and powers the connected generator. Once the kite reaches the end of the tether, it is automatically depowered by altering its angle to the wind to decrease its pull, and it is reeled back in. The next reel-out follows the reel-in. These alternating traction and retraction phases are referred to as pumping cycles. The system generates more energy during the reel-out phases than it consumes during the reel-in, resulting in a net positive power output (Vermillion et al., 2021). A variant of ground-gen systems uses multiple rotors connected by tethers kept aloft by a lifter kite (Tulloch, 2021). The entire structure rotates, and a ground-based generator converts the torque into electricity. Kites used for ground-gen systems are typically either soft-wing kites made from flexible membranes or fixed-wing kites constructed from carbon fiber-reinforced polymers (Fagiano et al., 2022; Vermillion et al., 2021). Soft-wing kites resemble kites used for paragliding or kite surfing while fixed-wing kites resemble conventional aircraft or drones. Hybrid-wing kites, which combine a rigid support structure with a fabric canopy, are also used in some cases. In contrast to the cyclic pumping motion of ground-gen systems, fly-gen systems produce electricity directly in the air using small onboard ram-air turbines attached to the kite (Aull et al., 2020). A conducting tether transmits the generated power to the ground. Fly-gen systems rely exclusively on fixed-wing kites, as installing a ram-air turbine on a soft-wing kite poses significant challenges (Fagiano et al., 2022).

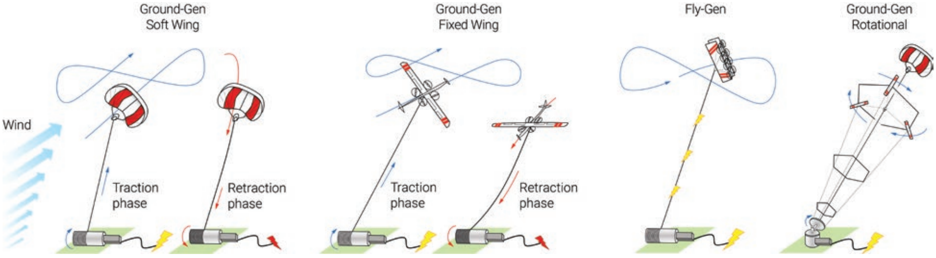


Figure 1.1. Operating principles of different airborne wind energy systems.
Source: Adapted from Fagiano et al. (2022).

1.6 INCORPORATING SOCIAL SCIENCE INTO AIRBORNE WIND ENERGY DEVELOPMENT

Recent advances in the sector, like the first externally validated power curve (SkySails Power, 2024) and the first semi-commercial AWE site (SkySails Power, 2023a), suggest that the technology is approaching the commercialization phase (BVG Associates, 2022). The inclusion of AWE in the German Renewable Energy Sources Act (i.e., EEG), which is often seen as a landmark for energy legislation in Europe, shows that there is also the political will to support technology commercialization (Airborne Wind Europe, 2024b). Multiple assessments propose a large potential for deploying AWE on- and offshore in Europe and beyond (BVG Associates, 2022; Coca-Tagarro, 2023; Vos et al., 2024), with the International Renewable Energy Agency calling the technology a potential "game changer" for offshore wind (p. 35; IRENA, 2021). Early and rigorous social science research into AWE can help the sector avoid falling into some of the same pitfalls as the wind turbine industry. Such research would allow the incorporation of 'soft' factors into the development and deployment of AWE from the start and facilitate design changes when the technology is still more malleable than later in the design process (Trueworthy et al., 2024). The historical development of wind turbines demonstrates that pioneering studies into nature impacts and residents' annoyance with sound emissions, shadow flicker, and obstruction lights can help develop effective mitigation methods and regulations (Bulling et al., 2015; Pohl et al., 1999, 2012, 2018). As a result, the burden on people and nature decreases, positively influencing technology acceptance.

1.7 RESEARCH OBJECTIVE AND APPROACH

This dissertation aims to uncover which findings and insights from existing wind energy acceptance research apply to AWE and what is different and deserves special attention. As decentralized energy infrastructures most directly affect residents, the empirical part of the work focuses on the local level by investigating which factors relate to the community acceptance of AWE. In line with Wüstenhagen et al., “community acceptance refers to the specific acceptance of siting decisions and renewable energy projects by local stakeholders, particularly residents and local authorities” (Wüstenhagen et al., 2007, p. 2685). It is one of three dimensions of the social acceptance of renewable energy innovations, in addition to socio-political and market acceptance. Chapter 2: elaborates on how (community) acceptance can be operationalized and measured and what is already known about the acceptance of other renewable energy technologies. Chapter 3: assesses the status quo of acceptance research for AWE through a literature review. Chapter 4: presents the results from structured field interviews with residents about how they perceive a local AWE system, and which factors relate to their acceptance thereof. Chapter 5: tests with a regression model which of the previously identified factors most strongly predict the community acceptance of AWE by pooling data from two resident surveys. Chapter 6: zooms in on one of the major factors by assessing what explains noise annoyance for AWE systems through a laboratory listening experiment. Finally, Chapter 7: draws conclusions from previous chapters, offers future research directions, and discusses the findings’ implications for practice and policy. Taken together, this work’s originality is threefold: a new synthesis of AWE research through a social scientific lens (Chapter 3), unprecedented empirical research (Chapters 4, 5, and 6), and a cross-disciplinary perspective on AWE by combining insight, theories, and methods from engineering, acoustics, and energy social science (all chapters).

CHAPTER 2

THEORETICAL BACKGROUND

The previous chapter established the critical role of comprehensive social scientific research on airborne wind energy (AWE) in supporting its responsible and effective deployment. This chapter outlines key concepts and theories essential to such research. Section 2.1 addresses how the acceptance construct, a crucial element for understanding societal responses to emerging technologies, can be defined and conceptualized. Section 2.2 explores how acceptance can be measured. Section 2.3 elaborates on the Integrated Acceptance Model (IAM) as this research's primary framework.

2.1 DECONSTRUCTING ACCEPTANCE: THEORETICAL INSIGHTS AND CRITIQUES

The beginning of social science research on technology acceptance can be traced back to the mid-70s (Petermann & Scherz, 2005), while acceptance research specific to wind energy emerged in the late 80s to early 90s (Ellis & Ferraro, 2016; Wolsink, 2018). Most energy social science research builds on sociology and political sciences (e.g., policy and institutions), human geography (e.g., space-related conflict and land use), economics (e.g., choice models and behavioral economics), and psychology (e.g., risk perception, values, norms, behavior, place identity, and attachment; Ellis & Ferraro, 2016; Gaede & Rowlands, 2018; Rand & Hoen, 2017). This cross-, multi-, and interdisciplinary approach has resulted in a diverse and somewhat fragmented body of research, differing widely in conceptual frameworks and methodologies (Ellis & Ferraro, 2016).

Research on energy technology acceptance typically aims to achieve two main objectives (Schäfer & Keppler, 2013): The first is to enhance our understanding of acceptance phenomena by examining the factors and mechanisms that foster or impede acceptance. The second goal is to use these insights to guide the introduction and implementation of technology and the development of technical innovations in ways that maximize acceptance and reduce negative impacts. Batel (2020) adds a third objective of critically assessing and challenging how power relations, such as the role of incumbents in the energy market, shape renewable technologies, their deployment, and people's responses to them. Technology acceptance research has a long history, and the present chapter will not be able to do full justice to it. Instead, it will present an overview of the most important notions of the acceptance concept relevant to this research.

The term acceptance has been widely used in energy research, but there is much conceptual ambiguity around it because it is applied and interpreted differently depending on the discipline and research context (Batel et al., 2013; Busse & Siebert, 2018; Ellis & Ferraro, 2016; Wolsink, 2019). Common differences concern the level (e.g., individual vs. societal), scale (e.g., local energy project vs. energy technology), considered actors (e.g., residents, consumers, investors, or regulatory bodies), and investigated responses (e.g., only positive vs. negative to positive). While arriving at a general and integrative definition of acceptance is difficult, it is important for research to delineate how it understands and uses the concept to facilitate comprehension, comparison, and practical meaning (Busse & Siebert, 2018; Wolsink, 2019).

2.1.1 Three dimensions of social acceptance: Socio-political, community, and market

The most influential and widely applied acceptance framework is inarguably from Wüstenhagen, Wolsink, and Bürer (2007) who coined social acceptance in their seminal paper (Busse & Siebert, 2018). According to their framework, social acceptance refers to a complex and dynamic process that involves all relevant actors and their positions across three interrelated dimensions: socio-political, community, and market. Socio-political acceptance refers to the acceptance of a given technology and related policies by the general public, policymakers, and other key stakeholders. Community acceptance describes the degree to which particular siting decisions and energy projects are accepted, especially by residents and local authorities. Market acceptance concerns the market adoption of energy innovation, including investors' readiness to finance it and users' willingness to adopt it.

Some have criticized the framework as reinforcing the separation between different levels and actors involved in renewable energy issues (Batel, 2018). Wüstenhagen et al., however, have always intended the framework as a conceptual tool for conducting research, and they acknowledge the interactions between the different levels (Wolsink, 2018). An example of such an interaction is that challenges related to community acceptance, like a rise in local protests, could potentially undermine broader socio-political approval, leading to policy changes that may heighten financial risks, impact investment decisions, and consequently weaken market acceptance (Ellis & Ferraro, 2016). Conversely, supportive policies like subsidy schemes that offer opportunities for new investors or spatial planning frameworks that encourage collaborative decision-making could increase market and community acceptance, respectively (Wüstenhagen et al., 2007).

Another common criticism is that the framework would disregard alternative responses to renewable energy implementation, for instance, support, uncertainty, resistance, inaction, or apathy (e.g., Batel et al., 2013). According to Wüstenhagen et al., the framework has always considered responses other than favorable ones, and the criticism should be seen more as reflecting current research practices: "Right from the start, 'acceptance' was meant to cover all dynamic positions and actions - taking initiatives, early adoption, support, resistance, opposition, apathy, tolerance, uncertainty, indifference - that are relevant for the degree of renewables' innovation [...]" (Wolsink, 2018, p. 291). Although the term social acceptance has faced criticism for potentially oversimplifying a complex social process, it is widely recognizable, especially in the context of wind energy research (Ellis & Ferraro, 2016). It is a useful conceptual tool with no adequate replacement at present, and it will, therefore, be used in this research.

2.1.2 Three key acceptance factors: Subject, object, and context

While not explicitly mentioned in the original publication, Wüstenhagen et al.'s framework builds on the assumption that three key factors characterize acceptance: subject, object, and context (Lucke, 1995; Wolsink, 2013). Specifically, someone (the acceptance subject) accepts or does not accept something (the acceptance object) within a given context (e.g., cultural, social, and political). Subjects can be individuals, groups, or the whole society. Examples include regulators, legislative authorities, policymakers, and the public at the socio-political level; producers, distributors, grid managers, financial actors, and consumers at the market level; and end users, residents, and local authorities at the community level (Wolsink, 2018). The acceptance of some subjects can be temporarily more relevant than others, depending on the technology readiness level (e.g., researchers and innovators early on and the general public later on; Schäfer & Keppler, 2013). Furthermore, subjects can take on different roles that might change over time (Kluskens et al., 2024). For instance, a previously uninvolved resident could join a citizen initiative against wind energy.

The acceptance object does not necessarily refer to a tangible object but may include innovation, infrastructure, policies, and projects. Subjects might focus more intensely on one rather than another aspect of the object, such as the permitting process, the distribution of benefits, or the spatial properties of an energy project (ibid.). Because acceptance can refer to different objects, residents can accept renewables in general while opposing a specific energy project at the local level. This phenomenon has been called the national-local or social gap (Batel & Devine-Wright, 2015; Bell et al., 2005). In media, public discourse, and early research, local opposition to new developments or technologies has often been attributed to the concept of NIMBYism – standing for Not in my backyard – which suggests that people may support a project in principle but oppose it if it is too close to home (Devine-Wright, 2009; Petrova, 2013; Wolsink, 2000). However, research has shown that NIMBYism cannot adequately explain local opposition. Studies find no strong, consistent evidence that residents closer to a project are more opposed than those farther away (for reviews, see Hübner & Pohl, 2014; Rand & Hoen, 2017). Moreover, labeling opposition as NIMBYism obscures the actual reasons for concern, often implying selfishness or ignorance as the root cause (Burningham et al., 2015; Devine-Wright, 2009; Petrova, 2013; Wolsink, 2000). This label can also delegitimize opponents' arguments, potentially heightening conflict rather than fostering constructive dialogue (Burningham et al., 2015).

Finally, the context can contain any factor or condition other than the acceptance subject or object that influences acceptance formation (Schäfer & Keppler, 2013). Examples are the social or organizational environment, cultural or economic factors, policy landscape, and deployment practices, including communication, participation, and decision-making opportunities (de Vries, 2017; Wolsink, 2013).

2.1.3 The dynamics of acceptance

The interaction between the acceptance subject, object, and context is dynamic, with each influencing the others. For instance, the same properties of an acceptance object (e.g., risks, benefits, and costs) can be perceived differently depending on the subject and context. This interplay shapes how acceptance evolves and what outcomes emerge from the process. Early research has suggested that community acceptance follows a U-shaped curve, with high acceptance of renewable energy projects before a local project is proposed, acceptance levels dipping during the planning process when residents are faced with the potentially polarizing realities of a concrete project, and acceptance recovering again after construction (Devine-Wright, 2005; Pasqualetti, 2002; Wolsink, 2007b). More recent research, however, emphasizes that the development of community acceptance over time is more nuanced and varies depending on other project-related factors, particularly community benefits and procedural justice (Bingaman et al., 2023; Mills et al., 2019; Windemer, 2023). Rudolph and Clausen even caution that "adaptation or familiarization should not be confused with (greater or regained) acceptance" (p. 65), as it could merely indicate residents' apathy or resignation and residents' need to get used to the project "may point to inadequacies of the planning procedures to deal with certain issues" (p. 71) (Rudolph & Clausen, 2021). A thorough analysis of acceptance can thus only be achieved by considering the subject, object, and context together.

2.2 MEASURING ACCEPTANCE: CONCEPTS, CHALLENGES, AND APPROACHES

As acceptance is understood differently across disciplines and studies, it tends to be measured differently (Haggett, 2021). The absence of a standardized approach to measuring acceptance and the frequent misalignment between the chosen metrics and the underlying concepts can hinder progress in understanding the social aspects of renewable energies (Batel et al., 2013). Studies may, in fact, assess different constructs instead of the same (ibid.). It is, therefore, important to carefully determine how acceptance should be measured.

2.2.1 Attitudinal and behavioral dimensions of acceptance

At the level of the individual, attitudinal and behavioral dimensions of acceptance can generally be distinguished (Schäfer & Keppler, 2013). Attitudinal aspects are included in most definitions of acceptance and can consist of an intention to act but not the action itself (ibid.). On the other hand, behavioral definitions of acceptance contain (the possibility of) observable behavior, usually together with a corresponding attitude (ibid.). Examples of behaviors include buying and/or using a technological innovation (e.g., solar panels) and advocating for or against an energy technology or a concrete project. Although useful, the distinction between behavioral and attitudinal acceptance measures is not always clear-cut. For example, while for Lucke (1995), acceptance is only given when attitudes and behaviors align, for Huijts et al. (2012) and Schweizer-Ries et al. (2010) acceptance can be indicated by a positive attitude alone or in combination with supportive behavior.

Additionally, Hagget (2021) noted that attitude and behavior concepts are defined and applied very differently in energy research across disciplines like sociology, psychology, geography, and economics: “There is some agreement that attitudes include an evaluative element and an element of learning; but—there are very significant differences within and between disciplines. There are differences about the emergence, existence, and strength of the relationship between attitudes and behaviors; the role of social context and wider influences; the stability of attitudes; and whether global or specific attitudes are most important (or if these are even meaningful concepts). Importantly, there is also considerable disagreement about if and how to measure attitudes” (Haggett, 2021, p. 129). Global attitudes refer to renewable energy technology in general, whereas specific attitudes concern a particular implementation of renewable energy (e.g., a local wind project).

2.2.2 Acceptance vs. acceptability: Definitional and disciplinary perspectives

Next to attitudinal and behavioral dimensions, Schäfer & Keppler (2013) also describe a normative acceptance dimension. This normative aspect can be part of the attitudinal dimension because personal and social norms influence attitude formation (e.g., Stern, 2000), but some authors understand it as a separate dimension (e.g., Kollmann, 1998). The term acceptability is sometimes used when considering normative aspects of technology. It was specifically coined during discussions about the social acceptability of technology that emerged in the 1990s (Schäfer & Keppler, 2013). These discussions primarily focus(ed) on the risks of controversial technologies, such as nuclear energy, genetic engineering, waste management, nanotechnology, and carbon capture and storage (L'Orange Seigo et al., 2014; Renn & Benighaus, 2013). Some authors argue that acceptability involves expert or moral evaluations regarding whether a specific facility, like a power plant or nuclear waste repository, presents a justifiable impact based on pre-defined criteria, while acceptance reflects the subjective willingness of individuals to have such a facility near them (Bertsch et al., 2016; Taebi, 2016).

Moesker et al. (2024) observed that the terms acceptance and acceptability tend to be used differently across disciplines: In social science studies, acceptance usually refers to the outcome of technology implementation or a positive response facilitating technology use, while acceptability refers to the process or attitude toward a given technology. In ethics of technology studies, acceptance (i.e., descriptive) is typically a measurable proxy for support, tolerance, or apathy, whereas acceptability (i.e., normative) is a moral judgment guiding technology implementation. In innovation studies, acceptance commonly applies to the actual use or adoption of a new technology, and acceptability refers to the willingness or intention to use it. In many cases, however, acceptance and acceptability are used interchangeably (for reviews, see Busse & Siebert, 2018; Moesker et al., 2024; Schäfer & Keppler, 2013).

2.2.3 Conceptualizing and measuring community acceptance in this research

Due to the emphasis on community responses to local energy projects and to avoid conceptual ambiguity, this research uses the term acceptance only in line with Wüstenhagen et al.'s definition (2007). Although acceptance operates at different levels according to that definition, the focus is on community acceptance, as residents are most directly affected by AWE deployment. Their experience with pilot projects can help to identify crucial points that need addressing in the technology development and deployment. Despite its emphasis on communities, this dissertation acknowledges that community acceptance is interconnected with the actors and positions in the socio-political and market dimensions.

This research adopts an attitudinal measure to assess community acceptance for four key reasons: First, acceptance is not always expressed as behavior. Opponents of local renewable energy projects are, in fact, more likely to act than supporters or neutrals (Firestone et al., 2018; Hübner et al., 2020; Liu et al., 2022; Sokoloski et al., 2018). Thus, if only measuring behavior, the research would probably underestimate acceptance of a given project. Second, for AWE, few operational projects exist, and none have an extensive public engagement process, providing limited opportunities for residents to find out about the project and act on it in time (BVG Associates, 2022). Third, the influential and widely validated Theory of Planned Behaviour shows that attitudes are a strong predictor of behavior as long as they are measured regarding the same entity, such as renewables in general or a local energy project (Ajzen, 1991; Ajzen & Fishbein, 2005; Armitage & Conner, 2001; Klöckner, 2013). Fourth, prominent studies on wind energy acceptance have established the use of attitudinal measures over the years (Hoen et al., 2019; Hübner et al., 2023). In this research, attitudes are understood in the psychological sense as "a relatively enduring and general evaluation of an object, person, group, issue, or concept on a dimension ranging from negative to positive. Attitudes provide summary evaluations of target objects and are often assumed to be derived from specific beliefs, emotions, and past behaviors associated with those objects" (American Psychology Association, n.d.). Neutral to positive attitudes toward a local project thus indicate acceptance, while negative attitudes reflect opposition or a lack of acceptance (Hübner et al., 2023).

2.3 CONCEPTUAL FRAMEWORKS AND MODELS IN ENERGY SOCIAL SCIENCE

Wüstenhagen et al.'s framework provides a valuable lens for examining complex socio-technical relationships related to energy innovations (Ellis et al., 2023). It is, however, more a framework for organizing research problems than a comprehensive acceptance model, as it does not explain or predict the factors that lead individuals or groups to accept or reject specific innovations (Busse & Siebert, 2018). A conceptual model or framework is thus needed to identify which factors affect the community acceptance of AWE projects most strongly.

2.3.1 The model guiding this research: The Integrated Acceptance Model

Over time, various authors have developed models and frameworks to explain community acceptance, such as Devine-Wright's five-stage model of psychological response to place change, Gross' community fairness framework, Huijts et al.'s technology acceptance model, and Walker et al.'s public engagement framework (Devine-Wright, 2009; Gross, 2007; Huijts et al., 2012; Walker et al., 2010). While each has its merits, this research adopts the Integrated Acceptance Model (IAM) as its guiding framework (Hübner et al., 2023). The IAM aligns best with the research objective because it captures a broad range of factors that may influence AWE's community acceptance, applies to existing and proposed energy projects, and has high explanatory power while remaining parsimonious[1]. The IAM includes five overarching categories that have substantially explained residents' attitudes toward local wind energy projects in past research with an adjusted R^2 of 0.76 to 0.78 (Hübner et al., 2023). The five categories are (1) economic impacts, (2) energy transition attitudes, (3) impacts on nature and residents, (4) the planning process, and (5) social norms (see **Figure 2.1**). Specifically, the IAM predicts that local acceptance is higher when residents perceive more positive impacts of the project on the local economy, have more positive attitudes toward the energy transition, experience fewer negative project impacts on nature and residents, perceive the planning process more positively, and expect the local community to approve the project.

1 **Parsimony**, often called the principle of simplicity, is a key concept in psychology. It emphasizes the importance of adopting the simplest explanation or solution for understanding a problem or phenomenon. A parsimonious model aims to use the smallest and most straightforward set of parameters to represent the data accurately

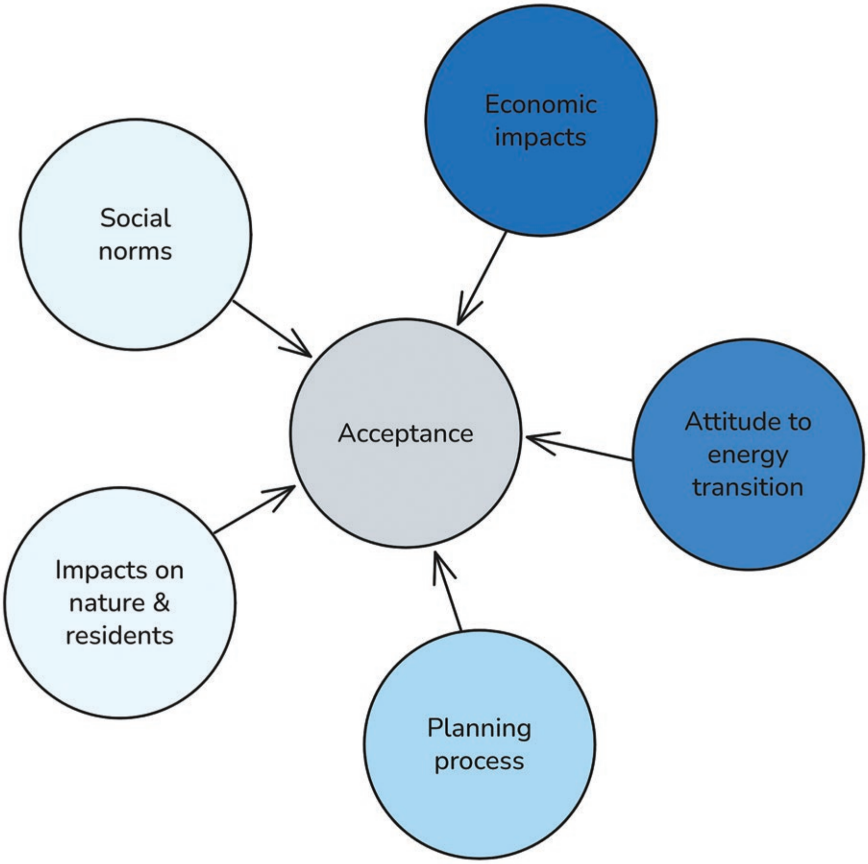


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Figure 2.1. The Integrated Acceptance Model (IAM) encompassing five key predictors of community acceptance.
Source: Adapted from Hübner et al. (2023).

The IAM's five categories are derived from the wealth of existing energy acceptance research. The following discusses the evidence base for each category in more detail to provide context for interpreting the results in the subsequent chapters. Regarding (1) **economic impacts**, abundant research shows that when project benefits are fairly distributed, residents tend to be more accepting of a local wind farm and perceive fewer negative impacts on humans and nature (Arezes et al., 2014; Baxter et al., 2013; Firestone et al., 2018, 2020; Health Canada, 2014; Hoen et al., 2019; Hogan, 2024; Leiren et al., 2020; Walker et al., 2014). Developers indeed increasingly offer monetary or in-kind benefits to host communities to overcome opposition, account for damages and adverse impacts, make the distribution of profits more equal, or comply with regulations or community expectations (Ellis & Ferraro, 2016; Olbrich & Fünfgeld, 2023; van Wijk et al., 2021). Benefits can include but are not limited to local jobs, landowner payments, community ownership and financial participation models, reduced electricity costs for residents, and measures to enhance the regional landscape and environment. However, benefits are not a panacea and are most effective when tailored to local needs, including the social, economic, and political context (Boomsma et al., 2020; Brannstrom et al., 2022; Hoen et al., 2019; Hogan, 2024; Hübner et al., 2023; Langer et al., 2017; Liebe et al., 2017; Olbrich & Fünfgeld, 2023). Conversely, if residents worry that the project impacts local tourism and property prices negatively, acceptance tends to be lower (Hoen et al., 2019; Hogan, 2024; Mills et al., 2019; Ólafsdóttir & Sæþórsdóttir, 2019).

Positive (2) **attitudes toward the energy transition** have repeatedly been linked to general acceptance of wind energy and proposed local projects (Kirchhoff et al., 2022; Sonnberger & Ruddat, 2017). This relationship is understandable, as individuals who support the energy transition are more likely to view a nearby wind farm as justified and appropriate than those who oppose the transition. Supporters of the energy transition have also been found to be more likely to invest in renewable energies, including wind energy (Breitschopf & Burghard, 2023). While energy transition attitudes have emerged as one of the strongest IAM predictors in past research (Hübner et al., 2023), they are generally less well-studied for project acceptance than the other four categories.

Perceptions of the (3) **planning process** are crucial in evaluating a proposed or existing wind energy project. Residents who judge the process as fair tend to be more accepting of the outcome and the project and view impacts on humans and the local economy less negatively and more positively (Baxter et al., 2020; Gross, 2007; Hoen et al., 2019; Hübner et al., 2019; Mills et al., 2019; Pohl et al., 2018). Procedural fairness appears to be primarily determined by whether residents can engage in the planning process, their input is taken seriously, they have an impact on the final result, they trust the developer, and the developer is open and transparent (Bleijenberg et al., 2019; Dwyer & Bidwell, 2019; Elmallah & Rand, 2022; Firestone et al., 2018; Liu et al., 2019; Postma et al., 2022; ter Mors & van Leeuwen, 2023; Walker & Baxter, 2017).

However, residents can expect different things from a 'just' process (Simcock, 2016). If they perceive that the developer only engages the local community for instrumental reasons – to secure project support – the engagement can even negatively influence residents' opinions (Goedkoop & Devine-Wright, 2016; Ryder et al., 2023; ter Mors & van Leeuwen, 2023). Engagement should, therefore, focus on relationship building, for instance, through informal efforts that exceed regulatory requirements, like appointing an unbiased community liaison (Dwyer & Bidwell, 2019).

Wind turbines exert perceptible (4) **impacts on residents and nature**. Residents are commonly bothered by *sound emissions* and visual effects, specifically *shadow flicker*, *obstruction lights*, and *landscape impacts*. Perceived negative *ecological effects* of wind farms can also cause concern among residents. The fourth predictor is thus a summary category, merging various resident and nature impacts, which will be discussed separately.

Sound emissions are among the most contentious impacts of wind turbines on well-being and are at the heart of social controversies around wind energy (Bednarek-Szczepańska, 2023; Kirkegaard et al., 2024; Taylor & Klenk, 2019). While sound impacts are a contested topic, even in the sciences (Kirkegaard et al., 2024; Taylor & Klenk, 2019), there is ample evidence to suggest that residents near wind farms can experience noise annoyance, sometimes combined with self-reported symptoms like sleeping disturbances, psychological distress, or effects on general functioning (Bakker et al., 2012; Godono et al., 2023; Haac et al., 2019; Hübner et al., 2019; Ki et al., 2022; Michaud, Feder, et al., 2016; Müller et al., 2023; Pawlaczyk-Łuszczyńska et al., 2014, 2018; Pedersen & Persson Waye, 2004, 2007; Pohl et al., 2018; Radun et al., 2019; Turunen et al., 2021). Noise annoyance and related symptoms are entangled with subjective factors like expected negative health effects, perceived procedural and distributive injustices, noise sensitivity, and visibility and landscape impacts of wind turbines (Haac et al., 2019; Hübner et al., 2019; Michaud, Keith, et al., 2016; Müller et al., 2023; Pawlaczyk-Łuszczyńska et al., 2018; Schäffer et al., 2019; Tonin et al., 2016). Crucially, current epidemiological evidence does not support the existence of lasting health impacts from wind turbine noise (Baliatsas et al., 2025; Poulsen et al., 2018a, 2018b; Turunen et al., 2021).

A wind farm's visibility is influenced by multiple factors, including distance, turbine count, and topography (Molnarova et al., 2012). Nonetheless, the evidence is mixed on whether visibility significantly influences the acceptance of wind projects and the experience of annoyance or health effects (Freiberg et al., 2019; Hoen et al., 2019; Pohl et al., 2018; Rand & Hoen, 2017). Some studies suggest that people's assessments of a wind farm's aesthetics and placement in the ***landscape*** may be more important than a wind farm's visibility (Firestone et al., 2015, 2018; Hoen et al., 2019). ***Shadow flicker*** is another visual aspect that can annoy residents (Haac et al., 2022; Hübner et al., 2019; Michaud, Feder, et al., 2016; Pedersen et al., 2007; Pohl et al., 2021). Shadow flicker occurs when the sun is low on the horizon and shining through the blades of a rotating wind turbine, which produces a moving shadow on the ground. To reduce annoyance, countries like Germany have introduced maximum exposure limits dictating that turbines must be temporarily turned off if they exceed the limit (Bund/Länder-Arbeitsgemeinschaft Immissionsschutz, 2020). Residents can also be bothered by wind turbines' ***obstruction lights***, especially at night, and even experience stress symptoms in response (Kim & Chung, 2019; Pohl et al., 2012; Rudolph et al., 2017). The typically red blinking obstruction lights are safety measures that alert airspace users in the dark and during low visibility (e.g., in fog). Due to concerns about how the lights impact humans and wildlife, some countries are introducing demand-based lights that only turn on when an aircraft is approaching, which appears to lower annoyance among residents (Aaen et al., 2022).

