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Abstract

Concerns for potential wildlife impacts resulting from land-based and offshore wind energy have created challenges for wind project development. Research is not always adequately supported, results ae not always readily accessible nor are they satisfactorily disseminated, and so decisions are often made based on the best available information, which may be

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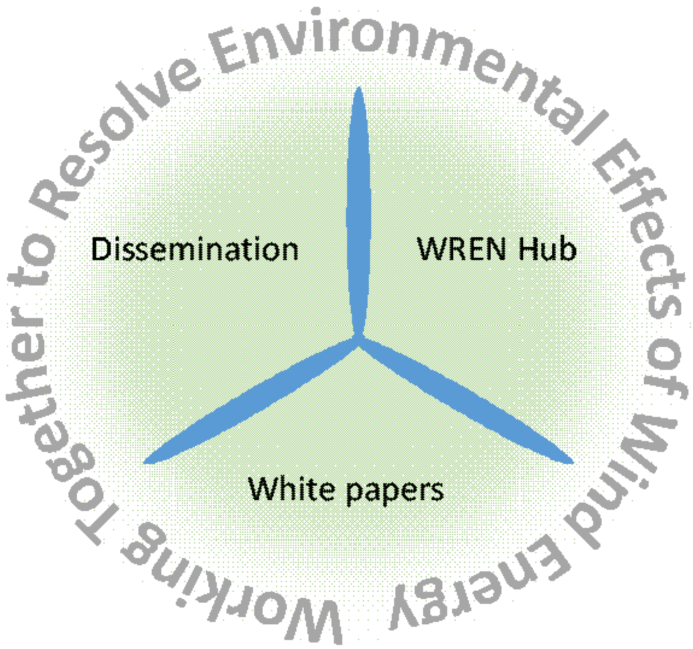
missing key findings. The potential for high impacts to avian and bat species and marine mammals have been used by wind project opponents to stop, downsize, or severely delay project development. The global nature of the wind industry—combined with the understanding that many affected species cross national boundaries, and in many cases migrate between continents—also points to the need to collaborate on an international level. The International Energy Agency (IEA) Wind Technology Collaborative Programs (TCP) facilitates coordination on key research issues. IEA Wind Task 34 – WREN: Working Together to Resolve Environmental Effects of Wind Energy is a collaborative forum to share lessons gained from field research and modeling, including management methods, wildlife monitoring methods, best practices, study results, and successful approaches to mitigating impacts and addressing the cumulative effects of wind energy on wildlife.

WREN develops products such as white papers, fact sheets, and short science summaries, and is involved in a number of activities including hosting a webinar series and outreach and information dissemination through participation in meetings, workshops, and conferences to increase and expand the knowledge base pertaining to wildlife challenges at wind energy facilities. This information is available on WREN Hub, hosted on the Tethys website.

KEY WORDS: cumulative impacts, environmental effects, population impacts, environmental trade-offs, adaptive management, risk estimation, dissemination, Tethys, wind energy



Caption: WREN aims to expand and disseminate the knowledge base of information pertaining to wildlife challenges at wind energy facilities.

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INTRODUCTION

Eleven countries participate in International Energy Agency (IEA) Wind in Task 34, Working Together to Resolve Environmental Effects of Wind Energy, also known as WREN. The countries include Canada, France, Ireland, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States and all are at different stages of wind energy deployment (Table 1). Concerns over the environmental effects from wind energy can result in barriers to deployment, for both land-based and offshore applications. The efforts conducted within WREN are focused on four areas to address environmental issues: 1) the expansion of international collaboration and knowledge transfer; 2) dissemination of scientifically based information and recommendations through outreach and engagement activities to government regulatory organizations and research, wind development, and environmental communities; 3) continued enhancement of WREN Hub as a dedicated, publicly available, centralized knowledge management system providing easy access to existing information pertaining to wind-wildlife issues for offshore and land-based wind energy; and, 4) publications on topics that focus on and advance the state of understanding of core, global concerns within the wind community. These publications are of relevance because they will fill a gap in the existing public literature. Topics include adaptive management; individual effects to population-level impacts; cumulative impacts of wind energy on wildlife; environmental trade-offs in decision making; and, environmental risk-based management.

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SIDE BAR TITLE: WHAT IS IEA WIND?

