



Review

Monsters or Wheels of Fortune?—A Review of Sustainability Conflicts Connected to the Expansion of Wind Energy Production with Reference to Don Quixote

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Abstract: Good solutions for sustainable development promote social, ecological, and economic aspects in synergistic ways. Wind energy projects have a large potential to achieve this, if their locations are carefully selected. On the contrary, placing wind turbines inside forest areas with high biodiversity, cultural significance, and recreational use generates conflicts between different dimensions of sustainability, and between supporters and opponents of such projects. The resulting green-versus-green dilemma involves a conflict between idealism and pragmatism, as incorporated in literature by the personalities of Don Quixote and Sancho Panza. Sustainable solutions require both aspects as well as realism. Forest areas have crucial climate benefits ranging from the absorption of CO₂ and other emissions, providing shade and cooling during heatwaves to the storage of humidity and water. Climate change is not solely a problem of rising temperature. It also involves changes in humidity and precipitation, and the related problems of desertification and deforestation. Accordingly, a strategy of deforestation for hosting wind farms seems questionable. Instead, constructing wind turbines with energy storage capacities on deserted ground and using their economic and energetic gains for a subsequent afforestation of the surrounding land would achieve synergetic sustainability benefits for biodiversity, human wellbeing, and the climate.



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1. Introduction

Wind energy is a strong and powerful source of energy, which humans have harnessed for centuries. Applications range from sailboats, prevalent in seafaring for many centuries to windmills that mill grain to produce flour. Making use of this energy resource for the production of electric energy in modern time is an elegant and important pathway to reduce emissions from non-renewable energy sources such as coal, oil, gas, or uranium. As is true for solar energy plants, wind can also produce electricity off-grid in remote rural regions [1,2]. Wind energy can thus substantially contribute to sustainable development and green growth by providing synergetic ecological, economic, and social benefits [3,4]. However, negative impacts of wind farms on animals, including protected species, and hence on biodiversity, in particular in relation to bats and birds, have also been identified. Detrimental effects on human health and wellbeing have likewise been reported. Therefore, being against the construction of windmills for energy production may indeed makes sense in some instances and at some locations.

A fight against windmills is a well-known deed of the heroic knight in the famous novel of “El ingenioso hidalgo don Quixote de la Mancha” by Cervantes [5]. It is so famous that Don Quixote’s windmill attack gave fighting against windmills a proverbial meaning in many languages worldwide, referring to a hope- and senseless fight against things that cannot and should not be fought.

A considerable number of media reports on opposition to modern wind energy projects as well as political discussion between advocates and proponents of certain projects make reference to Don Quixote. Various scientific articles addressing modern wind energy projects, and in particular their benefits and threats regarding sustainability, have likewise referred to the tale of Don Quixote and his fight against the windmills (e.g., [6–8]). This raises the question what—if anything—can possibly be learned from Don Quixote and his companion, Sancho Panza, in this context.

Merging physical objects and ideal psychic objects together in one expressive unit was typical for the writing style of Cervantes (cf. [9]). Accordingly, Ziolkowski [10] investigated specifically what the windmills in the novel of Cervantes may represent on a more abstract and psychological level. While previous interpretations considered them as metaphors for ‘grey everyday reality’ or ‘the principle of evil’, Ziolkowski concluded that the windmill the knight attacks is foremost “a satiric embodiment of the ‘wheel of Fortune’, a concept which finds its origin in Greek and Roman Antiquity, and becomes a stock image in medieval and Renaissance literature” (p. 865). The motive still gets attention in modern times, for example in esoteric tarot card decks based on older symbolic pictures [11,12]. It depicts the up and downs of destiny or fortune. On the one side of the Wheel of Fortune, creatures are lifted up (like Don Quixote was lifted up by a windmill blade), and on the other side they go down (like Don Quixote falling down harshly to the ground briefly afterwards). It hence also represents changes over time and changes of time.

Indeed, when seeing the windmills, Don Quixote explicitly states that they represent ‘fortune’ to him. He misperceives the windmills as giant, evil monsters, and perceives this encounter to be good fortune providing him an opportunity to fight for ‘the Good’.

The beginning of the windmill adventure in Cervante’s Don Quixote [5] shows this: “At this point they came in sight of thirty or forty windmills that there are on that plain, and as soon as Don Quixote saw them he said to his squire, “Fortune is arranging matters for us better than we could have shaped our desires ourselves, for look there, friend Sancho Panza, where thirty or more monstrous giants present themselves, all of whom I mean to engage in battle and slay, and with whose spoils we shall begin to make our fortunes; for this is righteous warfare, and it is God’s good service to sweep so evil a breed from off the face of the earth.” “What giants?” said Sancho Panza. “Those thou seest there,” answered his master, “with the long arms, and some have them nearly two leagues long.” “Look, your worship,” said Sancho; “what we see there are not giants but windmills, and what seem to be their arms are the sails that turned by the wind make the millstone go” (Volume I, Chapter 8, p. 1).

This dispute reveals the idealism of Don Quixote, who strives to fight for the ideal ‘Good’, and the pragmatic realism of Sancho, expressing a technological utilitarian view. Obviously, Sancho correctly perceived the windmills and their usefulness for humans. These mills were by no means monsters, but instead wheels of fortune for millers, farmers, and consumers alike.

Today, more than 400 years later, large-scale wind turbines have in fact become giants, and a race for building ever higher turbines is currently taking place. In 2023, the world’s largest and most powerful wind turbine was installed in Denmark. It can produce 80 GWh per year, has a rotor diameter of 236 m, and is 280 m high at the upright blade tip. “This

height makes it a giant in a world of giants, and for objective comparison, it is almost as tall as the Eiffel Tower in Paris, which reaches 330 metres" ([13], p. 1).

An even higher wind turbine was completed in 2024 in China with a hub height of 185 m and blade radiant of 155 m, thus amounting to 340 m up to the blade tip [14]. A still higher turbine with 365 m height up to the rotor blade tip will soon be completed in Schipkau, Germany [15].

Apparently, about 50 years after the seminal work of Meadows et al. [16] on "The Limits to Growth", the competition for ever bigger and higher sculptural industrial architecture is considered by many politicians, citizens, environmental activists, and scientists alike an ideal pathway for solving existing environmental problems. There is large public support for wind power production in European countries to achieve significant emission reductions through the substitution of the use of fossil fuels [17–19]. Accordingly, green political parties and green-minded people are at the forefront of promoting the further expansion of wind energy [20,21]. For this aim, advocates of further wind energy expansion are accepting the implementation of ever more giant wind turbines, even in natural areas with high biodiversity. However, corresponding projects create lines of conflict that are turning wind turbines into a complex, entangled green-versus-green dilemma [22]:

On the one hand, green policies and politicians promote wind energy expansion and people's acceptance of further wind power expansion is prominently influenced by their belief in the corresponding environmental benefits. On the other hand, some people, who likewise hold strong environmental attitudes and beliefs, prioritize the protection of the natural landscape and wildlife, such as birds and bats, over the benefits of renewable energy production [23,24]. In addition, there are also concerns about noise emissions from wind turbines with negative implications for human health and wellbeing [7]. Thus, at this point, the dispute between Don Quixote and Sancho Panza over the wind wheels seems open again:

Are they monsters, threatening biodiversity, the beauty of the landscape, and human health and wellbeing? Or, are they wheels of fortune, which bear profits not solely for investors, but ultimately also benefit nature as well as economies and society by reducing emissions and generating affordable, environmentally friendly power for industries and private households?

Accordingly, this study investigates the threats and potentials of the further expansion of wind energy production—with a partial focus on forest areas and Germany—based on the previous literature. The aim is to address important aspects ranging from site selection and public participation to policy aspects and needs for future research and development.