Independent of true ***ecological impacts***, residents sometimes expect wind farms to interfere with wildlife, which relates to more negative attitudes toward wind energy and local wind projects (Baxter et al., 2013; Brannstrom et al., 2022; Fergen & Jacquet, 2016; Slattery et al., 2012). Wildlife concerns, especially regarding birds and bats, often drive conflicts for contested projects and dominate the public discourse about wind energy (Frantál et al., 2023; Mohammed, 2024; Nordstrand Frantzen et al., 2023). The local effects of wind turbines, like bird and bat mortality, tend to be emphasized, while the overall environmental advantages of wind power over fossil fuel technologies are often ignored (Hübner et al., 2020).

Finally, (5) **social norms** are a strong driver of human behavior and attitudes (Cialdini et al., 1990; Stern, 2000), also in the context of wind energy. Social norms are formal or informal rules that govern behavior in groups or societies (Bicchieri, 2005). Injunctive norms define how individuals should act, while descriptive norms reflect typical behaviors in given situations (Cialdini et al., 1990). Research shows that injunctive norms predict attitudes toward wind energy (Jones & Eiser, 2009; Sokoloski et al., 2018). If residents experience social pressure from significant others to object to a proposed wind farm, they intend more strongly to engage in oppositional behaviors like lobbying against the proposal, sharing concerns with the developer, or attending demonstrations (Read et al., 2013). Conversely, showing project support can also become normative when avoiding conflict and suppressing criticism about the project serves to protect community harmony, such that residents act in line with descriptive norms (Figari et al., 2024). Occasionally, the true normative opinion in a group deviates from what individuals perceive the norm to be. When people mistakenly believe their private views differ from the group's, despite similar public behavior, they exhibit pluralistic ignorance (Katz et al., 1931; Sargent & Newman, 2021). Conversely, the false consensus effect leads individuals to overestimate support for their own views or actions. Both effects have been observed in the context of climate mitigation support, including for low-carbon energy infrastructure (Drews et al., 2022; Sparkman et al., 2022; van der Pligt et al., 1982). These social phenomena also occur for wind energy projects when a large group of project supporters overestimates opposition (pluralistic ignorance), while a few opponents falsely believe they represent the majority opinion (false consensus effect; Sokoloski et al., 2018).

2.4 CONCLUSIONS

This chapter has provided a structured foundation for understanding the concept of social acceptance in the context of renewable energy. It began by exploring the concept as it applies to new technologies, covering different dimensions of acceptance based on Wüstenhagen et al.'s framework: the socio-political, community, and market levels. Each level involves distinct but interacting groups and actor positions that influence how much a technology is accepted. Furthermore, acceptance can be understood as a subject's reaction (e.g., individual, group, or society) toward an object (e.g., a given technology or project) within a context shaped by cultural, social, organizational, economic, and policy aspects. The acceptance subject, object, and context continuously influence each other, and changes in one can lead to a different outcome, meaning that acceptance is dynamic and not immutable. The chapter also explored methods for measuring acceptance, highlighting the importance of aligning measurement approaches with the specific acceptance concept under study. Attitudinal measures, which capture people's evaluations or feelings toward a technology, were emphasized as essential in contexts where behavioral indicators – such as purchasing or protesting – are not readily available. The chapter then elaborated on the term acceptability, which is sometimes used interchangeably with acceptance and other times distinctively, depending on the discipline and research at hand. Finally, this chapter introduced the Integrated Acceptance Model (IAM) as the guiding model for this dissertation, noting its suitability due to its focus on specific drivers of acceptance at the community level. Using IAM, this research is set up to identify the factors that affect community acceptance of AWE and offer valuable insights into residents' responses to this emerging technology.

CHAPTER 3

MAPPING THE SOCIAL ACCEPTANCE OF AIRBORNE WIND ENERGY: A Literature Review[2]

2 **This chapter has been adapted from** Schmidt, H., de Vries, G., Renes, R. J., & Schmehl, R. (2022). The social acceptance of airborne wind energy: A literature review. *Energies*, *15*(4), 1384.

The previous chapter laid the theoretical foundation for the forthcoming empirical work. To systematically assess the acceptance of airborne wind energy (AWE), examining existing literature on this subject and evaluating its empirical support is essential. This chapter presents a comprehensive literature review on the social acceptance of AWE. It starts by clarifying the research aims and questions (Section 3.1), followed by a detailed explanation of the review method and findings (Sections 3.2 and 3.3). The chapter concludes with a discussion of the review's limitations and recommendations for future research (Sections 3.4 and 3.5).

3.1 INTRODUCTION

Like wind turbines, AWE systems are expected to impact people and nature. These impacts could include sound emissions, visual impacts, and ecological effects, as illustrated in Section 2.3.1. Potential acoustic impacts may arise from the sounds emitted by the AWE system's components, including the generator, winch, tether, and flying kite. The appearance of an AWE system, particularly its ground station, tether, kite, and the moving shadow cast by the kite during operation, could lead to visual impacts. While quantitative data on AWE systems' visual impacts is not publicly available, test flights suggest that the kite appears relatively small in the sky during operation. Even when the kite is fully reeled in, it typically remains 200-250 meters above the ground. However, the ground station remains visibly prominent, and the moving shadow may attract attention. Due to the kite's flying nature, ecological impacts will likely affect birds, bats, and ground-dwelling mammals, particularly in remote and rural areas where AWE systems are initially deployed (Bruinzeel et al., 2018; Directorate-General for Research and Innovation & ECORYS, 2018; Piancastelli & Cassani, 2020). These areas are often rich in wildlife, increasing potential conflicts between the technology and local ecosystems. Another concern is the perceived and actual safety of AWE systems. For example, an uncontrolled crash of an AWE system could cause damage to people or property. **Table 3.1** provides an overview of the technical specifications of various AWE prototypes currently being tested, the working principles of which have been explained in Section 1.5.

AWE's impacts on people and nature can elicit public concerns that should be taken seriously, no matter how 'irrational' they seem to developers or authorities. Failure to address public reactions can result in increased implementation costs, decreased political support for the energy technology in question, and limits on the sector's growth and contribution to renewable energy targets (Ellis & Ferraro, 2016). 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 from the public (Brunsting et al., 2010; Dütschke, 2010; Ellis & Ferraro, 2016). Therefore, it is important to understand the impacts of AWE and how they may shape public perceptions and social acceptance of the technology.

Table 3.1
Technical Specifications of Tested AWE Prototypes

Developer	Prototype name	Kite type	Electricity generation	Wingspan (m)	Wing surface area (m^2)	Operational height (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	(SkySails Power, n.d.)
Kitepower	Falcon	Soft-wing	Ground-gen	13.3 [b]	47 [c], 60 [d]	70–400	100	(Kitepower, n.d.-c)
Kitenergy	KE60 Mark II	Soft-wing	Ground-gen	12.5 [b]	42 [c], 50 [d]	100–400	60	(Kitenergy, n.d.)
EnerKíte	EK30	Hybrid-wing	Ground-gen	8–14	4–8	50–300	30	(EnerKíte, n.d.)
Mozaero	AP3	Fixed-wing	Ground-gen	12	12	200–450	150	(Mozaero, n.d.)
Kitemill	KM1	Fixed-wing	Ground-gen	7.4	3	200–500	20	(Kitemill, n.d.)
TwingTec	Pilot System	Fixed-wing	Ground-gen	5.5	2	Up to 300	10	(TwingTec, 2020)
Skypull	SP130	Fixed-wing	Ground-gen	2 × 1.3	2 × 0.5	Up to 75	1.5	(Skypull, n.d.)
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	(Windswept & Interesting, n.d.)
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	(someAWE, n.d.)
Kitekraft	SN7	Fixed-wing	Fly-gen	2.4	1.08	100 [g]	~12	(Kitekraft, n.d.)
Windlift	C1	Fixed-wing	Fly-gen	3.8	0.95	30–100	2	(Windlift, n.d.)

[a] Data on missing specifications were obtained directly from developers. [b] Projected wingspan. [c] Projected wing surface area. [d] Wing surface area when kite is laid out. [e] Rotary kite system. [f] Electricity generation using tensile torque transfer from the kite. [g] Tether length.

This chapter examines the existing body of research on the social acceptance of AWE and compares these findings to studies on the acceptance of wind turbines. Through this comparison, the review identifies gaps in the current literature on AWE and provides recommendations for future research. The aim of the review results in the following two research questions:

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

While the remainder of this dissertation focuses on community acceptance, the literature review adopts a broader scope. By exploring the wider social and societal context of AWE, the review establishes a foundation for understanding and interpreting the findings of subsequent studies. It is also important to note that much of the technical literature in this field does not explicitly distinguish between different dimensions of acceptance. Therefore, it is more effective to expand the literature search beyond the community level to identify relevant publications.

3.2 METHOD

3.2.1 Literature search

An initial scoping search was conducted in the English-language AWE literature between May and August 2021 to identify relevant publications. This search included Web of Science, Google Scholar, and two of the most influential publications on AWE (Ahrens et al., 2013; Schmehl, 2018). However, none of the identified publications focused primarily on the social acceptance of AWE. Instead, references to this topic were usually brief and scattered, with authors using various terms to describe aspects of social acceptance.

The scoping search demonstrated that conducting a thorough literature review required searching the full text of publications using a wide range of keywords rather than relying solely on titles or abstracts. Google Scholar was chosen as the primary database because of its extensive full-text search capabilities, which are unmatched by other general databases (Gusenbauer, 2018).

Between August and September 2021 and again in January 2022, Google Scholar was systemically searched using two sets of keywords combined with the operator AND (see Table A1 in Appendix A for the complete sets of keywords). The first set included synonyms for AWE, such as high-altitude wind energy, kite power, and airborne wind turbine. The second set contained terms related to social acceptance, such as public acceptance, local support, and community concern. These keywords were selected based on insights from the scoping search and published literature reviews on the social acceptance of wind turbines (Enevoldsen & Sovacool, 2016; Langer et al., 2016; Wiersma & Devine-Wright, 2014). The selection of AWE keywords was mainly informed by the doctoral promotor's 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 supervising PhD researchers, organizing the bi-annual Airborne Wind Energy Conference from 2015 through 2023, and editing two Springer textbooks on AWE.

Because Google Scholar limits searches to 256 characters, 64 separate searches were performed to combine the two sets of keywords in all possible ways. Search filters like publication year were not used to ensure no relevant literature was overlooked. To address Google Scholar's limitation of not being a peer-reviewed database, the results were cross-checked against a topic search in Web of Science using the same AWE-related keywords. The comparison confirmed that the Google Scholar results represented the existing peer-reviewed AWE literature, which increases confidence in the findings of this literature review. Using Web of Science alone would have excluded many relevant publications, as none of them included social acceptance terms in their titles, abstracts, or keywords. Hence, Google Scholar was the database of choice due to its superior full-text search function compared to Web of Science.

Three relevant publications identified during the scoping search did not appear in the final Google Scholar searches because the keywords were limited to the most applicable ones, as indicated by the scoping search. These three publications were added manually to ensure they were included in the review.

Additionally, posts were published on LinkedIn (Schmidt, 2021a) and in a ResearchGate forum focused on AWE (Schmidt, 2021b) to solicit any further relevant literature. Although these posts generated significant engagement – the LinkedIn post had over 4000 views, 54 reactions, and 13 shares, and forum members read the ResearchGate post 136 times – they did not lead to the discovery of additional literature.

3.2.2 Publication selection

After removing duplicates and non-scientific records (e.g., websites and brochures), 362 publications were retained for further screening. The following inclusion and exclusion criteria were then applied to select relevant studies:

1. The publication is written in English.
2. It refers to aspects related to the social acceptance of AWE.

3. It is a full-text version of a peer-reviewed journal article, book chapter, conference paper, or doctoral dissertation.
4. Its discussion of AWE's social acceptance reflects the authors' original contribution rather than a paraphrase of another source.

PhD researchers conduct a substantial amount of AWE research, so doctoral dissertations were included in the review. After applying these criteria, 40 publications remained for the review. Table A2 in Appendix A provides details on the authors, journals, publication types, and publication years. The largest group of excluded publications (*n* = 295) did not address the social acceptance of AWE despite containing relevant keywords. These articles were flagged during the Google Scholar searches but, upon closer reading, were found irrelevant to the topic. **Figure 3.1** illustrates the selection process in detail.

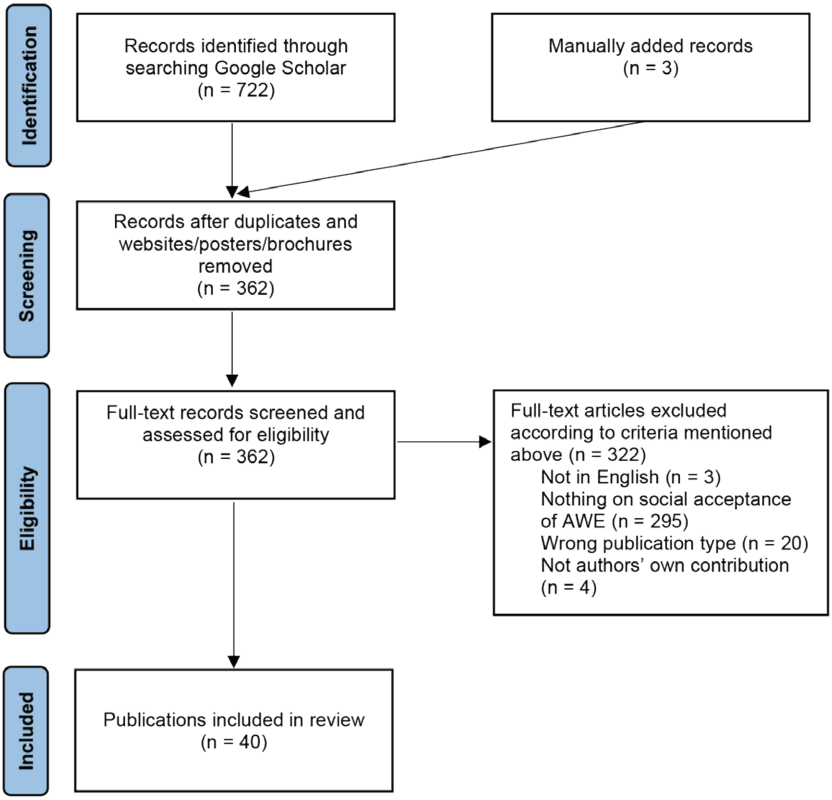


Figure 3.1. Flowchart outlining the literature selection process.

3.3 RESULTS

The 40 reviewed publications discussed five primary impacts of AWE on social acceptance: safety and related aspects, visual amenity, sound emissions, ecological impacts, and the siting of AWE systems. Notably, all claims regarding these impacts appear to be based on authors' assumptions rather than empirical evidence. Below, each of these impacts was examined, starting with the most frequently mentioned ones, contrasting them with empirical work on wind turbines from social science energy research, and assessing the claims' validity.

3.3.1 Safety aspects

The reviewed literature assumed that safety might affect public perceptions of AWE, with perceptions varying based on the type of AWE system. For example, one publication speculated that soft-wing kites might be seen as safer than fixed-wing or hybrid-wing kites due to their lighter materials (Paulig et al., 2013). However, even soft-wing kites could pose risks during uncontrolled crashes, as the mechatronic control unit suspended from the wing and the wing itself are heavy structures. This suggests that expert and non-expert perceptions may diverge, influencing their acceptance of various AWE systems.

Another publication hypothesized that fly-gen systems might raise concerns about electric tethers moving through the air (Abbate & Saraceno, 2019). While such concerns are understandable, future regulations for AWE sites are likely to mitigate public safety risks. Additionally, aviation professionals and regulators might view AWE systems as potentially threatening air traffic safety (Bronstein, 2011).

The literature emphasized that demonstrating reliable operation is essential for increasing support from investors, regulators, and the public (Girrbach et al., 2017; Salma et al., 2020; Salma & Schmehl, 2020; Sommerfeld, 2020). Key measures include establishing safety regulations (Archer et al., 2014; Gulabani et al., 2020; Salma et al., 2018), enhancing fault tolerance (Bauer, 2021; Girrbach et al., 2017), and minimizing the risk of accidents to an acceptable level (De Lellis, 2016). Furthermore, authors advocated for situating test sites far from populated areas until AWE systems are proven safe to avoid concerns among nearby residents (Cherubini et al., 2016; Piancastelli & Cassani, 2020; Roberts, 2018).

Safety concerns might currently influence the social acceptance of AWE more critically than that of wind turbines. In contrast to wind turbines, research on the risks of continuous, long-term operation is lacking because AWE systems have yet to be operated over extended periods, and universal, effective regulation still needs to be established (Salma et al., 2018). Unlike stationary wind turbines, AWE systems cannot be stopped mid-air if a malfunction occurs (Diehl, 2013). Whenever a part of the system is no longer working correctly, the system can, at best, be brought to a controlled landing. Controlled landings are only possible when the system is still in a flyable state, which is often not the case when something is broken, leading to a complete crash in the worst scenario (ibid.). For this reason, flying AWE systems might appear more hazardous and less acceptable than ground-based wind turbines. Future research should empirically test the impact of actual and perceived safety risks on the acceptance of AWE.

3.3.2 Visual amenity

Nearly half of the reviewed publications (17 out of 40) discussed the visibility of AWE systems in relation to social acceptance. Most suggested that these systems are less noticeable than wind turbines, primarily due to their high operating altitude (Alonso-Pardo & Sánchez-Arriaga, 2015; Archer et al., 2014; Bronstein, 2011; Cahoon & Harmon, 2008; De Lellis et al., 2016; Malz, 2020; Ye et al., 2020). Two studies claimed that the low visibility of AWE systems reduces public concerns (Roberts, 2018; Roberts et al., 2007), with one concluding that it makes them suitable for ecologically sensitive areas or tourist destinations (Bosch et al., 2014). 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 (Bronstein, 2011, p. 738). However, these claims overlook the visibility of the ground station, often the size of a standard shipping container, and subjective factors influencing visual impact, as will be explained below.

The literature also argued that the replacement of the tower with a relatively thin tether (De Lellis, 2016), the option to land the kite during low wind (Malz, 2020; Sommerfeld, 2020), and the reduction in shadow casting (Fagiano et al., 2010) reduce the visibility of AWE systems compared to wind turbines. AWE systems are expected to produce only weak and sporadic shadows because they operate between 300 and 600 meters and constantly change position during the pumping cycle. It should be noted that recent cross-country research 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 (Hübner et al., 2019). The low prevalence of annoyance from shadow flicker suggests that it may not be as significant an issue as it is often portrayed. However, this does not imply that wind turbines – or AWE systems, for that matter – have no visual impact on people.

The visibility of energy infrastructure is influenced by various factors, including distance, number of units, and landscape features (Molnarova et al., 2012). However, recent research suggests that a project's aesthetic evaluation and perceived fit within the landscape may be more critical than visibility alone (Firestone et al., 2018; Hoen et al., 2019).

Researchers have emphasized the importance of considering individuals' preferences for the physical appearance of energy infrastructures in the context of community, local, and socio-historical or cultural dimensions to understand their visual-spatial impacts better (Batel & Devine-Wright, 2021). In other words, research must go beyond examining visual impact as it only materializes in energy developments' physical characteristics (e.g., size, color, shape). Instead, it should recognize that "people's emotional and symbolic relations with the place where they live will impact on their acceptance, rejection or ambivalence toward RET [renewable energy technologies] in their locality depending on how these RET are seen as fitting or not that place" (Batel & Devine-Wright, 2021, p. 45). This concept is called project–place fit (Devine-Wright, 2009; Devine-Wright & Howes, 2010). Furthermore, it has been argued that research should also explore how landscape traditions – shaped by cultural, institutional, and ideological representations of landscape – affect community responses to proposed or existing developments. For instance, the countryside might be viewed as either an idyll that must be preserved or a practical place for farming and maintaining livelihoods, influencing perceptions of renewable energy projects.

Future studies should integrate insights from wind turbine research while accounting for AWE systems' unique features, such as kite colors, flight patterns (e.g., circles vs. figures of eight), flying speeds, and safety lights, which may influence social acceptance. For example, safety lights for aviation may become more prominent as AWE systems grow larger and operate at higher altitudes, potentially causing annoyance similar to that caused by wind turbine obstruction lights (Pohl et al., 2021).

3.3.3 Sound emissions

Similar to the visibility of AWE systems, the reviewed literature generally anticipated lower sound emissions from AWE systems than from wind turbines, attributing this to their high operating altitude (Archer et al., 2014; Bosch et al., 2014; Bronstein, 2011; De Lellis, 2016; Fagiano et al., 2010; Jehle & Schmehl, 2014; Key De Souza Mendonça et al., 2020; Khan & Rehan, 2016; Lunney et al., 2017; Piancastelli & Cassani, 2020; Roberts et al., 2007). Lower sound emissions were assumed to make the systems more suitable for installation in ecologically sensitive areas or tourist destinations (Bosch et al., 2014). One publication suggested making the ground station soundproof for ground-gen systems to reduce sounds further (De Lellis, 2016).

Three studies directly linked low sound emissions to increased social acceptance (Lunney et al., 2017; Roberts, 2018; Roberts et al., 2007). However, research on wind turbines demonstrates that sound pressure levels and the distance to the wind development are less important than sound quality, with amplitude-modulated sound appearing to be a major reason for noise complaints due to its attention-grabbing nature (Hansen et al., 2021; Hübner et al., 2019; Pohl et al., 2018). A shift in attention toward the source of the sound disrupts residents in their activity and is thus perceived as annoying (Pohl et al., 2018).

Next to sound quality, other subjective factors, such as perceiving the planning process unfairly, experiencing negative landscape impacts, or having unfavorable attitudes toward wind energy and local wind farms, are related to increased noise annoyance and stress symptoms (Health Canada, 2014; Hübner et al., 2019; Pawlaczyk-Łuszczyńska et al., 2014; Pohl et al., 2018). Reported stress effects include experiencing bad mood, anger, lack of concentration, difficulty falling asleep, or otherwise not sleeping well (Bakker et al., 2012; Pohl et al., 2018; Turunen et al., 2021). Financial participation in local wind projects, on the other hand, has been associated with reduced noise annoyance and stress effects (Arezes et al., 2014; Health Canada, 2014). Chapter 6: will discuss the topic of noise annoyance in more detail.

Insights from wind turbine research should be considered when assessing the acoustic impacts of AWE systems. While multiple developers have reported that the sound emissions of their AWE systems comply with local sound regulations (Hanna, 2020; Omexom Renewable Energies Offshore GmbH, 2020b), evidence from wind turbines suggests that some residents may still find the sound produced by AWE systems annoying. Strict imission regulations or setback distances may only partially resolve this annoyance. Therefore, future sound assessments should extend beyond measuring sound levels. They should include long-term monitoring of residents near AWE sites and analyze sound parameters, such as amplitude modulation, stress effects, and contextual conditions, to disentangle the various factors contributing to annoyance and stress symptoms (Hübner et al., 2019). Additionally, these assessments should account for subjective factors, including residents' perceptions of fairness in the participation process and their attitudes toward the local AWE site and AWE in general.

3.3.4 Ecological impacts

Collisions with birds and bats and disturbances to mammals and avian wildlife are expected to be AWE's most prominent ecological effects (Bruinzeel et al., 2018). The reviewed literature assumed fewer bird strikes compared to wind turbines due to AWE's higher operating altitude, except for the short take-off and landing phases (Bronstein, 2011; Key De Souza Mendonça et al., 2020; Lunney et al., 2017; Roberts, 2018). However, the moving tether poses risks because it moves faster than birds, making it difficult for them to anticipate, as shown in **Figure 3.2** (Bruinzeel et al., 2018).

Figure 3.2. Pilot operation of TU Delft's 20-kW kite power system before (left) and after (right) a bird collision with the tether.
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. Source: Max Dereta, 2011.

A single peer-reviewed study estimated annual bird fatalities from AWE systems to be within the range of bird fatalities recorded for wind turbines. Still, these results were based on comparisons with glider aircraft and power lines rather than field data and should be interpreted cautiously. The authors considered the number of bat strikes for AWE to be negligible (Bruinzeel et al., 2018).

AWE developers have commissioned several reports, albeit not peer-reviewed, to secure permits for (continued) prototype testing. These reports include field data on AWE's ecological impact, such as bat and bird flight patterns and breeding activity surveys. Two of these reports specifically documented how an operating AWE system affects local bird and bat populations (Håland, 2018; Omexom Renewable Energies Offshore GmbH, 2020a). All assessments concluded that the impact on local avian wildlife was negligible (David & Kawahara, 2018; Håland, 2018; Omexom Renewable Energies Offshore GmbH, 2020a). However, this does not imply that AWE systems are entirely harmless to birds and bats, as some engineers have claimed (Cahoon & Harmon, 2008; Ye et al., 2020). The findings from environmental impact assessments conducted at individual test sites are only transferrable to other sites to a limited extent because of varying ecological conditions (Bruinzeel et al., 2018; Håland, 2018; Omexom Renewable Energies Offshore GmbH, 2020a).

Therefore, longitudinal research across different ecosystems is needed, as species behavior varies with habitat, time of day, season (e.g., breeding season, migratory season), and weather conditions (Bruinzeel et al., 2018; Hanna, 2020). Understanding these dynamics is essential to mitigate potential adverse effects, such as through design adjustments or regulatory measures that apply to the construction, operation, and maintenance of AWE sites (Tulloch, 2021). The latter could, for example, include buffer zones for sensitive species during the breeding season and ongoing monitoring of sites and equipment (David & Kawahara, 2018; Hanna, 2020).

Taken together, the claim that AWE systems cause fewer bird strikes than wind turbines requires more empirical evidence. Besides, it is unknown how AWE's perceived or actual ecological impacts would influence the social acceptance of the technology. Research suggests that concerns about the wildlife impacts of wind turbines are common, especially among environmentally conscious individuals (Burch et al., 2020; Fergen & Jacquet, 2016; Slattery et al., 2012). Investigating how such concerns influence attitudes toward AWE is crucial.

Finally, one publication suggested that AWE's lack of towers reduces its ecological impact compared to wind turbines (Ranneberg et al., 2018). However, the authors did not specify if they refer to the effect on living organisms or more globally to the environmental footprint of AWE. The latter might also influence people's responses to AWE, as was suggested by another publication (Yan et al., 2017). Materials used in AWE systems, such as carbon-fiber-reinforced polymers for fixed-wing kites, are significantly more polluting than glass-fiber-reinforced polymers in wind turbine blades (van Hagen et al., 2023). Nonetheless, initial research suggests that AWE systems have an overall lower environmental impact because they use fewer materials and are more independent of local environmental conditions (ibid.). In contrast, in locations with lower average wind speeds, turbines need to be larger and thus require more materials. 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 difficult for wind turbine blades and partially explains turbines' high environmental footprint (Malz et al., 2021). Sustainability considerations, including material use and ecological effects, will likely influence how people respond to AWE compared to conventional wind energy.

3.3.5 Siting

The reviewed AWE literature expected that the siting of AWE systems influences the social acceptance of the technology and vice versa. For example, one group of authors proposed that the availability of suitable land and the density of systems in a specific area depends, in part, on the technology's social acceptance (Malz, 2020; Malz et al., 2021). However, this view overlooks the possibility that local communities may still oppose specific projects despite high public support for the technology (Batel & Devine-Wright, 2015; Bell et al., 2005). Such opposition often arises when residents perceive the decision-making process or the distribution of benefits as unfair, as explained in Section 2.3.1.

The literature also anticipated higher acceptance for offshore AWE systems because their visual and acoustic impacts are assumed to be less disruptive than those of onshore systems (Cherubini, 2017; Cherubini et al., 2018; Fagiano & Milanese, 2012; Sommerfeld, 2020). While there is some evidence that offshore wind turbines are favored, preferences vary based on factors such as the distance of dwellings and offshore sites to the coast (Hevia-Koch & Ladenburg, 2019). Offshore development has been related to some of the same discussion topics as onshore development, such as visual and acoustic impacts, economic or employment benefits, procedural justice concerns, and climate change mitigation (Wiersma & Devine-Wright, 2014). However, offshore wind farms also raise different issues, partially because they affect other stakeholders like beachgoers and coastal tourism operators (Wiersma & Devine-Wright, 2014; Wolsink, 2013). Issues such as impacts on tourism, marine wildlife, the fishing industry, and recreational activities like boating, yachting, surfing, and fishing are often discussed (Ferguson et al., 2021; Parsons et al., 2020; Petrova, 2013; Wiersma & Devine-Wright, 2014). Notably, the AWE industry plans to develop floating offshore systems, which may reduce impacts on marine ecosystems (Ampyx Power, n.d.; Cherubini, 2017; Farr et al., 2021). Nevertheless, how social acceptance of on- and offshore AWE systems differs and the reasons for such differences remain areas for further research.

Finally, as mentioned before, safety concerns also play a role in siting decisions. The literature recommended locating AWE test sites in remote areas to alleviate public safety concerns and acknowledged that the aviation sector may view AWE systems as risky. However, the literature did not elaborate on the disputes that might arise over the airspace allocation for AWE, nor did it recognize it as a siting issue. Airspace is a finite resource, and the AWE industry's requirements may conflict with those of military and civilian users, including airlines, emergency responders, and recreational pilots. Evidence of such tension is reflected in a 2011 request from Makani Power, a former U.S. AWE developer, to the Federal Aviation Administration (FAA; U.S. governmental agency) to include AWE systems in the National Airspace System. Before revising its policies, the FAA solicited public comments (Federal Aviation Administration, 2011). A total of 20 comments were submitted, of which around two-thirds were from AWE developers or proponents who argued that the systems could be safely integrated through measures like lighting, marking, constant monitoring of operating systems, and registration in navigation charts. In contrast, pilots and aviation associations raised concerns about potential collisions with low-altitude airspace users like agricultural or recreational pilots. Critics questioned whether marking and lighting could effectively mitigate these risks, noting challenges such as the visibility of thin tethers or the feasibility of equipping tethers with lights. One comment reflected the looming dispute over airspace resources, suggesting 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 not permitted – because creating additional prohibited zones for AWE would further strain already crowded airspace. However, such restrictions would significantly limit the scalability of AWE deployment. These discussions highlight the importance of addressing airspace conflicts when evaluating the social acceptance of AWE systems.

Overall, the influence of siting decisions on people's responses is heavily intertwined with visual, ecological, acoustic, and safety concerns, which are also expected to influence the social acceptance of AWE. Understanding these interconnected factors is crucial for making informed decisions about AWE development (see **Table 3.2** for an overview).

Table 3.2
Technical Factors Influencing Social Acceptance of AWE in the Reviewed Literature

Main Technology Factor	Impact on Social Acceptance
Safety	− Public safety concerns (e.g., regarding fixed-wing kites, fly-gen, aviation) + Industry safety regulations, system fault tolerance, accident prevention
Visibility	+ Low visual impact: high altitude, no towers, minimal shadow-casting, and kite retrieval in low wind
Sound emissions	+ Low sound due to high altitude
Ecological impacts	+ Few bird and bat strikes due to high altitude
Siting	+ Offshore and remote areas

Note. "−" indicates a hypothesized negative impact on social acceptance, while "+" indicates a hypothesized positive impact.

