



## IMPACTS OF RENEWABLE ENERGY ON BIODIVERSITY

**Smart curtailment of wind turbines: a win-win system based on optimization algorithms that optimise the balance between energy production and the risk of collisions with airborne fauna (BRIBAT)**

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### SOUTIENS INSTITUTIONNELS



## Context

- Exponential growth in wind energy
- The impacts on biodiversity are extensively studied: mortality and habitat loss
- Estimates of mortality rates comparable across countries (for the same installed capacity): numbers appear extremely high



300 000/an   
500 000/an  



## Context

- Exponential growth in wind energy
- The impacts on biodiversity are extensively studied: mortality and habitat loss
- Estimates of mortality rates comparable across countries (for the same installed capacity): numbers appear extremely high
- Several studies suggest significant demographic consequences (for protected species), which could call into question the viability of populations (e.g. Frick et al., 2017)

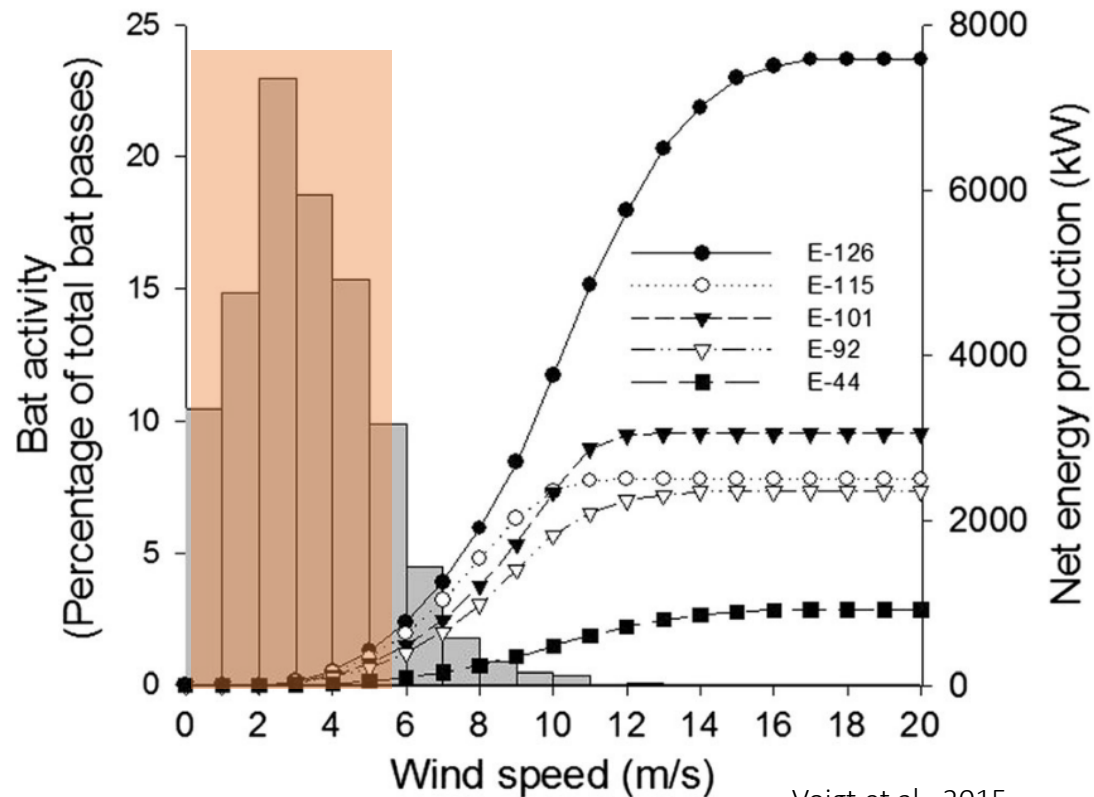


## Context

- Most effective solution: avoiding habitats that are too favourable (European and national guidelines, numerous scientific articles)
- This avoidance measure is not implemented sufficiently (Barré et al., 2022)
- The most effective mitigation measure is to shut down wind turbines in weather conditions that are too favourable for bats and when energy production is low: **curtailment**

## Context

- Principle of **conventional curtailment**: wind turbines are shut down when wind speeds fall below 6–5 m/s and the temperature is above 9–11°C