For this purpose, this review briefly addresses the possible impacts of wind farms on biodiversity, landscapes, and human health and wellbeing, as well as the emission reductions they achieve, their economic impacts, and sustainable development options for the future.

A review of media and scientific articles on wind energy referring to Don Quixote is presented beforehand to investigate how connections between the old tale and modern wind energy projects were made there. The final discussion and synthesis integrates the previous parts with an orientation to the search for synergetic solutions aiming at social, ecological, and economic benefits. It also addresses the question of possible lessons learned from Cervantes' story.

Table 1 provides an overview of the research steps and the distinct types of literature and media sources that were reviewed and integrated in this study. It also describes the main search terms and search platforms used for the identification of the considered literature. However, it needs to be noted that the literature reviews were conducted in an intuitive, selective way, in the sense that only sources raising interest based on titles and

abstracts were included. The reviews were furthermore ad hoc in the sense that one source could lead via its references to the identification of further sources, and some sources were identified on additional pathways such as, e.g., through personal communications and suggestions of reviewers.

Table 1. Outline of proceeding of this study in search and integration of different types of reviewed literature.

Research Steps	Main Search Platform	Main Search Terms
Steps 1 to 4: Reviews of four types of the literature		
1. Cervante's Don Quixote and the corresponding interpretative literature as analytical background	Google scholar	Don Quixote ¹ , fight, windmills
2. News articles and reported political discussions relating Don Quixote to modern wind turbines	Google	Don Quixote ¹ , controversy, conflict, wind energy ²
3. Scientific articles relating the windmill adventure of Don Quixote to modern wind turbines	Google scholar	Don Quixote ¹ , wind power, wind turbines/energy/farms
4. Review of scientific studies on sustainability related aspects of modern wind turbines	Google scholar	Wind energy/turbines/farms, sustainability and its diverse aspects ³
Final step: Integration and synthesis		
5. Integrative consideration, dialectic inquiry, synthesis and discussion of the overall literature		

¹ Alternatively, the spelling version Don Quijote was also used. ² Mainly, German translations of these search terms were used, and in addition location-based settings of Google may have facilitated German language search results. ³ Specific sustainability aspects of separate topical searches included, for example, biodiversity, collusion with birds/seabirds, noise, low frequency sound, soil pollution, material abrasion, landscape beauty, nature protection, injuries, fatalities, social, and economic impact.

2. Examples of Media Reports and Political Discussions Referring to Don Quixote

In Germany, the UK, and elsewhere, news articles and political discussions on wind power referring to Don Quixote typically cover the controversies between opponents and proponents of wind energy projects, and hence establish some analogy to the windmill tale. Their reference to Quixote can present the opponents of wind energy projects both in a favorable or unfavorable way.

For example, a news article in the Independent [25] depreciated the UK government's 2015 ban on constructing onshore wind farms, claiming that "Britain must stop being the lone Trumpian Don Quixote, aiming our lances at non-existent windmill demons! It is not only shameful in a global climate crisis—it's embarrassing" (1p). On the contrary, UK MP Nigel Evens [26] warned in the House of Commons of the "danger of industrialising some of our most beautiful countryside" with modern wind turbines, claiming that Don Quixote "was a few hundred years ahead of his time. If he was to travel around some parts of the country, he would find no shortage of monstrous giants to tilt at" (1p).

A news article by Guratzsch [27] in Welt stated that: "Tilting at windmills is not quixotism against new technologies, but home defense in the eyes of those affected". This article highlights the green-on-green conflict triggered by wind power controversies as "the desire for wind turbines has opened up deep rifts between local heritage and nature conservationists, people and bird lovers, Greens and Greens" (1p). The conflict has arisen since the "Annweiler municipality, and Energie Südpfalz want to install 40 wind turbines

on the ridges of the mountains. [...] Each around 200 meters high, taller than the Cathedral of Cologne. [...] Wingspan: 120 meters. Five there, six there, another ten there". Thus, "Don Quixote, when he comes to the Palatinate Forest, doesn't have to take on a few scattered knights, but battalions" (1p).

A news article in *Pforzheimer Zeitung* [28] used the reference to Don Quixote to explain the need for public participation in form of a community referendum on a wind energy farm in a forest near Birkenfeld (Baden-Württemberg, Germany). It explains that "the proverbial "fight against windmills" goes back to the Spanish novel character Don Quixote and stands for fighting in vain against conditions that simply cannot be changed. Since the end of 2023, opponents have been making [...] the accusation that the citizens are almost powerless to oppose the wind power plans of the local council majority in Birkenfeld" (1p). Accordingly, the article describes the accusation of the wind energy opponents that the promoters of the project are "presenting the population with a fait accompli, at best letting them line up like Don Quixote for a mock battle. This would destroy the Birkenfeld forest in favor of the municipal treasury and thus the habitat of ecologically valuable species". In this case, the opponents of the project will perhaps be successful in preventing the planned wind power farm, as presumably a citizen referendum will soon take place. In this context, the article also points to the high level of conflict, which has arisen in the community around the wind farm planning. Accordingly, the Mayor of the community welcomed the referendum, stating that "cracks were now running right through Birkenfeld families and that 'the sovereign' now had to speak". This argumentation is in line with studies showing that public participation can reduce the level of conflict surrounding possible wind energy projects.

The analogy to Don Quixote can accordingly be used to describe the wind energy opponents in sympathetic way, as brave engaged citizens fighting against politicians in power, wealthy investors, and others in support of the wind power project.

However, the analogy to Don Quixote can also serve to discard, ridicule, and reject the position of the wind energy opponents in political discourse. A further example of the latter is documented in a news article by Elias and Gerlitz [29], reporting that about 20 years ago, the then Minister President of Baden-Württemberg, Erwin Teufel, fought vehemently against what he described as the "Verspargelung of the landscape" by wind turbines. Verspargelung (literally translated: asparagization; referring to asparagus plantations) is a German neologism, which actually originated in the discussions on wind power expansion. The term describes the disfigurement of the landscape by a multitude of wind turbines shooting up all over the landscape much alike to asparagus stalks in agriculture.

To prevent this, Teufel tried to revoke the building permits granted for two wind turbines at Holzschlägermatte, a mountainous grassland area within the Black Forest close to the city of Freiburg. The then mayor of Freiburg, Dieter Salomon (Green Party), nevertheless commissioned the building of the two wind wheels in September 2003, stating that "Erwin Teufel fights like Don Quixote against windmills" ([29], p. 1).

3. Scientific Articles Addressing Modern Wind Energy with Reference to Don Quixote

Hoffman [6] published an article in the field of law with the title "A Don Quixote tale of modern renewable energy: counties and municipalities fight to ban commercial wind power across the United States". This article points to a lack of sensitivity to limits of growth, in particular in the USA, noting that "as goes history in the United States, if something produces a profit, Americans will make it bigger, faster, and better. That is certainly the case with windmills; they have been engineered into giant, towering and industrious windturbines" (p. 717).

A scientific study by Kazlova and Ullmann [30] suggested that the 21st century would be a nightmare for Don Quixote as “thousands of windmills are installed all over the globe and the number will increase tremendously over the next years” (p. 10).

Kovandžić [31] refers to the fight of Don Quixote against the windmills in a thesis on drivers and barriers for investments in wind energy in Serbia. A study by Rojas-Sola and Amezcua-Ogáyar [32] refers to Don Quixote when addressing technological aspects of windmills and conducting a wind evaluation of areas in Southern Spain.