3.4 DISCUSSION

This review evaluated existing literature on the social acceptance of AWE and identified knowledge gaps. Two key conclusions emerge, addressing the research questions of what the literature states about AWE's social acceptance and the extent to which it is based on scientific evidence. First, empirical research on AWE's social acceptance is notably lacking. This review could only identify 40 publications that discuss how the technology might impact people and nature. Most of these publications were authored by engineers (83% of authors), and none adopted a social science perspective. While 34 publications primarily focused on technical or economic aspects, they mentioned social acceptance tangentially. Consequently, claims about public responses to AWE were based on assumptions rather than scientific evidence, such as interviews, surveys, or experiments.

Second, the literature reflects a generally optimistic outlook on how the public will perceive AWE despite the absence of empirical validation. Authors frequently assumed that features such as reduced visibility (e.g., due to no towers, little shadow-casting, and high operational altitude) and low acoustic and ecological impacts would positively influence acceptance. Anticipated challenges were limited to specific siting decisions (e.g., onshore developments and sites in densely populated areas) and potential safety concerns (e.g., regarding fixed-wing kites, fly-gen systems, aviation safety, regulatory gaps, and unproven reliability).

This optimism seems rooted in an assumption that people will process information about AWE rationally and objectively. However, research on other energy technologies has shown that subjective factors, such as political orientation and emotional reactions to energy technologies or specific projects, influence how individuals seek, evaluate, and respond to information about energy developments (Hahnel et al., 2020; Jobin et al., 2019; Lu et al., 2021; Russell & Firestone, 2021). Additionally, contextual and procedural factors like perceptions of fairness in decision-making, benefits distribution, trust in developers, and place attachment significantly shape social acceptance (Devine-Wright, 2009; Ellis & Ferraro, 2016; Firestone et al., 2018, 2020). The reviewed literature overlooks these non-technical dimensions.

While optimism is essential for driving technically challenging innovations like AWE, overly positive assumptions about acceptance could lead developers and authorities to neglect potential social issues, ultimately hindering deployment and increasing the burden on residents (Perlaviciute et al., 2018). Some authors acknowledge that AWE could trigger opposition (Cherubini, 2017; Cherubini et al., 2018) and emphasize that understanding acceptance issues is critical for successfully developing and deploying the technology (Ahmed et al., 2012; Chihaia et al., 2019; Luetsch, 2011; Sommerfeld, 2020; Watson et al., 2019). It has even been argued that the commercialization of AWE hinges on cultivating a positive public vision of the technology (Kamp et al., 2018).

Specifically, negative perceptions among the public and key stakeholders – such as concerns over reliability and safety – could undermine support, deter investment, and impede large-scale deployment. Despite these acknowledgments, a study revealed that concerns about social acceptance are still much less common in the sector, accounting for only 7% of all mentioned concerns (Directorate-General for Research and Innovation & ECORYS, 2018). In comparison, issues like economic viability (25%) and lacking regulations (24%) receive significantly more attention.

In summary, the sector should become more aware that understanding and addressing social acceptance early in the development process is crucial for AWE's long-term success and offers the opportunity to adapt the (deployment of the) technology to align with societal needs and values.

3.4.1 Limitations of the review

This review has several limitations that could affect its comprehensiveness and the validity of its findings. First, grey literature, such as policy documents, stakeholder consultations, and industry and media reports, was not systematically analyzed. Although some non-peer-reviewed sources were included to address gaps in peer-reviewed studies, these were incorporated ad hoc rather than through a structured approach. Given the scarcity of peer-reviewed publications on AWE's social acceptance, systematically analyzing grey literature could provide additional and contextual insights, such as the perspectives of policymakers or community stakeholders, which are underrepresented in the reviewed publications. Second, the scope of selected publications was restricted to English-language studies. This potentially excludes valuable research conducted in other languages, particularly in regions where AWE is being developed or tested. This limitation may lead to an incomplete understanding of AWE's social acceptance in diverse cultural contexts. Third, the review frequently extrapolates findings from research on wind turbines to AWE, whereas it has not yet been empirically tested if these insights are transferable. While both technologies share similarities, AWE's unique characteristics – such as its higher operational altitude and reliance on tethered flying devices – may elicit distinct public perceptions. Therefore, the comparison with wind turbines is illustrative rather than absolute and awaits empirical validation.

3.4.2 Future research recommendations

This review highlights an urgent need for empirical social science research on AWE's acceptance. Approaches such as surveys, interviews, focus groups, and lab or field experiments are essential to deepen our understanding. The existing literature identifies five main aspects supposedly influencing AWE's social acceptance: visual, acoustic, safety, ecological, and siting impacts. However, related claims are unsupported by empirical data and focus narrowly on technical attributes. Although the literature did not explicitly restrict itself to the community level, for comparison's sake, the first four aspects could all be grouped under the 'impacts on nature and residents' category of the IAM (Section 2.3.1). Meanwhile, the siting aspect is related to the planning process category but neglects critical considerations such as perceived procedural justice and trust in project developers. Notably, the other three IAM categories – energy transition attitudes, economic benefits, and social norms – are not discussed. Future research should examine how the IAM framework can be applied to understand and predict community acceptance of AWE (Chapter 5:).

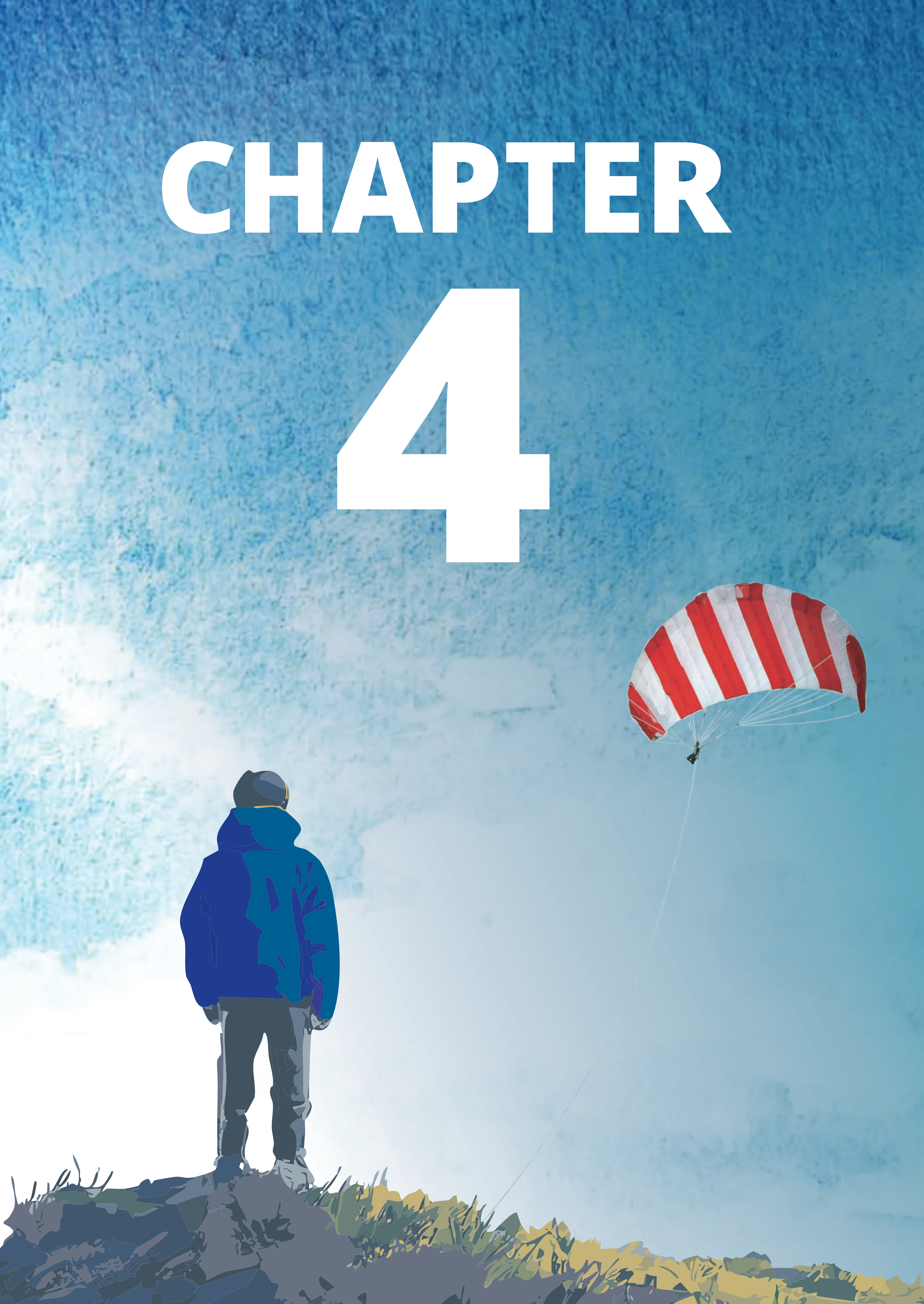
Besides, the literature fails to consider the broader social, cultural, and environmental context, although social acceptance is influenced by more than individual beliefs and perceptions, as described in Section 2.1.2 (Batel & Rudolph, 2021; Ellis & Ferraro, 2016). Factors such as local meanings of landscape, community characteristics, and policy contexts should be analyzed (Walker et al., 2010). Furthermore, 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 perceptions (Batel & Devine-Wright, 2015). Responses to energy technologies evolve over time, making it essential to view acceptance as a dynamic process shaped by stakeholder relationships, as illustrated in Section 2.1.3 (Batel & Devine-Wright, 2015; Walker et al., 2010). Future studies could learn from the large body of literature on different renewable energy technologies to inform research on AWE (Section 3.3).

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. However, the unique characteristics of AWE – such as its operation at higher altitudes, reliance on flying rather than stationary systems, and inability to stop mid-air operations – may raise distinct concerns, particularly regarding safety and while 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. As AWE technology evolves, research must adapt to account for changes in size, capacity, and deployment configurations, such as the planned use of multiple systems at one site, because public perceptions may vary across different stages of development (Faggiani & Schmehl, 2018). However, rather than viewing AWE's infancy as a limitation to research, it should be seen as an opportunity. Research can help identify people's needs and values regarding the technology and involve the public early in the development process.

3.5 CONCLUSIONS

How AWE's characteristics influence its social acceptance will depend on situational factors, such as policy context and landscape characteristics), as well as psychological factors like perceptions of fairness in planning and benefit distribution. This review highlights the need for empirical social science research to address these dimensions, moving beyond the optimistic but untested assumptions that dominate the existing literature. Collaboration between engineers and social scientists, informed by lessons from other renewable energy technologies, can guide the socially responsible deployment of AWE systems. By integrating societal values early, AWE can align with community needs and foster trust, enhancing its prospects for successful deployment.

CHAPTER 4



COMPARING THE COMMUNITY ACCEPTANCE OF AN AIRBORNE WIND ENERGY SYSTEM AND A WIND FARM IN GERMANY:

An Exploratory Study[3]

3 **This chapter has been adapted from** Schmidt, H., Leschinger, V., Müller, F. J., de Vries, G., Renes, R. J., Schmehl, R., & Hübner, G. (2024). How do residents perceive energy-producing kites? Comparing the community acceptance of an airborne wind energy system and a wind farm in Germany. *Energy Research & Social Science*, *110*, 103447.

The literature review in the previous chapter highlighted a gap in empirical research on the acceptance of airborne wind energy (AWE), revealing that assumptions about public perceptions are often speculative and sometimes biased. This chapter addresses these assumptions by presenting findings from an exploratory field study conducted among residents living near a pilot AWE project in Germany. Following the research objective (Section 4.1), the chapter introduces the research context and survey method (Section 4.2), provides a detailed presentation of the study results (Section 4.3), and concludes with a discussion of the study's limitations, suggestions for future research, and final reflections (Sections 4.4 and 4.5).

4.1 INTRODUCTION

The transition to sustainable energy requires understanding how people perceive and react to those innovations to minimize negative impacts on communities and prevent local opposition from hindering the expansion of renewables (Colvin et al., 2019; Reusswig et al., 2016; Upreti & van der Horst, 2004). The emergence of new energy technologies, such as AWE, presents an opportunity to integrate societal needs, concerns, and values early in the development process. AWE uses tethered flying devices to harvest higher-altitude winds, which are beyond the reach of conventional wind turbines (BVG Associates, 2022; IRENA, 2021). While AWE prototypes have been under development for over two decades, the technology is still in its infancy, with only a few pilot projects in operation (BVG Associates, 2022). This early stage of development allows for assessing the technology's social impacts before it becomes fully mature, enabling these considerations to be factored into its design (Oosterlaken, 2015; van der Waal et al., 2020).

To examine the social implications of AWE, it is necessary to understand its key features. AWE systems generally fall into two categories: ground-generation (ground-gen) and fly-generation (fly-gen) systems, as described in Section 1.5 (Cherubini et al., 2015). Ground-gen systems convert the kite's lift forces into electricity by flying the kite along a programmed trajectory. As the ascending kite pulls the tether from the drum, the generator attached to the rotating drum is powered. Once the tether reaches its maximum length, the kite is depowered and reeled back in, and the cycle starts again. In contrast, fly-gen systems generate electricity directly in the air through small onboard ram-air turbines, with the electricity transmitted to the ground via a conducting tether.

Despite over two decades of technical research on AWE, no empirical research exists on how people perceive the technology (Chapter 3:). Nevertheless, the literature on AWE is optimistic about the acceptance of the technology. Specifically, in the literature, five factors are hypothesized to influence social acceptance: visual amenity, sound emissions, ecological impacts, safety, and spatial siting (ibid.). AWE is believed to have lower visual and ecological impacts and produce less sounds than wind turbines due to its higher operational altitude, the absence of a tower, reduced shadow-casting, and the ability to retrieve the kite during low winds. These attributes are presumed to enhance social acceptance compared to wind turbines. However, safety concerns – such as aviation collisions and the lack of regulatory frameworks – and issues related to siting in densely populated areas are recognized as possible challenges.

The AWE literature lacks empirical support for these claims and overlooks individual preferences, experiences, and perceptions, assuming a purely rational assessment of the technology (ibid.). Research on established renewable energy technologies demonstrates that acceptance is closely tied to people's experiences with a given technology or energy plant. For example, research has repeatedly shown that residents' perceptions of the planning process and the distribution of benefits are related to their acceptance of a local energy project (Firestone et al., 2018; Gölz & Wedderhoff, 2018; Hoen et al., 2019; Hübner et al., 2023; Langer et al., 2016; Rand & Hoen, 2017; Wolsink, 2007b) and how they experience the project's impacts (Hübner et al., 2019; Pohl et al., 2018). The lack of knowledge about which factors influence the acceptance of AWE, combined with the persistent, unfounded assumptions in the AWE literature, can lead to a distorted understanding of the technology's social impacts (Chapter 3:). This could result in flawed policy and deployment decisions that disproportionately burden communities and trigger widespread opposition. Opposition, in turn, could increase implementation costs, reduce political support, and hinder AWE's contribution to renewable energy goals (Ellis & Ferraro, 2016). Therefore, empirical social science research is crucial to understanding how people perceive and respond to AWE. Such studies can identify key factors that must be addressed during development and deployment, facilitating the technology's integration into society (Aitken, 2010; Wolsink, 2018).

This chapter addresses the knowledge gap by testing the following six assumptions regarding the social acceptance of AWE:

1. Residents evaluate AWE systems more positively than wind turbines.
2. Visual impacts of AWE systems are rated more favorably than those of wind turbines.
3. Residents perceive fewer sound impacts for AWE systems than wind turbines.
4. Ecological impacts are rated more positively for AWE systems than wind turbines.
5. Safety concerns are highly relevant to the acceptance of AWE systems.
6. Remote sites are preferred for AWE systems.

While there are no commercial AWE systems in Europe yet, certain impacts – such as sound and aviation lights – can only be perceived near an AWE system. Therefore, the literature's assumptions were evaluated at a test site of AWE, thus focusing on community acceptance of AWE (see Section 2.1.1 for the acceptance dimensions) (Wüstenhagen et al., 2007). In line with past research, community acceptance was operationalized as residents' attitudes toward the AWE system (Rand & Hoen, 2017).

4.2 METHOD

Residents within a 5 km radius of an AWE test site in Northern Germany were recruited for the study. Following standard practices in community acceptance research, a structured questionnaire was used comprising both open- and closed-ended questions to assess residents' evaluations of the AWE system and nearby wind farm (Hoen et al., 2019; Hübner et al., 2023). The questionnaire primarily focused on visual, sound, ecological, and safety impacts, as well as attitudes toward local renewable energy projects and renewable technologies in general. During in-person appointments, fifty-five residents answered the questionnaire online or in vivo, of which one participant had to be excluded. Quantitative and qualitative data were analyzed using statistical methods and thematic coding, respectively. This section provides details about the research context, participant recruitment, survey design and measures, and statistical analyses. The institutional review board of Delft University of Technology approved the study.

4.2.1 Research context

The test site is located in a rural, flat region of Schleswig-Holstein, Germany, and is operated by a German AWE developer (**Figure 4.1**). The local council granted a permit for the site in 2017 as part of a research project from 2018 until 2022 (Junge et al., 2023). At the end of the research project, the permit was extended until autumn 2024 (Junge et al., 2023). The temporary and non-commercial nature of the site meant that no formal public participation process was legally required. Instead, the developer informed residents once the testing activity had increased and became more noticeable about a year after the operation began in December 2019 (ibid.). The developer sent letters about the project's purpose and impacts to households in two of the four adjacent municipalities. Six months later, an open day was held for the same households. The AWE system at this site utilized ground-gen concepts with soft-wing kites featuring wing surface areas between 40 and 160 m² (ibid.). Operating at 200 to 400 m altitudes, the system achieved a rated cycle power of up to 200 kW (cf. first row of **Table 3.1**). Flights were not continuous; most occurred during the daytime on weekdays, although some overnight flights were conducted (ibid.). The developer reported that the AWE system at this site had the most operational hours worldwide, making it a suitable location for evaluating community perceptions (ibid.). Additionally, the region's high density of wind turbines (Agentur für Erneuerbare Energien, 2022) provided an opportunity to compare residents' perceptions of the AWE system and wind turbines.

Figure 4.1. The studied test site, featuring a ground-generation airborne wind energy system with a soft-wing kite.
In the background, one of the many nearby wind farms is visible (Courtesy of the SkySails Group).

4.2.2 Participant recruitment

Participants were recruited through a multi-step process targeting all residents 18 years or older within a 5 km radius of the AWE system who were familiar with the test site. The following eight recruitment methods were employed:

1. **Address identification:** Using public online mapping services, such as Google Maps and DANord, 1,152 residential addresses were identified within a 2.5 km radius around the AWE system.
2. **Letters:** Letters introducing the study and inviting participation were mailed to all identified addresses (Appendix B1).
3. **Phone calls:** One week later, follow-up phone calls were made to addresses within a 2.5 km radius where phone numbers could be obtained through public telephone directories.

4. **Local organizations:** Study invitations were sent to local organizations and institutions through mail and social media, including a sports club, a community-supported agriculture organization, and a local church.
5. **Newspaper announcement:** The local newspaper published a study announcement.
6. **Online outreach:** Study invitations were posted on the hosting municipality's website, its Facebook page, and in three local Facebook groups.
7. **Posters and leaflets:** Recruitment posters were displayed in the area (Appendix B2), and one day before the start of the data collection, leaflets were distributed to addresses within approximately 2 km of the AWE system.
8. **Developer outreach:** The AWE system developer emailed study invitations to residents who had attended the site's open day the previous year.

While calculating an exact response rate was not feasible due to overlapping methods, **Table 4.1** summarizes the successes and failures of each recruitment method. Questionnaire responses revealed that most participants became aware of the study through letters (66.7%) and phone calls (33.3%), followed by neighbors, family or the leaflet (20.4%), the newspaper (13%), local organizations (7.4%), and the developer (3.7%). The percentages reflect that some participants heard of the study via multiple channels.

Table 4.1
Recruitment Methods and Corresponding Success Rates

Recruitment method	Number of addressees	Success/failure rate
Letters	1,152	40 letters returned as undeliverable.
Phone calls	244	94 answered (38.5%); 23 agreed to participate (24.5%).
Leaflets	~400	All delivered successfully.
Local organizations	8	Three responded, one confirmed sharing the study invitation with members.

Note. Not all the initially scheduled appointments took place due to cancellations.

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4.2.3 Survey design and measures

The questionnaire was developed to test the study's hypotheses and included constructs drawn from the literature on wind energy (Hübner et al., 2023; Rand & Hoen, 2017) and AWE acceptance (Schmidt et al., 2022) as well as exchanges with experts in the field of AWE. The questionnaire measured attitudes, perceptions, and preferences related to local renewable energy projects and energy technologies in general and their impacts. To ensure the questionnaire was relevant and reliable, measurement scales from established research were used where applicable (Hoen et al., 2019; Hübner et al., 2023). Identical questions and response scales were used for both wind turbines and AWE, with minor adjustments to the phrasing for the topic of AWE. Three types of scales were employed:

1. **Dichotomous scales** (yes/no).
2. **Bipolar scales**, ranging from -3 to +3, for constructs that could be assessed on a positive-negative continuum, such as attitudes. Bipolar scales are widely used in psychological research, such as for the prominent theory of planned behavior (Ajzen, 1991), because they effectively capture constructs with opposing dimensions. The bipolar-scaled items that might be more difficult to grasp are presented in **Table 4.2**.
3. **Unipolar scales**, ranging from 0 (not at all) to 4 (very), for one-dimensional constructs, such as the degree of annoyance experienced by participants.

The design of the open questions was guided by the following principles: using clear and accessible language, making questions specific but open enough to allow for different responses, and avoiding double-barreled questions that ask about multiple concepts at once.

Additional questions about commercialization preferences for the AWE system were included as part of a related Master's thesis project, such as the impact of kite size, hybrid AWE development, and sole night operation on support for commercialization (Kampermann, 2023). Overall, the questionnaire contained 124 items, covering a wide range of acceptance-related aspects. The codebook file in the associated database provides an overview of all the questions asked (Schmidt et al., 2024b) the following, only the items analyzed for this article are briefly described:

1. **Perceptions and attitudes**
   a. *Perceptions:* Participants were asked nine open-ended questions to explore their perceptions and experiences with the local AWE system and conditions for its commercialization. For example, they were asked, "How and when did you first hear of the AWE system?"

or "What would you change about the AWE system if you could?". Participants also indicated how frequently they perceived the AWE system using a 5-point scale, ranging from "every day" to "less than every couple of months".

b. *Attitudes:* Participants were asked to evaluate their attitudes toward (1) wind turbines and AWE systems in general, as well as (2) the local AWE system and the wind farm they considered closest to their home. Details of the wind farms referenced by participants are provided in **Table 4.3**.

2. **Technology impacts**

a. *Visual impacts:* To assess visual impacts, participants were asked whether they could see the AWE system or wind farm from their home, whether they perceived shadow-casting or aviation/obstruction lights from either energy plant, and how much they were annoyed by shadow-casting and lights. Annoyance was rated on a 5-point scale from 0 ("not at all") to 4 ("very"). Additionally, participants responded to two bipolar questions each about the impact of the AWE system and the wind farm on the landscape (**Table 4.2**).

b. *Sound impacts:* Participants were asked whether they heard sounds from the wind farm or the AWE system, and if so, how annoyed they were by these sounds. Annoyance was rated on a 5-point scale from 0 ("not at all") to 4 ("very"). They were also encouraged to describe the sounds they perceived in their own words.

c. *Ecological and environmental impacts:* Participants responded to one bipolar question each about the impacts of the AWE system and the wind farm on nature and wildlife (**Table 4.2**). They were asked to specify their ecological concerns if their rating for the AWE system was -1 or lower. Given the potential relevance of AWE's carbon footprint to social acceptance (Section 3.3.4), participants rated the extent to which they believed AWE to be more sustainable than wind turbines due to lower material consumption. This was measured on a 5-point scale from 0 ("not at all") to 4 ("very").

d. *Safety:* Participants rated their safety concerns for both the wind farm and the AWE system using a 5-point scale from 0 ("not at all") to 4 ("very"). If participants scored 1 or higher, they were encouraged to describe their specific safety concerns.

e. *Planning process:* Participants evaluated the planning process for the wind farm by answering whether the process had been fair, whether the developer had been open and transparent, and how satisfied they were with the developer's efforts to inform about the project. All items were rated on a 5-point scale from 0 ("not at all") to 4 ("very"). For the AWE system, similar questions were posed but focused on the ongoing operation of the test site, as no formal planning process had taken place.

f. *Siting preferences:* Participants indicated which locations they found most acceptable for the commercial use of AWE (e.g., agricultural areas, offshore). Given the limited knowledge about its siting preferences compared to wind turbines, these questions focused exclusively on AWE. This also helped to keep the questionnaire concise.

3. **Demographics**

a. *Basic information:* Participants provided sociodemographic details, including age, gender, and educational background.

b. *Financial benefits and proximity:* Participants were asked if they received financial benefits from local wind turbines and identified the wind farm they considered closest to their home.

c. *Distances:* Living distances to the perceived closest wind farm and the AWE system were calculated using Google Maps. This was achieved by using the geographical coordinates of the AWE system's ground station, the closest identified wind turbine, and residential addresses.

Three trained researchers administered the questionnaire in German during one week in June 2022. Most sessions were held in person at participants' homes, while nine participants completed the questionnaire via Microsoft Teams video calls due to scheduling constraints. The duration of each session ranged from 30 to 100 minutes, with an average time of 64 minutes. One researcher conducted 51.9% of the sessions, while the other two carried out 29.6% and 18.5%, respectively. Although a few sessions involved multiple participants, such as couples from the same household or a group of neighbors, most (55.6%) were individual interviews. In cases where multiple participants were present, each person responded to the questionnaire individually to ensure all perspectives were accurately captured.

Table 4.2
Construct Ratings Measured on Bipolar Scales

Construct	Item/question	Rating scale
General attitudes	Attitude toward wind farms in general	-3 (“bad“/ “useless”) to +3 (“good“/ “useful”); average across items used as the attitude score.
	Attitude toward AWE in general	Same as above
Project attitudes	Attitude toward the closest wind farm	Same as above
	Attitude toward the AWE system	Same as above
Landscape impact	“The wind farm…”	-3 (“compromises the landscape very much”) to +3 (“makes the landscape very attractive”)
	“The AWE system…”	Same as above
Landscape fit	“The wind farm is…”	-3 (“very unfitting for the regional landscape”) to +3 (“very fitting for the regional landscape”)
	“The AWE system is…”	Same as above
Ecological impacts	“The wind farm…”	-3 (“very unfitting for the regional landscape”) to +3 (“supports nature very much”)
	“The AWE system…”	Same as above

Note. Participants completed the items by selecting a response on the provided scales. Higher scores reflect more positive evaluations.

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Table 4.3
Characteristics of the Wind Farms Located Nearest to Participants' Homes

Location	% referring to wind farm	Mean distance in m (*SD*)	Start operation	Total turbines	Turbine type(s)	Hub height (m)	Total wind farm capacity (MW)	Shareholders
Bosbüll/ Klixbüll	48.1%	1481 (436)	1994	6	2 Siemens SWT-3.6-107; 1 Enercon E-70 E4 2.3; 1 Senvion MM82; 2 Enercon E-92	59-104	16.2	Residents/landowners in Klixbüll; municipality of Klixbüll
Klixbüll	24.1%	1487 (637)	2014	8	Siemens SWT-3.0-113	92.5	24	Residents/landowners in Klixbüll; municipality of Klixbüll; two regional water boards
Braderup	20.4%	1022 (336)	1995	8	4 Siemens SWT-3.6-107; 4 Siemens SWT-2.3	80	23.6	Residents/landowners in Braderup; municipality of Braderup
Risum-Lindholm	3.7%	3297 (1667)	2014	11	Vestas V112-3.075	94	33.8	Residents/landowners in Risum-Lindholm; municipality of Risum-Lindholm; local church
Niebüll	3.7%	3528 (342)	2011	5	Vestas V112-3.075	84-94	15.4	Residents/landowners in Niebüll

Note. Mean refers to the average living distance between participants' homes and the nearest turbine of the closest wind farm. *SD* denotes the standard deviation.

4.2.4 Statistical analyses

Quantitative data were analyzed using SPSS Version 28. Non-parametric tests were applied because the data was not normally distributed. Effect sizes (*r*) were calculated where applicable. As explained in Section 4.2.3, both unipolar and bipolar scales were used in this study, but the only inferential tests that included data from both scale types were bivariate correlations. When one variable takes only positive values and the other takes positive and negative values, the correlation is still computed as usual (Bain & Engelhardt, 2000). Therefore, the combination of unipolar and bipolar scales did not cause any statistical problems.

Respondents' answers to the open-ended questions were recorded in bullet points by themselves or the interviewer. The resulting qualitative data were analyzed through an iterative process of open and axial coding until distinct themes emerged. The principal researcher conducted the coding to maintain consistency, and progress was regularly discussed with the research team to ensure reliability.

4.3 RESULTS

4.3.1 Sample characteristics

A total of 55 residents participated in the study. However, one participant was excluded from all subsequent analyses because there was strong evidence that they could not properly understand or answer the questions. About one-quarter (24.1%) of the participants lived in Klixbüll, where the AWE site was located, and 42.6%, 20.4%, and 13% of participants were from the neighboring municipalities of Niebüll, Bosbüll, and Risum-Lindholm, respectively. Participants ranged in age from 34 to 85, averaging 61 years (SD = 12.29). Women (48.1%) and men (51.9%) were almost equally represented. By comparison, data from the regional statistical bureau suggests that 51.6% of the entire population across the four municipalities (N = 15,411) is female, and the average age of the adult population is around 53 years (n = 12,844; Statistikamt Nord, n.d.). The sample had a relatively high educational background: 37% of participants had completed an apprenticeship, 16.7% held a college or Bachelor's degree, and 20.4% had attained a Master's degree. On average, participants lived in two- or three-person households. Most (87%) had already lived in their homes when the AWE site was approved in late 2017.

The distance from participants' homes to the AWE system's ground station, a standard shipping container that housed the generator and the tether drum, ranged between 1,085 and 3,575 m, with an average distance of 1,987 m (*Mdn* = 1989.50, *SD* = 406.74). It is worth noting that the kite could be up to around 680 m closer to homes than the ground station itself. Most participants (77.8%) reported seeing the AWE system from their homes. Regarding frequency, 53.7% of participants noticed the AWE system weekly, 16.7% monthly, 14.8% daily, and 13% every few months. A very small percentage (1.9%) reported noticing it less frequently than every few months. These patterns suggest that most participants had sufficient exposure to the AWE system to evaluate its impacts. For comparison, participants' homes were located between 641 and 4,475 m from the closest wind turbine, with an average distance of 1,532 m (*Mdn* = 1355, *SD* = 762.34). Most participants (83.3%) reported that they could see the wind farm closest to their homes.

To assess potential response bias, participants were asked if they worked in the wind energy sector or benefited financially from local wind turbines. Only 3.7% of participants worked in the wind energy industry, which is too few to suggest any significant bias; therefore, these participants were not excluded from the study. Additionally, one-third of participants (33.3%) reported financial benefits from local wind turbines, mainly through ownership shares. However, there were no significant differences in attitudes toward the closest wind farm between those who benefited financially and those who did not (Mann-Whitney *U* test: $M = 2.56$ vs. $M = 2.15$; $p = .133$, $n = 54$). This finding indicates that financial compensation likely did not unduly influence participants' evaluations of the closest wind farm.