The International Energy Agency Implementing Agreement for Cooperation in the Research, Development and Deployment of Wind Energy Systems (IEA Wind) is comprised of 21 member countries, the European Commission, WindEurope (formerly the European Wind Energy Association), and the Chinese Wind Energy Association. Originally started in 1977, the purpose of this agreement is to provide a forum for member countries to engage in information exchange and work collaboratively on wind-specific research and development projects called tasks.

IEA Wind Task 34 (WREN – Working Together to Resolve Environmental Effects of Wind Energy) is one of 15 separate cooperative research tasks that the international wind community is engaged in. Information on the various research efforts currently supported by IEA Wind can be found at https://www.ieawind.org/.

Table 1. WREN members: installed wind capacity and percentage of electricity demand met (as of 2016)

WREN member	Total Wind Capacity Installed in Megawatts	National Electricity Demand Met by Wind Energy (%)
Canada	11,900	5.6
France	12,066	4.1
Ireland	2,800	20.9
Netherlands	4,206	***6.8***
Norway	873	1.6
Portugal	5,313	24.0
Spain	23,026	19.3
Sweden	6,422	12.3
Switzerland	75	0.2
United Kingdom	14,795	11.1
United States[1]	82,338	5.6

Source: IEA Wind TCP 2016 Annual Report

Bold italic indicates estimate.

[1] Includes small wind turbines

This overview article discusses the key elements of WREN Hub and the white papers WREN develops. Information pertaining to other WREN activities can be found at https://tethys.pnnl.gov/about-wren.

WREN Hub: Sharing Information on Environmental Effects of Wind Energy Development

Research and monitoring of wildlife interactions with all aspects of wind energy (turbines, towers, and transmission lines) has been underway for decades[1], and yet the results of such studies are not always readily available. As both the well-established land-based wind and the more nascent offshore wind industries continue to develop, the potential for legal and social acceptability must be considered, as well as the considerable uncertainty associated with environmental effects that hinders progress.[2,3,4] Sharing such information on the environmental effects of land-based and offshore wind energy development can: inform siting and permitting/consenting processes, allow for continued modification of equipment and operations to reduce risks to wildlife and their habitat by analyzing trends and data, and help the research community support the expansion of the wind energy industry, and emphasize the benefits to species at risk from lowering carbon emissions.[2]

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WREN Hub (Figure 1) is an online collaborative space created to support outreach and engagement for the international WREN initiative by disseminating knowledge and information. WREN Hub acts as a platform to bring together the international wind energy community, providing the means for researchers, regulators, developers, and key stakeholders to interact and pursue a better understanding of the potential effects of wind energy on wildlife, habitats, and ecosystem processes.[2] In addition, WREN Hub also supports WREN international activities by facilitating collaborative work, such as white papers and other planned products.

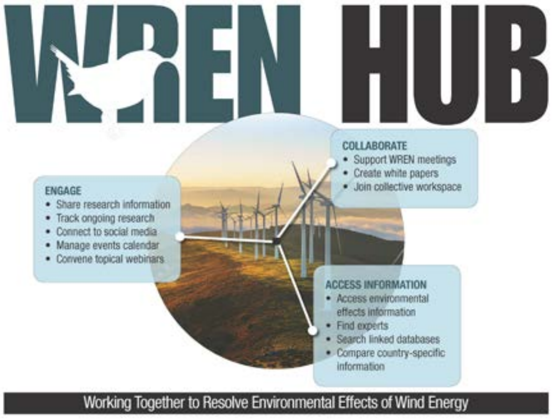

Figure 1. WREN Hub is a knowledge management system that provides public access to existing information on land-based and offshore wind energy wildlife issues, and also serves as the platform to engage the wind energy community around shared activities and information.

WREN Hub (https://tethys.pnnl.gov/about-wren) is hosted by the knowledge management system *Tethys* (http://tethys.pnnl.gov). *Tethys* was developed and is maintained by Pacific Northwest National Laboratory in the United States, and is used to collect, curate, and disseminate scientific information on potential effects of wind and marine renewable energy development. WREN Hub contributes journal articles, technical reports, presentations, and other media products to support the growing collection on *Tethys*. A few key attributes of *Tethys* include the Knowledge Base of over 3,500 curated documents–over 2,300 of which are directly relevant to wind energy–a Map Viewer, which displays Knowledge Base content that is georeferenced on a world map, webinars hosted on a quarterly basis and archived on *Tethys*, an interactive calendar of events, and *Tethys* Blasts, biweekly user updates that include new *Tethys* content, current news, and events.