None of the identified scientific studies referring to Don Quixote rejects the further development of wind power production in general terms. On the contrary, these studies all acknowledge and emphasize the environmental benefits and importance of renewable energy production. Furthermore, none of these previous scientific articles referring to Don Quixote addresses the tale in more detail, and none of them addresses the role of Sancho Panza. The following paragraphs shall illustrate how some further articles expressed substantial concerns as to where and how the further development of wind energy production should proceed.

Landscape-related concerns are expressed by Pasqualetti [33], who described large wind farms as both fascinating and challenging, but acknowledged at the same time that the “more vocal public reaction is one of hesitation and resistance to the distinctive landscape signature of wind power” (p. 383). The article refers to Don Quixote very briefly, describing the perception of wind farms from out of a driving car as “whirling machines bordering the highway and crowning every visible ridge, at highway speeds a seeming reversal of Don Quixote’s famous confrontation” (p. 381).

In addition to the visual impacts of wind turbines, Jensen et al. [7] also expressed concerns over effects of their noise emissions on human health and wellbeing. The article refers to Don Quixote claiming that many people nowadays, in particular those living nearby, consider modern wind turbines as threatening giants that are alienating the landscape, and hence perceive them in a similar way as Don Quixote perceived the windmills of his time.

Landscape concerns are also brought up by Shane [34], warning that “windmills popping up across California’s landscape, converting wind to electricity for the benefit of individual property owners, while towering over local landmarks and altering the character of California’s rural communities”. The study claims that “for local communities, these windmills may be the monsters of Don Quixote’s nightmares” (p. 413). The article also claims that Don Quixote was actually “looking for windmills”, and that the same is true for a small-scale wind power production movement in California which “calls for private property owners to install small wind turbines for personal use in order to become more self-sufficient” (p. 403). Accordingly, many homeowners in California have installed small wind turbines “to generate enough electricity to keep the lights and heat on without too much help from California’s creaking power grid” (p. 403). The reference to Don Quixote was thus used by Shane to describe a novel wind power movement “causing a paradigm shift, where centralized utilities may become less dominant while decentralized privately owned power systems take center stage” (pp. 403–404). Shane furthermore argues for the removal of legal barriers in this regard as Californian property owners are “thwarted by archaic or even hostile local land-use regulations” (p. 404) that often hinder or halt small turbine installation projects.

Nulkur [35] is concerned about biodiversity and nature protection, bemoaning the “impact of cutting down age old trees, altering landscapes, destroying habitat and displacing wild life” (p. 58). Nulkur furthermore contradicts the idea of wind energy production as a zero-emission endeavor, pointing to the quantity of electricity consumed, pollutants released, and fossil fuel required for building the fundamentals, tower structure, hub, and blades, and for the site development and infrastructure provision for roads and power

lines. The article reminds the readers not to forget in this context about energy required “to produce the construction equipment, steel, oil, copper, and wind mill equipment, road making machines, bitumen, cement, stone crushing equipment and cranes” (p. 58) for the production and construction of the wind turbines.

According to Nulkur [35], precaution is required when incentivizing corporations to install large wind turbines as the generation of benefits for corporations at the expense of harm to the environment needs to be prevented. For the further development of wind power production, Nulkur thus recommends to “check on our greed, acknowledge the existence of non-human beings and leave a bit of earth for them” (p. 60). He thus points to the three following needs for improvement:

- Better regulations about land use for windfarms to protect landscapes and biodiversity;
- Stronger environmental regulations for the production of windmill blades to reduce environmental pollution;
- Offshore wind power production as an alternative saving precious land.

In spite of the partially harsh critique of existing unsustainable practices in the expansion of wind power regarding site-selection, and production and construction of wind turbines, the article by Nulkur basically embraces the further development of wind energy production, expressing the hope that some day “man can turn them into giant friends which would prove Don Quixote wrong” (p. 60).

4. Threats to Biodiversity, the Beauty of the Landscape, and Human Health and Wellbeing

4.1. Threats of Onshore and Offshore Wind Turbines to Biodiversity and Natural Habitats

Collisions with wind turbine blades can have deadly effects on birds, bats, and insects [36–38]. According to Kikuchi [39] “wind farms kill millions of birds yearly around the world, and the high mortality of rare raptors is of particular concern” (p. 44). However, negative impacts can also occur for terrestrial, non-flying species, including mammals. For example, a study in Poland found an elevated stress level of roe deer near larger wind farms [40]. Consistent with this, two studies found that roe deer avoid proximity to wind turbines and lower population densities of roe deer and wild boar in areas with wind farms [41,42]. Negative impacts of wind power turbines have likewise been identified in studies on reindeer. As a consequence, some wind power projects in Norway have recently been prohibited as they jeopardize “reindeer husbandry as a traditional livelihood of the Sámi and their rights as an Indigenous people” ([43], p. 39).

Studies have also identified impacts of wind turbines on the behavior of ground squirrels. Higher levels of alertness and closer proximity to shelters were found among ground squirrels around wind turbines compared to those at control sites [39]. This indicates that ground squirrels perceive themselves to be under higher risk close to wind turbines, and hence have elevated stress levels there. Kikuchi attributes this to the noise emitted by wind wheels, and accordingly states that “it may be concluded that turbine noise affects the behaviour of squirrels” ([39], p. 52).

In Germany, bats are under legal protection, but the bat population is nevertheless shrinking [44]. Mortal collisions with wind turbines could contribute significantly to this negative trend. Voigt et al. [37] estimated that about 200,000 bats per year get killed in Germany alone by collisions with rotor blades of wind turbines that do not have curtailment mechanisms. Many additional casualties may result from modern, generally larger turbines, having such curtailment mechanisms, as these only provide limited protection to bats and birds. Voigt et al. accordingly generally recommend “the removal of wind turbines from habitats that are important for bats and the implementation of efficient curtailment schemes” (p. 8). Voigt et al. assures that there is enough potential for the substitution of the removed

turbines by novel turbines with curtailment schemes to be located at sites “suitable for wind energy production because of low bat activity” (p. 8).

A study of spatial needs for the further development of wind energy on behalf of the German Federal Office of the Environment [45] identified species protection legislation as a major obstacle to the expansion of wind energy. The German government thus granted exemptions from nature and species protection laws for the permission and construction of wind energy plants in certain wind power priority areas. Accordingly, project developers do not require a species protection report or biodiversity impact (pre-)assessment if the turbine is to be erected in an area designated for wind energy. The government cited climate protection targets as the reason for these exemptions. This seems difficult to comprehend, since climate change-related projects should be oriented towards sustainability, and hence the protection of nature and biodiversity.

Forests and other natural areas with considerable biodiversity including birds and bats are under severe pressure in Germany, as population growth, infrastructure, and industrial development projects generate immense space needs. Forest areas are thus cut down in the context of many projects, ranging from highway and airport construction, industrial area, and settlement expansions to flood protection by new or enlarged dykes and mining projects. A further reduction of forest areas for the implementation of solar and wind power plants should therefore be avoided. It needs to be taken into account that forest areas have themselves various climate related benefits on the global and local level, and benefit human health and wellbeing [46]. Possible alternative locations for wind energy plants include former industrial areas, monoculturally used agricultural land, and offshore areas.

However, research on offshore wind farms has also revealed negative effects on biodiversity, protected species, and natural habitats. Seabirds are at risk of colliding with wind turbine blades [47,48] and some bird species avoid offshore wind farms and areas close by so that natural habitat is lost to them [49,50]. For example, a study by Garthe et al. [51] found strong negative effects of offshore wind farms in the North Sea on seabirds of high conservation concern, as the abundance of loons (divers, family *Gaviidae*), decreased by 94% in offshore windfarm areas plus their 1 km surrounding zones. A study by Welcker and Nehls [52] found similar reductions in the populations of divers (90%) and little gulls (92%), as well as reductions ranging from 75–79% for gannets, terns, and alcids inside an offshore windfarm area in the German North Sea, whereas on the contrary, black backed gulls were attracted by wind farms.