Because no background information, especially about renewable energy attitudes, could be obtained from existing data sources for all residents living within a 5-km radius of the AWE system, participants and non-respondents were compared to estimate potential selection bias. The non-respondents were thirty-two residents contacted via phone during the recruitment who declined to participate in the study but agreed to answer a few basic questions over the phone. Importantly, there were no significant differences between participants and non-respondents regarding age (Mann-Whitney *U* test: $M = 66.00$ vs. $M = 60.87$; $p = .119$, $n = 82$), gender distribution (Pearson chi-square test: 48.4% male vs.51.9% male; $p = .758$, $n = 85$), attitudes toward the AWE system (Mann-Whitney *U* test: $M = 1.26$ vs. $M = 1.89$, $p = .310$, $n = 81$), or attitudes toward the closest wind farm (Mann-Whitney *U* test: $M = 1.41$ vs. $M = 2.02$, $p = .302$, $n = 81$). However, there were two notable differences. Non-respondents had significantly lower levels of education compared to participants (Fisher's Exact test: 29.6% with college/university degree vs. 40.8%; $p = .006$, $n = 81$), and they reported seeing the AWE system less often (Fisher's Exact test: 16% had never seen the AWE system vs. 0% *p* = .010, *n* = 85). Indeed, a common reason for non-respondents to decline participation was a lack of exposure to the AWE system.

Unless stated otherwise, the results reported in the following sections refer to the two local projects (i.e., the AWE system and the closest wind farm). Findings are presented in the order of the hypotheses, with quantitative and qualitative data integrated for each hypothesis. The results for the AWE system and the wind farm are compared to each other per hypothesis. Key descriptive statistics are summarized in **Table 4.4**.

Table 4.4
Descriptive Statistics for Key Independent Variables

Variable	AWE system				Wind farm			
	M	*Mdn*	*SD*	*n*	*M*	*Mdn*	*SD*	*n*
General attitude[ab]	2	2.50	1.30	54	2.39	3	1.24	54
Attitude to local project[a]	1.87	2.50	1.33	54	2.29	3	1.26	54
Landscape impact[a]	0.71	0	1.59	53	-0.64	0	1.63	53
Landscape fit[a]	1.06	1	1.67	53	0.64	1	1.96	53
Shadow-casting annoyance	[c]	[c]	[c]	[c]	0.80	0	1.21	15
Aviation/obstruction light annoyance	0.45	0	1.18	22	0.66	0	1.28	41
Noise annoyance	1.32	1	1.25	19	1.08	1	1.09	26
Impact on nature and species conservation[a]	0.26	0	1.21	53	-0.13	0	1.47	53
Safety concern	0.57	0	0.95	53	0.49	0	0.82	53
Living distance (m)	1987.35	1989.50	406.74	54	1531.98	1355	762.34	54
Information satisfaction	1.36	1	1.34	47	2.38	3	1.50	37
Developer transparency	2.20	3	1.34	44	3.06	3	1.19	32
Fairness of site operation /planning process	2.49	3	1.25	45	2.69	3	1.15	32

Note. M = mean, Mdn = median, SD = standard deviation, and n = sample size.
[a] Scales range from -3 to +3; all remaining scales range from 0 to 4, except for distance.
[b] General attitudes refer to AWE systems in general and wind turbines in general.
[c] Shadow-casting annoyance was only measured for the wind farm because no participant perceived a shadow of the AWE system at home.

4.3.2 Participants' attitudes and general impressions

On average, participants held positive attitudes toward both wind turbines in general (*M* = 2.39, *SD* = 1.24) and AWE systems in general (*M* = 2, *SD* = 1.30). Similarly, attitudes toward the closest wind farm were positive (*M* = 2.29, *SD* = 1.26), and attitudes toward the local AWE system were somewhat positive to positive (*M* = 1.87, *SD* = 1.33). Statistical tests showed that there were no significant differences between general attitudes toward wind turbines and AWE systems (Wilcoxon-signed rank test: *p* = .062), nor were there significant differences between attitudes toward the local projects (Wilcoxon-signed rank test: *p* = .051). However, there were discrepancies in the correlational results across the wind farm and the AWE system. For the AWE system, positive attitudes were moderately associated with information satisfaction, perceived developer transparency, and fairness of site operations (**Table 4.5**). In contrast, for the wind farm, only satisfaction with information showed a significant positive correlation with attitudes (**Table 4.5**).

Qualitative data provided further insights into participants' attitudes. Those with somewhat positive to very positive attitudes toward the AWE system, here referred to as 'supporters', viewed the technology as innovative, interesting, and unusual. Supporters highlighted the renewable nature of the AWE system and believed it could contribute to reducing reliance on nuclear energy and fossil fuels. They also mentioned that AWE negatively impacts residents and the environment less than existing renewable technologies. On the other hand, participants with neutral to very negative attitudes, referred to as 'critics', tended to be indifferent toward AWE or dismiss the AWE system as a test project or even as a playful experiment. Critics expressed skepticism about whether AWE could meaningfully contribute to the energy transition. Importantly, even among supporters, there were uncertainties about how much energy AWE could realistically produce.

Table 4.5
Kendall's Tau-b Correlations Between Local Project Attitudes and Key Independent Variables

Variable	Attitude wind farm	Attitude AWE system
	τ (*p*)	τ (*p*)
Information satisfaction	**.42** (.002) *n* = 37	**.38** (.002) *n* = 47
Developer transparency	.28 (.068) *n* = 32	**.47** (.001) *n* = 44
Fairness of site operation / planning process	.21 (.172) *n* = 32	**.35** (.004) *n* = 45
Landscape impact[a]	**.34** (.002) *n* = 53	**.31** (.005) *n* = 53
Landscape fit[a]	**.49** (< .001) *n* = 53	**.42** (< .001) *n* = 53
Aviation/obstruction light annoyance[b]	–**.38** (.007) *n* = 41*	–**.50** (.009) *n* = 22*
Noise annoyance[b]	–**.53** (.002) *n* = 26*	–**.44** (.020) *n* =19*
Impact on nature and species conservation[a]	**.39** (< .001) *n* = 53	**.40** (< .001) *n* = 53
Safety concerns	–**.27** (.029) *n* = 53	–.15 (.201) *n* = 53
Living distance (m)	–.06 (.584) *n* = 54	.06 (.548) *n* = 54

Note. τ = correlation coefficient, p = *p*-value, n = sample size. Bold correlations are significant at $p < .05$.
[a] Scales range from -3 to +3; all remaining scales range from 0 to 4, except for distance.
[b] Only participants reporting perceiving the impact from home rated annoyance with that impact.

4.3.3 Evaluation of visual impacts

While participants' attitudes toward the AWE system and the wind farm were similar, five key differences emerged regarding their visual impacts: (1) the landscape impact was rated more positively for the AWE system; (2) perceptions of fairness and developer transparency were positively associated with landscape impact and fit for the wind farm but not for the AWE system; (3) participants reported no shadow-casting from the AWE system, whereas shadow-casting was noted for the wind farm; (4) more respondents perceived the obstruction lights from the wind farm compared to the aviation lights from the AWE system; (5) and a higher percentage of participants was annoyed by the wind farm's obstruction lights compared to the AWE system's lights. Each of these differences is discussed in more detail below.

First, participants rated the AWE system's impact on the landscape more positively than the wind farm's. On a scale from -3 to +3, participants' average rating of the AWE system's landscape impact was neutral to somewhat enhancing (M = 0.71, SD = 1.59), while the wind farm was rated as neutral to somewhat compromising the landscape (M = -0.64, SD = 1.63). This difference was statistically significant (Wilcoxon signed-rank test: z = 4.32, p < .001, r = .50; medium effect size). The landscape fit, measured on a scale from -3 to +3, was rated as somewhat fitting for the AWE system (M = 1.06, SD = 1.67) and as neutral to somewhat fitting for the wind farm (M = 0.64, SD = 1.96). However, this difference was not statistically significant (Wilcoxon signed-rank test: p = .143). Qualitative responses revealed that, despite the generally positive ratings of the AWE system's landscape impact and fit, even participants with a more positive attitude toward the AWE system expressed concerns about the potential visual effects if multiple AWE systems were deployed in the same area.

Second, while participants' attitudes toward both the AWE system and the wind farm were positively correlated with their ratings of landscape impact and fit (**Table 4.5**), characteristics of the planning process were only associated with landscape ratings for the wind farm. Specifically, for the wind farm, both process fairness and developer transparency showed significant positive correlations with landscape fit (τ = .32, p = .029, and τ = .40, p = .008, respectively), while process fairness was also positively associated with landscape impact (τ = .32, p = .031). This means that participants who perceived the planning process as fairer and the developer as more transparent were more likely to rate the wind farm as enhancing and fitting well into the landscape. In contrast, for the AWE system, neither fairness nor transparency were significantly related to landscape impact or fit (all p's > .220).

Third, participants reported no shadow-casting from the AWE system on their properties, whereas over a quarter of participants (27.8%) reported shadow-casting from the wind farm (**Table 4.6**). On average, those affected by shadow-casting from the wind farm were between not and slightly annoyed (M = 0.80, SD = 1.21). It is worth noting that the AWE system casts a very irregular and faint shadow (Kessler, 2021) when compared to wind turbines, and participants lived significantly farther from the AWE system than the wind farm (Sign test: M = 1987.35 vs. M = 1531.98; z = - 4.49, p < .001).

Fourth, more participants perceived the wind farm's obstruction lights at home compared to the AWE system's lights (75.9% vs. 40.7%; **Table 4.6**). Similar to wind turbines, the AWE system has aviation lights on the kite and the ground station that warn airspace users at night (Junge et al., 2023).

Fifth, while the average level of annoyance caused by aviation/obstruction lights was between none and minimal for both the wind farm (*M* = 0.66, *SD* = 1.28) and the AWE system (*M* = 0.45, *SD* = 1.18), more participants were annoyed by the wind farm's lights than the AWE system's lights (14.8% vs. 5.6%; **Table 4.6**). Following conventions in the literature, residents were characterized as annoyed when they scored at least a 2 on a scale from 0 to 4 (Miedema & Vos, 1998). Attitudes toward both the AWE system and wind farm were negatively associated with the corresponding aviation/obstruction light annoyance (**Table 4.5**).

The wind farm was notably more perceptible than the AWE system (**Table 4.6**). Most participants who could see the AWE system from home (71.4%) reported that they only noticed it when the kite was visible in the sky (note: 19% of the total sample did not specify when they could see the AWE system and were not considered in the statistic). This indicates that the AWE system is often visible only during operation, unlike wind turbines, which remain constantly in the landscape. Besides, qualitative data revealed that participants associated the operating kite with positive leisure and childhood activities, such as flying a kite, kitesurfing, paragliding, sailing, or spending time at the beach. Observing the kite in motion reminded participants that it was generating renewable energy and sparked curiosity about how the technology worked. The kite's movements tended to be described as playful, calming, and soft, providing a dynamic contrast to the nearby static energy plants. However, it was also reported that the kite's motion could create a sense of unrest and was harder to adapt to than wind turbines' more predictable, steady movements. This suggests that while the AWE system may evoke positive associations for some, its dynamic nature could also contribute to feelings of unease for others.

Table 4.6
Perception of Visual Impacts at Home and Prevalence of Related Annoyance

Variable	AWE system	Wind farm
	Percentage (Number)	
Local project visible at home[a]	77.8% (42)	83.3% (45)
Shadow perception	0% (0)	27.8% (15)
Annoyed by shadow-casting[b]	-	3.8% (2)
Aviation/obstruction light perception	40.7% (22)	75.9% (41)
Annoyed by aviation/obstruction lights[b]	5.6% (3)	14.8% (8)

Note. Only participants reporting perceiving a given visual impact at home were asked to rate their corresponding annoyance.
[a] Visibility includes observation from inside the house or on the property.
[b] Annoyance is defined as a rating ≥2 on a 0–4 scale.

4.3.4 Assessment of sound impacts

Similar to the results for visual impacts, four differences emerged for sound impacts across the AWE system and the wind farm: (1) participants reported hearing the wind farm more frequently than the AWE system at home; (2) a slightly higher proportion of participants was highly annoyed by the wind turbine sound than the AWE sound; (3) participants described the sound from the wind farm and the AWE system differently; (4) and perceived process fairness and developer transparency were negatively correlated with noise annoyance for the AWE system only. Each difference will be described in more detail in the following.

First, more participants reported hearing sound from the wind farm (48.1%) compared to the AWE system (35.2%) at home. On average, noise annoyance levels were minimal for both the wind farm (M = 1.08, SD = 1.09) and the AWE system (M = 1.32; SD = 1.25). However, the sample sizes for these subgroups were too small to determine whether there was no significant difference.

Second, although the overall noise annoyance levels were relatively low for both projects, there was a slight difference in the proportion of participants who were highly annoyed by the sound. Those who scored at least a 3 on the noise annoyance scale were classified as highly annoyed, and the percentage was marginally higher for the wind farm compared to the AWE system (**Table 4.7**).

Table 4.7
Perception of Sound at Home and Prevalence of Related Annoyance

Project	Sound perception	Prevalence of noise annoyance	
		Annoyed residents (score ≥ 2)	Highly annoyed residents (score ≥ 3)
		Percentage (Number)	
AWE system	35.2% (19)	13.1% (7)	7.5% (4)
Wind farm	48.1% (26)	11.1% (6)	11.1% (6)

Note. Sound had to be perceptible on one's property or inside the house with open or closed windows. Only participants perceiving sound at home were asked to rate their noise annoyance *(scale: 0–4)*.

Third, participants described the sounds from the wind farm and the AWE system differently. The wind turbine sounds were described as droning, beating, swishing, and whirring or was compared to a wind gust. The regular, rhythmic nature of the wind turbine sounds was also emphasized. In contrast, the sounds from the AWE system were perceived as more irregular and unpredictable. Participants described the sound of the tether as howling, whistling, whirring, or hissing. The kite was reported to make a fluttering sound. This unpredictability was a source of annoyance, making the sounds harder to get used to. The type of sound and the pitch were also reported to be annoying. Participants noted that the sound is most perceptible when the kite changes direction, consistent with the AWE developer's sound impact assessment (Junge et al., 2023). Interestingly, familiarity with the AWE sound appeared to influence participants' evaluation: Over half of the participants (53.7%) reported that they had not heard the AWE sound at home or near the site. There was a general assumption among these participants that the AWE system was quiet, especially compared to wind turbines, which all participants had heard before.

Lastly, noise annoyance was negatively correlated with participants' attitudes toward both the AWE system and the wind farm (**Table 4.5**) but not with living distance (p = .270 and p = .690, respectively). However, a notable distinction emerged: for the AWE system, noise annoyance was also significantly negatively correlated with perceived fairness and developer transparency (τ = -.42, p = .048 and τ = -.50, p = .016, respectively; n = 17). In contrast, no such relationships were found for the wind farm (p = .434 and p = .955, respectively; n = 15).

4.3.5 Appraisal of ecological impacts

When assessing ecological impacts, participants rated the AWE system more favorably than the wind farm. On a scale ranging from -3 to +3, participants' average rating for the AWE system's impact on nature and species conservation was neutral (M = 0.26, SD = 1.21), while the wind farm was rated slightly more negatively, with an average score between neutral and slightly compromising (M = - 0.13, SD = 1.47). This difference was statistically significant (Wilcoxon-signed rank test: z = 2.08, p = .038).

When participants who reported at least somewhat negative impacts of the AWE system (n = 5) were asked to explain their concerns, they mentioned the potential for bird collisions with the tether or the kite. Some believed that birds might mistake the kite›s shadow for a predatory bird, leading to disturbance or avoidance. Other participants worried the AWE system's loud and irregular sound could disturb wildlife, including birds. Despite these concerns, participants generally expressed uncertainty about the AWE system's ecological impacts due to a lack of knowledge about the technology. For both the AWE system and the wind farm, participants' attitudes toward the project were positively correlated with their perceived ecological impacts (**Table 4.5**). This means that participants who believed a project positively impacted nature tended to hold more favorable attitudes toward it.

In addition to ecological impacts, participants were asked to evaluate the sustainability of AWE system materials compared to wind turbines (Section 3.3.4). On average, participants agreed somewhat to moderately that future commercial AWE systems would be more sustainable due to their lower material consumption (M = 2.84, Mdn = 3.00, SD = 1.19, n = 51). Participants also noted advantages such as the lack of heavy foundations and the resulting ease of decommissioning AWE systems compared to wind turbines. However, participants disagreed about the land footprint of AWE; Some believed that it required less space than wind turbines, while others thought that the technology might take up more land.

4.3.6 Safety perceptions

Consistent with the previous pattern of rather slight differences between the AWE system and wind farm, only two differences were detected regarding safety concerns. Participants were not at all to slightly concerned about safety, with no significant difference across the AWE system (M = 0.57, SD = 0.95) and the wind farm (M = 0.49, SD = 0.82; Wilcoxon signed-rank test: p = .830). However, a difference emerged in how safety concerns related to participants' attitudes toward the local projects. For the wind farm, higher safety concerns were associated with more negative attitudes toward the project. In contrast, safety concerns about the AWE system were not significantly related to attitudes toward it (**Table 4.5**). Interestingly, safety concerns for both the AWE system and wind farm correlated negatively with general attitudes toward their respective technologies (τ = -.33; *p* = .006 and τ = -.29; *p* = .020, respectively, *n* = 53).

Participants' qualitative responses provided additional insights into the nature of their safety concerns, which diverged across technologies. For the wind farm, participants mentioned risks such as fire, ice throw, and rotor blades falling off. For the AWE system, participants expressed worries about the tether snapping and the kite either crashing or flying away. Concerns were also raised about the kite potentially colliding with aircraft and vehicles or even distracting drivers, thereby creating a traffic hazard. Additionally, participants were concerned that the AWE system was located near the approach path for a local emergency helicopter. While safety measures, including a no-fly zone, were implemented during the operation of the AWE system, participants appeared to be unaware of these precautions (Junge et al., 2023). Participants especially recognized the safety risks of AWE in more densely populated regions. They generally appreciated that the local AWE system had a safety radius, which helped mitigate risks. However, they also expressed frustration that access roads sometimes had to be blocked during operation, causing occasional disruptions (ibid.).

4.3.7 Siting preferences

The main finding from the qualitative data is that regardless of participants' attitudes toward the local AWE system, they generally preferred AWE systems to be located farther away from houses. Specifically, participants with more negative attitudes believed that AWE systems occupied too much space and were unsuitable for densely populated areas, such as Germany, partially because of potential noise and aviation light annoyance. As a result, participants affected by the impacts of the local AWE system advocated for restricting AWE system operation to daytime hours in populated areas to minimize disturbance. While participants with more positive attitudes toward the local AWE system were less likely to think that AWE takes up too much space, they still had a general preference for siting AWE systems away from residential areas. Despite this preference, quantitative results revealed no significant relationship between living distance and participants' attitudes toward the local AWE system. In other words, living closer to the AWE system did not necessarily relate to more negative evaluations of the local AWE system (**Table 4.5**).

When asked about the most acceptable locations for commercial AWE system deployment, participants favored agricultural areas, followed by offshore sites, natural areas that are neither protected nor actively farmed, and the edges of settlements (**Table 4.8**). Additional locations that participants (*n* = 22) suggested were mainly remote areas, such as deserts, mountains, forests, uninhabited coastlines, and regions in between settlements. Areas where other renewable energy plants cannot be installed and integrating AWE into existing solar farms were also proposed. Four participants suggested installing AWE systems on rooftops, especially on high-rise buildings. However, those who made this suggestion had not seen the aviation lights of the local AWE system at home, and only one had heard the AWE system before outside his house. The fact that they were not affected by the impacts of the AWE system might explain their openness to urban deployment.

Table 4.8
Approval Rates for Potential Commercial AWE Deployment Sites

Site	Percentage (number)
Agricultural areas	69.2% (36) *n* = 52
Offshore sites	64.7% (33) *n* = 51
Unprotected, unfarmed natural areas	40.4% (21) *n* = 52
Edges of settlements	25% (13) *n* = 52

Note. Residents were asked to select all that apply from a list of the four sites.

4.4 DISCUSSION

The study tested six key hypotheses with residents living within 5 km of an AWE system in Germany : (1) residents evaluate AWE systems more favorably than wind turbines; residents rate (2) visual, (3) sound, and (4) ecological impacts more positively for AWE systems than for wind turbines; (5) safety perceptions are highly relevant to the acceptance of AWE systems; and (6) remote sites are preferred for AWE system placement. Contrary to these hypotheses, the findings reveal that residents rated sound, ecological, and safety impacts similarly for the AWE system and wind turbines. The only exception was visual impacts, which were rated somewhat more positively for the AWE system, as hypothesized. The following sections will discuss these findings and their implications in detail.

First, the findings on the different impact categories of AWE are presented and discussed. Where applicable, they are compared with results for wind turbines to evaluate the evidence for each hypothesis. Additionally, it is examined how the current findings for wind turbines align with prior research. If the wind turbine results in this study differ greatly from those of earlier research, the generalizability of the comparisons between AWE and wind turbines may be limited.

Starting with AWE-specific findings, residents generally expressed positive attitudes toward AWE systems overall and somewhat positive to positive attitudes toward the local AWE system. Those with more favorable attitudes toward the local AWE system were more likely to be satisfied with the developer's communication, perceive the developer as more transparent, and view the site operation as fairer. These moderate correlations align with existing research on wind turbines, which emphasizes the importance of transparent and fair project implementation in shaping project attitudes (Firestone et al., 2018; Gölz & Wedderhoff, 2018; Hübner et al., 2020; Rand & Hoen, 2017). Interestingly, both supporters and critics of the local AWE system focused on similar aspects of the technology but viewed them widely differently. Supporters valued the research being conducted on AWE, which might become a complement to existing renewable energy sources. In contrast, critics doubted whether AWE could ever achieve the technological standard of modern wind turbines.

Regarding visual impacts, most residents who could see the AWE system from their homes reported noticing it only during operation (71%). Because the AWE system operates intermittently, its reduced visibility likely lowers its visual impact. Residents rated the AWE system's impact on the landscape as neutral to somewhat enhancing and its fit into the regional landscape as somewhat fitting. The more residents perceived that the AWE system enhanced and fitted the regional landscape, the more positive their attitude tended to be toward the AWE system. These moderate correlations are consistent with research on wind turbines (Hoen et al., 2019; Rand & Hoen, 2017). None of the participants reported experiencing shadow-casting from the AWE system on their property, which was to be expected. The kite's changing flight altitude makes it highly unlikely for observers to be struck by a shadow repeatedly in a short time frame (Kessler, 2021). About 41% of participants noticed aviation lights from the AWE system, but the average annoyance was lower than slight, with only about 6% of respondents being at least somewhat annoyed. Similar to findings in wind turbine research, residents who were more annoyed by aviation lights tended to hold more negative attitudes toward the AWE system (Aaen et al., 2022; Pohl et al., 2021). This strong correlation between annoyance and attitudes emphasizes the need for effective mitigation solutions. Initial evidence from wind turbines suggests that demand-based obstruction lights, which activate only when an aircraft approaches, can somewhat reduce annoyance levels (Aaen et al., 2022). Such lighting systems are now required for wind turbines in Germany and may also become a requirement for future AWE systems (Bundesnetzagentur, 2020). However, the developer of the studied AWE system noted that prospective AWE systems might require more intense lighting for airspace safety. The feasibility of implementing demand-based aviation lights will depend on the maturity of AWE technology.

Regarding sound impacts, 35% of residents reported hearing the AWE system from their homes, with annoyance rated as slight on average. Approximately 13% of participants felt at least somewhat annoyed. Those who experienced greater annoyance were likelier to hold negative attitudes toward the AWE system and view the site operation as less fair and the developer as less transparent. These moderate to strong correlations align with past research on wind turbines, highlighting the link between noise annoyance and negative perceptions of wind energy projects and their planning processes (Hübner et al., 2019; Pohl et al., 2018).

For ecological impacts, residents generally rated the AWE system's effect on nature and species conservation as neutral. However, participants who perceived greater ecological harm tended to have more negative attitudes toward the AWE system. This pattern mirrors findings from prior studies on wind turbines, which show that wildlife-related concerns affect attitudes toward wind energy and local wind farms (Baxter et al., 2013; Fergen & Jacquet, 2016; Mulvaney et al., 2013; Slattery et al., 2012). In this study, ecological concerns were more strongly related to residents' attitudes toward the local AWE system than anticipated based on AWE literature. However, these concerns were less influential than noise and aviation light annoyance. Research suggests that residents tend to focus on localized issues, such as the potential impact on birds and bats, rather than recognizing the broader environmental benefits of wind energy over fossil fuels (Hübner et al., 2020). Indeed, the most common ecological concern in this study was how the AWE system would impact birds.

Regarding safety, residents expressed less than slight concerns about the AWE system. However, the data collection revealed that participants had a varying understanding of the system's components, which likely influenced these safety perceptions: Participants commonly believed the kite was solely made of fabric and would not cause damage in a crash, overlooking the heavy control unit suspended beneath the kite. Despite these misconceptions, safety concerns did not correlate with residents' attitudes toward the local AWE system but were moderately linked to their attitudes toward AWE systems in general. These results suggest that while the local AWE system appeared relatively safe to residents, broader concerns about the technology's safety could negatively affect its socio-political acceptance (see Section 2.1.1 for the acceptance dimensions). The primary safety concerns revolved around potential accidents involving airborne components, such as the kite crashing or colliding with people or objects. Providing clear, accurate information to the public about the likelihood of such incidents and the safety measures in place – such as designated safety radiuses, no-fly zones, and airspace monitoring – could help alleviate unnecessary fears.

Regardless of their attitude toward the local AWE system, participants generally preferred AWE systems to be located farther away from residential areas. When given different placement options, they rated agricultural areas as the most acceptable, followed by offshore sites, natural areas that are neither protected nor farmed, and the edges of settlements. However, this preference for remote locations should be interpreted with caution. Residents' attitudes toward the local AWE system were unrelated to how far they lived from it. This aligns with previous research on wind turbines: Hypothetical scenarios, such as choice experiments or proposals for regional wind energy development, often reveal a preference for placing wind turbines farther away from dwellings (Cranmer et al., 2020; Jones & Richard Eiser, 2010; Meyerhoff et al., 2010). However, studies consistently show that actual distance to operational wind projects is unrelated or only minimally related to residents' attitudes, as other factors are typically more important to project acceptance (Hoen et al., 2019; Rand & Hoen, 2017). Furthermore, past research shows that negative expectations about visual, sound, health, and ecological impacts before a project's construction (Fergen & B. Jacquet, 2016; Wilson & Dyke, 2016) or before people are virtually exposed to a wind turbine (Cranmer et al., 2020) are often unmet. In other words, when people do not know the realities of a proposed energy development yet, they tend to assume 'the worst'. This tendency may have contributed to participants in this study favoring remote sites for unknown future AWE projects, even though they reported positive average attitudes toward the existing AWE system.

In the following sections, the evidence for the six hypotheses is assessed while accounting for the generalizability of the findings. The **first hypothesis** that residents would evaluate AWE systems more positively than wind turbines was not supported. Participants showed no significant differences in attitudes toward AWE systems and wind turbines in general or concerning the local projects. Notably, attitudes toward the closest wind farm and wind turbines in general were more positive in this study than in previous research (Hoen et al., 2019; Hübner et al., 2020; Pohl et al., 2018). This suggests that the finding of equal evaluations may not generalize to contexts where wind turbines are less positively perceived. The ownership model of the wind farms may explain the higher acceptance levels for wind turbines in this study. All the wind farms referred to in this study were owned by residents and local institutions (**Table 4.3**), which has been shown to increase acceptance due to perceptions of fairer planning processes and benefit distributions (Baxter et al., 2020; Hogan, 2024; Rand & Hoen, 2017). Additionally, familiarity with wind turbines, developed in the region over the past 30 years, likely contributed to the more favorable attitudes toward wind energy in this study: As evidenced by the conversations with participants, they had become used to wind turbines. Research suggests that post-construction evaluations of low-carbon infrastructures are more positive (Huijts et al., 2019; Wilson & Dyke, 2016) and that familiarity relates to less negative assessments of impacts like sound (Dällenbach & Wüstenhagen, 2022). However, as Rudolph and Clausen caution, familiarity or adaptation should not be equated with acceptance, as it might also reflect resignation or apathy, signaling planning processes' inadequacies to address certain issues (Rudolph & Clausen, 2021).

The **second hypothesis** that visual impacts would be rated more positively for AWE systems than for wind turbines was largely supported: Participants rated the AWE system's influence on the landscape significantly more favorably than for the wind farm, reported no shadow-casting for the AWE system, and were less likely to perceive and be annoyed by the aviation lights of the AWE system compared to those of the wind farm. However, the AWE system's fit within the regional landscape was not rated significantly better, and the average annoyance from aviation lights was not substantially lower than for the wind farm. As discussed earlier, the better landscape fit rating for the wind farm may reflect residents' familiarity with wind turbines in the region. Besides, the percentage of residents perceiving obstruction lights and the average annoyance were lower for the wind farm than reported in past studies (Pohl et al., 2021). Regarding shadow-casting, participants reported noticing no shadow from the AWE system at home, likely due to the kite's changing flight altitude and position. In contrast, shadow-casting is a known problem for wind turbines. Still, it is surprising that more participants in this study (i.e., 27.8%) reported shadow-casting from wind turbines than in previous research, which typically finds 1.3% to 11% of residents affected (Hübner et al., 2019; Pohl et al., 2021). Despite this, the average annoyance from shadow-casting was lower here (Hübner et al., 2019; Pohl et al., 2021), possibly due to regulatory limits in Germany that cap shadow duration to 30 minutes per day or 8 hours per year (Bund/Länder-Arbeitsgemeinschaft Immissionsschutz, 2020). This discrepancy with earlier studies might further be explained by recent findings suggesting that subjective factors, such as individual perceptions of wind turbine aesthetics and demographics variables, influence annoyance beyond the mere perception of shadows (Haac et al., 2022).

The **third hypothesis** that residents would evaluate the sound impacts of AWE systems more positively than those of wind turbines received only partial support. While fewer residents reported hearing the AWE system from their homes compared to the wind farm, the prevalence and intensity of noise annoyance were similar for both. However, the percentage of highly annoyed residents was slightly higher for the wind farm. Notably, the overall prevalence and average level of noise annoyance for wind turbines in this study were lower than in past research (Hübner et al., 2019; Pohl et al., 2018, 2021). As some literature suggests, the lower detection of AWE sound may reflect the system's limited operational time rather than it being inherently quieter. Residents described the AWE system and wind turbine sounds quite differently, often emphasizing the irregularity of the AWE sound as a source of annoyance. Past research highlights the importance of sound quality in explaining annoyance for wind turbines (Hansen et al., 2021; Pohl et al., 2018; Schäffer et al., 2018). Future studies should explore how sound variability contributes to annoyance with AWE sound.