Metrics used to track the use of *Tethys* material indicates that the information reaches a broad audience and that WREN Hub supports the wind energy and wildlife community, ensures that current information is widely shared, and helps to minimize duplication of research effort to answer important questions.[2] WREN Hub continues to be a stable, reliable resource and fulfills its purpose of enhancing understanding about the interactions of wind energy development with wildlife and acts as a tool to help decrease concerns and resolve conflicts about development of this low-carbon energy source. As countries transition towards renewable energy sources, broad sharing of information and collaborative activities

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will aid in the ability to predict potential consequences and adaptively manage risk and uncertainty to accelerate advancement of the wind energy industry in an environmentally responsible manner.

KEY WIND ENERGY ENVIRONMENTAL WHITE TOPICS

One of the primary activities of WREN is the development of white papers on topics that are of high interest to WREN members but where information is not readily available within the existing public literature. These white paper topics include: adaptive management, individual effects to population-level impacts, cumulative impacts of wind energy on wildlife, environmental trade-offs in decision making (e.g., balancing the local effects of a wind facility on sensitive species against its global benefits such as carbon dioxide emission reduction), and environmental risk-based management. WREN members have determined these topics are high-valued subject matter where gaps in the publicly available literature exist. At least one white paper will be published each year between 2018 and 2020.

Once all papers are completed, a report discussing the interrelationships of these topics will be developed. These papers will be published as IEA Wind Technical Reports or in peer-reviewed journals. To date, the white paper on adaptive management has been published and can be found at https://tethys.pnnl.gov/publications/assessing-environmental-effects-wren-white-paper-adaptive-management-wind-energy. A manuscript discussing how the individual effects of wind power development on wildlife can be used to predict population-level impacts on wildlife has been submitted to a journal. Other white papers are forthcoming.

Adaptive Management White Paper

Adaptive management (AM) is a learning-based management approach that is used to reduce scientific uncertainty and has been applied to many types of development including filling of wetlands and various forms of renewable energy.[5,6,7] Identified as a tool to advance the wind energy industry, AM is a flexible process allowing wind energy projects to adapt monitoring and mitigation over time by using hypothesis-driven data collection, enabling lessons to be learned from previous developments and leading to improved risk management.[8,9] However, application of AM in wind energy development has been limited, primarily occurring in the United States with other countries practicing certain principles.[10] The WREN nations have developed a white paper that explores how AM principles are used by the wind energy industry in several nations and identifies how the process and its implementation might be improved.[11]

Implementing AM in wind energy development is challenging, due to the need to create an adaptable and flexible process that does not hinder project financing or the efficiency of the permitting process. For instance, it can be difficult to create an adaptive process that allows or requires developers to curtail or alter operations or apply mitigation hierarchy, especially once power purchase contracts or agreements are signed. Wind energy projects often face the combined challenges of high costs for implementing AM—including ongoing costs for monitoringa—and potential loss of revenue due to required mitigation, including curtailment of operations.[12]

Implementation of AM is further complicated by a lack of legislation or regulation that requires and defines AM, as well as a lack of tools to assist with consistent implementation. Most WREN member countries have no formal use, specific laws, or regulations for AM. However, natural resource legislation, regulation, and guidelines for wind energy project development in some member countries include explicit use of AM or the application of its principles.

Examples of AM applied at individual energy wind projects were found. However, the spatial and temporal scales over which many wildlife species of concern may be affected by wind energy are much greater than that of an individual project site. This mismatch of scales limits the ability of an individual project to meaningfully reduce scientific uncertainty and facilitate an iterative learning process. To be most effective, the implementation of AM should be considered at a larger spatial and temporal scale than individual projects.

Based on these challenges, the WREN AM paper suggests the need to:

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- Adopt a universal definition of AM that is coupled with an agreed-upon set of eligibility criteria and is consistent with the regulatory context in which it is being applied
- Optimize the spatial and temporal scales over which AM is applied to reduce scientific uncertainty
- Apply AM to minimize undue financial pressure on projects while ensuring that the natural resources of the nation or region are protected
- Establish formal processes and structures within national or regional regulatory bodies to make use of environmental impact data from existing projects to generate knowledge that can be applied to the planning and management of future projects.

