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REVIEW

Wildlife and renewable energy: German politics cross migratory bats

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Abstract The catastrophic nuclear meltdowns at Fukushima triggered a worldwide demand for renewable energy. As one of the few countries, Germany decided on an accelerated shift towards green energy, resulting in substantial conflicts with international conservation goals. Currently, large numbers of wind power facilities are erected in Germany, yet with unforeseen consequences for wildlife, particularly for endangered and protected bats. Presumably, more than 250,000 bats are killed annually due to interactions with German wind turbines, and total losses may account for more than two million killed bats over the past 10 years, if mitigation measures were not practiced. More than 70 % of killed bats are migrants, because major migratory routes cross Germany. Consequently, Germany's environmental policy is key to the conservation of migratory bats in Europe. Prospective increases in wind power will lead to the installation of larger wind turbines with potentially devastating consequences for bats. The higher net energy production of modern wind turbines at low wind speeds may exacerbate the conflict between green energy and conservation goals since revenue losses for companies increase. We conclude that evidence-based action plans are urgently needed to mitigate the negative effects of the operation of wind energy facilities on wildlife populations in order to reconcile environmental and conservation goals.

Keywords Alternative energy · Chiroptera · Conservation · Migratory species · Wind energy facilities · Wind parks · Green energy

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Introduction

Over the past two decades, wind turbines have been promoted in many North American and European countries, particularly after the galvanizing event of Fukushima when several nuclear power plants were destroyed by a tsunami. In response to this traumatic event and in consideration of greenhouse gas emissions known to affect global climate, German politicians decided against the continuation of nuclear and conventional power production and for the promotion of renewable energy with a strong emphasis on wind power. Currently, a major domain of renewable energy production stems from wind power facilities in Germany, which already makes up about 34 % of the national renewable electricity production (Berkhout et al. 2014).Yet, the total wind power-generating capacity is estimated to increase by about 30 % from 35 GW in 2013 (Berkhout et al. 2014) to 46 GW until 2020 (BRD 2010a). Accordingly, numerous wind power facilities are currently erected in Germany. By 2014, about 24,000 on-shore wind turbines had been installed in Germany (Berkhout et al. 2014), and Germany ranks third worldwide with respect to net energy production derived from wind power, outnumbered only by China and the USA (Berkhout et al. 2014). Yet, considering its smaller geographical size, Germany exceeds China and the USA by a factor of about 10 and 16, respectively, when it comes to net energy production per kilometer squared (0.096 MW km^{-2}

for Germany compared with 0.0095 MW km^{-2} for China and 0.006 for the USA). Recent studies highlight that renewable, so-called green energy may come at environmental costs as well (Rydell et al. 2010; Voigt et al. 2012; Northrup and Wittemyer 2013; Lehnert et al. 2014), raising concerns about whether German energy politics are in conflict with international legislation such as the EU Habitats Directive 92/32/CEE (Annexes II and IV) and also international conservation goals such as the "UN Convention on Migratory Species of Wild Animals" (conventions dated Bonn 1979 and London 1991).

Discussion

Consequences of German environmental policy for protected wildlife species

Numerous studies in North America and Europe have demonstrated over the past years that large numbers of bats are killed at wind turbines (Barclay et al. 2007; Arnett et al. 2008; Baerwald and Barclay 2009; Rydell et al. 2010; Amorim et al. 2012; Georgiakakis et al. 2012; Camina 2012; Hayes 2013). Indeed, bats are the taxonomic group of vertebrates which is most drastically affected by renewable energy, specifically wind energy. Most bat fatalities at wind turbines occur between mid July and end of September (90 % of all bat fatalities in Europe; Rydell et al. 2010), and almost 70 % of recorded bat fatalities in Germany represent migratory species such as *Nyctalus noctula* (Schreber 1774) (34 % of all deaths), *Pipistrellus nathusii* (Keyserling and Blasius 1839) (26 %), *N. leisleri*, (Kuhl 1817) (5 %), and *Vespertilio murinus* (Linnaeus 1758) (4 %) (Rydell et al. 2010). Owing to its central geographical location on the European continent, Germany provides highly important ecological stepping stones for many long distance bat migrants from northeastern populations (Steffens et al. 2004). The increasing density of wind turbines throughout this country may however disrupt the migratory routes of bats and thus weaken the connectivity between breeding and wintering areas (Fig. 1). The transboundary importance of Germany for migratory corridors has not been widely recognized in environmental and energy policy of Germany, let alone followed by corresponding action plans, even though bats, and particularly migratory species, are protected by law and UN conventions.

