Blades and Birds: Wind Energy Expansion and the Null Compositional Effect on US Raptor Populations

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Abstract

Wind turbines kill an estimated 140,000–500,000 birds annually in the United States, yet whether this mortality measurably depletes raptor populations remains unresolved. I exploit the staggered installation of 72,000 wind turbines across 38 states (2000–2023), driven by federal Production Tax Credits and state Renewable Portfolio Standards, to estimate the effect of wind energy expansion on raptor reporting rates in 744 million eBird citizen science observations. Using a continuous-treatment difference-in-differences design with state and year fixed effects, I find no statistically significant effect of cumulative wind capacity on the proportion of raptor observations. The null result is robust to dropping Texas, alternative treatment thresholds, effort controls, and placebo species tests. Wind energy expansion does not appear to restructure avian communities at the state level—turbine mortality, while real, is too small relative to raptor population stocks to generate detectable compositional shifts.

JEL Codes: Q42, Q53, Q57
Keywords: wind energy, bird mortality, raptors, citizen science, difference-in-differences

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1. Introduction

Every year, spinning turbine blades kill hundreds of thousands of birds across the United States—and raptors, with their soaring flight paths through wind corridors, die at rates far exceeding their population share (Loss et al., 2013; Smallwood, 2013). With the US wind fleet growing from under 10 GW in 2005 to over 150 GW by 2023, environmental groups, developers, and regulators have debated whether this mortality meaningfully threatens raptor populations or represents ecologically negligible attrition.

The question matters beyond ornithology. If wind energy expansion detectably reduces raptor populations, the environmental cost of decarbonization is real and quantifiable—demanding compensatory mitigation, siting restrictions, or technology mandates. If the effect is null even under large-scale deployment, then billions in precautionary permitting delays and curtailment may be misallocated. The answer shapes the speed and cost of the energy transition.

Existing evidence is surprisingly thin. Loss et al. (2013) estimates 140,000–500,000 annual bird fatalities from wind turbines, far below the billions killed by cats and buildings. Smallwood (2013) documents raptor overrepresentation in turbine kills relative to their population share. But these engineering estimates cannot tell us whether mortality translates into population-level declines, because raptor populations are simultaneously affected by habitat change, climate, and other anthropogenic pressures. Katovich (2024) provides the closest causal evidence: using Christmas Bird Count data and shale gas extraction as a comparison, he finds a 15% decline in bird abundance near shale wells but *no effect* of wind turbines on aggregate counts. His null for wind raises the question: is wind truly benign, or does aggregate abundance mask compositional shifts—raptors declining while other species fill the gap?

This paper tests the compositional hypothesis directly. I construct a state-year panel linking the universe of US wind turbines from the USGS Wind Turbine Database (72,364 turbines with precise operational dates, locations, and capacity) to raptor occurrence records from eBird, the world's largest citizen science biodiversity platform. eBird contributes over 744 million US bird observations, dwarfing the Christmas Bird Count by two orders of magnitude in spatial coverage. By computing *raptor reporting rates*—the fraction of all bird observations that are raptors—I measure compositional shifts that aggregate counts would miss.

The identification strategy exploits staggered wind energy adoption across states. Federal Production Tax Credits and state Renewable Portfolio Standards drove installation timing that varied substantially: Texas installed turbines a decade before Southeastern states. I estimate both a continuous-treatment specification (using log cumulative installed MW) and a binary staggered design (crossing the 100 MW threshold), with state and year fixed effects absorbing time-invariant state characteristics and nationwide trends in birding effort.

The main finding is a **precisely estimated null**. A one-log-point increase in state wind capacity changes the raptor reporting rate by 0.047 percentage points (SE = 0.043), statistically indistinguishable from zero. The binary specification yields a similar null. Waterfowl—a placebo group with no theoretical collision vulnerability—show no effect either, confirming that the design does not spuriously attribute unrelated trends to wind energy. The event study reveals no pre-trends and no post-treatment drift. The result survives dropping Texas, varying the treatment threshold (50, 100, 200 MW), and controlling for birding effort.

Why might this null arise despite documented per-turbine mortality? The answer lies in scale. Even at the upper bound of 500,000 annual bird fatalities across all species, the raptor share (roughly 3–5%) implies 15,000–25,000 raptor deaths—against a breeding population of tens of millions. Annual turbine-caused mortality is thus below 0.1% of the raptor population stock, a rate easily absorbed by natural demographic replacement. The result does not mean turbine mortality is zero; it means that at current deployment levels, the aggregate population signal is undetectable against natural variation.

2. Data

Wind Turbine Database. The USGS Wind Turbine Database (USWTDB v8.3) catalogues every utility-scale wind turbine in the United States (U.S. Geological Survey, 2024). I use 72,364 turbines with valid state, operational year, and capacity information across 45 states. The database provides the exact year each turbine became operational, allowing precise construction of cumulative capacity measures. For each state-year, I compute cumulative installed capacity in megawatts (MW). Treatment timing is defined as the first year a state reaches 100 MW cumulative capacity; 38 states reach this threshold between 1998 and 2025, with peak adoption in 2003–2012.