By improving AM for wind energy projects, scientific uncertainty can be reduced and the lessons learned can be applied to inform the licensing and operation of new wind energy development around the world.

Individual Effects to Population Impacts

Adverse interactions between wind energy facilities and wildlife have been substantially documented worldwide, especially on birds, bats, and marine mammals. Individual effects range from physiological stress, displacement or habitat loss, to direct mortality through collision. When cumulated over multiple individuals, these effects can have the potential to negatively affect the long-term fate of a population. The licensing framework generally focuses on assessing effects to individuals within a restricted temporal and spatial scope. Yet, from a conservation point of view, there is a need to upscale these effects to the level of the broader population to which these individuals belong. Such a shift in the policy- and decision-making process is an essential step in balancing the costs of wind energy on wildlife with the wider societal benefits it provides.

WREN has developed a white paper, Individual Effects to Population Impacts, which identifies and discusses the methodological issues related to the assessment of population-level impacts of wind energy plants, beginning with delineating the spatial and temporal boundaries of a population. Biogeographical or genetic-based delimitation are scientifically sound approaches but may be difficult to implement in practice. Nonetheless, we argue that the definition should take into account the underlying demographical processes for a given species as well as its conservation status. Alternatively, a tiered approach[13] can help reconcile the different scales of interest.

Further challenges pertain to the definition, prediction, and detection of a population impact. Depending on the species, different demographic parameters can be used as impact assessment metrics, such as population size or density,[14,15] population growth rate, [16,17] mortality,[18,19] breeding success or fecundity,[20,21] and survival rate.[20,22] Quantifying an impact on any of these parameters requires a baseline to be compared against. This comparison could be temporal (such as a Before-After design)[23,24,25] or spatial (such as a Control-Impact design).[26,27] A combination of these study designs (BACI-designs)[28,29,30] generally allow for more robust conclusions because they better account for potential change of the overall environmental conditions. Change be described by magnitude, as well as within a probabilistic framework, wherein the variability and likelihood of change are further metrics that are particularly useful in the context of risk-based decision-making.[21,31,32]

Various statistical and modeling techniques are available to predict impacts during preconstruction assessment, with the most basic one being extrapolating available data across larger areas and time frames.[33] More sophisticated approaches such as matrix population models[19,34] allow forecasting of future population growth rate through linear algebra and can be used in population viability analysis to compute the risk of extinction of a population.[35,20,22] More recently, so-called individual-based models have been developed,[36,16,37,15] which simulate the birth, death, and movements of all individuals within the model domain in discrete time steps. Although very powerful, such models remain computationally intensive and data heavy.

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Ultimately, the central question that needs to be answered by decision-makers is how to set impact thresholds. Three types of thresholds can be distinguished: ecological, utility, and decision. Ecological thresholds are triggered by a shift in the dynamics of a system (e.g., turning the growth rate of a population negative), and are usually estimated from population models. Utility thresholds are triggered by a shift in the value of a management outcome. A good example is the highest harvest rate achievable without depleting a population. Methods of setting utility thresholds include Potential Biological Removal[19,34] and Acceptable Biological Change.[38] Lastly, decision thresholds are the set of conditions that should prompt a management response. Generally, these decisions will be informed by ecological and/or utility thresholds.

No matter which methodological approach is taken to assess population-level impacts and how thresholds are set, a key consideration from a policy perspective is the reconciliation of precautionary approaches with risk-based approaches. Acknowledging the environmental and demographic stochasticity inherent to population dynamics, along with the imperfect nature of any model, is important when assessing potential impacts on species of concern. Policies that support the use of adaptive management, where the aim is to reduce scientific uncertainty while protecting biodiversity, will promote the adoption of assessments at the population level to adequately balance the development of wind energy with the protection of wildlife populations.