Voigt et al., 2015




## Context

- Principle of **conventional curtailment**: wind turbines are shut down when wind speeds fall below 6–5 m/s and the temperature is above 9–11°C
- Effectiveness varies greatly, and significant production losses are required to achieve a high level of mortality reduction (e.g. 90%) (Whitby et al., 2021)
- Two more sophisticated curtailment types exist/are possible: **acoustic-based curtailment** (Rabie et al., 2022) and **algorithm-based curtailment** (a single peer-reviewed study published; Barré et al., 2023)

## Context

- Only one study has been published on curtailment algorithms, suggesting that they are superior to conventional curtailment


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Drivers of bat activity at wind turbines advocate for mitigating bat exposure using multicriteria algorithm-based curtailment



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## Context

- Only one study has been published on curtailment algorithms, suggesting that they are superior to conventional curtailment
- **However, the optimal methods for training and using algorithms to make them operational had not yet been investigated**



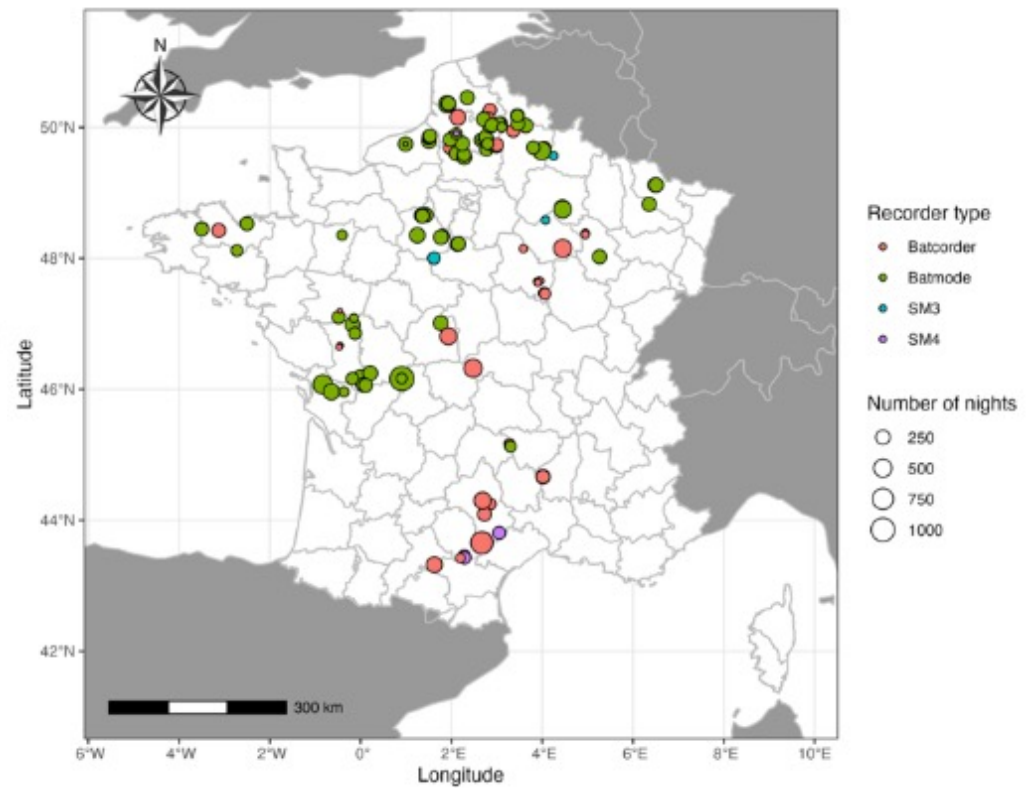
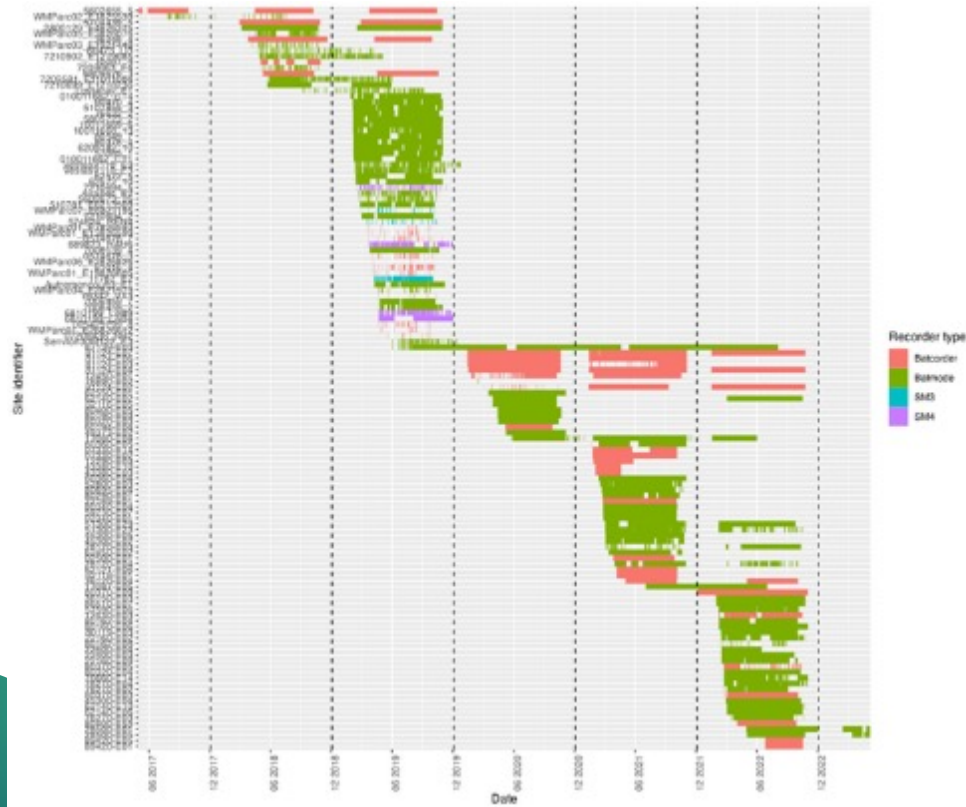
## Aims