How many bats are killed at German wind turbines?

In Europe, reported cases of bat fatalities at wind turbines vary largely with respect to number and species composition (Rydell et al. 2010). This variation is most likely associated with local variation in species richness, but may also be caused by differences in habitats (high or low elevations, forested, and open habitats) as well as differences in applied search protocols. For example, studies covering the whole annual activity period of bats are rare, and most of them tolerate relatively large gaps between search events, despite the fact that several days or even weeks of daily searches per month are more appropriate. In addition, surveys have only recently begun to consider carcass removal by scavengers and search efficiency in the estimation of annual bat fatalities at wind turbines (Arnett et al. 2008). Currently, standardized protocols are recommended that control for these biases (Rodrigues et al. 2008), thus avoiding systematic underestimations when numbers of bat carcasses at wind turbines are reported. When controlling for such biases, surveys revealed that about 10–12 bats are killed annually at each wind turbine in Germany where no mitigation measures have been implemented (Brinkmann et al. 2011). Assuming that these numbers are representative for all types of wind turbines and for all of Germany, it can be inferred that in each of the past 5 years more than 200,000 bats were killed at on-shore wind turbines in Germany if mitigation measures were not practiced. This is equivalent to 6–8 killed bats annually per MW installed net energy production (Berkhout et al. 2014). For the contiguous United States of the America, it is estimated that wind farm facilities caused about 600,000 bat fatalities in 2012 (Hayes 2013), which is equal to 10 killed bats annually per MW installed net energy production. Thus, our estimate for wind turbine-related bat fatalities in Germany is in a similar range as the one suggested for the contiguous USA. Summarizing, cumulative numbers of wind turbine-related bat fatalities suggest that more than 2,000,000 bats could have been killed by wind turbines over the past 10 years in Germany if no mitigation measures were implemented.

What kills bats at wind turbines?

A key question for the solution of wind turbine-related bat fatalities is why bats are killed at wind turbines. Are, for example, bats attracted to wind turbines because they hunt for insects at wind turbines (Rydell et al. 2010) or because they swarm at these prominent structures for social reasons (Cryan et al. 2012)? If the physical structure of wind turbines attracts bats, pre-construction surveys may underestimate the post-construction mortality risk for bats. Still, pre-construction assessments seem to be essential for evaluating a possible negative impact of wind turbines on target species or on nearby maternity roosts. In addition to these general questions, it is crucial to understand the proximate causes of death at turbines. Baerwald and colleagues (2008) revealed that bats may die of barotrauma at wind turbines, i.e., killed bats may show no external signs of injuries such as bone fractures. Instead, bats killed by barotrauma exhibit extensive hemorrhages in the thoracic and abdominal cavities (Baerwald et al. 2008; Fig. 2) and/or hemorrhages in the middle or inner ears (in more than 50 % of all bats studied by Grodsky et al. 2011).