Understanding the Cumulative Impacts of Wind Energy on Wildlife

All across the globe, nations are investing in wind farms, both on land and offshore. This rapid and large-scale development of wind energy challenges the ability to anticipate (and subsequently verify) the impacts on biodiversity. It is known that wind energy can have multiple negative effects on wildlife, both direct (e.g., collisions) and indirect (e.g., habitat loss and barrier effects).[39,40,41] Most impact studies for wind farm permitting purposes focus primarily on species-specific impacts associated with a single wind farm and have, on that basis, led to the conclusion that the threats of these single wind farms to wildlife are acceptable (with or without mitigation measures). However, with a rise in the number of wind farms, the risk of negative effects on wildlife will inevitably increase. After all, where a single wind farm in itself may present little conflict, a growing number of wind farms and their related infrastructure could eventually start to have a serious impact on individual species or ecosystems over an increasingly large geographical scale. Yet, at the moment, these cumulative impacts on the environment at large are usually not adequately addressed because suitable assessment tools are lacking.

Both ecological and economic spatial planning needs to be based on informed decision-making to ensure legal and social acceptance for wind farm permitting. Informed decisions will require reliable information on cumulative effects of multiple wind farms. However, there are complexities related to the cumulative effects assessment (CEA) that make it difficult to acquire reliable information and perform analyses in a statistically sound manner. For example, it is unclear on what spatial and temporal scales CEA should be applied. Another strongly debated aspect of CEA is how to cope with the combined uncertainties of different elements of the assessment.[42,43] For offshore wind specifically, the marine environment makes it very difficult to gather data and understand ecological processes.

Internationally, there is a growing need to establish common approaches, standards, and tools to assess the cumulative effects of wind farm development that can be integrated in future research, monitoring, spatial planning, and governance practices.[44,45,46,47,48,49,50] Using existing literature and lessons learned, this white paper will provide a scientific review of these and other complexities, as well as possible methodological solutions, thereby identifying the elements central in assessing cumulative impacts of wind energy both on land and offshore. The paper's focus will be on the practical options and concepts to assess cumulative effects. Additionally, the white paper will provide an overview of the legislation on, and implementation of, CEA in different nations around the world.

In conclusion, this white paper will provide recommendations for the best available methods for CEA and identify the next steps needed to facilitate the successful implementation of the assessment of cumulative effects.

Environmental Trade-offs in Decision Making

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Increased development of wind energy has led to concerns for the environment, not in the least impacts on wildlife populations due to habitat loss, disturbance and collisions. While both the environment and renewable energy can be termed a public good, the costs and benefits derived from these public goods may be perceived differently at different spatial scales. The challenge of reconciling concerns of the potential negative impacts of wind energy projects to the local environment compared to the (inter)national benefits of development with regards to reducing greenhouse gas emissions is not uncommon.[51] Still, piecemeal development may well impact the environment at spatial scales. These types of challenges are occurring in many jurisdictions within the international communities, even where wind energy appears to be well-established. This conflict is commonly referred to as Green versus Green. Although it should be well understood that human activities have consequences, not all of which are positive, it is not always common practice to consider the consequences of such actions public goods derived from the environment. Thus, the challenge of balancing environmental (often perceived to be local) with climate benefits (often perceived to be global) requires a better understanding of specifically what the trade-offs might be and how some of the concerns can be mitigated. Addressing these challenges can be helpful in order to achieve a transition towards cleaner energy systems while keeping natural conservation interests prioritized. It is important to note that global benefits do not rest with the deployment of renewable energy to mitigate against climate change—conservation of the environment also has global benefits, including intrinsic value and economic and social benefits.[52]

Decision-making processes regarding wind energy development therefore need to take into account such trade-offs, balancing conservation of the environment with the deployment of wind energy. Wind energy development is only one of several sectors cumulatively impacting the environment. However, wind energy also contributes to reducing the greenhouse gas emissions impacting the environment. Cross-sectoral prioritization and trade-offs across spatial scales therefore need to be considered simultaneously (e.g. roads vs. wind energy, afforestation vs. wind energy). Decision-making processes can be helped by providing the framework and associated tools to take into account all public goods somehow affected by the development of wind energy and other human activities.

These perspectives will be addressed in-depth in a WREN white paper. Advanced methods to assist in managing trade-offs and priorities within complex systems and processes to ensure that the correct metrics are taken into account with regard to the desired outcome are currently rarely used. Existing approaches to understanding the decision processes for making trade-offs within these very divergent communities, the legal options available, and the importance of transparency by policy makers will therefore be examined. Identifying solutions that engage the local communities and contribute to a better understanding of how to come to a balanced outcome will finally be explored.