- **How can algorithms be trained and used to optimise their effectiveness in protecting bats from rotating blades?**
- Assessing whether or not site-specific data should be included in model training
- Assessing whether the algorithm should be based on real-time or past weather observation data
- Assessing the required taxonomic resolution, and how the curtailment threshold should be set

# Methods

## Acoustic data at nacelle height

- 123 sites, 25588 night, 96393 bat passes



# Methods

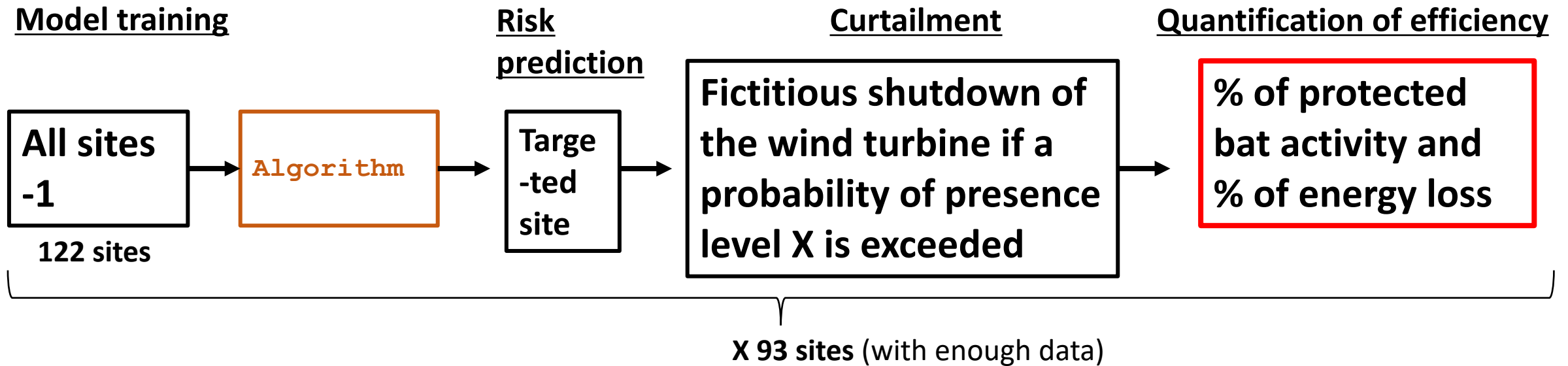
## Model training

- 1 model per guild sensitive to collisions (MRE=Pipistrelles, LRE=Noctules), that predict the presence probability of bats by 20min time slots
- Modelling the presence/absence at  $t+1$  in relation to environmental conditions at  $t_0$ , to be consistent with the logical of curtailment in the field

$$\text{Presence/absence } t+1 \sim \text{Environnemental variables } t+0 + (1|\text{Year}) + (1|\text{Material}) + (1|\text{Site})$$