Marine fishes and mammals are negatively affected by the noise of windfarms, in particular during the construction phase, but they are also attracted by the ‘reef effect’ of wind turbine installations and can benefit from a ‘reserve effect’ as fishermen avoid wind farms [53]. For example, a study on the effects of the first Dutch offshore wind farm in the southern North Sea on the marine ecosystem by Lindeboom et al. [54] observed changes of the ecosystem as a new fauna diversity emerged at the feet of the turbines, and some fish species seemed to find shelter within the wind farm. According to Mann and Teilmann [55] more research leading to “a predictive model of the impact of offshore wind farms on various marine species” (p. 3) is required. A recent impact study on behalf of the US government [56] identified potential negative impacts from offshore wind power plants on marine mammals, in particular for the highly endangered North Atlantic right whales, also under pressure (indirectly) from fishery activities.

4.2. Material Abrasion and Possible Soil Pollution

A further possible threat of wind farms to natural habitats results from the erosion of wind turbine blades due to contact with solid airborne particles and rain [57]. The eroded material contains noxious particles including micro-plastic, carbon fiber, and per- and

polyfluorinated alkyl substances (PFAS). The blade erosion can thus possibly pollute the soils around the turbines in operation. Therefore, more research on the severity and impact of such pollution is required.

The contamination of wild boar liver is known to be a sensitive indicator for soil pollution with PFAS as these can accumulate therein [58]. In the German Federal State of Rhineland-Palatinate, the State Investigation Office has recently advised the population against eating the liver of wild boar, and the marketing and further processing of wild boar liver was concomitantly prohibited [59]. PFAS levels in 30 investigated liver samples from different populations clearly surpassed the legal threshold of 50 µg/kg, with an average measured value of 310 µg/kg. This finding is very recent, and the role of wind turbine abrasion, as a possible contributing source, is therefore unclear so far. Wind turbines are not the only possible source of PFAS pollution in forests sheltering wild boars. However, it is important to investigate the role of wind turbines in this context. If wind turbines contribute significantly to the soil poisoning with PFAS, this would speak against locating wind turbines on agricultural land or inside forests. On agricultural land, food is produced, and in forests, food products are also harvested (game, fish, berries, mushrooms, herbs). In particular, when considering forest areas, cleaning up soils after PFAS pollution has occurred seems extremely difficult.

Apart from material abrasion during conventional operation, accidents involving damages or the destruction of the rotor blades may also lead to soil pollution. For example, a news article in Report 24 [60] explains that after a wind turbine blade crashed on agricultural land, “the area around the defective wind turbine must be searched carefully for parts that are sometimes tiny and difficult to see. Glass fiber reinforced plastic (GRP), carbon fiber reinforced plastic (CFRP), hardened foam and balsa wood are [...] components of the rotor blades. GFRP and CFRP not only pose health risks, but also risks to the environment. Fine splinters and particles of these fibers are dangerous for the respiratory tract, and CFRP in particular can even have a carcinogenic effect. Both GFRP and CFRP are also non-biodegradable and pollute soil and water” (p. 1). Clean-up activities after such an accident are presumably even more difficult and less effective in forest areas, compared to agricultural areas where top soil layers can be removed and exchanged more easily, if required.

4.3. Emission of Low Frequency Sounds

Wind turbines can have adverse effects on human health and wellbeing due to the emission of low frequency sound, which can be experienced as stressful and sleep disrupting [7,61]. Such psychological effects are far from harmless since chronic stress is related to severe physical illnesses such as heart attacks, strokes, and some forms of cancers. Some studies also indicate possible concrete physiological links between the sonic, oscillatory mechanical forces of wind turbines and dysfunctional processes on the cellular level that may eventually trigger pathogenic processes in humans and animals [62–64].

Recently, a court in France ordered a wind farm to stop operation because of concerns over the protection of rare species and residents' complaints over noise emissions [65]. In this case, the interests of citizens aiming at health and wellbeing, and of a rare bird (*Aquila chrysaetos* ('aigle royal' or [in English] golden eagle)) for adequate living space were valued higher than the interests of the wind industry. How far similar verdicts can be expected in other countries remains open at this point, but this possibility obviously constitutes a risk for wind energy investments both near residential areas as well as in forests of high biodiversity.

In 2020, the federal legislation in Germany granted considerable autonomy to the federal states to define the minimal distance between large wind turbines and residential areas.

Since then, the minimal distances required in various federal states have been shrinking. In North Rhine–Westphalia, the most populous State of Germany with 18.2 million inhabitants, the minimal distance requirement was dropped totally for so-called wind energy priority areas designated for wind power production in the regional and municipal land use plans. With this change, the legislation in North Rhine–Westphalia seems in contradiction with the French court ruling described above. This seems awkward. When considering the possible negative effects of wind turbine noise on human health and wellbeing, a considerable distance of wind turbines from residential areas is required to protect the residents and uphold their quality of life.

Noise emissions from land wind turbines also have a disturbing impact on animals [66]. This is likewise true for marine ecosystems surrounding offshore wind farms. Here, the extremely loud noise emission occurring in the construction phase, for example due to pile-driving activities or cable-laying activities, seems to be problematic in particular for marine mammals who are known for their sharp acoustic senses [56]. According to Bailey et al. [67] a “measure that could reduce or eliminate the need for pile-driving is the development of floating wind turbine technologies, which are now being considered for deep water (>50 m) sites” (p. 9).

4.4. Landscape Beauty, Subjective Perceptions, and Symbolic Meanings

The impressive view of prestigious large-scale wind turbines appears novel and interesting to many persons [33], and may even attract tourists to the surrounding areas in some cases. According to Frolova et al. [68] “wind turbines can be perceived as sculptural elements in the landscape, evoke positive association by thematic relation to modern structures, and become associated with technological efficiency, progress, environmental cleanliness and utility” (p. 324). In a similar manner, Leibenath and Otto [69] note that “the wind turbine represents a landmark, a symbol of innovation and of the future” (p. 8), but add that others regard it as a ‘lesser evil’ (compared to e.g., nuclear plants), and some as ‘matter of taste’. The last denomination points to the subjectivity of this issue. Still, subjectivity does not mean irrelevance as landscape issues are of crucial significance for public attitudes regarding wind turbines [70,71].

In fact, negative emotional reactions and aesthetic evaluations of wind turbines on landscapes prevail in particular among affected citizens [72], and there are detrimental impacts on tourism and recreation as well as further negative externalities. For example, studies found negative effects of wind turbines on hotel occupancy rates [73] and lower levels of wellbeing in the proximity to wind turbines [74]. Though many people have a positive attitude towards wind energy, the impact of wind turbines on the landscape and their noise emissions are rather judged negatively, and reduce the value of residential properties in their vicinity [7,75]. According to Wolsink [76], the “visual evaluation of the impact of wind power on landscape values is by far the dominant factor in explaining why some are opposed to wind power and others are supporting it” (p. 1188). The corresponding study found that the acceptance of wind turbines depends on the landscape type with high levels of acceptability in industrial, harbor, and military areas and low levels in recreational and nature areas.