Risk-Based Management and Wind Energy

Risk-based management is broadly defined as a system for the identification, assessment, and priority-setting of risks so the appropriate level of resources can be applied to minimize, monitor, and control deleterious outcomes, taking into account the inherent uncertainties in the system. In terms of the wind energy industry, risk-based management will help inform permitting and operational decisions to minimize unwanted outcomes, such as impacts on wildlife, while maximizing energy production.

Risk is considered to be a function of the probability of an event occurring, and the consequence of the event, should it occur**.** Generally, there is limited information available to develop a risk evaluation, leading regulators to err on the side of caution when permitting a wind energy project. This approach often leads to overestimates of likely impacts to wildlife; alternately, this approach could also miss important unexpected outcomes.[53]

A WREN white paper is under development that will explore methods used to evaluate risk at land-based and offshore wind farms, as well as develop recommendations for robust risk estimation techniques and assumptions. The purpose of improved risk estimates will be to inform future wind farm development, and to provide consistent and accessible methods for data collection and analysis. Although wind farms currently undergoing consenting/permitting processes may

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benefit from the outcome, the intent of this white paper is not to complicate ongoing processes but to develop a base of knowledge and analyses that will accelerate future wind development.

The precautionary approach often followed for permitting wind farms, particularly in new areas, assumes that the potential presence of an individual animal at a wind farm will result in an impact to that animal. In addition, installation activities or operational modes that are discontinuous or sporadic are assumed to occur continuously. With these assumptions, the risk may be perceived to be higher than it actually is, leading regulators to make decisions that are more conservative than warranted if they were better informed. The wind industry often faces undue pressure and incurs excessive costs responding to these findings. In addition, allocating costs to monitoring and mitigation of activities that are perceived to be risky may take focus and investments away from other interactions that are putting wildlife at higher levels of risk, eventually leading to losses in populations that are undergoing declines from pressures.

Activities at land-based wind farms that may have an impact on wildlife include: disturbance from construction, habitat loss, and disturbance or blade strike during operation. Impacts from offshore wind include: acoustic disturbance during construction, disturbance from vessel traffic during construction and maintenance, changes in sedimentation and flow patterns, and disturbance or blade strike during operation.

Although monitoring activities focus on impacts to individual animals, the more important measures for the health of the ecosystem are impacts on populations, particularly those that are already depleted, afforded special protection under national or international management regimes, or under increasing stress from other natural or anthropogenic activities. Assessing the risk to wildlife populations is an inexact science, often with few comprehensive surveys of target populations available, and a poor understanding of life histories and distributions of population segments over time and space.

Further, few investigations of the potential consequences of collision or other stressors on wildlife have been carried out; early indications show that regulatory assumptions that equate all collisions with fatalities are incorrect. Additional investigations are needed to understand the degree of injury and survivable risk from collisions and other stressors to accurately assess the level of risk to individuals and ultimately to populations.

Conclusion

Concerns over the environmental effects of wind energy continue to challenge the large-scale deployment of both offshore and land-based wind projects. The vision of WREN is to form the leading international forum to exchange and disseminate up-to-date, robust knowledge on peer-reviewed scientific research and methods for assessing and monitoring the environmental effects of wind energy development. To address these concerns, WREN will develop white papers to focus on and advance the state of understanding on several core issues of global concern within the wind community.[54]

Although proponents emphasize the global benefits of wind energy in reducing carbon dioxide emissions to mitigate climate change, opponents often point to the costs involved for biodiversity and ecosystem services through land/seascape changes at smaller spatio-temporal scales. This mismatch between global and long-term public (climate) benefits and local and short-term private (environmental) costs, and the respective negligence of each other’s arguments, hampers development. The clue in reconciling such “Green versus Green” debates for and against wind energy development lies therefore in scaling strategic planning and decision-making processes to intermediate spatial and temporal scales.

Environmental impacts from renewable energy development are usually addressed in the approval process applying the mitigation hierarchy.[12] To apply the mitigation hierarchy actively throughout a wind energy project’s life cycle, AM has been promoted. AM is an iterative decision-making tool to plan and manage environmental risks associated with single wind energy projects through targeted monitoring. Options for applying AM in wind energy projects to mitigate impacts on the environment have been assessed[55], including required monitoring at relevant spatial scales.