Importantly, noise annoyance did not correlate with the proximity of either the wind farm or the AWE system, consistent with prior research on wind turbines (Hübner et al., 2019; Pohl et al., 2018). This trend may be explained by the effectiveness of sound emission regulations, the greater role of sound quality, and the influence of subjective factors on noise annoyance, such as visual impacts (Health Canada, 2014; Pawlaczyk-Łuszczyńska et al., 2014) and the perceived fairness and transparency of the planning process (Hübner et al., 2019; Pohl et al., 2018, 2021). For the AWE system, noise annoyance was negatively correlated with residents' perceptions of the fairness of site operation and the developer's transparency. This was not the case for the wind farm, likely because the closest wind farms were often in neighboring municipalities, leaving participants less involved or informed during the planning process. This disconnect could explain why participants struggled to evaluate fairness and transparency for the closest wind farm. However, it would not explain why developer transparency and planning process fairness positively correlated with landscape ratings for the wind farm but not the AWE system. Overall, these findings suggest that both sound characteristics, such as the irregularity reported by residents, and fairness and transparency play a role in noise annoyance for AWE systems. Given the early development stage of AWE, the industry is only beginning to investigate sound emissions. These correlational results should, therefore, be interpreted cautiously, as will be elaborated in the limitation section.

The **fourth hypothesis**, which was that residents would rate the ecological impacts of AWE systems more positively than those of wind turbines, was not supported. Residents rated the AWE system's impact on nature and species conversation as neutral, with no significant differences from the wind farm. The limited public awareness of AWE and sparse research on its ecological impacts (Section 3.3.4) may have contributed to the observed difficulty of participants in assessing the technology's environmental effects. In contrast, decades of research and public discourse have shaped perceptions of wind turbines, particularly regarding wildlife impacts (Arifi & Winkel, 2021; Schuster et al., 2015). Concerns about birds have especially prominently influenced public and political attitudes toward wind energy development, often hindering proposed projects (FA Wind, 2019; Nordstrand Frantzen et al., 2023). Comparing residents' evaluations of ecological impacts across wind turbines and AWE, therefore, suffers from an imbalance because the evidence bases and public narratives are differently developed. Nevertheless, it is noteworthy that the environmental impacts of wind turbines were not that negatively perceived in this study. This more favorable perception may be attributed, at least in part, to residents' extraordinarily positive attitudes toward and familiarity with the local wind farms.

The **fifth hypothesis**, which is that safety perceptions are crucial to AWE system acceptance, was also not confirmed. On average, residents expressed only slight concern about the safety of the AWE system, with worries no greater than those for the wind farm. However, as previously discussed, misconceptions likely influenced residents' perceptions of safety risks. Future research should explore how important safety perceptions are in technology acceptance beyond the local level, particularly among regulatory authorities and the general public.

The **sixth hypothesis**, which was that remote sites would be more acceptable for AWE systems, was supported. Residents generally preferred locating AWE systems farther from residential areas, regardless of their attitude toward the local AWE system. However, the quantitative data showed no correlation between residents' attitudes toward the local AWE system and their proximity to it. In other words, those living farther away did not consistently rate the AWE system more positively, nor did those living closer rate it automatically more negatively. This finding underscores the need to interpret preferences for remote sites cautiously. **Table 4.9** summarizes the key findings on how the AWE system compares to the wind farm across the impact categories.

Table 4.9
Summary of Key Findings: Comparison Between AWE System and Wind Farm Across Impact Categories

Impact category	AWE system	Difference to wind farm
Visual impacts	Neutral to somewhat enhancing landscape; landscape rating moderately positively correlated with attitude. Somewhat fitting landscape; fit moderately positively correlated with attitude. No shadow casting reported. 41% noticed aviation lights, with minimal annoyance and 6% affected; aviation light annoyance strongly negatively correlated with attitude.	Fewer participants saw the AWE system from home. Landscape impact significantly more positive (medium effect size). No participants reported shadow casting, while for the wind farm, they did. Nearly half as many participants noticed aviation lights, and only one-third as many participants were annoyed by the AWE system's lights compared to the wind farm's obstruction lights.
Sound impacts	Minimal noise annoyance and 13% affected. Annoyance moderately negatively correlated with attitude.	Fewer participants heard the AWE system. The AWE system's sounds were perceived as more irregular and high-pitched.
Ecological impacts	Neutral impact; ecological impact positively moderately correlated with attitude. Main concerns focus on bird impacts.	Ecological impact rated slightly more positive.
Safety	Minimal safety concerns; concerns negatively correlated with attitudes toward AWE in general.	Concerns centered on airborne risks, while for the wind farm, they focused on ground risks.
Siting	Preference for remote, less populated locations. Proximity to the AWE system unrelated to attitude.	N.A.[a]

[a] Siting aspects were not measured in relation to the wind farm.

Overall, the findings suggest that factors beyond remoteness should guide the selection of future AWE sites. While living distance was unrelated to attitudes toward the local projects, residents tended to hold more negative attitudes when they experienced greater impacts on themselves or the environment and perceived the developer as less transparent or the operation as less fair. Furthermore, when residents perceived less transparency and fairness, they tended to report more impacts, specifically landscape impacts for the wind farm and noise annoyance for the AWE system. This finding highlights that how a project is implemented is linked to residents' experience of project impacts and their attitudes. Assuming at least some causal connectedness, developers should prioritize fair and transparent planning processes, minimize impacts on nature (e.g., bird strikes), and address resident concerns (e.g., sound emissions, aviation lights, and landscape impacts). Chapter 7: further discusses these considerations.

4.4.1 Limitations of the study

This study has several general limitations that should be considered when interpreting the findings:

1. **Site-specific results:** The results are based on data from a single AWE system prototype developed by one company and located at a single site in Germany. Different AWE system designs, such as fly-gen versus ground-gen systems or soft-wing, fixed-wing, and hybrid-wing kites, may produce varying visual, sound, and other impacts. Furthermore, residents' perceptions of AWE may evolve as the technology matures and mitigation measures, such as demand-based aviation lights or sound reduction strategies, are implemented.
2. **Comparison with wind turbines:** The attitudes toward the closest wind farm in this study were more positive than those reported in past research. Annoyance related to obstruction lights, shadow-casting, and sound was also lower than in previous studies. This discrepancy limits the generalizability of the comparison between the AWE system and the wind farm to other contexts where wind turbines are viewed less positively than in this research.
3. **Differences in scale:** The AWE system had a nominal power output 8 to 17 times smaller than the referenced wind farms in this study (**Table 4.3**). While this makes direct comparisons of community acceptance challenging, the study's aim was not to determine whether residents prefer an AWE system over an entire wind farm but to understand their experiences with an AWE test site while considering their responses to local wind farms for which community acceptance has been well-researched.
4. **Correlational data:** The findings are based on correlational data, meaning relationships can be identified between community acceptance and other factors, but causality cannot be established. Moreover, the study did not assess the relative importance of different factors while

controlling for others. Future regression-based analyses could help determine the most influential predictors of community acceptance for AWE (Hübner et al., 2023).

5. **Sample size and sampling method:** The sample may have limited the study's statistical power. Recruiting participants was particularly challenging due to the limited availability of long-operating AWE projects, which are often in sparsely populated areas. Additionally, the convenience sampling method without compensation likely attracted only highly motivated individuals, potentially introducing sampling bias. However, the non-response analysis showed no significant difference in attitudes toward the AWE system between participants and non-respondents reached during the phone recruitment.

Finally, there are a few specific limitations regarding the different technology impacts of AWE. Concerning the visual impacts, participants evaluated one AWE system prototype against an entire wind farm (**Table 4.3**) with many more wind turbines nearby, creating an uneven comparison. How residents might perceive the landscape impacts of multiple AWE systems or an entire AWE park is unclear. Additionally, the findings on the perception of and annoyance caused by aviation lights for the AWE system should be interpreted cautiously, as the system was only operational during a limited number of nights.

The findings on sound impacts must be considered within their specific context. As this study represents the first of its kind, it primarily aimed to determine whether residents were affected by the sound of an AWE system at all. Consequently, the study measured noise annoyance but did not assess associated stress symptoms, such as difficulties with concentration or sleep, which are better indicators of true stress levels combined with reported annoyance (Pohl et al., 2018). For example, past research found that while 9.7% to 18.3% of participants reported being moderately to very annoyed by wind turbine sound, only 1.1% to 9.9% were strongly annoyed, as defined by experiencing minimal one stress symptom alongside being at least somewhat annoyed at least once per month (Hübner et al., 2019; Pohl et al., 2018). Based on this, the current study may have overestimated the proportion of residents experiencing significant distress from AWE sound.

Additionally, while the AWE system complied with local sound regulations (Junge et al., 2023), it had not yet been optimized to minimize sound emissions, unlike modern wind turbines. The AWE industry has so far focused on improving system reliability and scaling the technology rather than addressing sound reduction. However, developers are aware of current noise challenges (ibid.) and are beginning to develop measurement methods and knowledge to mitigate impacts. For example, the developer of the studied AWE system identified two key approaches for sound reduction: (1) design modifications, such as deploying larger kites at lower speeds or adjusting the kite and support line designs, and (2) operational changes, like slowing the kite at specific points in its flight path or adjusting the path to avoid sound-sensitive areas. Because sound emissions typically decrease as flight speed slows, these adjustments could significantly reduce noise annoyance (Glegg & Devenport, 2017). Lastly, the results are constrained by the site-specific nature of the sound emissions for this AWE system, which were influenced by local conditions such as topography and the ambient sound environment (Junge et al., 2023). Additionally, sound emissions will likely vary across different AWE system designs, including ground- and fly-gen systems, diverse flight trajectories, and variations in kite types such as soft-wing, hybrid-wing, and fixed-wing models. To gain a comprehensive understanding of sound impacts, further research is needed to investigate a range of AWE system designs at various stages of development, employing more detailed measures of annoyance and acoustic properties.

4.4.2 Future research recommendations

Building on the results and their limitations, the following six directions for future research are recommend:

1. **Conduct more field studies and add experimental and qualitative research:** Additional survey studies should examine the community acceptance of AWE, ideally across different designs and regions. This would test the generalizability of the findings and identify similarities and differences in community responses for various AWE systems. The limited availability of AWE projects will remain a challenge for recruiting affected communities. However, experimental designs could complement field studies to explore the influence of AWE design parameters on human perceptions (as an example, see the Master thesis by van Zweden, 2024). Both within-subjects and between-subjects experimental designs would be suitable. In a within-subjects experiment, participants could be exposed sequentially to multiple AWE system designs that vary in generation mode (i.e., fly-gen vs. ground-gen) and kite type (i.e., soft-wing, hybrid-wing, or fixed-wing kites). This approach would allow researchers to compare an individual's attitudes or preferences across different designs, revealing design-dependent differences. Alternatively, a between-subjects design would assign participants to one specific AWE system design, enabling comparisons of attitudes or preferences between groups exposed to different systems. To further leverage the

early development stage of AWE, qualitative research methods, such as focus groups and interviews, can help to explore what needs, values, and expectations different actors have regarding AWE and how design requirements can meet them.

2. **Assess noise annoyance and mitigation in more depth:** Future research should assess the extent and source of noise annoyance to facilitate the development of mitigation measures. Experimental studies, such as laboratory listening experiments, should identify the components (e.g., tether, kite, generator) and sound qualities that contribute most to annoyance (Chapter 6:). Field studies could combine annoyance measures with stress symptom reports to better estimate the impact of sound emissions on residents and inform regulations.
3. **Use predictive models:** Studies should employ acceptance models to quantify the influence of various factors, for example, visual, sound, and economic impacts, on residents' attitudes (Hübner et al., 2023). These models should consider that the predictive importance of certain factors, particularly perceived economic benefits, may vary depending on whether the project is at a commercial stage. Even with commercial projects, the relevance of these factors is likely to change across the planning, construction, and post-construction phases (Wolsink, 2007b). Comparing data from AWE sites at varying stages of implementation, such as test sites, semi-commercial sites, and full commercial operations, could provide valuable insights. However, pooling data from multiple sites would help address the challenge of small sample sizes, as AWE systems are often located in sparsely populated areas.
4. **Run longitudinal studies:** Tracking residents' attitudes toward an AWE system over time, from pre-construction to operation and potentially decommissioning, would provide insights into how experiences with a project causally influence attitudes. This would also help clarify whether negative expectations or other factors drive preferences for remote sites.
5. **Investigate socio-political and market acceptance:** Community acceptance is only one dimension of renewable energy deployment. Future research should also explore AWE's socio-political and market acceptance as they will heavily influence the technology's uptake and deployment. For example, while this study found that safety plays a minor role in the local acceptance of an AWE system, it is likely important for some socio-political and market actors like regulatory authorities and

investors (Directorate-General for Research and Innovation & ECORYS, 2018; Salma et al., 2020).

6. **Initiate interdisciplinary collaboration:** Social science, environmental science, and other relevant academic disciplines should work together with the engineering-dominated field of AWE. Taking a holistic view of AWE at such an early stage offers a unique opportunity to integrate valuable research findings into the technology and industry development.

4.5 CONCLUSIONS

This pioneering study on the community acceptance of an AWE system reveals that residents perceive the visual impacts of a local AWE system more favorably than those of a nearby wind farm. In contrast, sound, ecological, and safety impacts are rated similarly. The findings further suggest that the community responses to AWE systems share significant parallels with established renewable energy technologies. Notably, the study highlights that impacts on nature and residents are related to lower acceptance, and residents' experience of how a project is implemented is linked to their evaluations of the local AWE project. These insights underscore the importance of addressing both technical and social dimensions during the development and deployment of AWE to improve the technology's integration into communities.

CHAPTER 5

PREDICTING THE COMMUNITY ACCEPTANCE OF AIRBORNE WIND ENERGY WITH THE INTEGRATED ACCEPTANCE MODEL:
A European Cross-Country Study[4]

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The previous chapter's field study revealed that community acceptance of a local airborne wind energy (AWE) project is related to perceived impacts on residents and the environment – such as sound, visual aspects, and ecological effects – as well as perceptions of fairness and transparency. Building on these insights, this chapter uses the Integrated Acceptance Model (IAM) to analyze combined data from two surveys to identify the strongest predictors of community acceptance for AWE. The chapter opens with an outline of the study's motivation (Section 5.1) and method (Section 5.2), followed by a presentation of the results (Section 5.3), identified limitations, recommendations for further research, and concluding insights (Section 5.4 and 5.5).

5.1 INTRODUCTION

The first-ever field study on the community acceptance of an AWE test site is a starting point for deriving recommendations for AWE development and deployment (Chapter 4:). In line with research on established renewables (Aaen et al., 2022; Firestone et al., 2018; Gölz & Wedderhoff, 2018; Hoen et al., 2019; Hübner et al., 2019; Mulvaney et al., 2013; Pohl et al., 2018; Rand & Hoen, 2017; Slattery et al., 2012), the study found that project impacts on residents and nature (i.e., sound emissions, landscape impacts, aviation lights, ecological impacts) and dissatisfaction with procedural aspects (e.g., perceiving the developer as untransparent and the operation as unfair) related to more negative attitudes toward the AWE site. While the findings are useful, more research is needed to substantiate them and identify which factors predict acceptance most strongly, especially across AWE sites and regions. Knowing the main acceptance drivers is crucial for formulating effective and targeted measures.

The most parsimonious framework to date to predict the local acceptance of renewable energy projects is the Integrated Acceptance Model (IAM; Hübner et al., 2023). Local or community acceptance refers to residents' acceptance of a given local renewable energy project (Wüstenhagen et al., 2007) expressed by their attitude toward that project, ranging from negative through neutral to positive. By synthesizing the wealth of existing energy acceptance research, the IAM offers five overarching categories that can substantially explain residents' attitudes towards a local project (**Figure 2.1**): **(1) economic impacts** (e.g., Baxter et al., 2013; Hoen et al., 2019; Leiren et al., 2020; Walker et al., 2014), **(2) energy transition attitudes** (e.g., Breitschopf & Burghard, 2023; Kirchhoff et al., 2022; Sonnberger & Ruddat, 2017), **(3) nature and resident impacts** (e.g., Aaen et al., 2022; Fergen & Jacquet, 2016; Hübner et al., 2019; Mulvaney et al., 2013; Pohl et al., 2021; Rand & Hoen, 2017; Slattery et al., 2012), **(4) the planning process** (e.g., Gross, 2007; Hoen et al., 2019; Hogan, 2024; Walker & Baxter, 2017), and **(5) social norms** (Huijts et al., 2012; Johansson & Laike, 2007; Jones & Eiser, 2009; Read et al., 2013; Sokoloski et al., 2018). Specifically, the IAM predicts that local acceptance is higher when residents perceive more positive impacts of the project on the local economy, have more positive attitudes toward the energy transition, experience fewer negative project impacts on nature and residents, perceive the planning process more positively, and expect the local community to approve the project. While the IAM can substantially predict local acceptance across wind energy projects (R2adj between 0.76 and 0.78 in Hübner et al., 2023), it should be noted that context-specific aspects should always be considered, such as through placed-based approaches (Devine-Wright & Peacock, 2024). Given the different scopes and limitations of other frameworks (Section 2.3), the IAM is used to examine which factors predict the community acceptance of AWE.

Currently, no commercial AWE developments exist, so the study focuses on actively used AWE test sites. There are presently only a few active AWE test sites in Europe that are regularly used and close to residential areas (Airborne Wind Europe, 2024a). Besides, the population density around such sites tends to be low because they must be located in open, flat areas due to present operation and safety principles (Salma & Schmehl, 2023; SkySails Power, 2023b). The spatial setting makes it difficult to recruit a sample large enough at one test site to calculate the IAM. Therefore, part of the data collected in a previous study at a German site (i.e., Study 1; Schmidt et al., 2024a) is pooled with additional data from an Irish site (i.e., Study 2; DEM-AWE, n.d.). The Irish site features a very similar AWE system, increasing the comparability of data.

5.2 METHOD

In this section, the similarities and differences between Study 1 and Study 2 are described regarding three main aspects of the methodology: the investigated AWE test sites, the survey design, and the participant recruitment. In addition, the applied statistical analyses are explained. The institutional review board of Delft University of Technology approved the study.

5.2.1 Research context

Both test sites are situated in open, relatively flat areas in semi-rural regions. At both sites, ground-gen soft-wing AWE systems flying in figure-of-eights are tested (see **Figure 5.1**). Different prototypes were used at Site 1 before the data collection, ranging in wing surface area between 40 and 160 m^2 (Junge et al., 2023). The kite's flight altitude was approximately 200 to 400 m, and the rated power output was up to 200 kW (ibid.) At Site 2, only one prototype was tested with a wing surface area of 60 m^2, a flight altitude of up to 350 m, and a rated power of 30 kW (Kitepower, n.d.-a). Site 1 was in operation for about two-and-a-half years at the time of data collection (Junge et al., 2023), while Site 2 was only active for about half a year (DEM-AWE, n.d.). Accordingly, the total operation time at Site 1 was substantially longer than at Site 2. Both test sites had temporary permits for research and development (R&D) projects (ibid.). However, while no public participation process was organized for Site 1, and the neighbors were only informed after the testing had started, Site 2 underwent the regular permitting procedure for wind energy developments in Ireland (DEM-AWE, n.d.; Schmidt et al., 2024a). That included a public announcement of the proposed site before application, community outreach to every home within a 2 km radius prior to planning, and a public consultation period, during which residents could submit written comments. Site 1 was established and is used by a regional AWE developer, whereas Site 2 was developed by a multinational energy company and is used by a foreign AWE developer.

Figure 5.1. Airborne wind energy systems in operation at Site 1 (left) and Site 2 (right). A drone captured the photo at Site 1, while the photo at Site 2 was taken from the ground, differently affecting the perception of the kites' sizes (Courtesy of SkySails Group and Kitepower B.V.).

5.2.2 Participant recruitment

In Study 1, all adults within 5 km of the test site who knew the site could participate. To recruit participants, the research team posted letters to and called all identifiable addresses within 2.5 km of the site, placed announcements in local media as well as on social media/websites, and distributed leaflets to houses within a 2 km radius (see Section 4.2.2 for details). The recruitment occurred between May and June 2022. In Study 2, any adult living in the wider county could participate. However, only residents living within a 5 km radius of the site who had perceived the AWE system before were asked about their experience with the site. About 500 adults lived within the 5 km radius (Central Statistics Office, 2022)[5]. The participant recruitment focused on the major town closest to the site and occurred in two phases: a main phase and a follow-up phase. During the main phase in April 2024, the research was announced through regional media, on social media, at a local information event (Appendix C1), and via flyers in local shops (Appendix C2). Paper questionnaires with the

5 The estimate is based on the number of residents 20 years and older living in the census areas, which approximately match the 5 km recruitment radius around the test site.

option to access the web version were distributed to about 140 households in town and along the roads adjacent to the site (Appendix C3). Residents who completed the paper questionnaire could return it to a secure mailbox installed at the local supermarket. During the follow-up about two months later, questionnaires were posted to 39 houses closest to the site (2-3 km distance) because few responses had been received from direct site neighbors. About one month later, door-to-door visits occurred to a subset (19) of the same households to remind them about the survey.

5.2.3 Survey design and measures

In Study 1, the questionnaire was administered in structured interviews with the respondents, while in Study 2, respondents self-administered the questionnaire due to lacking resources. For Study 2, a shortened, translated version of the questionnaire from Study 1 was used (Section 4.2.3). In the following, only the items used to assess the six constructs of the IAM in both studies are described: (1) community acceptance, (2) impacts on residents, (3) planning process, (4) economic impacts, (5) social norms, and (6) attitude toward the energy transition.

1. **Community acceptance** was operationalized as attitudes toward the local AWE site and assessed by two pairs of opposite adjectives on 7-point bipolar scales ranging from -3 ("very bad"/"very useless") to +3 ("very good"/"very useful"). The items' average was used as an indicator for acceptance (r = .82, p < .001, n = 71).
2. **Impacts on residents:**
   a. *Visual impacts*: Respondents were asked whether they perceived aviation lights[6] from home and how much it annoyed them[7].
   b. *Sound impacts*: Respondents stated whether they heard sounds from the AWE system and, if so, how much it annoyed them. Annoyance was rated on a 5-point scale from 0 ("not at all") to 4 ("very").
   c. *Landscape impacts* were assessed by two pairs of opposite statements on 7-point bipolar scales ranging from -3 ("compromises the landscape very much"/"very unfitting for the regional landscape") to +3 ("makes the landscape much more attractive"/"very fitting for the

6 Questions about obstruction lights only applied to Site 1 because no night-time flights had occurred at Site 2 before the data collection.

7 The questionnaires also included questions about the perception of shadow and corresponding annoyance, but due to concerns about the items' validity, shadow annoyance was not considered in the data analysis. Excluding the variable did not change the results because all participants' maximum values remained the same.

regional landscape"). The items' average was used as the landscape impacts score (r = .85, p < .001, n = 63).

d. *Total score:* The landscape impact scores were recoded into a 4-point scale to compute a total impact score. The maximum score of noise annoyance, aviation light annoyance, and the recoded landscape impacts was then used as an indicator for impacts on residents. Perceived project impacts on nature were not measured in Study 2 and, therefore, were not included in the impacts factor.

3. **Planning process:** Because no public planning process had occurred for Site 1 (Section 5.2.1) and the IAM's categories are intended to be adapted to the research context, the planning process variable was operationalized as 'fairness & transparency'. Specifically, respondents rated the fairness of the site's operation, the developer's openness and transparency, and their satisfaction with the developer's effort to inform about the site on 5-point scales from 0 ("not at all") to 4 ("very"). The items' average was used as a total score (Cronbach's α = .86).
4. **Economic impacts:** In Study 1, respondents were asked to anticipate how a hypothetical commercial deployment of AWE would affect the local economy. Because Study 1 respondents struggled to imagine the effects, the Study 2 sample was asked to report the impacts of the existing AWE site on the local economy. In both cases, respondents rated on 7-point bipolar scales the impacts on four economic sectors: agriculture, tourism, property values, and remaining economic branches (Cronbach's α = .80). As the total economic impacts correlated significantly with acceptance in both studies, it was assumed that collating the measures into one scale is justified (r = .54, p < .001, n = 52, and r = .51, p = .002, n = 24, respectively).
5. **Social norms**: Participants were asked to estimate how the local community evaluates the AWE site on a 7-point scale ranging from -3 ("disapproves very much") to +3 ("approves very much").
6. **Attitudes toward the energy transition** were assessed by four pairs of opposite adjectives on 7-point bipolar scales ranging from -3 ("very bad"/"very uneconomical"/"very poorly implemented"/"very unfair") to +3 ("very good"/"very economical"/"very well implemented"/"very fair"). The items' average was used as the attitude score (Cronbach's α = .82).

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5.2.4 Statistical analyses

A linear multiple regression analysis was applied to test if the IAM predicts the acceptance of AWE in this study. A power analysis with G*Power assuming an alpha error probability of 0.05 and a large effect size (based on Hübner et al., 2023) showed that for power levels of 0.95 and 0.80, sample sizes of 63 and 43, respectively, would be sufficient to observe a significant regression model for the IAM (Faul et al., 2007). Owing to missing data, 51 cases were included in the regression model, which satisfies the threshold for a power of 0.80. Due to heteroscedasticity and outliers in the data, the heteroscedasticity-consistent standard error HC4 was used in calculating the regression (Hayes & Cai, 2007; Kaufman, 2013; Rosopa et al., 2013; Uchôa et al., 2014). Using the standard error HC4, all assumptions of the multiple linear regression model were satisfied (i.e., independence of observation, normality, linearity, no multicollinearity, and homoscedasticity).

5.3 RESULTS

In this section, the two samples are first compared to each other and, where possible, to their respective local populations to assess if pooling the samples is justified. The correlational analyses and the linear multiple regression results are then reported for the combined sample.

5.3.1 Samples' characteristics and comparison

Table 5.1 presents the characteristics of the samples separately and combined. The average age of participants in Study 1 was ten years higher than in Study 2. In fact, Study 1 had oversampled older residents (Section 4.3.1), while Study 2's sample was representative of the estimated average age of the adult local population (Central Statistics Office, 2022). The percentage of women was somewhat lower in Study 1 than in Study 2, but it was representative of the local population (Statistikamt Nord, n.d.). The proportion of women in Study 2 (56.3%) was slightly higher than that of the underlying population (51%: Central Statistics Office, 2022). The education level in Study 2 was higher than in Study 1 but comparable to the national average (Central Statistics Office, 2023). In contrast, the education level in Study 1 was somewhat higher than the national average (Statistisches Bundesamt, 2021). The low percentages of respondents working in the wind energy industry were comparable across the two samples. However, while one-third of Study 1's sample received financial benefits from local wind energy projects, nobody did in Study 2. Finally, respondents in Study 1 lived closer to the test site.

Although the two samples exhibited some differences in demographic characteristics, particularly in age, household size, and financial compensation for local wind projects, these disparities were not substantial enough to preclude pooling the data, consistent with the approach taken in previous research (Pohl et al., 2021).

Table 5.1
Sample Characteristics for Study 1, Study 2, and the Combined Sample

Characteristic	Study 1 (*N* = 54)	Study 2 (*N* = 20)	Combined (*N* = 74)
Age (*M*, *SD*, range)	60.87 (12.29) 34–85 *n* = 54	50.65 (15.90) 26–81 *n* = 17	58.42 (13.84) 26–85 *n* = 71
Gender			
Male	51.9 % (28)	37.5 % (6)	48.6 % (34)
Female	48.1 % (26)	56.3 % (9)	50 % (35)
Undisclosed	0 % (0)	6.3 % (1)	1.4 % (1)
	n = 54	*n* = 16	*n* = 70
Highest educational level			
Tertiary	40.8 % (22)	64.7 % (11)	46.5 % (33)
Secondary	51.9 % (29)	35.3 % (6)	49.2 % (35)
Primary	7.4 % (3)	0 % (0)	4.2 % (3)
	n = 54	*n* = 17	*n* = 71
Employed in the wind energy industry	3.7 % (2) *n* = 54	5.9 % (1) *n* = 17	4.2 % (3) *n* = 71
Receiving financial benefits from local wind projects	33.3 % (18) *n* = 54	0 % (0) *n* = 17	25.4 % (18) *n* = 71
Distance from AWE site[a]			
1-2 km	50 % (27)	35 % (7)	45.9 % (34)
2-3 km	48.1 % (26)	35 % (7)	44.6 % (33)
3-4 km	1.9 % (1)	20 % (4)	6.8 % (5)
4-5 km	0 % (0)	10 % (2)	2.7 % (2)
	n = 54	n = 20	*n* = 74

Note. The numbers in brackets behind the percentages indicate the frequency count.
[a] The distances were measured from the approximate location of the ground stations. During short periods of the operational cycles, the kite at Site 1 could fly up to at most 680 m closer to houses, and the kite at Site 2 up to at most 250 m closer.

Due to the small sample in Study 2, inferential testing could not be applied to identify if there were substantial differences in the IAM constructs across the two samples[8]. However, the means and standard deviations across the two samples seemed sufficiently comparable to justify pooling the data (**Table 5.2**), aligning with the approach adopted in previous research (Pohl et al., 2021). After

8 A power analysis conducted using G*Power, with an alpha level of 0.05 and an assumed large effect size, indicated that sample sizes of over 50 would be necessary to achieve a power of 0.80 for detecting true differences.

combining the data, the pooled sample had a slightly to somewhat positive attitude toward the local AWE site, was slightly to somewhat affected by project impacts, evaluated procedural aspects as somewhat fair and transparent, rated economic impacts as neither negative nor positive, expected the community to be slightly approving of the site, and had slightly positive attitudes towards the energy transition.

Table 5.2
Descriptive Statistics for IAM Constructs by Study and in the Combined Sample

Variable	Study 1			Study 2			Combined		
	n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Acceptance of the local AWE site[a]	54	1.87	1.33	19	1.26	1.47	71	1.71	1.38
Impacts on residents[b]	54	1.17	1.23	11	1.91	1.51	65	1.29	1.30
Fairness & transparency[b]	47	2.10	1.17	17	1.98	1.23	64	2.07	1.17
Economic impacts[a]	52	0.29	0.77	19	-0.18	1.32	71	0.16	0.96
Social norms[a]	52	1.06	1.53	19	0.26	1.73	71	0.85	1.61
Attitude toward the energy transition[a]	54	1.09	1.13	19	0.14	1.75	73	0.84	1.37

[a] Response scale: -3 to +3. [b] Response scale: 0 to 4.

5.3.2 Correlation and regression results for predicting community acceptance

The regression aimed to predict acceptance from the five IAM categories: impacts on residents, ‘fairness & transparency’, economic impacts, social norms, and attitude toward the energy transition. As seen in **Table 5.3**, all predictor variables were significantly correlated with the dependent variable acceptance and were thus included in the regression model. The variable impacts on residents was most strongly correlated with acceptance (negative correlation), followed by ‘fairness & transparency’ and social norms (both positive correlations). Economic impacts and the attitude toward the energy transition were moderately and positively correlated with acceptance. The correlation results align with what the IAM would predict. The intercorrelations between the predictors ranged from .27 to .63 (all p’s < .05), remaining below the threshold of .7, and the tolerance values in the regression model exceeded 0.1. This indicates that the constructs are sufficiently distinct (Hair et al., 2013).