Often there is a strong polarization between proponents and opponents of wind energy projects, which can trigger intense social, political, and legal conflicts. For example, in the context of a wind energy project to be implemented in a forest area of the Westerwald, a study by Jobert et al. [77] encountered exchanges of public letters that were described as “mud-wrestling”. Accordingly, “interviewees described the local population as deeply split into opponents and proponents” (p. 2758). Several aspects have presumably facilitated the observed escalation. Firstly, the selected site was a forest area frequently used for leisure

activities. Secondly, a “major point of opposition was that some private landowners would profit while the rest of the population had to ‘suffer’” (p. 2757) as public externalities were not compensated. A third aspect could be the lack of polycentric participatory governance: “Because German legislation gives developers a ‘foot in the door’, the municipality was unable to keep wind turbines off its territory. To conclude: Given the policy framework, local authorities and the local opposition could not prevent the wind park” (p. 2758). There is broad evidence that a top-down approach towards environmental governance promotes conflicts as local communities and their residents are disempowered. Often, local people become objects instead of participants in corresponding planning processes [78,79].

The visual salience obviously increases with the height of turbines. Their sheer monumentality makes modern large-scale wind turbines symbols of human engineering virtue and technological progress [80]. If located in natural areas, they also symbolize dominance of man over nature [81]. These aspects contradict basic assumptions and beliefs of many green-minded people as reflected in the New Environmental Paradigm by Dunlap [82]: The “existence of ecological limits to growth, importance of maintaining the balance of nature, and rejection of the anthropocentric notion that nature exists primarily for human use” (p. 6).

The notion of a dominance of man over nature is likewise contrary to the deep ecology approach endorsing a “holistic and dynamic conception of human–nature interactions [...] informed by the view of social and ecological systems as integrated complex adaptive social-ecological systems that shape each other in a co-evolutionary fashion” ([83], p. 6).

People with deep ecology beliefs may accordingly reject giant wind farms in natural landscapes because of environmental concerns and their symbolic meaning. Also, among average citizens, the acceptance of wind farms will be rather low if the territory for their implementation is highly valuable to them. The natural beauty of the landscape, biodiversity, and human use of an area, such as, e.g., for recreation, sports, tourism, forestry, access to non-wood forest products or hunting, may play a role here. Resulting resistance against wind power can in turn delay projects, increase their costs, and eventually even prevent them [77].

Instead of starting solely from wind-maps, planning processes could also start with nature protection maps that denote natural areas with endangered birds and bat populations as well as natural areas with high scenic value and significant amounts of nature-oriented tourism. Such areas do not seem suitable for the planning of wind turbines. The subjective evaluation, place attachment, and sense of place of the resident population should be considered in the context of wind power projects. For example, Müller et al. [84] developed and tested a tool for participatory mapping of meaningful places for the siting of wind turbines in Switzerland.

In the current German wind power expansion planning, aspects of cultural and natural heritage seem not to be of primary interest. Various current projects are located in natural areas of high cultural value, and consequently trigger opposition, conflict, and polarization.

One example is the planned construction of 18 new wind turbines inside the Rheinhardswald forest, which is also called Märchenwald [i.e., fairy tale forest], as some fairy tales written up by the Brothers Grimm, are imagined to have originated there. The forest hosts a nice medieval castle, the Sababurg, commonly known as ‘Dornröschenschloss’ [i.e., the castle of Sleeping Beauty]. The planning raised considerable resistance and emotions in the population, as the cutting down of the forest has begun in 2024, even though some legal battles in relation to the project were not yet finally decided at that point [85].

A second example is the planning of 27 to 40 wind turbines with hub heights of approximately 200 m in the forest surrounding Altötting and adjacent communities [86]. Altötting hosts a famous pilgrimage chapel attracting a considerable number of visitors. According

to Wikipedia “The chapel is considered a Bavarian national shrine and is one of the most important and most visited pilgrimage destinations in Germany and Europe. The hearts of Bavarian rulers are kept inside the chapel” [translated from the entry ‘Gnadenkapelle (Altötting)’ of the German language Wikipedia]. There is considerable resistance against the wind power expansion in the surrounding forest areas. In January 2024, a municipal referendum was conducted in the adjacent community Mehring, where some of the turbines were planned. A clear majority decided against the construction of wind turbines on Mehring municipal land. However, expanding wind energy is now considered a political priority. Therefore, in the future wind turbines may be built, at least in the State-owned forests of Bavaria, without approval of the respective municipality [87].

On 2 November 2024, a demonstration against the wind energy project in Altötting asked for more public participation in the decision making on wind energy projects. Apart from a demand for democratic participation on the local level, the demonstration aimed at nature, landscape, forest, and climate protection. According to the organizers, “the massive clearing of forests for wind turbines under the guise of climate protection, raises questions such as: ‘How much oxygen does a wind turbine produce?’ or ‘How much drinking water does a wind turbine store?’ and ‘How much cooling shade does a wind turbine provide?’” ([88] p. 1). These questions emphasize the positive climate related effects of forests, which wind farms do not provide.

The perceived fairness of the decision processes leading to the implementation (or else rejection) of wind turbines is a crucial factor determining their acceptance [89]. If the planning and decision-making process leading to the construction of wind power plants is neither transparent, nor participative, then the perceived symbolic meaning of wind generators may easily shift from a pure symbol of dominance of man over nature, to a symbol of the dominance of the ruling political agents.

A deliberative democracy should aim to prevent that dissenters are discounted and “become ‘objects of legislation’ rather than relevant participants in the planning process” ([90], p. 708). In the latter case, the high wind turbine towers may potentially turn into a symbol of oppression in the eyes of opponents who have no power to prevent their construction near their home or accustomed area for recreation. Such an interpretation would not be surprising since high and massive towers—such as, for example, on castles, mountain tops, and town gates—have represented the political might of rulers through many centuries [91], so that corresponding associations may easily arise.

Further visual externalities increasing with the height of wind turbines are due to nightly light pollution from aviation obstruction lights that are required to minimize the risk of collisions of aircrafts [92]. Subjective annoyance caused by resulting light pollution can cause stress and sleep disorders, and lower the acceptance of wind turbines [93]. The loss of night darkness may also alter peoples’ sense of place negatively [94]. Technological approaches for minimizing the light pollution by wind turbines; for example, demand-based aviation obstruction lights are being developed, but their potential is limited [95].

Negative visual impacts of wind turbines for residents and tourists could be avoided to a considerable degree if they are located offshore, and even more so if they are located quite distant to the coast, so that their visibility is limited to the people on ships passing by. Accordingly, an “advantage of offshore wind energy is the lack of immediate neighbors which could lead to higher societal acceptance” ([55], p. 2).

4.5. Injuries and Fatalities in Connection with Construction and Operation of Wind Turbines

An important aspect barely considered in previous studies are injuries and fatalities in connection with the construction and operation of wind turbines.

Considering offshore turbines, a report claims that fatalities and accidents in offshore wind have been declining in relative terms as safety organization reviews progress [96]. According to the report covering 12 leading operators and turbine manufacturers, the number of injuries per million hours worked in operation and construction fell from 5.5 in 2016 to 2.8 in 2022. Furthermore, no fatal accidents have been reported for the last ten years. However, according to different study by Perry [97], the number of safety incidents at various offshore wind companies nearly doubled more recently from 868 in 2022 to 1679 in 2023 and “globally, the offshore wind sector also recorded one fatality in 2023, which occurred during onshore turbine assembly in France” (p. 1).

For the total wind energy sector, much higher numbers of fatal accidents have been reported based on an analysis of press reports and official information released worldwide before 2023 [98]. The report counted 225 fatalities connected to wind energy production, including 135 wind industry and direct support workers or small turbine owners and operators, and 94 public fatalities. The latter number also included workers not directly dependent on the wind industry.

The low fatality numbers reported for offshore turbines suggest that in spite of the obvious dangers and difficulties connected to operations at sea, fatal accidents are presumably occurring much more frequently in connection to onshore wind energy production. A reason for this could be that offshore turbines are located remote from residential areas, so public fatalities (e.g., from falling blades or collapsing structures) are hardly possible.