# Methods

## Curtailment simulations: general principle

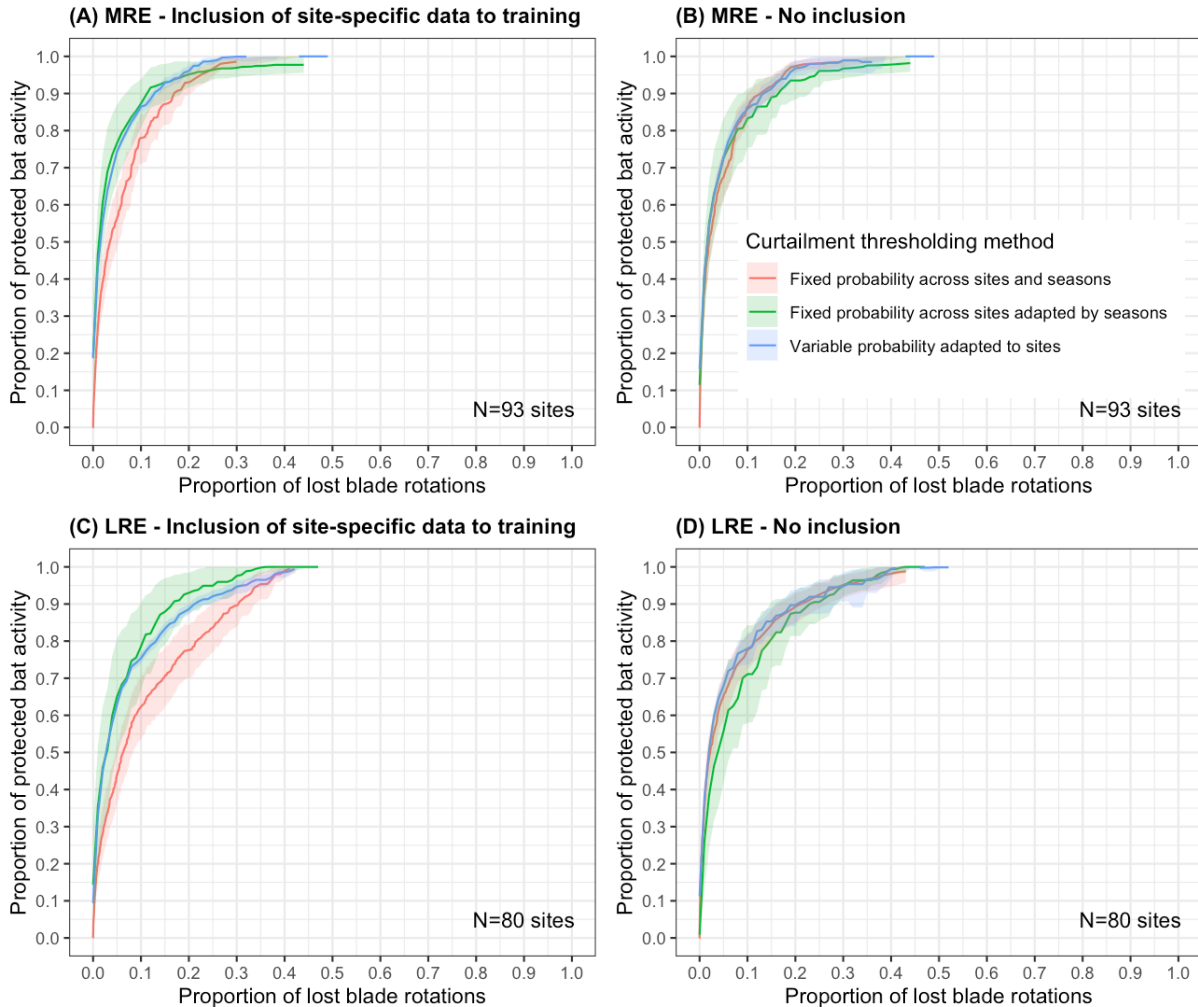


### Simulation adapted for different scenarios:

- Whether or not to include data from the target site in the training
- Probability threshold defined at national level, by season, or by site
- Decision to apply curtailment on a guild-by-guild basis or a combination of both
- Real-time vs past weather data