Table 5.3
Correlations Between Acceptance and IAM Predictors in the Combined Sample

Variable	*r*	*p*	*n*
Impacts on residents	-.73	< .001	64
Fairness & transparency	.56	< .001	63
Economic impacts	.48	< .001	70
Social norms	.53	< .001	70
Attitude toward the energy transition	.39	< .001	72

The overall regression model is significant and highly fits with $R^2_{adj} = .69$. The impacts on residents emerged as the strongest predictor of acceptance, followed by 'fairness & transparency' (see **Table 5.4**). In other words, residents' acceptance of the AWE site was most strongly predicted by how annoyed they reported being by sound, landscape impacts, and/or aviation lights. Furthermore, their acceptance depended substantially on how fair they perceived the site's operation and how transparent they found the developer to be. Social norms and attitudes toward the energy transition did not predict acceptance significantly in the regression model. While economic impacts were also statistically insignificant at .05 ($p = .09$), the standardized (i.e., beta) coefficient of 0.343 suggests a trend that may warrant further investigation.

Table 5.4
Regression Analysis of Acceptance Using IAM Predictors ($n = 51$; $R^2_{adj} = .69$)

Effect	Beta	*Robust SE*	95% *CI*		*p*
			LL	*UL*	
Intercept	1.768	0.455	0.852	2.685	<.001
Impacts on residents	-0.505	0.162	-0.832	-0.178	.003
Fairness & transparency	0.302	0.135	0.029	0.574	.031
Economic impacts	0.343	0.199	-0.058	0.744	.092
Social norms	0.070	0.094	-0.119	0.260	.457
Attitude toward the energy transition	0.001	0.119	-0.239	0.241	.994

Note. *SE* = standard error; *CI* = confidence interval; *LL* = lower limit; *UL* = upper limit.

5.4 DISCUSSION

This study pooled data from resident surveys at two AWE test sites to assess whether the Integrated Acceptance Model (IAM), which has successfully explained wind project acceptance, could also predict residents' attitudes toward AWE. Pooling of the data served two purposes: to achieve a sample size large enough to calculate a sufficiently powered regression model and to detect universal patterns that generalize across (at least two) sites and regions.

The IAM effectively explained residents' acceptance of AWE sites, as evidenced by an adjusted R^2 of 0.69. However, this result primarily stemmed from just two of the five included explanatory variables: perceived impacts on residents and 'fairness & transparency'. Perceived impacts on residents capture the degree of annoyance caused by landscape impacts, sound, and aviation lights. 'Fairness & transparency' reflects residents' perceptions of how fairly the site operation is and how transparently the developer communicates. Unlike prior applications of IAM in wind energy research (Hübner et al., 2023), residents' acceptance of the AWE sites did not depend on their attitudes toward the energy transition nor the extent to which they perceive other community members to approve or disapprove of the site (i.e., social norms). Although economic impacts did not meet the statistical threshold for significance in the regression model (p = .09), the medium-sized regression coefficient suggests that this factor may still meaningfully relate to acceptance.

That **economic impacts** failed to achieve statistical significance in the regression could be explained by the fact that the variable was measured differently in the two studies, which could have introduced incongruency in the data: In Study 1, participants were asked to consider how a hypothetical commercial deployment of AWE in the region might affect the local economy. However, interviews revealed that respondents found it challenging to imagine these impacts. In response, Study 2 participants had to assess the actual impacts of the AWE test site on specific economic sectors, including agriculture, tourism, property values, and other branches. Due to its remote location in the peatlands and temporary, non-commercial operation, the test site had little impact on the first three sectors. Furthermore, the residents might not have been aware of the test site's limited but real economic contributions to other sectors, such as employing two local workers and supporting local businesses through developer staff's use of amenities like shops and accommodation (DEM-AWE, n.d.). The relatively neutral ratings in both studies suggest uncertainty about tangible economic impacts, which may help explain why this variable did not significantly predict local acceptance.

One possible explanation for the lack of explanatory power of **energy transition attitudes** is that AWE is not yet commercialized and, as a result, is not seen as contributing to renewable energy goals (BVG Associates, 2022). At the time of the study, electricity generated by the AWE test sites was stored on-site in batteries and not fed into the grid (DEM-AWE, n.d.). Besides, due to AWE's lacking maturity, laypeople find it difficult to estimate how much energy it can produce and whether it could substantially add to the energy transition (Section 4.3.2). In general, while established wind energy is a cornerstone of the energy transition, the addition of AWE represents a change to the current transition paradigm. It is, therefore, plausible that attitudes towards the energy transition affect the acceptance of AWE differently than for established wind energy.

Regarding **social norms**, prior research has shown that residents opposing a planned wind energy project tend to be more vocal and active than those who support it or are neutral (Firestone et al., 2018; Hübner et al., 2020; Liu et al., 2022; Sokoloski et al., 2018). By openly presenting its concerns, the so-called loud opposing minority gains more easily the attention of the local public and media, thereby shaping the discourse about a project (Bednarek-Szczepańska, 2023; Bjärstig et al., 2022; Diamond et al., 2024; cf. Schneider & Rinscheid, 2024). The distorted discourse can negatively influence public opinion and the perception of prevailing local norms regarding renewable developments (Read et al., 2013; Sokoloski et al., 2018). However, due to their smaller scale, temporary nature, and limited operational hours, it can be assumed that the AWE test sites were less subjected to public debate than the average commercial wind farm. Residents might, therefore, find it more difficult to gauge how other community members view the site. This difficulty became evident during the interviews with participants at Site 1, where no public planning process had taken place, and there had thus not been a formal forum for people to be exposed to others' opinions. While the planning process for Site 2 was public, the COVID-19 pandemic limited the community engagement that could take place. Additionally, as test sites do not generate profits, concerns about unequal benefit distribution, which often dominate discourses around commercial wind projects, are less prominent (Baxter et al., 2013; Brannstrom et al., 2022; Leer Jørgensen et al., 2020). These circumstances might explain why social norms did not predict the acceptance of the AWE sites.

In summary, residents' acceptance was primarily related to factors they could directly observe, such as perceived project impacts, the operation's fairness, and the developer's transparency. Other factors that are important for the acceptance of mature wind energy, such as social norms emerging from public discourse and the technology's role in the energy transition, seem to lack sufficient tangibility or visibility for AWE at this stage.

5.4.1 Limitations of the study

Several limitations should be considered when interpreting these results. Although the sample size was sufficient to achieve a statistical power of 0.80, a larger sample would have been needed for a more robust power of 0.95. Additionally, nature impacts – moderately correlated with acceptance in Study 1 (**Table 4.5**) – were not measured in Study 2 and thus could not be included in the regression analysis. Nature impacts, particularly bat and bird mortality, remain central to public debates on wind energy (Baxter et al., 2013; Brannstrom et al., 2022; Frantál et al., 2023; Nordstrand Frantzen et al., 2023; Wilson & Dyke, 2016). While AWE may pose less risk to wildlife than conventional wind turbines, future research should explore how perceptions of environmental impacts affect acceptance of AWE. Finally, stress complaints were not accounted for when assessing residents' annoyance with project impacts, although they are a more accurate indicator of stress response (Hübner et al., 2019; Pohl et al., 2018). Consequently, the study may have overestimated the effect of landscape impacts, sound emissions, and aviation lights on residents.

5.4.2 Future research recommendations

As AWE is still emerging, it is plausible that other factors that are less relevant to mature wind turbine technology are important. For example, as suggested, residents' belief in AWE's potential may be more predictive than their energy transition attitudes at this stage. It was considered to include safety perceptions of the AWE site as an additional predictor because the sector assumes them to be a major acceptance factor (Section 3.3.1). However, perceived safety was not significantly correlated with acceptance in the combined sample. Future research should thus explore which other variables can help predict community acceptance of AWE test sites beyond resident impacts and 'fairness & transparency'. Furthermore, future studies should apply the IAM to larger samples across AWE systems and regions to test the replicability and generalizability of these findings. As AWE moves closer to commercialization and begins to impact local economies and contribute to energy goals, it would be relevant to investigate if variables like economic impacts and energy transition attitudes become more predictive of acceptance. Given that AWE might initially especially be deployed in island nations, remote communities, and the Global South, it would be valuable to investigate if and how the IAM would have to be adapted to explain acceptance in non-Western and indigenous contexts

(BVG Associates, 2022; Krupnik et al., 2022; SkySails Power, 2023a). Indigenous communities commonly oppose wind energy projects because these projects often disregard traditional beliefs and knowledge, fail to respect tribal ways of life, and threaten natives' reliance on natural resources and land for survival (Kim et al., 2018; Lakhanpal, 2019; Normann, 2021; Ulloa, 2023). As a result, wind energy development in tribal areas is associated with neocolonial and extractive practices, including land grabbing and the perpetuation of existing environmental and social injustices (Cormack & Kurewa, 2018; Normann, 2021; Ulloa, 2023; Zárate-Toledo et al., 2019).

In summary, while resident impacts and 'fairness & transparency' emerged as significant predictors of local acceptance, additional research is needed to identify other relevant factors, especially as AWE evolves and scales up.

5.5 CONCLUSIONS

To date, AWE suppliers have predominantly concentrated on the technical, economic, and policy dimensions of technology development and deployment, which is understandable given the industry's race toward commercialization. Suppliers are pressured to address remaining technological challenges, secure necessary investments, and navigate the regulatory void, particularly regarding airspace regulations (Salma & Schmehl, 2023). However, assuming that community acceptance of AWE sites will naturally follow once these technical and policy hurdles are overcome would be a mistake. The findings reveal that residents who experience greater negative impacts from AWE test sites and are dissatisfied with the developer's transparency and fairness of site operations tend to be less accepting of the sites. These results align with established research on other renewable energies, such as wind farms, where project impacts and procedural justice aspects have been shown to play a crucial role in local acceptance.

CHAPTER 6

EXPLORING NOISE ANNOYANCE AND SOUND QUALITY FOR AIRBORNE WIND ENERGY SYSTEMS: A Listening Experiment[9]

9 **This chapter has been adapted from** Schmidt, H., Yupa-Villanueva, R. M., Ragni, D., Merino-Martínez, R., van Gool, P., & Schmehl, R. (2025). Exploring noise annoyance and sound quality for airborne wind energy systems: Insights from a listening experiment. *Wind Energy Science*, *10*(3), 579-595.

The last two chapters underscored the significant role of noise annoyance in community perceptions and acceptance of airborne wind energy (AWE) projects. This chapter investigates the acoustic and individual factors contributing to noise annoyance, aiming to inform techical design adjustments and mitigation strategies to reduce sound impacts on residents. The chapter begins with a focused discussion of noise annoyance (Section 6.1), followed by an outline of the study's method (Section 6.2). Next, it presents the results from the acoustic analyses and listening experiment (Section 6.3). The chapter closes with a reflection on study limitations, recommendations for future research, design implications, and concluding insights (Sections 6.4 and 6.5).

6.1 INTRODUCTION

Like all wind energy technologies, AWE systems must adhere to environmental regulations on sound emissions to minimize their impact on nearby communities (van Kamp & van den Berg, 2021). Noise is a primary source of opposition to wind turbines and plays a central role in debates about their social acceptance (Bednarek-Szczepańska, 2023; Kirkegaard et al., 2024; Taylor & Klenk, 2019). While the health impacts of sound emissions remain contentious, even within the scientific community (Kirkegaard et al., 2024; Taylor & Klenk, 2019), substantial evidence shows that people living near wind farms often report noise annoyance, frequently accompanied by complaints such as sleep disturbances, psychological distress, and general functional impairments (Bakker et al., 2012; Godono et al., 2023; Haac et al., 2019; Hübner et al., 2019; Ki et al., 2022; Michaud, Feder, et al., 2016; Müller et al., 2023; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen & Persson Waye, 2004, 2007; Pohl et al., 2018; Radun et al., 2019; Turunen et al., 2021). Noise annoyance is commonly defined as a negative reaction to sound emissions (Pohl et al., 2018).

AWE systems are often considered quieter than wind turbines because they operate at higher altitudes, where sound may dissipate more effectively (for a review, see Chapter 3:). However, this assumption overlooks several key factors influencing how sound is perceived. These include expected health impacts and individual dispositions, such as heightened noise sensitivity, especially to low-frequency sounds (Haac et al., 2019; Michaud, Keith, et al., 2016; Pedersen et al., 2010; Pedersen & Persson Waye, 2007; Schutte et al., 2007). Broader perceptions about the technology's aesthetics and fairness of planning processes and attitudes towards wind energy projects or the technology itself also affect the experience of noise annoyance (Haac et al., 2019; Hoen et al., 2019; Hübner et al., 2019; Ki et al., 2022; Michaud, Keith, et al., 2016; Müller et al., 2023; Pawlaczyk-Łuszczyńska et al., 2018; Pedersen & Larsman, 2008; Pedersen & Persson Waye, 2007; Schäffer et al., 2019; Tonin et al., 2016). Technical features of AWE systems, like tethers, onboard rotating components, and the high operating speeds of kites, can further contribute to specific annoyance-inducing sound characteristics. For example, tonal elements and sound modulation have been found to induce more annoyance in wind turbines (Hansen et al., 2021; Lee et al., 2011; Schäffer et al., 2018; Torija et al., 2019; Yokoyama & Tachibana, 2016; Yonemura et al., 2021).

Although research on the sound emissions of AWE systems is still limited, a recent Master thesis provided preliminary insights into the sound profiles of two AWE prototypes (Bouman, 2023). It compared a fixed-wing kite to a soft-wing kite (see Section 1.5 for an explanation of kite systems), finding that the fixed-wing kite exhibited a narrowband sound spectrum resulting from laminar flow on the suction side of the wing[10]. In contrast, the larger soft-wing kite produced a broadband sound spectrum primarily determined by turbulent boundary-layer[11] trailing-edge[12] noise. In simpler terms, the fixed-wing kite has air flowing smoothly over its surface in a laminar boundary layer, minimizing turbulence. Sound is produced when small disturbances (vortices) form at the trailing edge as the laminar flow detaches. For the soft-wing kite, the airflow is less smooth and more chaotic due to a turbulent boundary layer. The interactions of this turbulent airflow with the trailing edge produce a broader range of sound frequencies. These differences in sound patterns stem from the aerodynamic characteristics of each kite type, which are influenced by their shapes and surface materials. While these findings highlight the physical characteristics of AWE sound, their connection to noise annoyance remains unexplored.

The first field study examining noise annoyance associated with an AWE system (Chapter 4:) found that 35.2% of residents living, on average, 2 km from a soft-wing AWE system could hear its sound from their homes. Of these, 13.1% reported being annoyed (scoring at least 2 on a scale from 0 to 4), and 7.5% were highly annoyed (scoring at least 3). Among the investigated impacts – sound, aviation lights, and shadow – sound emissions caused the highest average levels of annoyance and affected the greatest number of residents. Additionally, noise annoyance showed the third strongest correlation with attitudes toward the AWE system, after aviation light annoyance and developer transparency, highlighting the importance of sound as an impact factor. However, the study did not explore how specific types of sound emissions affected annoyance, leaving an important gap in understanding the full impact of AWE sound on communities.

10 The **suction side** of a wing or rotor blade is the upper surface, where the flow moves faster, creating a low-pressure region compared to the lower surface. This pressure difference generates the lift force. Suction refers to the lower pressure acting as if it "pulls" the wing or rotor blade upward.

11 A **boundary layer** may be laminar or turbulent. A laminar boundary layer is a smooth and orderly flow along a surface where fluid particles move in layers with minimal lateral mixing. This type of flow is common in regions of lower velocities and decreasing pressure along the flow. In a turbulent boundary layer, the flow exhibits chaotic motion, with significant mixing and increased energy dissipation. This flow type occurs at higher velocities and increasing pressure along the flow. It is characterized by higher skin friction than the laminar boundary layer.

12 The **trailing edge** is the rear-most part of a wing or rotor blade where the flows along the upper and lower surfaces meet again and proceed further downstream as wake flow. This region plays a critical role in generating lift, drag, and noise due to the interaction of the two flows and the shedding of vortices.

The AWE industry has historically focused on improving system reliability and scalability with less attention to sound mitigation. However, developers are increasingly recognizing the challenges posed by sound emissions (Junge et al., 2023) and are beginning to develop measurement methods and gather insights to mitigate its effects. Early acoustic research plays a critical role in identifying factors contributing to noise annoyance. This knowledge can help guide the design of quieter systems before designs become fixed.

Most research on wind turbine sound has used conventional metrics, such as the equivalent sound pressure level (L_{eq}) or its *A*-weighted version (L_{pAeq}), which accounts for the sensitivity of the human ear to mid-range frequencies from 500 Hz to 6 kHz (Kephalopoulos et al., 2014; Pieren et al., 2019). However, these metrics often fail to capture specific sound properties that are strongly linked to annoyance (Bockstael et al., 2011; Pedersen & Persson Waye, 2004; Persson Waye & Öhrström, 2002; Pieren et al., 2019). For example, the tonal and high-frequency content of turbine sound (Oliva et al., 2017; Persson Waye & Agge, 2000; Yokoyama & Tachibana, 2016). Other metrics, like the Effective Perceived Noise Level (EPNL), were developed for aircraft noise and include factors like spectral content and tonal components (Noise Standards: Aircraft Type and Airworthiness Certification, 2017). While useful, they may not fully address the unique sound characteristics of AWE systems.

Sound quality metrics (SQMs) provide an alternative approach by focusing on perceptual aspects of sound, such as loudness, tonality, and sharpness (Greco et al., 2023). These metrics have been used in research on wind turbines (Merino-Martínez, Pieren, et al., 2019; Persson Waye & Öhrström, 2002; Pockelé & Merino Martínez, 2024) and aircraft noise (Merino-Martínez, Vieira, et al., 2019; More, 2010; Pereda Albarrán et al., 2017, 2018; Sahai, 2016; Vieira et al., 2019), showing promise for better understanding annoyance.

This chapter investigates to what extent SQMs predict noise annoyance caused by AWE systems. Participants were not required to be familiar with SQMs, as these metrics were objectively derived from acoustic analyses of recorded AWE sounds. The research also explores psychoacoustic annoyance (PA) models, which combine multiple SQMs into a single predictor of annoyance. PA models were compared with the conventional EPNL metric to evaluate their effectiveness in predicting annoyance. By analyzing recordings from both soft-wing and fixed-wing kites, this chapter uses a controlled listening experiment to assess annoyance ratings for AWE systems.

6.2 METHOD

This section explains the methods for recording sound samples and conducting the listening experiment. It includes details about the sound recordings, participant characteristics, annoyance ratings, and laboratory procedures. The institutional review board of Delft University of Technology approved the study.

6.2.1 Sound recordings

For the listening experiment, nine sound recordings were collected from three different AWE systems, with three recordings from each prototype. Each recording was 25 seconds long, extracted from longer audio recordings. All three AWE systems used ground-based electricity generation (Section 1.5). Of these, one was a soft-wing kite (Kite A), and the other two were fixed-wing kites (Kites B and C)[13]. Additional details about the kites and the sound measurement campaigns are provided in **Table 6.1**.

The recordings were chosen to represent the typical sound emissions during the reel-out phase of the AWE systems' operation. In this phase, the kites perform high-speed crosswind maneuvers while the reel-out speed is kept relatively low to maximize energy production. This operational setup results in the most significant sound emissions from the kites, which include contributions from onboard components (e.g., ram-air turbines), wing flutter, and vibrations of the tether. By contrast, the ground station (e.g., the generator) emits minimal sound during this phase due to the relatively low reeling speed.

Since specific sound regulations for AWE systems do not currently exist, the sound pressure levels of the recordings were normalized to an *A*-weighted sound pressure level (45 dBA). This normalization aligns with European wind turbine regulations, which typically require sound levels to remain between 35 dBA and 55 dBA during the day (Solman & Mattijs, 2021). Normalization refers to adjusting the sound pressure levels of recordings to a consistent reference value, ensuring that all samples are directly comparable. *A* weighting is a standard method used to adjust sound measurements to reflect the sensitivity of the human ear, particularly to frequencies between 2 and 5 kHz. Normalizing the sound levels also ensures that the acoustic evaluation focuses on other aspects of sound quality, such as tonality or roughness, rather than just loudness (Boucher et al., 2024).

13 The word kite is used in this chapter to refer to the airborne component of the AWE system.

Table 6.1
Investigated AWE Systems and Corresponding Sound Measurement Campaigns

Variable	Kite A	Kite B	Kite C
Kite type	Soft wing	Fixed wing	Fixed wing
VTOL propellers	None	Present, inactive	Present, inactive
Ram-air turbine	Present, tied down	None	Present, active
Flight pattern	Figure of eight	Circle	Circle
Wind speed (m/s)	5–10	9	8–9[a]
Max airspeed (m/s)	38	42	43
Max altitude (m)	253	231	150
Distance to microphone (m)	428–620	305–689	Approximately 100–700
Test location and type	Field; standard flight test	Inoperative airfield; standard flight test	Inoperative airfield; tow test[b]
Recording instrumentation	Brüel & Kjær 4189 microphone at 1 m height and 650 m downwind from the winch of the ground station. Brüel & Kjær UA-650 windscreen over the microphone to reduce wind sounds. Brüel & Kjær sound level meter 2250.	Brüel & Kjær 4189 microphone at 1 m height and 679 m downwind from the winch of the ground station. Brüel & Kjær UA-1650 windscreen over the microphone to reduce wind sounds. Brüel & Kjær sound level meter 2250.	Three Brüel & Kjær 4189 microphones at equal distances along the driving route.

Note. VTOL: vertical take-off and landing.
[a] Ambient wind speed; towing speed was higher.
[b] The kite was flown crosswind in loops of 60–70 m diameter while the ground station was being towed by a truck to simulate a wind field. The vehicle sounds were mainly emitted at the ground level and absorbed by padded microphone covers.

6.2.2 Psychoacoustic Listening Laboratory

The listening experiment was conducted in the Psychoacoustic Listening Laboratory (PALILA) at the Faculty of Aerospace Engineering, Delft University of Technology. PALILA is a specially designed, soundproof booth for studying how humans perceive aeroacoustic sounds, such as those from aircraft, drones, and wind turbines. The booth measures 2.32 m in length, 2.32 m in width, and 2.04 m in height, with a background sound level of just 13 dBA. For further details on PALILA's design and acoustic characteristics, see Merino-Martínez et al. (2023).

The audio system used in the experiment included a Dell Latitude 7420 laptop (Intel® Core™ i5-1145G7 vPro® processor, 16 GB RAM), connected via a universal audio jack to a pair of Sony WH-1000XM4 headphones. These closed-back headphones support binaural (two-ear) hearing with a 40 mm dome driver unit, a 4 Hz to 40 kHz frequency range, and a 105 dB/mW sensitivity at 1 kHz. The system was calibrated using a G.R.A.S. 45BB-14 KEMAR head and torso simulator to ensure accurate sound reproduction. During the experiment, participants sat at the booth's center, with the laptop on a table in front of them, as shown in **Figure 6.1**.

Figure 6.1. Laboratory setup used for the listening experiment on noise annoyance.
Source: Roberto Merino-Martínez

6.2.3 Participant recruitment and experimental procedure

Participants were recruited through convenience and snowball sampling (Passer, 2014), primarily targeting students and employees of the university (Appendix D). Participants were eligible when they reported no hearing impairments and felt physically well on the day of the experiment. Data collection occurred between June and September 2023.

A trained experimenter briefed each participant individually and obtained written consent before the participant completed the experiment independently. The experiment began with a questionnaire to collect information about participants' hearing ability, history of hearing-affecting incidents, and well-being. Participants then engaged in a practice round to familiarize themselves with the listening part and rating scales. The listening part consisted of two counterbalanced blocks: one for AWE sounds (the focus of this chapter) and one for wind turbine sounds (not reported here). A mandatory one-minute break separated the blocks. The sequence of sound recordings within each block was randomized to reduce potential biases on annoyance ratings, such as learning or order effects (Passer, 2014). Participants listened to each sound recording once and provided an annoyance rating. A replay of recordings was not possible. After completing the listening tasks, participants answered additional questions on noise sensitivity, familiarity with AWE systems, and demographic information. At the end of the session, participants were debriefed and given a €20 voucher as compensation for their time. On average, participants took 22 minutes to complete the experiment, excluding the experimenter's briefings.

6.2.4 Annoyance ratings and questionnaire

Noise annoyance was defined according to the ISO 15666 standard as an adverse reaction to sound, which may include feelings of dissatisfaction, bother, or disturbance caused by sound exposure (Acoustics — Assessment of Noise Annoyance by Means of Social and Socio-Acoustic Surveys, 2021). To measure annoyance in line with the definition and recommended practice for psychoacoustic research (Alamir et al., 2019), the study used the International Commission on Biological Effects of Noise (ICBEN) scale and recorded ratings on both a verbal and a numerical scale. The average of these two scales was calculated to improve reliability (Acoustics — Assessment of Noise Annoyance by Means of Social and Socio-Acoustic Surveys, 2021):

1. The **5-point verbal scale** ranged from "not at all" (0) to "extremely" (4). Participants were asked: "Imagine you are at home and hearing the noise at home; how much does the noise bother, disturb, or annoy you?"
2. The **11-point numerical scale** ranged from 0 ("not at all") to 10 ("extremely"). Participants were asked: "Imagine you are at home and hearing the noise at home; what number from 0 to 10 best shows how much you are bothered, disturbed, or annoyed by the noise?"

The original wording of the scales was slightly modified here to acknowledge the laboratory setting.

Participants also self-reported their hearing ability on a 5-point scale (from "poor" to "excellent"), which is a valid alternative to audiometric testing (Hong et al., 2011). They provided information on hearing impairments (e.g., use of hearing aids, tinnitus, ear diseases, or exposure to loud environments) and general well-being (e.g., whether they had a cold or were fatigued).

Noise sensitivity was assessed using the 12-item condensed NoiSeQ scale, a validated measure with a high internal consistency of α = .87 (Griefahn, 2008). Participants rated their agreement with statements on a 4-point scale, such as: *"When I am at home, I quickly get used to noise"* (reverse coded) and *"When people around me are noisy, I find it hard to do my work."* Participants were also asked about their familiarity with AWE systems and whether they had ever heard one. Demographic information (e.g., age, gender, education level) was also collected. A custom graphical user interface (GUI) developed in MATLAB R2021b guided participants through the experiment.

6.2.5 Analyses

6.2.5.1 Statistical analyses

To analyze annoyance ratings, responses from the verbal and numerical scales were transformed to a 0–100 scale and averaged (Brink et al., 2016). The verbal and numerical scales were strongly correlated in this study, justifying their combination (Tau-*b* correlations: .75 to .88). This transformation enabled the calculation of the percentage of highly annoyed (%HA) participants for each kite type, defined as those scoring 72 or higher on the 100-point scale (Acoustics — Assessment of Noise Annoyance by Means of Social and Socio-Acoustic Surveys, 2021; Miedema & Vos, 1998).

Linear-mixed effects models were used to identify annoyance predictors and assess differences in annoyance between the three kites. Linear-mixed effects models have been successfully employed in research on wind turbine noise annoyance (Merino-Martínez et al., 2021; Schäffer et al., 2016, 2019). This type of analysis can separate fixed effects (e.g., acoustic predictors) from random effects (e.g., individual differences among participants). In this study, sound recordings were nested within kite types as each participant rated all recordings associated with the three kites. Furthermore, participants formed another level of nesting, as each individual provided multiple ratings across the different kite types. The nested structure was accounted for by including random effects for both participants and kite types (Judd et al., 2017). The conditions were contrast-coded to facilitate interpretation and included as random effects. This approach enabled the modeling of variability in annoyance ratings arising from individual participant characteristics and variations among the kite types.

Predictor variables were introduced stepwise (Aguinis et al., 2013). First, participant characteristics were included as fixed effects to evaluate their predictive value for annoyance ratings. Second, the SQMs were added as fixed effects, with each metric assessed in separate models to prevent multicollinearity. Third, the effects of the SQMs were randomized to investigate whether their influence varied across individuals. Finally, interaction terms between participant characteristics and SQMs were included to determine if participant traits could explain individual differences in how SQMs impacted annoyance ratings.

The goodness of fit of the final models was assessed using the -2 log-likelihood ratio, comparing models with only fixed effects to those with both fixed and random effects. Separate linear mixed-effects models were used to assess the predictive effectiveness of the EPNL and PA models for annoyance ratings. All statistical analyses were conducted using R version 4.4.0 (R Core Team, 2023), with the linear mixed-effects models fitted using the 'lme4' package (Bates et al., 2024).

6.2.5.2 Acoustic analyses

The EPNL (Kephalopoulos et al., 2014; Pieren et al., 2019) and five SQMs (Merino-Martínez et al., 2021) were calculated for each considered sound wave of every recording to assess their ability to predict annoyance. The SQMs were:

- Loudness: The perception of sound intensity, calculated using the ISO 532-1 standard (Acoustics Methods for Calculating Loudness, Part 1: Zwicker Method, 2017).
- Tonality: The perception of spectral irregularities of pure tones, based on Aures' method (1985).
- Sharpness: The perception of high-frequency components, using DIN 45692:2009's (Measurement Technique for the Simulation of the Auditory Sensation of Sharpness, 2009).

- Roughness: The perception of rapid sound fluctuations (15-300 Hz), calculated using Daniel and Weber's method (1997).
- Fluctuation strength: The perception of slow sound level fluctuations, following Osses Vecchi et al. (2016).

The five SQMs were analyzed over time using a subset of the full sound recordings to evaluate the consistency of the metrics across the 25-second duration. The 5th percentile values, representing levels exceeded during 5% of the recording time, were used for this assessment. It is important to note that descriptive terms such as 'harsh', 'beating', and 'tonal' are employed later to interpret the SQM results from the acoustic analysis. Participants did not provide these terms during the experiment, but they were instead derived from the analysis for explanatory purposes. psychoacoustic annoyance (PA) metrics, which combine multiple SQMs into a single value, were calculated using models from Zwicker and Fastl (1999), More (2010), and Di et al. (2016). All metrics were computed using the open-source MATLAB Sound Quality Analysis Toolbox (SQAT) v1.1 (Greco et al., 2023).

6.3 RESULTS

This section summarizes the sample's demographics, followed by key acoustic findings. It then concludes with an analysis of annoyance ratings and SQMs.

6.3.1 Sample characteristics

The study included 75 participants, of which 73.3% were male, 24% female, and 2.7% non-binary. The substantially higher proportion of male participants can be attributed to recruitment from a technical university. Participants' ages ranged from 18 to 66 years, with an average age of 28 (SD = 9.57). The sample was highly educated: 74.7% held a Bachelor's or Master's degree, 16% were currently or previously enrolled in university, and 8% held a doctoral degree. Participants generally reported very good hearing abilities (M = 4.07, SD = 0.64, on a 1–5 scale) and medium noise sensitivity (M = 1.56, SD = 0.38, on a 0–3 scale).

Approximately half of the participants (n = 37) were familiar with AWE systems. However, only 17.3% (n = 13) had heard an AWE system before the experiment. The high familiarity with AWE systems likely stems from the presence of a prominent research group at the faculty, exposing them to AWE through academic activities. Despite this familiarity, most participants had theoretical knowledge rather than practical experience with the technology. Consequently, experience with AWE sounds was not treated as a confounding factor in subsequent analyses.