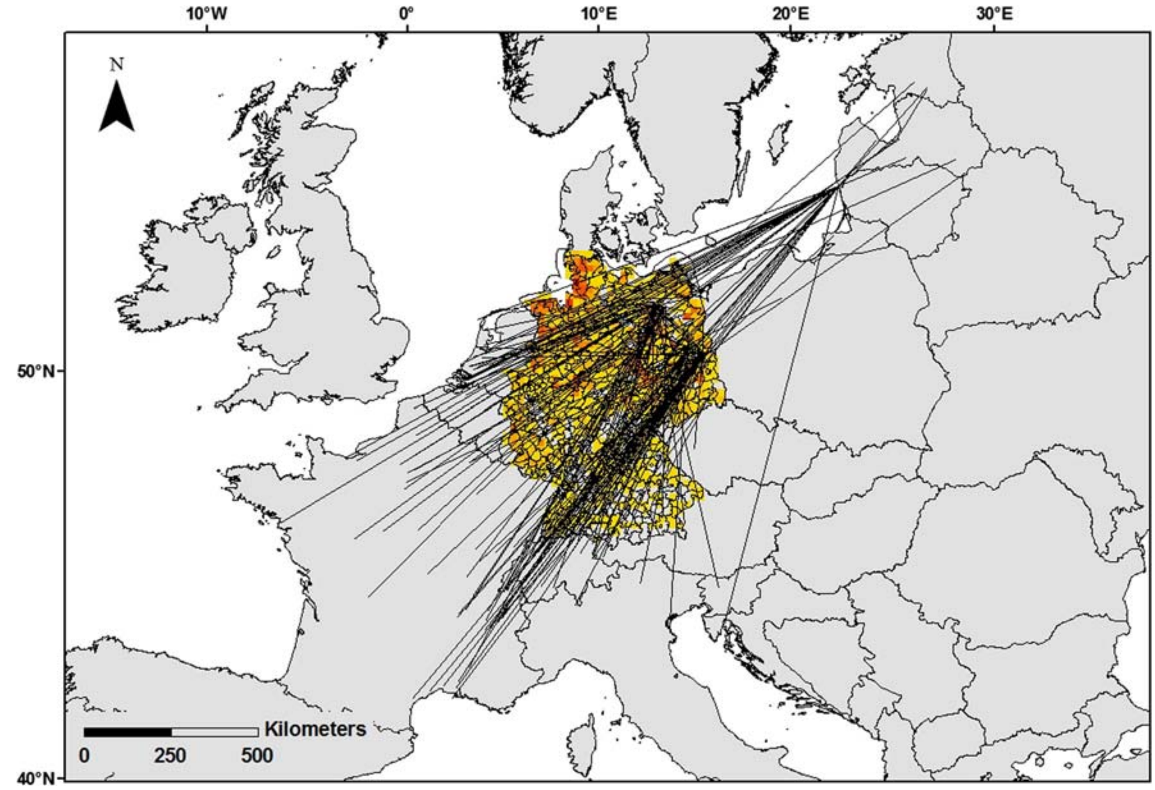

Fig. 1 Number of wind turbines per 20×20 km^2 grid cell in Germany (EEG-Anlagenregister Deutschland 2014) in relation to migratory movements of a long distance migrant *Pipistrellus nathusii* (source: Steffens et al. 2004; Petersons 2004). *Red* and *yellow* grid cells indicate high densities of wind turbines (*white grid* cells those without wind turbines; the highest density is 293 wind turbines in a 20×20 km^2 grid cell). *Solid lines* connect the sites where bats were banded in Northeastern and Central Europe with sites where banded individuals were recovered, mostly in Southwestern and Western Europe

Barotrauma is most likely caused when bats are subject to sudden air pressure reductions near moving turbine blades. Recent studies highlight that both blunt-force trauma caused by direct collision and barotrauma caused without physical contact may be responsible for the deaths of bats at wind turbines (Grodsky et al. 2011). Possibly, large wind turbines with longer blades inflict stronger physical forces on bats, i.e., a stronger reduction in air pressure in the tailwind vortices, and these may result in a higher percentage of bats killed by barotrauma in relation to those killed by blunt-force trauma. Such considerations are important because bats killed by bone fractures via blunt force trauma may fall to the ground close to the wind turbines and are likely to be found by searchers. In contrast, bats suffering from barotrauma may experience mild symptoms that may allow them to survive for minutes, hours, or even days before they eventually die. Such bats are almost impossible to find because they do not drop dead in close proximity to the turbines. If mild but nonetheless lethal