Environmental conflicts commonly focus on effects on wildlife within the footprint of single wind energy projects. However, the extent to which these observed effects may impact the species at larger spatial scales remains unclear. Current practice so far has not been able to set clear criteria on how to progress from individual effects to population impacts, where the first relates to objectively/empirically deduced quantities and the latter indicates thresholds of what is acceptable for society. It is also difficult to extrapolate local effects, both direct and indirect, to demographic impacts at the

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population level. We reviewed the international literature to elucidate the linkages between local and population-level effects and provide options for obtaining objective impact thresholds at appropriate spatial scales.

Upgrading from local effects to population-level impacts necessitates agreement across sites, as population may be influenced by several wind energy facilities. Such cumulative and transboundary impacts have been debated as to how it should be defined and at what spatial extent it should be studied. Internationally, there has been a growing need to establish common standards and methods of how issues related to cumulative effects of wind energy can be integrated in future research and monitoring practices. As biogeographic ranges generally do not follow national borders, these standards need to be adopted internationally.

Given the multifaceted aspects pertaining to permitting and operational decisions of wind energy projects, there is a need for a risk-based framework to inform regulators and operators when permitting a wind energy project. Associated risk estimation techniques will allow for the assessment and evaluation of the extent and likelihood of impacts of wind energy development on the environment. This in turn may guide (adaptive) management actions to reduce such potential risks on populations of vulnerable species, on ecosystem health, and of cumulative impacts. Providing insight into how to employ risk-based approaches may help wind energy and environmental stakeholders to better determine the trade-offs between climate mitigation and environmental conservation and directly targeted monitoring and mitigation efforts.

These topics are clearly interrelated but operate within different spatial contexts (Figure 2). “Green versus Green” debates and regional decision-making sets the premise for AM and the extent of which impacts are required to be mitigated at single wind energy projects. The locally monitored effects on wildlife and consequent mitigation measures will require knowledge on how to upgrade from individual to population impacts, and from regional to biogeographic levels. As a result, this knowledge provides input that can be used when assessing cumulative impacts from regional to international scales and encouraging transboundary collaboration across wind energy projects and associated stakeholders. When knowledge on cumulative and transboundary impacts are known, it may affect how regional decision-makers assess the trade-offs and balance between reducing global climate emissions versus the local environment. Within a risk-based management framework, multidisciplinary criteria can be developed and tested to examine trade-offs between climate mitigation and local environment effects, cumulative impacts of wind energy projects, and challenges of estimating population-level impacts from effects on individuals. In all, these white papers synthesize the current knowledge base and give different perspectives on central holistic topics. Understanding how best to reconcile potentially conflicting wind energy development and environmental conservation may stimulate future wind energy development with least environmental impact.

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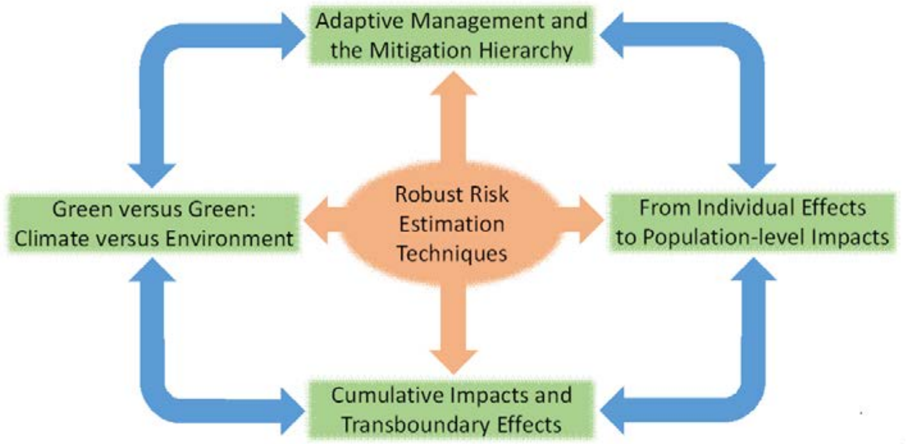

Figure 2. Interlinkages between central issues pertaining to addressing environmental concerns of wind energy globally.

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