6.3.2 Acoustic results

Given that this dissertation focuses on the social science dimension of noise annoyance, only the main acoustic findings are summarized here. More detailed acoustic analyses can be found in the original publication (Schmidt et al., 2025).

Spectrograms[14] revealed that each kite (soft-wing A, fixed-wing B, and fixed-wing C) produced distinct sound profiles, likely in part due to differences in flight patterns (e.g., figure-eight vs. circular trajectories) and kite design (e.g., fabric vs. rigid structures). Time-averaged sound pressure levels[15] showed that the fixed-wing kites (B and C) tended to have more pronounced tonal components, while the soft-wing kite (A) produced broader, more evenly spread sound. Kite

14 **Spectrograms** visually represent how a sound's frequency content changes over time. They show how loud each frequency is at a given moment.

15 **Time-averaged sound pressure levels** (SPLs) provide a single measure of loudness over a specified time period by averaging all sound pressure values in that interval.

C, in particular, displayed peaks attributable to its ram-air turbine, resulting in higher sharpness and tonality values.

An analysis of the SQMs revealed that loudness[16] varied across recordings but tended to be highest for recording C3; tonality and sharpness were notably higher for Kite C, aligning with its more tonal and high-frequency sound seen in the spectrograms. In contrast, Kite A generated lower tonality and sharpness. Regarding roughness, Kite B produced the 'harshest' sounds, while Kite C was the least 'harsh'. In terms of fluctuation strength, Kite B had the strongest 'beating' effect, whereas Kite C exhibited less pulsation. These differences in acoustic characteristics are important for annoyance responses, as will be explored in the next section.

6.3.3 Sound quality and its influence on noise annoyance

The average noise annoyance ratings for the three kite types ranged from approximately 34 for Kite A to 54 for Kite C (**Figure 6.2**). For comparison, Merino-Martínez et al. (2021) reported higher annoyance ratings (61-72 when converted to a 0-100 scale) for wind turbine sounds in a laboratory experiment, even though their sound levels (38 dBA) were lower than those used here (45 dBA).

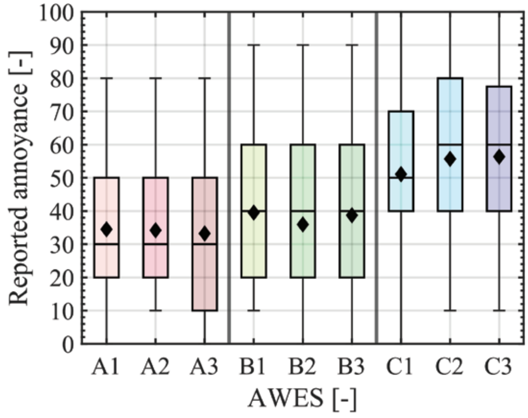

Figure 6.2. Box plots of annoyance ratings by recording, categorized by kite type. The diamond marks the mean, and the horizontal line marks the median.

16 SPLs are physical measurements that capture in decibels (dB) how much acoustic energy is present, while the SQM **loudness** considers human hearing sensitivities – such as how certain frequencies are perceived as louder – thus offering a better reflection of how "loud" the sound feels to an actual listener.

The percentage of participants classified as highly annoyed (%HA) varied across kite types from approximately 1% to 23% (**Table 6.2**), with Kite C showing the highest %HA, followed by Kite B and then A. This pattern corresponds to higher sharpness and tonality values for Kite C compared to the other kites. The %HA observed here (1–23%) is narrower than the 2–34% range predicted by Schäffer et al. (2016) for wind turbine sound exposure in similar laboratory conditions.

Table 6.2
Percentage and Frequency of Highly Annoyed Participants (%HA) by Kite Type

Kite Type	%HA
A (soft wing)	1.3 (2)
B (fixed wing)	6.7 (5)
C (fixed wing)	22.7 (17)

Annoyance differences across kite types: Using a linear mixed-effects model, pairwise comparisons revealed significant differences in annoyance ratings among all kite types ($p < .05$): Kite C was rated as the most annoying ($M = 54.39$, $SD = 22.91$), followed by Kite B ($M = 39.78$, $SD = 22.04$), and Kite A was the least annoying ($M = 33.98$, $SD = 20.47$).

Impact of participant characteristics on annoyance: A separate linear mixed-effects model was calculated to examine whether noise annoyance depended on participant characteristics. Noise sensitivity significantly predicted annoyance ratings ($t = 2.035$, $p < .05$), with noise-sensitive individuals rating the sounds as more annoying. Neither age ($p = .187$) nor familiarity with AWE systems ($p = .956$) significantly predicted annoyance ratings.

Impact of sound quality metrics (SQMs) on annoyance: A linear mixed-effects model of the relation between annoyance ratings and SQMs showed that only sharpness significantly predicted annoyance ($t = 2.285$, $p = .023$). This finding aligns with the fact that Kite C exhibited higher sharpness values and was perceived as more annoying than the other two kites. Tonality, loudness, roughness, and fluctuation strength showed no significant effects on annoyance (all p's > .05).

Individual differences in SQM impact on annoyance: To evaluate whether the impact of the SQMs on annoyance varied across participants, models treating SQMs as random effects were compared with fixed-effects models, computing the -2-log likelihood ratio between these models. Random-effects models for loudness ($\chi^2(1) = 18.725$, $p < .001$), sharpness ($\chi^2(1) = 9.121$, $p = .003$), tonality ($\chi^2(1) = 7.146$, $p = .008$), and roughness ($\chi^2(1) = 8.723$, $p = .003$) provided better fits, indicating that individual differences influenced how these sound qualities affected participants' annoyance ratings. Fluctuation strength did not show significant variability ($p > .05$).

Interactions between SQMs and participant characteristics: To explore whether the measured participant characteristics could account for the observed differences in SQM impact, interactions between SQMs and participant characteristics (i.e., noise sensitivity, age, and familiarity) were examined in the random-effects models. The results revealed that familiarity with AWE systems weakened the impact of loudness on annoyance ($t = -2.902$, $p = .005$). That is, the effect of loudness on annoyance was weaker for those more familiar with AWE systems. Furthermore, age weakened the impact of tonality on annoyance ($t = -2.233$, $p = .028$). Older participants were less affected by tonality in their annoyance ratings, independent of their self-reported hearing ability. Other SQMs (sharpness, roughness, and fluctuation strength) showed no significant interactions with participant characteristics (all p's > .05).

The full model, which included interactions between SQMs and participant characteristics, explained 19% of the variance in annoyance scores due to fixed effects and 82% when random effects were also considered. This highlights the importance of accounting for individual differences in sound perception.

Predicting annoyance with the Effective Perceived Noise Level (EPNL) and psychoacoustic annoyance (PA) models: Finally, it was examined whether EPNL, as a conventional metric, and three PA models (Di et al., 2016; More, 2010; Zwicker & Fastl, 1999) could predict annoyance ratings. Linear mixed-effects models indicated that EPNL was not a significant predictor ($p = .515$). Similarly, the PA models comparing estimated annoyance scores with reported annoyance did not show significance (all p's > .05). Because PA models rely heavily on loudness, the normalization of all recordings may explain why these metrics failed to predict annoyance effectively.

6.4 DISCUSSION

This study used a controlled listening experiment to investigate how sound quality metrics (SQMs) relate to noise annoyance in AWE systems. Among the SQMs examined, only sharpness emerged as a significant predictor of annoyance. The investigated fixed-wing kites elicited higher annoyance than the soft-wing kite, likely due to sharper and more tonal sound profiles. In contrast, the soft-wing kite, though louder, produced a broadband sound linked to the aerodynamic features of its fabric-based design. The tonal signature of fixed-wing kite C likely arose from its ram-air turbine.

Participant characteristics played a role in annoyance responses: Individuals familiar with AWE systems were less annoyed by louder sounds than unfamiliar individuals, and older participants were less bothered by more tonal sounds than younger participants. However, these effects should be interpreted with caution, given the non-representative nature of the sample. Participants familiar with AWE systems may have held more positive attitudes toward AWE, potentially explaining their lower levels of noise annoyance – a pattern reported in studies on wind turbines (Dällenbach & Wüstenhagen, 2022; Hoen et al., 2019; Hübner et al., 2019). Noise-sensitive individuals were generally more annoyed by the recordings, aligning with wind turbine research (Haac et al., 2019; Michaud, Keith, et al., 2016; Pedersen et al., 2010; Pedersen & Persson Waye, 2007; Schutte et al., 2007). Contrary to similar research on wind turbines and drones (Kawai et al., 2024; Merino-Martínez et al., 2021), the Effective Perceived Noise Level (EPNL) and psychoacoustic annoyance (PA) models did not predict annoyance in this context, likely due to normalization of sound pressure levels across recordings.

This study builds on findings from research on wind turbines and drones, which share acoustic and operational similarities with AWE systems. Wind turbine studies often focus on sound pressure levels, while few investigate SQMs. However, some work suggests that tonality and loudness can predict annoyance (Merino-Martínez et al., 2021; Yonemura et al., 2021). By contrast, drone research has given more attention to SQMs, consistently identifying loudness, tonality, and sharpness as major predictors of annoyance (Casagrande Hirono et al., 2024; Green et al., 2024; Kawai et al., 2024; König et al., 2024; Torija & Nicholls, 2022). Drones or unmanned aircraft are similar to AWE systems in their dynamic flight stages and use of propeller-like mechanisms. While the current research confirmed sharpness as a key predictor of annoyance, tonality and loudness were significant only when interacting with participant characteristics (i.e., age and familiarity).

6.4.1 Limitations of the study

These findings should be viewed in light of several limitations.

1. **Convenience sampling:** A convenience sample of students and employees at a technical university introduces potential selection bias and limits generalizability, especially to residents in areas where AWE systems might be deployed. The sample was relatively young, predominantly male, and highly educated, which does not represent the full range of people encountering AWE sound in real-life settings.
2. **Laboratory conditions:** The controlled laboratory environment, while ensuring consistency, did not replicate real-world listening conditions. Participants rated annoyance without contextual factors like visual exposure to AWE systems, other environmental sounds (e.g., traffic), or social and psychological influences (e.g., perceptions of fairness), all of which can shape noise annoyance in the field.
3. **Short-term annoyance** ratings cannot capture the potential cumulative effects of extended or repeated sound exposure.
4. **Sample size:** Although 75 participants are a sizable sample for a listening study (Alamir et al., 2019), subtle effects or interactions – particularly those related to individual differences (e.g., age, familiarity, noise sensitivity) – may not have been accurately detected.
5. **Limited prototypes and operational conditions:** The study only investigated three ground-gen AWE prototypes (one soft-wing and two fixed-wing kites) during reel-out, so the results may not apply to other AWE designs or operational conditions, which can be assumed to exhibit different sound profiles. Furthermore, the ram-air turbine of Kite A was tied down to better study the acoustic properties of the kite itself. However, regular operation suggests that the turbine is a major noise source.
6. **Recording challenges:** The study's methodology faced challenges due to varying distances to the microphone (100–700 m) and the kites' movement. Normalizing to 45 dBA helped to eliminate some fluctuation in the recordings, but the dynamic flight patterns still introduced variability different from stationary wind turbines. Additionally, the observer's location affects which sound sources dominate. For instance, the kite might prevail when positioned overhead, while sounds from the generator or tether vibrations may be louder closer to the ground station. Environmental factors such as wind sounds and ground reflections could also have influenced the recordings despite using windscreens.

These limitations underscore that the findings offer only restricted applicability to real-world conditions. As noted by Schäffer et al. (2016), results from laboratory and field studies should be seen as complementary, not directly interchangeable.

6.4.2 Future research recommendations

To address these limitations and advance the understanding of AWE sound perception, future research should examine annoyance during different stages of AWE systems' operational cycles to identify the phases most likely to cause annoyance and enable targeted mitigation strategies. For drones, annoyance often peaks during take-offs and landings (Green et al., 2024; Kawai et al., 2024), suggesting that AWE systems might exhibit a similar pattern. Including a broader range of AWE prototypes would capture diverse sound profiles and operational characteristics. Conducting field studies under realistic conditions – accounting for background sound, visual exposure, and project characteristics – would yield more ecologically valid insights into annoyance. Researchers should also explore extended exposure and repeated sound events, focusing on issues like sleep disruption and stress. Past research on wind turbine sound shows that measuring stress symptoms next to self-reported annoyance helps to estimate better sound-related disturbance (Pohl et al., 2018). Engaging a wider demographic, especially those living near proposed or current AWE sites, would ensure that findings better reflect the populations most affected. Lastly, developing sound prediction models specifically designed for AWE operations (e.g., varying speed and flight trajectories) is crucial to mitigate noise annoyance more effectively.

6.4.3 Design and operational implications

The still early development stage of AWE systems provides unique opportunities to mitigate annoyance through targeted optimizations:

- **Tunable system parameters**: Unlike conventional wind turbines, AWE systems allow for adjustments to size, speed, altitude, and flight patterns. For instance, larger kites flying higher might reduce sharpness and amplitude modulation, while faster, lower-altitude operations could work in areas less sensitive to loudness (e.g., industrial areas). Research on wind turbines shows that stronger amplitude modulation is related to more annoyance (Hansen et al., 2021; Lee et al., 2011; Schäffer et al., 2018).
- **Ram-air turbine optimization**: The onboard turbine powering the kite's control unit and sensors can be engineered for minimal sound emissions

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without negatively affecting the system's energy output and economic performance.

- **Flight path design**: Optimizing flight paths by using larger figure-eight loops or controlling reel-in and reel-out speeds may reduce modulation effects and tonal sound, respectively.
- **Customized configurations**: AWE systems can be tailored to specific sites, balancing energy efficiency with acoustic considerations. Quieter setups may suit residential areas, whereas more efficiency-driven designs might be fine in remote locations.
- **Proactive engagement**: Industry actors should involve communities early, sharing psychoacoustic data to clarify potential sound impacts and designing and testing mitigation strategies collaboratively (Kirkegaard et al., 2023; Solman et al., 2023).

By leveraging these design possibilities, the AWE industry can more effectively address sound issues, potentially reducing community impacts and facilitating the technology's implementation.

6.5 CONCLUSIONS

This research identifies sharpness as a primary predictor of noise annoyance caused by AWE systems, with fixed-wing kites rated as more annoying than a soft-wing kite. While the soft-wing kite had a louder sound profile, the fixed-wing kites had sharper and more tonal sound signatures. Individual factors, such as familiarity with AWE systems and participant age, influenced how loudness and tonality contributed to annoyance. Older participants were less sensitive to tonal sounds, while those familiar with the technology were less bothered by sounds perceived as louder. This underscores the subjective nature of sound perception. The conventional sound measure EPNL and the psychoacoustic annoyance models did not reliably predict annoyance in this study, highlighting the need for tailored acoustic models for AWE. From a design perspective, targeted optimizations – such as adjusting flight patterns, refining the ram-air turbine, and tailoring system parameters – could help mitigate noise annoyance. Future research should extend to real-world settings, incorporate long-term sound exposure, and evaluate additional AWE prototypes.

CHAPTER 7

GENERAL DISCUSSION

The Science, Technology, Engineering, and Mathematics disciplines are commonly seen as the architects of the energy system, responsible for creating the technologies and financial instruments that drive the energy transition (Krupnik et al., 2022). When the solutions developed by these fields are met with resistance or fail to gain traction, social sciences are called on to analyze, critique, and solve these issues (ibid.). This reactive approach, where social insights are incorporated only after challenges arise, limits the influence of social scientists on shaping the energy transition (ibid.). In contrast, proactive integration of social research during the early stages of technical development could offer new perspectives and ways of understanding this domain and promoting a just energy transition[17] (Kirkegaard et al., 2023; Krupnik et al., 2022).

The airborne wind energy (AWE) field provides a unique opportunity for this proactive approach. AWE is still in its developmental phase, with design choices, deployment practices, and regulatory frameworks not yet fixed. This dissertation is among the first research to explore the social dimensions of AWE, focusing on community acceptance – residents' approval of local energy projects – and its influencing factors. It demonstrated that community acceptance depends on technical characteristics, subjective perceptions, and the fairness and transparency of project implementation. Stronger perceived impacts – such as sound emissions, landscape impacts, and aviation lights – corresponded with lower community acceptance, while fair and transparent implementation was related to higher acceptance. Noise annoyance emerged as a critical factor, shaped by both psychoacoustic properties and individual characteristics.

The following sections revisit the key findings from the research (Section 7.1), identify critical limitations (Section 7.2), and outline implications for future research (Section 7.3), policy and practice (Section 7.4).

17 A just energy transition involves shifting from fossil fuels to sustainable energy sources in a manner that ensures, at a minimum, distributive justice (i.e., fair distribution of the costs and benefits of the transition), procedural justice (i.e., inclusive and transparent decision-making processes), and recognitional justice (i.e., special consideration of the interests of marginalized or vulnerable groups, Romero-Lankao et al., 2023).

7.1 SUMMARY OF FINDINGS

A comprehensive review of the AWE literature (Chapter 3:) revealed a rather optimistic perspective within the sector. The claim that AWE would be more socially acceptable than conventional wind turbines due to lower visual, sound, and ecological impacts was common but lacked empirical support. Only safety and siting issues were recognized as potential acceptance bottlenecks. These optimistic assumptions could lead to poorly informed policies, suboptimal design decisions, and deployment practices that increase rather than reduce public concerns and jeopardize the technology's long-term success. Moreover, the review showed that until recently, research on AWE had been dominated by technical studies, with minimal interdisciplinary collaboration outside the technical domains.

To assess the validity of the sector's assumptions, a field study (Chapter 4:) compared residents' perceptions of a local AWE system and a nearby wind farm. The results showed that while the AWE system was perceived as less visually intrusive, it was rated similarly to the wind farm regarding sound, safety, and ecological impacts. Residents experiencing greater negative impacts were less accepting of the AWE system, while perceptions of developer transparency and fairness correlated with higher acceptance and lower noise annoyance.

Expanding on these findings, a cross-country study in Germany and Ireland (Chapter 5:) identified key predictors for community acceptance of AWE. Understanding the key factors driving acceptance is essential for developing effective, targeted mitigation measures and deployment practices. Using the Integrated Acceptance Model (IAM), the study showed that impacts on residents, such as noise annoyance, visual impacts, and aviation light annoyance, were strong negative predictors of acceptance. Developer transparency and fairness emerged as significant positive predictors. However, variables like attitudes toward the energy transition, perceived economic impacts, and social norms did not predict acceptance. This lack of influence likely reflects the temporary and non-commercial nature of the investigated AWE projects at the time of study.

As noise annoyance emerged as a critical factor in community acceptance of AWE in the earlier studies, a controlled listening experiment was conducted to investigate the acoustic and individual factors influencing noise annoyance. The goal was to guide technical design improvements and mitigation strategies to reduce the impact of sound emissions on residents. The results revealed that fixed-wing kites were perceived as more annoying than soft-wing kites, likely due to their sharper and more tonal sound. Sharpness and individual noise sensitivity were significant predictors of annoyance, with sharper sounds causing more annoyance and noise-sensitive participants being more annoyed overall. Additionally, older participants were less bothered by tonal recordings than younger participants. Familiarity with AWE also played a role, as participants already familiar with the technology reported less annoyance to (subjectively) louder recordings than those who were unfamiliar.

The research builds extensively on studies of established renewables, particularly wind turbines. Overall, the patterns observed for AWE align closely with those found in wind energy acceptance research: (1) **Perceived project impacts**, including landscape impact and fit, sound emissions, and aviation lights, negatively affect community acceptance. These findings mirror previous research on wind energy projects (c.f., Aaen et al., 2022; Haac et al., 2019; Hoen et al., 2019; Hübner et al., 2019, 2023; Pohl et al., 2021; Rand & Hoen, 2017); (2) **developer transparency and fair project operation** positively predict community acceptance, which is a common finding in wind turbine research (c.f., Gross, 2007; Hoen et al., 2019; Hogan, 2024; Hübner et al., 2023; Walker & Baxter, 2017); and (3) **noise annoyance** is tied to both objective factors like sound quality (e.g., loudness, tonality, and sharpness) and subjective factors, such as noise sensitivity, technology familiarity, and fairness and transparency perceptions, similar to wind energy projects (Haac et al., 2019; Hübner et al., 2019; Lee et al., 2011; Merino-Martínez, Pieren, et al., 2019; Michaud, Keith, et al., 2016; Müller et al., 2023; Oliva et al., 2017; Pawlaczyk-Łuszczyńska et al., 2018; Schäffer et al., 2018, 2019; Tonin et al., 2016; Yokoyama & Tachibana, 2016; Yonemura et al., 2021).

However, AWE diverges from wind turbine research in notable ways. **Perceived economic impacts** (c.f., Arezes et al., 2014; Baxter et al., 2013; Brannstrom et al., 2022; Firestone et al., 2018; Hoen et al., 2019; Hogan et al., 2022; Leiren et al., 2020; Walker et al., 2014), **social norms** (c.f., Hübner et al., 2023; Huijts et al., 2012; Johansson & Laike, 2007; Jones & Eiser, 2009; Read et al., 2013; Sokoloski et al., 2018), and **energy transition attitudes** (Breitschopf & Burghard, 2023; Hübner et al., 2023; Kirchhoff et al., 2022; Sonnberger & Ruddat, 2017), which are predictors of wind energy acceptance, did not predict community acceptance in this research. This discrepancy either suggests that these factors do not apply to AWE or – more likely – did not apply *yet* during the technology's experimental and non-commercial stage at the time of study.

Specifically, in the German study, participants assessed the hypothetical economic effects of future potential AWE projects, while in the Irish study, they evaluated the rather limited, temporary impacts of the test site (Chapter 5:). These contexts may have diminished the influence of economic factors. The weak influence of energy transition attitudes on acceptance could reflect

AWE's emerging stage. AWE is not yet commercialized and does not currently contribute to renewable energy goals, making it challenging for laypeople to see its role in the energy transition. Social norms may have failed to predict acceptance due to limited public debate surrounding the small-scale, temporary AWE test sites. Unlike commercial wind farms, these sites either lacked formal planning processes (Germany) or extensive media coverage (Ireland), reducing opportunities for residents to gauge community views. The lack of public discourse, combined with the COVID-19 pandemic's negative impact on community engagement, may have reduced the relevance of social norms in shaping acceptance. The significant relationship of only three out of five IAM predictors with community acceptance of AWE suggests that, while it is a useful framework, its applicability to AWE remains uncertain at this development stage. Future research should revisit these predictors once AWE reaches commercialization.

Based on the dissertation's findings, three major conclusions emerge that imply a call to action:

1. **Balancing optimism with empiricism:** While optimism is necessary to drive investment and development in high-risk, long-horizon innovations like AWE, this optimism must be grounded in empirical evidence. Although AWE shows promise, particularly regarding visual impacts, robust social science research is needed to guide effective policies and practices as the technology scales up. This calls for methodological approaches that go beyond basic metrics to fully capture the complexity of social responses, such as using diverse acoustic and psychoacoustic parameters to study noise annoyance.
2. **Integrating social and technical dimensions:** The sector's persistent optimism regarding the social acceptance of AWE, together with the pressure to bring the technology onto the market, has led to an overemphasis on technical advancements, which overshadows social considerations. However, this research demonstrates that social acceptance is equally critical. Addressing community concerns like visual and sound impacts requires effective and targeted mitigation strategies integrating social insights and technical know-how.
3. **Recognizing subjective and contextual factors:** Community acceptance depends not only on objective project impacts but also on subjective perceptions shaped by individual traits (e.g., noise sensitivity) and contextual factors (e.g., fairness in planning). The sector must consider these dimensions when developing and rolling out the technology.

7.2 LIMITATIONS OF THE RESEARCH

While the limitations specific to each study have been discussed in their respective chapters, three overarching limitations that apply to the entire research should be highlighted:

1. **Design-specific focus:** This research was constrained by the limited availability of long-operating AWE projects, which restricted the investigation to a few ground-gen AWE systems. Furthermore, the fieldwork exclusively focused on soft-wing kites. However, AWE systems vary significantly in their design and operation, including aspects such as the working principle (i.e., ground-gen vs. fly-gen), kite type (i.e., soft-wing, fixed-wing, or hybrid-wing), tether characteristics (e.g., diameter, length, and materials), use of ram-air turbines, and operational altitude (Section 1.5; **Table 3.1**). These design differences can affect key impacts like visual, sound, ecological, and safety-related effects. As a result, the findings of this research may not be directly applicable to other types of AWE systems.
2. **Early development stage:** AWE technology is still in its early stages of development and is expected to undergo significant evolution as the sector scales up, mitigates impacts, and potentially converges toward a single configuration. This ongoing development will likely alter the technology's impacts and the way they are perceived. Additionally, the surveyed residents in this research had limited exposure to AWE systems, as the observed projects operated intermittently and rarely at night. The analyzed audio recordings did also not accurately reflect typical operating conditions. Residents' perceptions and responses may differ significantly when exposed to continuous operation, particularly when multiple AWE systems are deployed in one area. This research should, therefore, be viewed as a snapshot of people's perceptions at the current stage of AWE development, which may not fully capture future ones as the technology matures.
3. **Sample constraints:** The scope of the field findings was limited by the challenges of recruiting participants. Long-operating AWE projects are rare and often located in sparsely populated areas, resulting in relatively small, cross-sectional samples drawn from only two WEIRD countries (i.e., Western, educated, industrialized, rich, and democratic). This sample limitation restricts the generalizability of the findings and prevents causal inference. Exploring acceptance in non-Western and Indigenous contexts is particularly important because AWE is

expected to be deployed first in island nations, remote communities, and across the Global South (BVG Associates, 2022), given its suitability for difficult-to-access terrain, hurricane/typhoon-prone areas, and small-scale projects, as well as more lenient permitting procedures in some developing countries. In these regions, traditional beliefs, cultural practices, and reliance on natural resources and land may significantly influence how renewable energy projects are perceived (Kim et al., 2018; Lakhanpal, 2019; Normann, 2021; Ulloa, 2023). Moreover, establishing causality is crucial to identifying which factors mitigation measures and interventions should prioritize.

These limitations highlight the need for future research to address the gaps identified and to provide a more comprehensive understanding of AWE's acceptance in diverse contexts and under different operational conditions, as will be discussed in the next section.

7.3 FUTURE RESEARCH DIRECTIONS

The previous chapters identified recommendations for future research based on the limitations of the underlying studies. These recommendations can be grouped into three main directions for future research:

1. **Understanding the interplay of social acceptance factors:** This and past research on energy acceptance have shown that the perceptions of different aspects of renewable energy development, such as noise annoyance, visual impact, and fairness, are *closely connected*. Future studies should examine their relationships in greater depth to fully understand how these factors jointly influence the community acceptance of AWE. Additionally, acceptance is not static; it can change over time as people gain experience with an energy project (Section 2.1.3). However, with a few notable exceptions (Bingaman et al., 2023; Firestone et al., 2012, 2020; Jalali et al., 2016; Landeta-Manzano et al., 2018; Mills et al., 2019; Penneman et al., 2023), most studies are cross-sectional and focus only on the period around project approval or after installation, leaving a gap in our understanding of how acceptance develops over the lifespan of a project (Batel, 2020; Ellis & Ferraro, 2016; Rand & Hoen, 2017). To address this, *longitudinal studies* should track residents' attitudes from pre-approval to operation and decommissioning. This would help identify causal relationships between residents' experiences and their evolving perceptions of AWE projects. Understanding these patterns is essential

for designing effective communication strategies, engagement processes, and mitigation measures.

2. **Studying diverse systems, contexts, and stakeholders:** Community acceptance research should go beyond a single type of AWE system. *Different AWE designs*, such as fly-gen and ground-gen systems, may elicit different responses due to differences in appearance, sound emissions, and other environmental impacts. Future studies should test whether findings from one design apply to others or if distinct factors shape acceptance for each system. Acceptance should also be studied across *geographic, cultural, and economic settings*. AWE may be commercially deployed first in the Global South or Indigenous communities, where unique social, economic, political, environmental, and historical conditions influence perceptions of renewable energy development (Cormack & Kurewa, 2018; Kim et al., 2018; Lakhanpal, 2019; Mang-Benza & Baxter, 2021; Normann, 2021; Ulloa, 2023; Zárate-Toledo et al., 2019). Exploring how acceptance factors differ in these contexts is important rather than assuming that findings from the Global North will apply universally (van der Horst et al., 2021). Moreover, energy acceptance research often relies on single case studies, which limits generalizability. Differences in research methods, questions, definitions, and sampling strategies make it difficult to compare findings across studies (Rand & Hoen, 2017; Wolsink, 2019). A shift toward *comparative and multi-case studies* would provide a deeper understanding of acceptance patterns. Additionally, case studies often fail to account for external factors that shape local dynamics. Social conflicts over renewable energy projects are rarely isolated; they are influenced by past disputes in different locations, time periods, and even concerning similar technologies and policies: A phenomenon known as 'controversy spillover,' where past conflicts shape attitudes and resistance in new contexts (Cuppen et al., 2020). Focusing on individual cases for analytical purposes can lead to overlooking these broader influences. Finally, research must *move beyond the community level* by investigating the role of other key stakeholders (e.g., developers, policymakers, and media) and how their interactions with the public and hosting communities shape social acceptance (Batel & Devine-Wright, 2015; Walker et al., 2010). Community acceptance is just one dimension of renewable energy deployment (Section 2.1.1) and does not fully represent a technology's overall social acceptance (Wolsink, 2018). The adoption of renewable

energy is often constrained by institutional[18] barriers, with socio-political and market acceptance playing a critical role in the success of AWE (Section 2.1.1). Vested interests in the fossil fuel and conventional wind energy industries, along with the slow adoption of financial subsidies and regulatory frameworks (BVG Associates, 2022; Salma et al., 2018), can create significant obstacles, potentially hindering the long-term success of AWE (Wolsink, 2018).

3. **Adapting to Technological and Deployment Changes:** As AWE technology continues to evolve, research must keep pace with changes in size, capacity, and deployment configurations. For example, future projects may involve multiple systems operating at the same site, which could lead to new social and environmental concerns. Research should examine how these *advancements influence community perceptions*. As previously discussed, implementing measures like demand-based aviation lights and sound mitigation mechanisms (Section 6.4.3) will also significantly change how AWE projects affect nearby communities. Furthermore, some developers will likely achieve commercialization faster than others. Comparing data from AWE sites at *varying stages of commercialization*, such as test sites, semi-commercial sites, and fully commercial operations, provides valuable insights into how acceptance levels and drivers shift at different stages of development (Section 5.4.2). Understanding these dynamics can help developers and policymakers anticipate and address potential concerns as AWE scales up.

7.4 POLICY AND INDUSTRY RECOMMENDATIONS

Based on the findings of this research, four major recommendations emerge for policymakers and industry stakeholders. These recommendations aim to support AWE's responsible development and deployment by ensuring that technical and policy advancements align with social considerations.

7.4.1. Strengthen the evidence base through interdisciplinary research

Interdisciplinary research can help identify and address key challenges before technology designs and operational practices become fixed (Kirkegaard et al., 2023). Developers should use research and development (R&D) projects

18 In the sense of Geels' (2002; 2017) work on socio-technical transitions, "institutional" refers to the rules, norms, and structures that shape and stabilize existing socio-technical systems. These institutions can be formal (e.g., laws, policies, market regulations) or informal (e.g., cultural beliefs, industry norms, and stakeholder expectations).

to study how residents perceive AWE's impacts, what factors drive annoyance, and which mitigation strategies are most effective (see Gaßner et al., 2022 and Müller et al., 2023 for an interdisciplinary study on wind turbines).