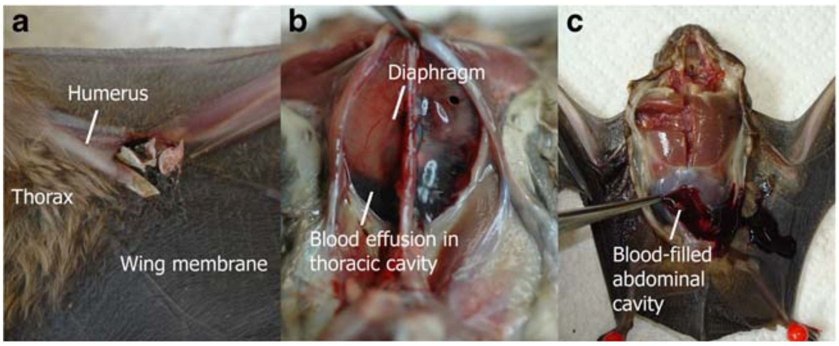

Fig. 2 Blunt-force trauma (**a**) and barotraumata (**b**, **c**) in three noctule bats (*Nyctalus noctula*) killed at wind turbines. **a** Ventral view of an open fracture of the left humerus at the height of the elbow joint. **b** Ventral view of the opened abdominal cavity with blood effusion in the thoracic cavity visible behind the diaphragm (hemothorax). **c** Ventral view of opened carcass without bone fractures, but severe bleeding in the abdominal cavity (hemoabdomen) (picture courtesy: Gudrun Wibbelt, IZW)

barotrauma is a significant cause of death for bats at wind turbines, the total number of bat fatalities may be largely underestimated. And if taller wind turbines cause a larger proportion of bats to die of barotrauma, the recent and future installation of larger turbines may result in an increasing number of unrecorded bat deaths.

Do bat populations suffer from increased mortality at wind turbines?

Considering the massive losses of bats at wind turbines, a key question for conservationists is as follows: Are bat colonies or populations affected by the increased mortality risk of individual bats at wind turbines? In theory, bat populations should be quite susceptible to additional causes of mortality because of their low fecundity (Jones et al. 2003). Additionally, fatalities of pregnant bats during spring migration in Germany could aggravate a negative effect of wind turbines on bat populations. Although urgently required, conclusive studies on the population level effect of wind turbines have not yet been conducted (but see Roscini et al. 2013), because they require collection of baseline demographic data such as age structure, dispersal, and recruitment in multiple colonies over a prolonged period of time and most importantly some knowledge about the location of source populations from which killed bats originated from. Affected bat populations could be as far away from Germany as Fenno-Scandinavia, Baltic Countries, Belarus, and Russia (Voigt et al. 2012; Lehnert et al. 2014). Lastly, it is important to note that the question of population effects is not relevant from a legislative point of view, because effects at the individual level (i.e., the killing of an individual of a legally protected species), and not the population level, are the subject of EU legislation.

Avoidance, mitigation, or compensation?

According to legal requirements in Germany, wind turbines should not be erected when bat activity is high at the designated location. Pre-construction surveys require substantial monitoring efforts, but even if monitoring is commissioned, efforts are limited in time because of limited funding for more comprehensive surveys. A recent study highlights that bats may even be attracted to wind turbines (Cryan et al. 2014), which makes pre-construction surveys of limited use for predicting the mortality risk for bats at an operating wind turbine. In summary, avoidance measures may prove difficult and thus inefficient, because surveying techniques are prone to bias. Even if wind turbine sites may prove unsuitable because of high bat activity, we have not heard of cases in Germany where turbines were forced to stop operation or where they were even deconstructed. Also, to the best of our knowledge, measures for repelling bats from wind turbines have not proven to be efficient or practical. For example, bats avoided wind turbines when exposed to the high electromagnetic fields (>2 V/m) of radar (Nicholls and Racey 2007, 2009), yet such measure may not be practical for several reasons. Electromagnetic radiation may impose a health risk on bats, causing thermal overheating, and possibly also on humans in proximity to the radar. Accordingly, this avoidance measure may not be acceptable for the public, for authorities, for conservationists, and for animal welfare groups. Compensation measures for increased bat fatalities at wind turbines, e.g., improving habitat or roost quality, are inefficient, because source populations of killed bats may be far away and difficult to locate (Voigt et al. 2012). Also, trading bat fatalities at wind turbines against habitat improvements (e.g., installation of bat boxes) is not consistent with the EU legislation.