# Main results

Inclusion or not of site data, and how to define the curtailment probability threshold



The training method which does not incorporate site-specific data when training the models, combined with a nationally defined curtailment threshold, produces a result that is at least as good as that of the other methods

# Main results

Inclusion or not of site data, and how to define the curtailment probability threshold

Bat guild	Threshold definition method	Protection level	Site-specific data in training	Estimated annual energy loss Sites with energy data (N=13)
LRE	national	0.9	inclusion	0.199 (0.076-0.212)
LRE	national_season	0.9	inclusion	0.124 (0.029-0.178)
LRE	site	0.9	inclusion	0.118 (0.101-0.130)
LRE	national	0.9	none	<b>0.076 (0.046-0.103)</b>
LRE	national_season	0.9	none	0.130 (0.035-0.178)
LRE	site	0.9	none	0.107 (0.059-0.136)
LRE	national	0.95	inclusion	0.204 (0.126-0.215)
LRE	national_season	0.95	inclusion	0.166 (0.047-0.208)
LRE	site	0.95	inclusion	0.160 (0.130-0.166)
LRE	national	0.95	none	<b>0.123 (0.066-0.150)</b>
LRE	national_season	0.95	none	0.178 (0.077-0.202)
LRE	site	0.95	none	0.160 (0.071-0.237)
MRE	national	0.9	inclusion	0.078 (0.037-0.098)
MRE	national_season	0.9	inclusion	0.058 (0.010-0.251)
MRE	site	0.9	inclusion	0.058 (0.053-0.069)
MRE	national	0.9	none	<b>0.052 (0.038-0.092)</b>
MRE	national_season	0.9	none	0.128 (0.010-0.251)
MRE	site	0.9	none	0.064 (0.053-0.069)
MRE	national	0.95	inclusion	0.098 (0.072-0.117)
MRE	national_season	0.95	inclusion	0.230 (0.016-0.251)
MRE	site	0.95	inclusion	0.074 (0.064-0.091)
MRE	national	0.95	none	<b>0.071 (0.052-0.111)</b>
MRE	national_season	0.95	none	0.219 (0.026-0.251)
MRE	site	0.95	none	<b>0.069 (0.064-0.074)</b>

This is confirmed for specific levels of protection.

The estimated energy losses over a year round curtailment to protect 90% of both guilds are 7.6% high-flying species (LRE) and 5.2% for pipistrelle species (MRE)

35% of these losses can be eliminated by restricting the curtailment period to April to November without altering the overall level of protection



# Main results

Efficiency per guild vs both guilds combined

Protection	Guild	Rotation losses on the study period
0.90	MRE	0.125
0.90	LRE	0.203
<b>0.91</b>	<b>LRE+MRE</b>	<b>0.198</b>

The annual loss of blade rotations is no higher when the two guilds are combined

→ Very good news from an operational point of view, as in practice the curtailment should protect both guilds

# Main results

## Realtime weather vs past

Protection	Guild	Rotation losses – realtime weather	Rotation losses – past weather
0.90	MRE	0.125	0.160
0.90	LRE	0.203	0.250
<b>0.91</b>	<b>LRE+MRE</b>	<b>0.198</b>	<b>&gt; 0.250</b>

Using past averaged weather data is far less effective than using real-time weather data, as we are inferring what might happen based on past data (cumulative uncertainty)



## Lessons learnt and implications

The study provides practical recommendations on how to train and use a curtailment algorithm – aspects that have never been studied before

It challenges preconceived ideas regarding the need to calibrate the curtailment algorithm to the site when using very large amounts of data

Encouraging results for the transfer of algorithms into a field tool



## Limits and perspectives

A simulation framework based on empirical data, which is inevitably less convincing to stakeholders than a field test implementing the algorithm (although it theoretically yields the same result)

A field test will take place with the support of ADEME in 2026–2027

# MESSAGES CLÉS

- 1 | The algorithms appear able to provide high levels of protection whilst maintaining moderate energy losses
- 2 | Among possible use, the simplest to apply is at least as efficiency as other more complex methods
- 3 | Algorithms have to be used in real-time with a constant link with the weather station of the nacelle
- 4 | This imply to build a technical solution with SCADA engineers (ADEME project to come)

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Thanks for your attention

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