Exceptions from this could be due to collisions between passenger ships and wind turbines, which could potentially cause very high numbers of casualties. The probability of such an event is low, because offshore wind turbines are stationary objects depicted in sea cards. Still, according to Lewis [99], the first collision of a cargo ship with a wind turbine took place at the Danish Orsted's Gode Wind 1 offshore plant on 24 April 2023. Fortunately, no injuries were reported, and in spite of material damage and water ingress, the vessel was able to reach an adjacent port.

Apart from the differences between onshore and offshore wind turbines, the relation between the height of wind turbines and corresponding safety risks for workers in construction and maintenance as well as for residents and passers-by would be important to investigate in future research.

4.6. Economic Impact of Wind Energy Production

State funding and incentives are a main driver of wind power capacity development [100,101]. The corresponding German energy policy was highly effective in the promotion of renewable energy. A main mechanism was to guarantee investors the possibility to feed the generated power into the public energy grids with subsidized, elevated tariffs. There were also additional incentives such as direct public support for investments, credits with improved conditions, or tax exemptions. Germany has thus become the leading producer of wind energy in Europe [46]. Concurrently, however, electricity prices for private household increased substantially, partly caused by the funding mechanism for the fixed feed-in tariffs. Other reasons for the observed price increase include the general inflation, increased prices for gas and oil, and the German decision of opting out of atomic energy production. Some studies therefore conclude that without the increased production of renewable energy, including wind energy, the electricity price increases would have been even higher. This is, however disputed.

The investors in wind energy and corresponding landowners surely achieved substantial financial profits based on the guaranteed feed-in tariffs. In some cases, social benefits in the form of financial participation of the broader public were achieved; for example, if communities function as investors or owned the land of a wind energy project. In some cases,

cooperatives, including larger number of investors, accomplished it. However, the achieved financial gains were, to large extent, funded by taxpayers and electricity consumers.

Still, a related issue of concern for the owners and investors is the long-term continuation of their wind energy projects as subsidized fixed feed-in tariffs are granted for a restricted time-period of usually 20 years. For them, the question arises, what happens thereafter, and how economically viable will the further production of wind energy be then. Small wind power producers (below 100 kw) may thereafter still feed power into the public grid, but for dynamic market prices. This usually offers the possibility to further continue the energy production with some profitability, as investment cost have already been returned in previous years.

However, for larger scale wind turbines (>100 kw), no such guarantee is provided. For example, in Karlsruhe, a wind turbine of considerable size that started energy production in 1997 and produced 80,000 kwh in 2023 has been stopped recently. It will presumably be demolished, because no energy supplier is willing to take the wind power it produces. A corresponding newspaper article [102] states in regard to this wind turbine: “It almost seems like a bad joke: With the Renewable Energy Sources Act (EEG), the German government wants to plan and approve renewable energies more quickly. At least that’s what the government advertises on its website. However, due to the requirements of the EEG, the operators of a wind turbine now have to switch it off. If they fail to do so and continue to use it to supply electricity, they face a hefty fine. Even though the wheel is working perfectly” (p. 1).

This example contradicts the sustainability of the recent policy strategy for expanding wind energy production in Germany. On the one hand, forest areas are cut down to construct new turbines as these are profiting from the feed-in guarantee with subsidized pricing for 20 years. On the other hand, existing wind turbines may stop energy production, after the feed-in guarantee period is concluded, because they are no longer able to sell the generated electricity. It is unclear how often this market access problem arises, so corresponding research is needed. However, the more wind turbines are installed, the more overproduction of electricity may result during windy times, thus limiting the potential to sell wind energy in the free market. Thus, the many new subsidized wind turbines, which are currently planned and constructed, may well be crowding out already existing wind wheels from the market after the 20 years of feed-in subsidies of these have passed.

A possible strategy to cope with the termination of public funding is to demolish existing turbines and replace them by new, larger ones, which are then subsidized again for 20 years. For example, at Holzschlägermatte in the Black Forest near Freiburg, two wind turbines have been demolished in 2023 and 2024—after the 20 years of operation—to be replaced by one larger scale wind turbine with a height of 229 m. The new wheel is expected to generate an output of 9 to 10 million kWh per year, and hence about two times more than the two former turbines taken together [29].

Such a repowering strategy seems economically attractive for owners and investors. However, the landscape and ecological impact and noise emissions of such a giant new wind turbine remains to be seen and should be closely monitored. It is located on a mountain area at approx. 835 m altitude within a touristic region with high biodiversity and of special sociocultural significance, as it includes the highest German mountain (Feldberg, 1494 m) apart from the Bavarian Alps and at the same time is in vicinity to a city of considerable size.

A question arising in the context from this and similar repowering build-ups is how sustainable such a strategy is on the long term. During the last 20 years, technological options for improved and larger turbines have been developed. The negative environmental impacts, and economic and resource losses from demolishing older turbines, may thus

be currently compensated by effective technology gains. However, what will happen in 20 years, when subsidized feed-in tariffs for the new giant wind wheels end? Will they then be demolished again and replaced by even more giant wind turbines, or could there be some limits to growth?

Apart from restricted funding durations, wind impacts leading to the erosion of the turbine blades during operation can also reduce the operation time of turbines [57]. Building the fundamentals, access roads, and grid-infrastructure, fabricating the hubs and blades, and building up the turbines on site is costly and requires vast amounts of energy and resources. In remote forest areas and mountainous terrains, the construction costs are particularly high if new roads and grid infrastructure need to be constructed. This is another aspect speaking against wind farms in forests.

A further, rather macro-economic, issue is the volatility of the energy supply generated by wind turbines. Storage capacities are required to prevent the negative economic effects of underproduction of wind energy during calm days and overproduction on days with strong winds. Solar power and wind power and other renewable energy resources can complement and mutually compensate each other to some extent. However, on some days there is neither much sun nor wind, so that renewables alone can currently not guarantee the reliable electricity supply needed. Before a substantial further increase of wind energy electricity production becomes economically viable, possibilities and capacities for the storage of wind generated energy need to be implemented. One of the corresponding options, which has a large scalability, is the storage of hydrogen produced by wind and solar power plants [103,104]. Accordingly, research and development actions and policies should be directed towards the further development and implementation of corresponding options for energy storage.

On the contrary, public investments in wind power plants located inside forests or at further sites with high biodiversity and nature quality seem questionable. This is particularly true for southern regions of Germany, where average wind speeds are generally much lower than in the northern coastal regions. A study by Jung and Schindler [105] thus concluded that the two southern federal states of Bavaria and Baden-Württemberg, with large-scale forests such as the Bavarian Forest and the Black Forest, have rather few suitable locations for wind power plants, except for exposed mountain tops that have a large impact on characteristics of the landscape.

4.7. Climate Impact of Wind Energy Production and Forests

Wind energy significantly reduces CO₂ emission when compared to power production by fossil fuels, which it partially compensates. However, wind farms also cause such emissions, in particular in the manufacturing and construction phase, and to lesser degrees in the maintenance and dismantling phases. Guezuraga et al. [106] conducted a life cycle assessment of 2 MW wind turbines and calculated for the emissions 9 gCO₂/kWh when assuming a 20-year life period. The calculated CO₂ emissions were thus much smaller than those calculated for conventional coal power plants (1046 gCO₂/kWh) and modern combined power and heat plants using natural gas (228 gCO₂/kWh). Therefore, in spite of considerable construction emissions, the emission reduction potential of wind energy is large, and its important role in the energy transition towards renewables is therefore undisputed.