The most widespread mitigation measure for wind turbine-related bat fatalities is to define a threshold wind speed, a so-called cut-in speed, at which the rotors start to operate. This can be an efficient mitigation measure because bats are only active at rotor height at relatively low wind speeds (Fig. 3). Thus, if wind turbines are switched off or feathered at low wind speeds—when net energy production is low anyways—bat fatalities may be drastically reduced (Baerwald et al. 2009; Arnett et al. 2013). In addition, bat activities vary seasonally, e.g., bats are inactive in winter and most active during migration. These factors can also be incorporated into the operation schedules of turbines (Rodrigues et al. 2008). Indeed, the enforcement of cut-in speeds for the operation of

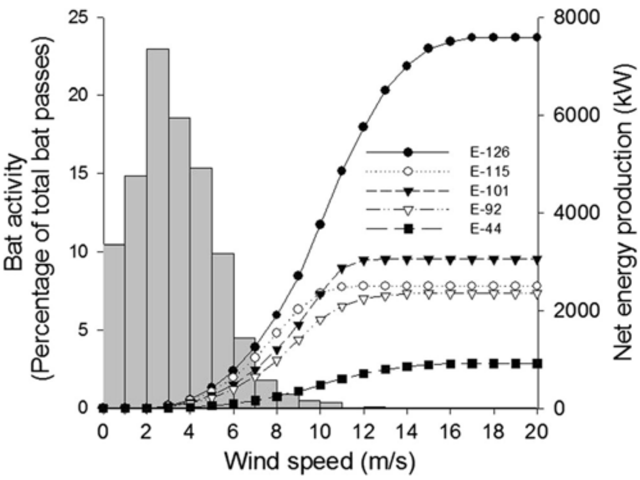

Fig. 3 Overlap between bat activity (percentage of total bat passes in 1 m/s categories; n_{total}=9287 bat passes) and net energy production (kW) for selected wind turbines in relation to wind speed. Bat passes were assessed via acoustical recordings at about 125 m above ground between April and October (2011 and 2012) at wind turbines located in southern (Bavaria), western (Rhineland-Palatinate), and northern Germany (Lower Saxony). Data on net energy production is from Enercon (2012); *numbers* in the legend represent the diameter of circular areas covered by the rotor blades. Novel larger wind turbines are starting to yield a higher net energy production at lower wind speed and thus overlap stronger with bat activities

wind turbines may reduce bat fatalities by as much as 60–80 % (Baerwald et al. 2009; Arnett et al. 2013). Most commissioned operation protocols employ cut-in speeds of 6–7 m s^{-1} at ambient temperatures higher than 13–15 °C (measured at nacelle height) and limited to the season of highest bat activity in autumn. Notably, some bats, particularly the migratory species *N. noctula* and *P. nathusii*, may still be active at wind speeds higher than 7 m s^{-1}. Therefore, the current practice of cut-in speeds may selectively affect those species that can forage or migrate in stronger winds.

Recently, situation-dependant operation protocols, so-called algorithms, were developed for the operation of wind turbines. These algorithms consider a number of parameters such as temperature, wind speed, season, and time of day as well as recorded bat activities for defining a set of operation rules for wind turbines. When using such algorithms, operation of wind turbines is only stopped when some parameters, such as ambient temperature and wind speed, fall above or below pre-defined threshold values in 10-min intervals. From a company perspective, these algorithms come at a lower revenue loss compared with aforementioned more static operation protocols. From a conservation perspective, algorithms promise to reduce bat fatalities by more than 80 %, from about 10–12 to two bats killed per year per wind turbine (e.g., Brinkmann et al. 2011). However, these algorithms have been formulated for a single type of turbine (E-70; Enercon 2012) and for a limited number of sites of varying geographical background, and therefore, their efficiency is questionable for other types of wind turbines and geographical areas, for example these algorithms seem to work reasonably for *N. noctula*, but not necessarily for species of the genus *Pipistrellus*. It has also been criticized that the abrasion of wind turbines is larger when operation is frequently switched on and off. Finally, the widely recommended acceptance of an arbitrary number of two bat fatalities annually per wind turbine may not necessarily be consistent with national and EU legislation, which prohibits killing of single individuals of a protected mammalian species. Also, with increasing numbers of wind turbines, fixed "per capita" fatality rates, i.e., defined numbers of tolerated bat fatalities per year and wind turbine are unacceptable because of limited bat population sizes.