The wind energy sector has shown that research into social and environmental impacts leads to more effective regulations and mitigation strategies (Bulling et al., 2015; Pohl et al., 1999, 2012, 2018). The AWE sector should take a similar approach by using standardized, empirically derived definitions and measures from social sciences to achieve three key objectives:

- **Ensure comparability across studies:** Using consistent research methods, such as the acceptance stress scale (Pohl et al., 2018), will allow for reliable cross-study comparisons.
- **Support the development of effective regulations:** Robust empirical evidence can inform policies beyond purely technical solutions, addressing the social dimensions of AWE deployment (Kirkegaard et al., 2023).
- **Improve regulatory compliance:** Clear, standardized assessment criteria can help monitor whether AWE projects meet regulatory requirements.

Building a strong empirical evidence base will not only guide mitigation strategies and regulations but also help counter misinformation (Winter et al., 2022) and build trust with local communities and the public.

7.4.2. Develop effective mitigation strategies

As research on AWE's social and environmental impacts progresses, targeted mitigation strategies should be developed to reduce negative effects on local communities and nature. While AWE developers have so far prioritized improving system performance and reliability, this research highlights the need to focus on impact reduction. There is still much room for improvement, particularly for sound emissions (Section 6.4.3). Two key approaches for sound mitigation are:

- **Design modifications:** Optimizing onboard ram-air turbines, refining kite and tether designs, and adjusting materials to mitigate sound emissions.
- **Operational changes:** Modifying flight speed, altitudes, and flight patterns (e.g., using larger figure-eight loops, flying larger kites at higher altitudes, adjusting reel-in and reel-out speeds, slowing the kite at specific points in its flight path[19], or avoiding noise-sensitive areas).

19 This adjustment could reduce noise annoyance because sound emissions typically decrease as flight speed decreases (Glegg & Devenport, 2017).

Additional mitigation strategies include demand-based aviation lights to minimize annoyance by activating the lights only when an aircraft is approaching and wildlife protection measures, such as cameras, sensors, and algorithms to detect or anticipate birds and bats, allowing temporary operational adjustments to prevent collisions (e.g., adjusting operation when an animal is approaching or pausing operations during migration seasons or after agricultural activities in the surrounding area[20]). To ensure these mitigation measures effectively address both objective impacts and the subjective perception thereof, they should be evaluated through controlled laboratory studies (e.g., listening experiments) and field studies that reflect actual deployment conditions.

7.4.3. Implement inclusive community engagement and co-production

Beyond mitigating project impacts, ensuring fair and inclusive deployment processes is critical for community acceptance. Developers should apply best practices for participatory planning from the test phase to full commercialization, even when no formal public engagement requirements exist for test sites. The fairness of the engagement process depends on several factors:

- **Transparency:** Developers must provide honest, clear, and accessible information about the project and its potential impacts (Aitken et al., 2014; de Vries, 2014; Firestone et al., 2018).
- **Trust:** Residents should be able to trust the developer and feel that they genuinely consider concerns rather than merely try to minimize opposition (Aitken, 2010; Dwyer & Bidwell, 2019; Gölz & Wedderhoff, 2018; Liu et al., 2019). If residents believe the developer engages with the local community solely to gain project support, such engagement may negatively impact their opinions (Goedkoop & Devine-Wright, 2016; Ryder et al., 2023; ter Mors & van Leeuwen, 2023). Engagement should, therefore, prioritize trust building through informal initiatives beyond regulatory requirements, like appointing an impartial community liaison (Dwyer & Bidwell, 2019).
- **Influence:** Community members should have meaningful opportunities to participate and shape project decisions, not just provide feedback (Firestone et al., 2018; Liu et al., 2019; Walker & Baxter, 2017).

Effective engagement requires recognizing that residents bring valuable perspectives and knowledge to the discussion. Open participation should be

20 Agricultural activities, such as harvesting, ploughing, or mowing, can disturb insects and small animals, making them more active and attracting birds and bats to the area. This increases the risk of bird and bat collisions with wind energy infrastructure (Bulling et al., 2015).

seen as an opportunity to shape better outcomes, regardless of whether the input aligns with a project's economic or strategic interests. Developers should actively encourage transparent dialogue, even when community concerns challenge or oppose the project (Clausen et al., 2021; Elmallah & Rand, 2022; Figari et al., 2024). Meaningful exchanges between developers, planners, scientists, and local communities can improve ongoing projects and AWE's broader development (Cuppen & Pesch, 2021). Social conflict should not be viewed as a risk to be minimized but as constructive input that can drive more socially responsible technology development and deployment (ibid.).

Implementing ownership and benefit-sharing schemes can promote a fair distribution of project profits (Baxter et al., 2020; Hogan, 2024). However, their effectiveness depends on aligning them with the community's specific needs (e.g., level of financial risk), resources (e.g., financial strength), the social and political context, and perceptions of fairness and trust in the developer (Boomsma et al., 2020; Brannstrom et al., 2022; Hoen et al., 2019; Hogan, 2024; Hübner et al., 2023; Knauf & le Maitre, 2023; Langer et al., 2017; Liebe et al., 2017; Olbrich & Fünfgeld, 2023). To ensure meaningful compensation, developers must first identify the relevant stakeholders –those living near the project or those experiencing direct negative impacts–, understand their priorities and concerns, and tailor compensation mechanisms accordingly.

Expanding participation beyond the planning stage to include technology development, implementation, and operation of AWE plants – known as co-production – offers significant advantages over traditional, legally mandated public involvement that occurs only during the deployment phase (for an overview of co-production in the wind energy sector, see Solman et al., 2021). Co-production ensures that community concerns are not merely acknowledged but actively addressed and improvements are found together rather than relying solely on compensation for experienced impacts. It also democratizes decision-making by giving citizens an active role in shaping the design, implementation, and use of local energy infrastructure, empowering them to contribute positively rather than limiting their engagement to opposition (Clausen et al., 2021; Elmallah & Rand, 2022; Jami & Walsh, 2017).

Moreover, effective participation should extend beyond local communities to include a broader range of stakeholders, such as environmental organizations, national, regional, and local authorities, regulatory agencies, financial institutions, utility companies, local authorities, research institutions, and businesses. Given AWE's early stage of development, there is a unique opportunity to establish innovative and inclusive engagement practices.

7.4.4. Develop a robust regulatory framework

Good policies are essential for ensuring that AWE is deployed safely, fairly, and in a socially responsible manner. At present, no AWE-specific regulations exist, which creates uncertainty for both developers and communities. The development of clear policies should be a priority, with three regulatory areas touching on social aspects requiring immediate attention:

- **Immission regulations:** Existing wind turbine sound and visual impact standards do not fully apply to AWE. Research on public perceptions of AWE impacts can help shape effective new regulations, as seen with wind turbine shadow flicker annoyance guidelines in Germany (Bund/Länder-Arbeitsgemeinschaft Immissionsschutz, 2020; Pohl et al., 1999).
- **Airspace integration:** AWE systems need dedicated regulations to ensure their safe operation alongside conventional air traffic and to minimize risks to people and property (Salma et al., 2020).
- **Community engagement requirements:** Formal guidelines should be established to ensure developers engage with local communities extensively throughout the planning and construction process. Similar policies already exist for wind farms in many countries, where public participation or benefit-sharing schemes are required for project approval (Aitken et al., 2014).

The regulatory and technical development should happen in parallel and feed into each other to make the process more efficient and effective and prevent the technology from being locked into a form incompatible with future regulations. Given the slow response of policymakers to AWE developments, the industry must take an active role in shaping the regulatory landscape. Industry associations like Airborne Wind Europe can advocate for AWE-specific policies, at least at the European level, and encourage developers to adopt voluntary best practices, such as committing to financial benefit-sharing (e.g., establishing a certification for socially responsible developers as for wind energy in some regions; Thüringer Energie- und GreenTechAgentur, n.d.). Efforts to shape policy are already underway, with the International Energy Agency's task on AWE leading discussions on safety, market-entry, and social acceptance. A coordinated approach between industry, researchers, and policymakers will be crucial for creating a regulatory framework that supports both the commercial success and social sustainability of AWE.

These recommendations highlight the importance of integrating social science insights into AWE development from the outset. If the sector fails to do so, social considerations – not the sky – will ultimately limit AWE's success. However, by investing in interdisciplinary research, developing targeted mitigation strategies, fostering inclusive community engagement, and establishing a strong regulatory framework, the AWE sector can avoid common pitfalls faced by established renewable energy technologies. The early stage of AWE presents a unique opportunity to proactively shape development and deployment practices that are both technically and socially feasible. Taking these steps now will help ensure that AWE gains public trust and contributes to a just energy transition.

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APPENDICES

APPENDIX A

Review Keywords and Publication Details

Table A1
Keyword Selection for the Literature Search

	Airborne wind energy keyword set	Social acceptance keyword set
Included	"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"

	Airborne wind energy keyword set	Social acceptance keyword set
Excluded[a]		“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”

Note. Individual keywords from the same set were combined with the operator OR. Keywords from different sets were combined with the operator AND.

[a] These social acceptance keywords did not yield any additional results in combination with the airborne wind energy keywords.

Table A2
Publication Details of the Reviewed Literature

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 Electrical Machines	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

Author(s)	Year	Title	Publication Type	Publication Medium	Professional Background Author(s)[a]	Identification
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 Conversion Engineering 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 wind energy converters	Journal article	Renewable Energy	3 engineers	Google Scholar
Chihaia, Nicolaie, Cîrciumaru, El-Leathey, & Constantin	2019	Market Potential Of Unconventional Wind Turbines. A Technology Review	Conference paper	Proceedings of 2019 International Conference on Hydraulics and Pneumatics	5 engineers	Google Scholar

Author(s)	Year	Title	Publication Type	Publication Medium	Professional Background Author(s)[a]	Identification
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
de Lellis, Mendonça, Saraiva, Trofino, & Lezana	2016	Electric power generation in wind farms with pumping 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	Toward 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

Author(s)	Year	Title	Publication Type	Publication Medium	Professional Background Author(s)[a]	Identification
Key de Souza Mendonça, Braga, & Bornia	2020	Airborne wind energy systems: Current state and challenges 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 Electrical Systems	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 the electricity system	Journal article	Wind Energy	4 engineers	Google Scholar
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

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Author(s)	Year	Title	Publication Type	Publication Medium	Professional Background Author(s)[a]	Identification
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 airborne wind energy systems	Journal article	Wind Energy	3 engineers	Google Scholar

Author(s)	Year	Title	Publication Type	Publication Medium	Professional Background Author(s)[a]	Identification
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 of two line kites for power generation	Conference paper	2017 4th Asia-Pacific World Congress on Computer Science 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

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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.

APPENDIX B

Recruitment Materials First Field Study

B1: Invitation letter to residents

Delft, den 20.05.2022

Einladung – Befragung zur örtlichen Flugwindkraftanlage

Sehr geehrte/r ...

wir laden Sie ein, sich an unserer Befragung zur Flugwindkraftanlage in Klixbüll zu beteiligen. Die Befragung ist Teil einer Doktorarbeit zur Akzeptanz von Höhenwindenergie, gefördert durch die nationale niederländische Wissenschaftsorganisation (NWO). Mehr Details hierzu finden Sie auf der Rückseite.

Wer führt die Befragung durch und warum?
Um die Akzeptanz von Flugwindkraftanlagen besser verstehen zu können und um Empfehlungen für die Planung anderer Anlagen geben zu können, möchten wir Sie als Anwohner befragen. Die Befragungen werden von Sozialforschern der Technischen Universität Delft und der MSH Medical School Hamburg durchgeführt.

Warum sollten Sie sich beteiligen?
Durch Ihre Teilnahme haben Sie die Möglichkeit, zu einer bürgernahen Energiewende beizutragen. Aus der Befragung werden Empfehlungen für zukünftige Flugwindkraftanlagen abgeleitet und die Ergebnisse werden mit Höhenwindenergie-Entwicklern besprochen.

Die Gemeinde Klixbüll sowie der Betreiber der Flugwindkraftanlage unterstützen das Projekt.

Wie können Sie sich beteiligen?
Wir bitten Sie um ein persönliches Interview bei Ihnen zuhause (Dauer: ca. 45 Minuten). Ihre Kontakdaten haben wir öffentlich zugänglichen Quellen entnommen (Digitaler Atlas Nord unter https://danord.gdi-sh.de). Beim Umgang mit Ihren Angaben und Daten halten wir uns selbstverständlich an die Datenschutz-Grundverordnung (DSGVO). Nach Zugang dieses Schreibens wird

Sie die Projektleiterin anrufen, um einen Termin zu vereinbaren. Die Befragung wird Anfang Juni durchgeführt.

Es würde uns sehr freuen, wenn Sie sich beteiligen.

Wie können Sie das Forschungsteam kontaktieren?
Falls wir Sie nicht erreicht haben, können Sie sich gerne bei uns melden, um einen Termin auszumachen. Gern können auch Ihre Partnerin oder Ihr Partner, Ihre Kinder (ab 18 Jahren), Bekannte oder Nachbarn teilnehmen und sich bei unserer Projektleiterin Helena Schmidt melden. Telefonisch: Montag – Freitag, von 09 Uhr bis 17 Uhr unter der Nummer 00 31 15 27 89 461 oder per E-Mail an h.s.schmidt@tudelft.nl. Helena Schmidt steht Ihnen auch persönlich für Rückfragen zur Verfügung.

Mit freundlichen Grüßen, im Namen des gesamten Projektteams

Helena Schmidt   Valentin Leschinger   Florian Müller
Technische Universität Delft & MSH Medical School Hamburg

Akzeptanz von Höhenwindenergie

Herausforderung	Höhenwindenergie steckt noch in den Kinderschuhen. Es gibt bisher keine permanenten kommerziellen Anlagen. In wenigen Pilotanlagen in Europa testen Entwickler ihre Prototypen. Entsprechend wenig ist darüber bekannt, wie Menschen, speziell Anwohnerinnen und Anwohner, die Technologie wahrnehmen.
Projekt	In ihrer Doktorarbeit befasst sich Helena Schmidt (TU Delft) genau damit. Wie wird Höhenwindenergie von den Menschen wahrgenommen und beurteilt, welche Faktoren beeinflussen die Wahrnehmung und welche Maßnahmen werden als entlastend empfunden (z.B. bzgl. Geräuschemissionen). Gemeinsam mit Forschern der MSH Medical School Hamburg führt sie eine Befragung zur Flugwindkraftanlage in Klixbüll durch. Aus den Daten werden Empfehlungen für zukünftige Anlagen abgeleitet und die Ergebnisse werden an Höhenwindenergie-Entwickler übermittelt. Das Projekt wird von der Gemeinde Klixbüll und SkySails Power unterstützt.

Projektpartner	Lehrstuhl für Windenergie der Technischen Universität Delft (Niederlande) und die Arbeitsgruppe Gesundheits- und Umweltpsychologie der MSH Medical School Hamburg
Fördermittelgeber	Nationale niederländische Wissenschaftsorganisation (NWO)
Hintergrund	Flugwindkraftanlagen nutzen die starken und stetigen Winde in mehreren hundert Metern Höhe, um Strom zu produzieren. Seit 2019 testet die Firma SkySails Power ihre Flugwindkraftanlage in Klixbüll (s. Foto). Das Konzept von SkySails Power basiert auf einem Zugdrachensystem bestehend aus Bodenstation mit Start- und Landemast, Generator, Winde und Drachen. Der Drachen ist über ein Seil mit einem Generator am Boden verbunden. Wenn der Drachen auf bis zu 400 Meter Höhe aufsteigt, zieht er das Seil von der Winde ab und treibt so den Generator an. Ist das Seil vollständig ausgezogen, gleitet der Drachen zurück, während die Winde das Seil wieder einzieht. Da das Einholen des Seils nur einen Bruchteil des erzeugten Stroms benötigt, liefert die konstante Ein- und Ausfahrbewegung Strom. Bis zu 200 Kilowatt kann die Anlage dabei generieren.

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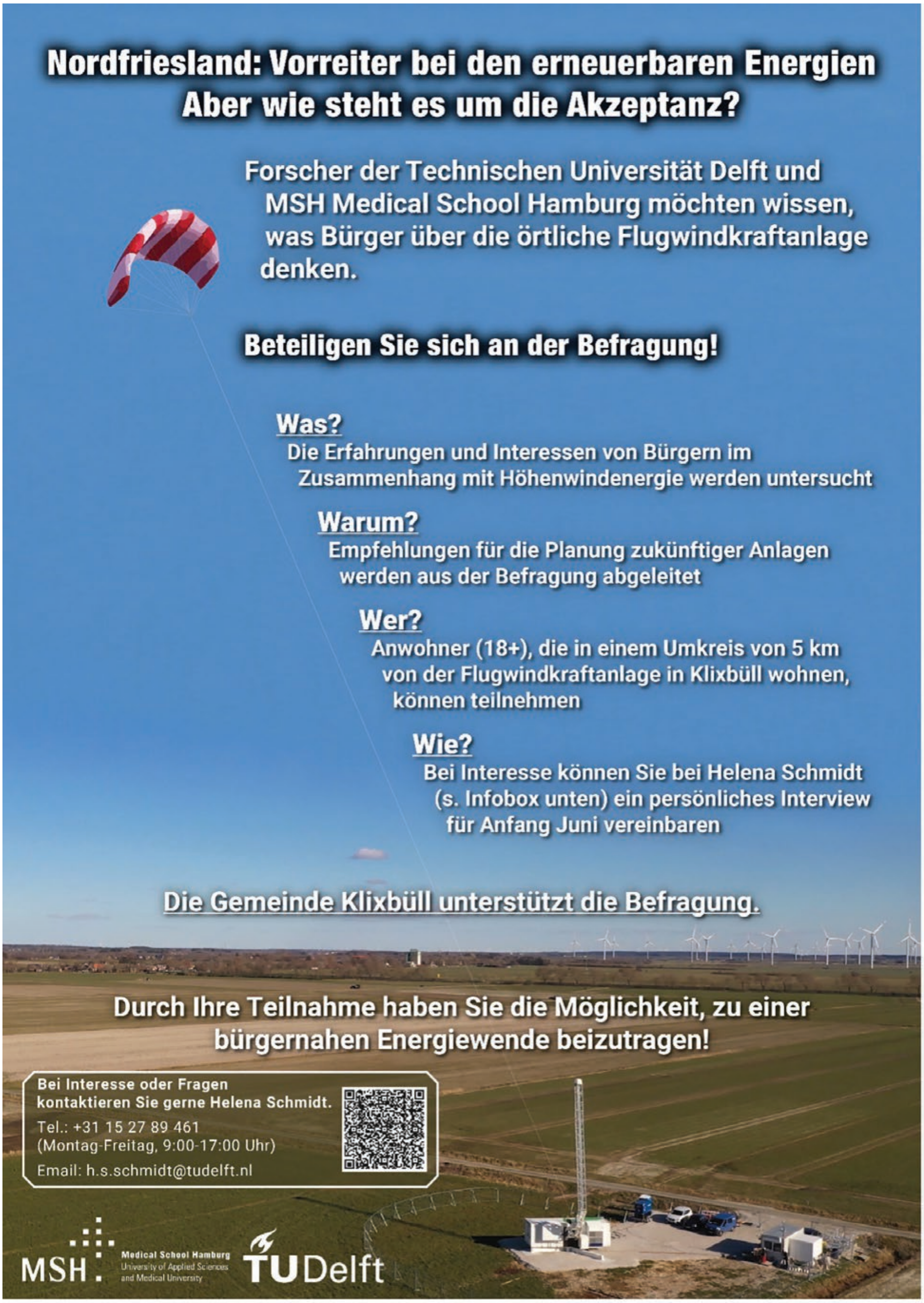
Die Flugwindkraftanlage in Klixbüll (mit freundlicher Genehmigung von SkySails Power).

B2: Recruitment poster



Design: Dylan Eijkelhof

APPENDIX C

Recruitment Materials Second Field Study

C1: Poster information event

Design: SEAI

C2: Recruitment flyer

Design: Dylan Eijkelhof

C3: Invitation letter to residents

Invitation – Community Survey about Kite Energy in County Mayo

Dear resident,

Airborne wind energy –sometimes called kite energy– is a new type of wind energy technology that the energy company RWE is testing in Bangor Erris in collaboration with its technology partner Kitepower and Mayo County Council, with funding from the EU (i.e., Interreg North-West Europe programme). Airborne wind energy harnesses the strong and steady winds at altitudes greater than several hundred metres to produce renewable electricity.

We are writing to ask for your help with improving our understanding of residents' views on airborne wind energy. The best way we know how to do this is by asking people living close to airborne wind energy sites to share their thoughts and opinions with us. You are one of the few people worldwide who live close to such a site.

To make sure we hear from all different types of people in your area, please have one adult (**age 18 or over**) in your household complete the survey.

If you want to learn more about the research first, meet us at the **public information event** we are hosting **with SEAI** (Sustainable Energy Authority of Ireland) in the **Bangor Erris Community Hall** on Wednesday, **April 10th, from 4.30 pm to 6.30 pm**. We will provide more information about the survey, and SEAI will cover home energy retrofit grants and solar PV for homeowners.

The airborne wind energy test site in Bangor Erris (© Kitepower).

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Who is conducting the survey?

Interreg North-West Europe
Co-funded by the European Union
DEM-AWE

The survey is part of a doctoral thesis on the acceptance of airborne wind energy at Delft University of Technology (funded by the Dutch Research Council) and a Master's students project at Politecnico di Milano (sponsored by university funds).

The Interreg North-West Europe project that co-finances the local test site and includes the airborne wind energy supplier Kitepower and Mayo County Council as project partners supports the survey. However, the research is independent and does not directly impact the technology testing in Bangor Erris.

Why should you participate?
By participating, you can contribute to a more socially just energy transition. Recommendations for future airborne wind energy projects will be derived from the survey, and the results will be discussed with airborne wind energy developers.

How can you participate?
We hope that you can **complete the survey on the Internet** so that we can summarise the results more quickly. To complete the survey online, enter the web address below into your Internet browser or scan the QR code with your mobile phone. You can complete the survey online until April 30, 2024.

https://edu.nl/pn7ed

If you cannot or do not want to fill in the survey online, **you can complete the attached questionnaire instead** (Don't forget to sign the declaration of consent on the next page if you complete the paper questionnaire!). **Please return the completed questionnaire to the collection box we have put up in the Centra store in Bangor Erris** (you can ask the staff for help locating the box). Return the questionnaire ideally before April 12, but at the latest, by April 30.

If you have any questions, please feel free to contact us.
We thank you very much for your support!

Helena Schmidt Giovanni Romano Andrea Trebbi

Survey coordinator: Helena Schmidt,Tel.: +31 15 27 89 461, E-Mail: h.s.schmidt@tudelft.nl

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APPENDIX D

Recruitment Poster Listening Experiment

Design: Helena Schmidt

ACKNOWLEDGMENTS

When I was younger, I never dreamed of doing a PhD. In fact, I didn't even consider it until I desperately sought work after graduating from my second Master's program in Environmental Psychology, and research appeared to be the only viable career path. So, when I was offered the PhD position in the Wind Energy section at TU Delft, I decided to give it a shot – at least until the first official assessment moment (the Go/No-Go meeting after nine months). And somehow, I stuck with it and rode it out till the end. Of course, I know that it didn't just happen 'somehow' but for good reasons: the topic piqued my interest, my ambitious side drove me to continue, and I enjoyed working with the people around me. The genuine and heartfelt support of my colleagues, family, and friends carried me through my PhD – especially during the tougher times.

Thank you, **Roland**, for being so enthusiastic about my research project from the first moment we met – an online job interview during COVID-19 – until the very end. Being my promotor required you to leave your 'engineering' comfort zone and get acquainted with the unfamiliar world of social sciences. If it weren't for your openness to new ideas, approaches, and concepts, we couldn't have collaborated across disciplines so effectively. I admire your dedication and passion for airborne wind energy, and your scientific curiosity greatly encouraged me along the way.

Gerdien, I asked you to become my daily supervisor because I felt I needed more social science expertise in the project, as I was surrounded by engineers – unsurprisingly, at a technical university. Back then, I couldn't have imagined how well we'd work together: we both value structure, accountability, and high quality. I'm grateful to you for always believing in me, being the reliable constant I needed during my PhD, and reading (almost) everything I wrote throughout. I'm impressed by how tirelessly you work to integrate social science perspectives into predominantly technical research.

Reint Jan, when you initially proposed the PhD position to me while I was still an intern in your research group at Hogeschool van Amsterdam, I had my doubts, but I am glad I followed your suggestion. Due to the sheer amount of your other responsibilities (seriously, how do you manage?), you weren't as involved as my other two supervisors, but I could always count on you when needed. I especially appreciate that you asked the right questions to make me focus on the core issue (commonly: "What main message do you want to deliver with your publication?"), kept reminding me to craft my work in a way that would bring me joy, and often provided very practical and pragmatic advice for problems I was struggling with.

I want to thank all three of you for listening to my concerns over the years, being empathetic, and having my back.

I admit that I was initially a bit worried about joining a technical research group as the only social scientist in a very technical faculty (Aerospace Engineering!). So, I was relieved when I realized that you – **Dylan, Rishi, Jelle, Uri, and Uwe** – would treat me as a peer and not with the disdain some STEM scientists have for social scientists, even though our research, background knowledge, and skill sets often seemed worlds apart. Thank you for answering all my questions about airborne wind energy, even when the answers seemed obvious to you. I hope you learned something from me, just as I learned from you.

When I first started my PhD, I often felt disconnected from the social science realm. I'm glad I built valuable connections with other social scientists in the field over the years, particularly with the health and environmental psychology group at MSH Medical School Hamburg. **Gundula**, thank you for taking me under your wing, being a tough but fair critic, and showing me how our research relates to reality. I also want to thank you, **Florian and Valentin**, for contributing your knowledge, skills, and advice to my doctoral research. I enjoyed collaborating with you and am glad I got to spend a couple of months with your research group in Hamburg, where I learned a lot from our daily discussions.

Stefanie and Kristian, I enjoyed working with you over the years and am grateful for your assistance, encouragement, and interest in my research.

Thank you to **Johannes** and the entire **Kitepower** team for supporting my research, sharing your experiences with people's reactions to your test sites, and taking an interest in my research recommendations.

I also look back with gratitude on all other exchanges I had with colleagues and stakeholders from the airborne wind energy sector, including my remaining co-authors, my fellow PhD researchers from the NEON consortium, conference and summer school attendees, and members of related research projects I worked with (specifically, JustWind4All and MegaAWE).

Thank you to my amazing friends – especially **Liisa, Simy, Sarah, Dzhem, Niko, Raquel, and Nick** – for keeping me sane by meeting me for walks, coffee, and dinner, listening to my concerns, and always being there. Thank you also to all my friends and family abroad (**Katha, Katrin, Julia, Helena, and Marina**) who were always just a text away and with whom I've spent memorable moments over the last years!

Ich bin vom ganzen Herzen dankbar für die Unterstützung und Liebe meiner Familie, vor allem meiner Eltern. Danke, dass ihr in den vier Jahren immer hinter mir standet und mir geholfen habt, wo ihr nur konntet. **Mama**, danke, dass du mir stundenlang am Telefon zugehört und gut zugesprochen hast, mit mir auf Reisen gegangen bist, wenn ich aus meinem Arbeitsalltag rausmusste, und meine deutschsprachigen Texte redigiert hast. Danke, **Papa**, für deine Hilfe bei steuerlichen und vertraglichen Fragen, das Teilen deiner Erfahrung mit Unternehmenspolitik und dein Feedback zu meinem Manuskript.

Last but not least, I am eternally grateful for having you by my side, **Tudor**. You are my rock. Sometimes, people ask me if it isn't annoying or challenging when both partners are doing a PhD, but I see it as a benefit. You could better relate to what I was going through because you had similar experiences. You comforted me when I was stressed or felt like an impostor. With you, I could complain about the publication system, unnecessary bureaucracy, and the often intangible practical impacts of research. You sent me funny academic memes and useful research tools to help me cope – emotionally or practically. I don't know what I would have done without you or whether I would have even made it this far. Te iubesc!

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EDUCATION

2019 – 2020 Master of Science in Environmental Psychology
University of Groningen

2018 – 2019 Master of Science in Clinical Psychology
Leiden University

2014 – 2017 Bachelor of Science in Psychology
Erasmus University Rotterdam

2009 – 2013 Upper secondary school („Abitur“)
Geschwister-Scholl Gymnasium Unna

EXPERIENCE

2021 – 2025 PhD Researcher
Delft University of Technology

2020 – 2021 Research Intern
Amsterdam University of Applied Sciences

JOURNAL PAPERS

1. Schmidt, H., de Vries, G., Renes, R. J., & Schmehl, R. (2022). The social acceptance of airborne wind energy: A literature review. *Energies*, *15*(4), 1384. https://doi.org/10.3390/en15041384

2. Schmidt, H., Leschinger, V., Müller, F. J., de Vries, G., Renes, R. J., Schmehl, R., & Hübner, G. (2024). How do residents perceive energy-producing kites? Comparing the community acceptance of an airborne wind energy system and a wind farm in Germany. *Energy Research & Social Science*, *110*, 103447. https://doi.org/10.1016/j.erss.2024.103447

3. Schmidt, H., Yupa-Villanueva, R. M., Ragni, D., Merino-Martínez, R., van Gool, P., & Schmehl, R. (2025). Exploring noise annoyance and sound quality for airborne wind energy systems: Insights from a listening experiment. *Wind Energy Science, 10*(3), 579-595. https://doi.org/10.5194/wes-10-579-2025

4. Schmidt, H., Müller, F. J., Leschinger, V., de Vries, G., Schmehl, R., Renes, R. J., & Hübner, G. (2025). Predicting the community acceptance of airborne wind energy with the Integrated Acceptance Model: A European cross-country study. *Manuscript submitted for publication.*

DATASETS

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1. Schmidt, H., Leschinger, V., Müller, F. J. Y., De Vries, G., Renes, R. J., Schmehl, R., & Hübner, G. (2024). *Survey data on residents' assessment of an airborne wind energy system in Germany* [Data set]. 4TU.ResearchData. https://doi.org/10.4121/FC1E49CA-08B6-435D-9888-A73F334EDD92

2. Schmidt, H., Yupa Villanueva, R., Ragni, D., Merino-Martinez, R., van Gool, P., & Schmehl, R. (2025). *Noise annoyance ratings for airborne wind energy systems: Data from a controlled listening experiment* [Data set]. 4TU.ResearchData. https://doi.org/10.4121/2716B49F-B44C-400A-A873-EEA276B081F6

3. Schmidt, H., Müller, F. J. Y., Leschinger, V., De Vries, G., Schmehl, R., Renes, R. J., & Hübner, G. (2024). *Resident perceptions of an onshore airborne wind energy test site in Ireland: Survey data* [Draft data set]. 4TU.ResearchData. The dataset will be published when the corresponding publication is accepted.