However, the study by Guezuraga et al. [106] did not include the scenario of a wind farm constructed inside a forest. When planning a wind power turbine in a forest, multiple climatic benefits get lost [46]. Firstly, forests produce wood, which represents a to some extent CO₂ neutral energy itself. Secondly, forests absorb CO₂, as well as toxic emissions from traffic and industrial production (e.g., NO, SO₂, SO_x). Thirdly, forests have direct

climatic cooling effects, because they provide shade, and have the ability to store and retain humidity and water. This benefits and protects humans, animals, and plants during potential heatwaves, and protects human settlements from flooding in times of extreme rains. The root system of intact forests provides a protection from soil erosion, and thus likewise protects human settlements from landslides, which can occur as consequence of intense and enduring rain. Accordingly, placing wind turbines inside forest areas is not a good strategy if the aim is to prevent climate change and its negative impacts. A better idea is to place wind turbines on deserted or agricultural land, and subsequently plant new forests around them. Such newly generated forests could protect residents of adjacent human settlements from negative impacts of climate change, as well as from the low frequency sound of the wind turbines, and they would reduce the visibility of the turbines in the landscape.

4.8. Airborne Wind Energy System (AWES) as Technological Option

AWES represents a new approach to the generation of electricity with potentially higher resource efficiency, larger energetic potential, and less negative environmental impacts and social conflict than conventional wind turbines on solid towers [107–109]. According to van Hagen [110] the following main advantages could promote the wide spread application of AWES in the future:

- At higher altitudes, which can be solely reached by AWES (e.g., 500–1000 m), the wind blows stronger and more frequently than below.
- AWES can be designed to react flexibly in relation to the altitude where they operate, so they can operate at any time in the altitude with best wind conditions.
- The material requirements for the construction of AWES are much smaller because no solid tower structure needs to be built.

In a comparative LCA, van Hagen [110] calculated an emission efficiency of 7.8 kgCO₂eq/MWh for a large-scale 5 MW AWE system compared to 13.0 kgCO₂eq/MWh for a conventional ground-based wind turbine with the same power. However, no such large-scale AWE system is operative, so this calculation was based on modelling the impact of a fictitious AWE system. For a different (fictitious) AWES even lower emission rates of 5.6 kgCO₂eq/MWh were calculated by Wilhelm [111], who accordingly states that “airborne wind energy is expected to pose an additional renewable technology that might overcome some of the problems with wind energy within a few years” (p. 728).

This appears plausible, since high altitude AWES are not only less material intensive and more energy efficient, they perhaps also have the potential to provide a more stable energy supply than conventional wind turbines due to their flexible operation altitude. In addition, AWES presumably have less negative impact on biodiversity and the landscape. Thus, perhaps, this new technology can in future even render the conventional wind turbines an antique technology.

According to a review of 40 previous studies [112], airborne energy systems can also gain higher social acceptance than conventional wind turbines. The absence of a massive tower and the higher operational altitude reduce the visual impact and noise perceived by humans as well as the frequency of collisions with bats and to some extent birds. Still, substantial safety concerns regarding AWES exist, and additional challenges for avoiding collisions with aircraft arise from the new technology. Schmidt et al. [112] thus recommend placing AWES in remote areas and/or offshore, because this seems beneficial considering both safety concerns and public acceptance.

A recent study in Northern Germany [113] compared the social acceptance of an actual operative AWES with the acceptance of wind farms nearby. The tested AWES applied ground-based electricity production, and used a kite with soft wings of varying sizes

reaching up to 160 m², operated at heights up to 400 m, and reached a maximal power of 200 kW. The visual impact of the AWES was rated even slightly positive on average in this study, whereas the impact of the wind farms was perceived on average (slightly) negative. No corresponding differences between AWES and conventional wind farms were observed for noise perception, safety concerns, and ecological damages expected by the survey participants. The study also identified doubts of some survey participants as to whether airborne wind energy production could be able to produce substantial amounts of electricity and contribute to the energy transition.

Indeed, before large-scale AWES can contribute significantly to global energy production vast technological challenges need to be overcome. As Vermillion et al. [107] put it, AWES “can be viewed as a control system designer’s paradise or nightmare, depending on one’s perspective” (p. 330). However, a tremendous progress took place in the development of the technology in recent years, and further progress is ongoing. According to Fagiano et al. [114], AWES developers are currently scaling up real prototypes to the 1 MW level by using kite sizes of 500–700 m², and series products with continuously increasing power can be expected to enter the market over the next years. In their view, public funding should support research and development in the AWES sector. Academic research could cooperate with private companies to achieve a further development so that a substantial contribution of AWES to global energy production can be realized rather sooner than later.

5. Discussion

Sustainable pathways in renewable energy production should aim to benefit all dimensions of sustainability by achieving positive economic, social, and ecological outcomes. Wind power production has the potential to achieve such synergies. The question is, however, where wind turbines should be located, and how they can be designed and integrated in the energy supply system to achieve sustainable outcomes.

Not only from the perspective of deep ecology, but also from an analytical and integrative perspective on sustainability, the impact on nature and biodiversity should be given more weight than economic benefits in the overall assessment of wind energy projects. Such a strong valuation of ecological aspects seems by no means in conflict with the aim of considering social, economic, and ecological aspects of sustainability in a balanced way. The environment and its natural resources are the fundament on which the economic and social pillars of sustainability reside, and therefore need to be sustained to keep these two pillars in balance so that the satisfaction of human needs can be furthered [115].

Forests and other areas with high nature and landscape quality, biodiversity, cultural, touristic, and recreational value need to be avoided as locations for prospective wind farms. Wind turbines should also be located a considerable distance from human settlements to avoid noise disturbance of residents. Instead, deserted land, former industrial or mining sites, and agricultural areas with monocultural land use are possible locations. Additionally, the further development and expansion of offshore wind farms seems a promising way to reduce land use conflicts and boost wind energy production. Moreover, research and development activities for AWES should be strengthened to gain the technological know-how and ability of harvesting wind energy in novel ways to further renewable energy production. A clear research and development priority in this regard is the construction and experimentation with concrete prototypes of larger-scale AWES. Many previous studies have been conducted on the rather theoretical level of the analysis of prototype models which still have to prove their functionality in practice.

Apart from this research gap on large-scale wind power generation, there also seems to be a research and development gap in relation to small-scale wind energy production systems. According to Shane [34], such facilities may be attractive to small-scale producers

as they increase their energy independence. However, the potential of small-scale wind production appliances seems underdeveloped, and more knowledge of the corresponding drivers and barriers and its social acceptance is needed. This seems evident, for example, when comparing its rare application to the immense small-scale production of photovoltaic energy installed on the roofs of so many private consumers in many countries. Actually, considering the threatening giantism of the historic windmills to Don Quixote, and of modern wind turbines to some citizens of today, suggests at face value that the further development of small-scale wind power production could be a pathway to circumvent many sustainability problems and conflicts triggered by large wind turbines. Ultimately many small-scale appliances also have a potential to add up to substantial productivity. Research supporting the further development and larger scale practical application of both AWES and of small-scale wind energy production appliances should be prioritized, aiming at an expansion of wind energy production that is circumventing sustainability conflicts identified in this study.

A rapid trend towards ever higher and larger wind turbine towers is currently ongoing, as described in the Introduction. This trend entails severe dangers for sustainable development if biodiversity, landscape protection, and health concerns are ignored in the planning of corresponding wind farms. A new focus of research and development on AWES and small-scale wind energy production may offer possibilities to replace this trend in the future while offering potentially more sustainable approaches.