Unfortunately, we cannot compare the efficacy of mitigation measures and its dependency on, for example, geographical location, habitat structure, and wind turbine type, because we lack comparative data on wind turbine-related bat fatalities on a larger scale. This unsatisfying situation originates from a combination of factors such as a large heterogeneity in the quality of surveys, lack of central documentation of raw data, and the fact that some authorities do not even request post-construction surveys for bat carcasses. Because of this, we are missing the decisive parameters to establish algorithms and cut-in speeds that result in the least number of bat fatalities.

The most effective reduction in bat fatalities results from cut-in wind speeds at which bats stop flying and/or at which bat fatalities at wind turbines cease to occur. This may come at a larger revenue loss for companies, but may better conform to EU legislation and national conservation goals. Novel wind turbines with higher net energy production may produce larger revenues at even low wind speeds (Fig. 3), and such a development may complicate the implementation of cut-in speeds, because absolute and relative monetary losses for energy companies may increase at the same cut-in speed with increasing wind turbine size (Fig. 3). This may exacerbate the conflict between the wind energy industry and conservationists in the future.

Conclusions

German environmental policy decided on a fast-track transformation towards renewable energy production, causing substantial concerns among conservationists about the associated risks for wildlife species, particularly bats. Lessons learnt in Germany may be insightful for other countries, particularly in relation to the avoidance or reduction of conflict scenarios between environmental and conservation goals, and in relation to practiced mitigation measures that aim to reduce the negative consequences of wind power production on wildlife species. Current estimates of wind turbine-related bat fatalities suggest that more than 250,000 bats could be killed at German wind turbine facilities each year, if mitigation measures are not commissioned. If wind turbine-related mild barotrauma causes delayed death in bats, this number may be largely underestimated. Irrespective of this, estimated bat fatalities for Germany suggest that the implementation of mitigation measures is vital. It seems strongly advisable to implement even relatively high cut-in speeds during migration periods in order to take into account that most migratory species are active even at strong winds. Such mitigation measures would help in particular migratory bat species that pass German wind turbines twice a year during their seasonal journeys between Northeastern (Poland, Baltic countries, Belarus, and Fennoscandinavia) and Central and Southwestern Europe (Germany, France, Switzerland, and Benelux). The adoption of mitigation measures is also crucial for some sedentary species in Germany such as *P. pipistrellus* (Schreber 1774), and *Eptesicus serotinus* (Schreber 1774) that are frequently killed by wind turbines. The wind power-generating capacity in Germany is estimated to increase by 30 % until 2020, and the environmental policy aims at a steady increase thereafter until renewable energy constitutes 80 % of the total energy production in Germany (BRD 2010b). These plans imply a drastic increase in the number of wind turbines, particularly larger ones with a higher net energy production. If increasing wind turbine sizes cause disproportionately more bat fatalities as it is reported for North America (Barclay et al. 2007), effective management plans are urgently needed to reduce the mortality risks for bats. With respect to evidence-based action plans, we recommend that the following questions are urgently addressed:

- Whence do migratory bats killed at German wind turbines originate? Are source populations suffering from increased fatalities at wind turbines?
- Do European bats use specific habitats as migratory corridors? If so, where are these corridors and how are they best protected?
- Are bats suffering from mild barotrauma at wind turbines and does this postpone death? Are reported bat fatalities underestimated because of unrecognized bat fatalities?

Lastly, we urge companies to reveal original data generated by pre- and post-construction surveys for meta-analysis. Also, it is essential to reconsider operation permits of older wind turbines, when bat and bird fatalities were not considered, and to pay careful attention to the repowering of such wind turbines. Because of Germany's central location in Europe, Germany's environmental policy is crucial for the conservation not only of local sedentary bats but particularly also for the conservation of migratory bats from northeastern populations. Thus, we argue for an evidence-based action plan that parallels or preferably precedes future developments of wind power production in Germany. Finally, we appeal to policy makers to reconcile environmental and conservation goals in order to develop Germany's investment in renewable energy as a trend-setting model example for other countries.

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