Furthermore, the development and implementation of storage capacities for wind power turbines seems an important prerequisite for the further increase of the share of renewable energy. A stable supply of wind generated energy could be promoted with such storage capacities. The generation of hydrogen during windy times of overproduction of power seems a promising approach in this regard [103,104]. Currently, overproduction of wind energy in high wind times strains the grids and causes considerable costs for their curtailment for example in Great Britain and Germany [116]. Using energy production overshoots for the generation of hydrogen could secure energy supplies in times with low winds. This may prove economically profitable, even though the production of electricity from generated hydrogen is highly energy intensive [117].

Cutting down forests to produce wind and solar power does not seem to be the appropriate approach for counteracting climate change and its effects. Climate change is not only about temperature, but also about humidity, precipitation, and the lifeworld of flora and fauna. Forest cover is central for all these aspects, and forest-protection and afforestation are thus crucial for combatting climate changes and its negative effects. The problems of deforestation, desertification, and climate change are interconnected, and therefore in need of synergetic approaches [118,119]. Thus, for example, afforestation projects including wind turbines to be constructed on monoculturally used agricultural land or deserted areas could be a sustainable option. Surrounding such wind towers by a newly generated forest—eventually with irrigation supported by the gained wind power—seems more responsible than destroying forests for wind farms. The emission reduction achieved by wind power should not be played off against biodiversity losses and landscape deterioration.

A possible lesson learned from Don Quixote and Sancho Panza seems to be the need for participatory governance and decision-making. Don Quixote was superior to Sancho Panza in the past aristocratic time, so the latter could not prevent the former from starting his irresponsible self-destructive attack, even though Sancho was right in the quest of the windmill in the 17th century. One may thus argue that the disaster of the windmill attack could have been prevented by empowering Sancho to participate in the decisions taken during the adventure. This makes Sancho Panza a representative and symbolic figure of

ordinary people suffering the consequences of irresponsible actions taken by those with political and financial power. It would be interesting to explore how cultures with different prevailing attitudes regarding elite hierarchies, on the one hand, and towards egalitarianism and participatory governance, on the other hand, differ in their interpretations of Don Quixote's story, and how this might influence people's attitudes towards large-scale wind energy projects.

Rural population and farmers are often not sufficiently empowered to participate in land-use-related decision-making processes, even though they may sometimes perceive things more realistically than political leaders. A well-known problem of the latter for political elites is that because of their high societal position, they may easily lose connection to the ground. This is another analogy to Don Quixote, who lost connection to the ground when he was taken up by the wing of the spinning windmill.

These considerations point to the importance of polycentric governance and public participation for the planning of wind power projects. Participatory planning and democratic decisions on the local level are suitable to reduce and mitigate social conflicts arising over the construction of wind turbines.

Two important aspects of polycentricity and participatory governance, for example allowing democratic public votes on relevant issues, are subsidiarity and real democratic power. Subsidiarity ensures that democratic votes are taken on the level of governance that is mainly concerned with an issue (local, regional, national) and ensures a somewhat pivotal role of more local entities, which limits the power of superior levels. Real democratic power means that public votes are strongly binding and cannot be easily overridden by governmental or administrative rulings. The political system of Switzerland realizes these principles to a considerable extent, and may therefore be considered a role model for other democracies. Democratic voting on important aspects of governance on various levels from local to cantonal and federal is an important element of direct democracy in Switzerland, which empowers its residents in many regards. Making more use of such elements of direct democracy could also be helpful for other countries and empower their residents in similar ways.

Another lesson learned concerns the struggle between idealism and pragmatism in the search for sustainable solutions. The single instance of the windmill adventure does not prove a general superiority of pragmatism over idealism when tackling economic, political and environmental affairs. Instead, pragmatism and idealism may well complement each other in many ways. Klein [120] thus argues "that a quixotified Sancho Panza, as a combination of theoretical idealism and practical realism, is necessary for managerial statesmanship" (p. 43). Ortega [121] accordingly describes the congeniality of the relationship between Don Quixote and Sancho Panza as follows: "One cannot live without the other. This brotherhood, imposed at the same time by the internal necessity of the elements of our psyche which seek to complement themselves within the self, and also by the external need of the facts of life which force us to lean on our neighbor, has two names of great value. Internally it is called spiritual peace; externally it is called democracy" (p. 410). However, a democracy admired in this way needs to be more than a 'tyranny of the majority' [4].

In the typical modern time conflicts between opponents and supporters of certain wind energy projects, the borders between idealism, realism, and pragmatism may vary greatly depending on the specific case. To some extent advocates of both positions may be motivated to varying degrees by self-oriented considerations. For example, an attitude of 'not in my backyard' may prevail among some opponents, and some supporters may be motivated mainly by financial interests. Still, members of both parties may also have idealistic motivations, and hence incorporate aspects of both Don Quixote and Sancho Panza in the green-versus-green wind energy dilemma. However, both parties may assume

for themselves to have greater idealism and realism than the other party. This can partially be explained by processes of positive self-categorization, and simplified ingroup–outgroup perception, which can promote intergroup conflict according to social psychological theories [122,123]. Thus, both parties may assume for themselves to be fighting for the ‘Good’, similar to Don Quixote when attacking the windmills.

When looking at the rationality and realism of both parties, it becomes clear that different types of knowledge and considerations of a different time and spatial scales could also be in conflict with each other. Those preferring the protection of the local landscape, endangered species, and/or human health and wellbeing from a concrete wind farm planning are often concerned about their adjacent lifeworld and life experience in the here and now, and the immediate future. Scientific knowledge and evidence on negative effects of windfarms substantiate these concerns.

On the contrary, those advocating for a wind power project that causes concrete, direct biodiversity losses mainly refer to scientific climate models predicting positive global climate benefits of the windfarm for the future. Thus, as is true for climate models, their mode of thinking is predominantly scientific, the spatial scale of their considerations is global, and the considered time frame is large.

The power relation between opponents and proponents of wind power projects depends strongly on the specific legal and political policy context of each case [124]. Still, generally speaking, the Wheel of Fortune (or in this case of ‘power’) has somewhat turned in this regard in Germany. Originally wind power was advocated and promoted by pro-environmental grass root movements. Thus, in the 1990s, some wind energy pioneers were confronted with strict state regulations and the ruling political parties were skeptical of the idea of wind power. Now, a large-scale wind power expansion policy is operative, the ruling parties are supportive of wind energy expansion, and some pro-environmental grass root movements are fighting against this to protect biodiversity and natural landscapes from wind energy projects.

The current situation may entail the danger that political decision-makers misinterpret the sustainability guideline of thinking globally and acting locally. They may easily interpret it wrongfully by disempowering communities on the local level for the global ‘Good’. Polycentric and participative governance structures including public votes are possible approaches to prevent such a possible disempowerment. Granting minority rights and rights of indigenous people are another possibility to prevent the disempowerment of local communities, as illustrated by the Norwegian court decisions [43] protecting the traditional livelihood of the Sámi against disturbances caused by windmills.

Generally speaking, the balance between the interests of local communities and national governments or large-scale investors in relation to wind energy projects should give pivotal consideration to the lifeworld of residents, who are immediately affected [124]. The principle of acting local and thinking global should grant autonomous power to local communities to act on their own behalf, so that beneficial and sustainable activities on the local level can add up to sustainable development on the global scale. In a similar vein, protection of natural spaces and biodiversity in local and regional areas can add up to sustainable ecological development on the global scale. On the contrary, sacrificing biodiversity in local areas and regional landscapes for an assumed Global Good may deteriorate ecological sustainability globally when the regional destruction is added up over many negatively affected places in the world. Many beneficial processes at a small scale may add up to substantial benefits when adding them up. An example could be small-scale renewable energy production using solar and wind power. On the contrary, there are countless examples of giants, both political and architectural, causing catastrophes

and even ruining entire nations. Thus, apart from the adventure of Don Quixote, fighting gigantism may sometimes make sense.

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