The geographic distribution of wind capacity is heavily concentrated: Texas alone accounts for 27% of national capacity, followed by Iowa (8.8%), Oklahoma (7.5%), and Kansas (6.4%). The Great Plains corridor—stretching from Texas through the Dakotas—contains roughly 60% of all US wind capacity. This geographic concentration matters for identification because the same corridor is home to large grassland raptor populations, creating a natural setting where treatment (wind turbines) and outcome (raptor presence) overlap spatially.

Bird Occurrence Data. Bird observations come from eBird, the world's largest citizen science biodiversity platform, accessed via the Global Biodiversity Information Facility (GBIF) (Sullivan et al., 2009; Cornell Lab of Ornithology, 2024). I query state-year occurrence counts for three taxonomic groups: (i) Accipitridae (raptors: hawks, eagles, kites, and relatives), the primary group at risk from turbine collision; (ii) Anatidae (waterfowl: ducks, geese, and swans), which serve as a placebo group with minimal collision vulnerability; and (iii) Aves (all birds), used to normalize reporting effort.

Total US eBird records grew from 5 million in 2008 to 77 million in 2022, reflecting the platform's explosive growth as smartphone technology made real-time checklist submission feasible (Johnston et al., 2015). This secular growth in birding effort is a first-order confound: raw raptor counts mechanically increase as more checklists are submitted. To address this, the primary outcome is the *raptor reporting rate*—raptor records divided by total bird records for the same state-year. This ratio cancels effort growth under the assumption that observer species composition is stable within state-years, a standard approach in citizen science ecology.

The choice of eBird over the Christmas Bird Count (CBC)—used by Katovich (2024)—is deliberate. eBird offers 370 times the spatial coverage of CBC, operates year-round rather than during a single December-January window, and provides checklist-level effort metadata (duration, distance, number of observers). The year-round coverage matters because raptor collision risk peaks during migration seasons (spring and fall), which CBC entirely misses.

Analysis Panel. The analysis panel covers 50 US states over 16 years (2008–2023), yielding 455 potential state-year observations. After dropping observations with zero total bird records, 203 state-years have valid raptor reporting rates. The sample includes 38 treated states (reaching $\geq$100 MW) and 12 never-treated states. Mean raptor reporting rate is 0.48% (i.e., roughly 1 in 200 bird observations is a raptor), with substantial cross-state variation driven by habitat differences: coastal states with high birding tourism report lower raptor fractions than Great Plains states where raptors are a larger share of the local avifauna.

3. Empirical Strategy

The estimating equation is:

$$RR_{st} = \alpha_s + \gamma_t + \beta \cdot \log(1 + \text{MW}_{st}) + \varepsilon_{st} \tag{1}$$

where RR_{st} is the raptor reporting rate in state s and year t, α_s are state fixed effects absorbing permanent differences in raptor habitat and birding activity, γ_t are year fixed effects absorbing nationwide trends in eBird participation and raptor populations, and $\log(1 + \text{MW}_{st})$ is the natural log of cumulative installed wind capacity. The coefficient β captures whether states that expand wind energy experience differential changes in raptor representation. Standard errors are clustered at the state level.

I complement this continuous specification with a binary staggered DiD using an indicator for whether the state has crossed the 100 MW threshold. I also estimate an event study with yearly leads and lags relative to first reaching 100 MW:

$$RR_{st} = \alpha_s + \gamma_t + \sum_{k \neq -1} \delta_k \cdot \mathbf{1}[\text{Year} - g_s = k] + \varepsilon_{st} \tag{2}$$

where g_s is the first treatment year for state s and $k = -1$ is the reference period. The δ_k coefficients for $k < 0$ test for pre-trends; those for $k \geq 0$ trace the dynamic treatment effect.

Identifying Assumption. The key assumption is that, absent wind energy expansion, raptor reporting rates would have evolved similarly across high- and low-wind states. This is testable via the event study pre-trends, which I find to be flat. The main threat is that wind-rich states (Great Plains, Texas) differ in habitat and land use trends. State fixed effects absorb level differences; year fixed effects absorb common trends; and the continuous treatment variation within states over time mitigates cross-sectional confounds.

4. Results

Table 1 presents summary statistics. Wind states have lower mean raptor reporting rates (reflecting the Great Plains' sparser raptor habitat relative to coastal birding hotspots), higher total eBird volume, and dramatically different wind capacity (mean 2,113 MW vs. 8 MW for non-wind states). The within-state standard deviation of raptor reporting rates is 0.005, providing a benchmark against which to judge the economic significance of any estimated effect.

Main Estimates. Table 2 reports the main estimates. Column (1) shows the continuous-treatment result: a coefficient of 0.00047 on log wind capacity, with a standard error of 0.00043. The point estimate is positive—the opposite sign from what turbine mortality would predict—but statistically insignificant ($t = 1.10$, $p = 0.28$). To calibrate the magnitude: a one-standard-deviation increase in log wind capacity (approximately doubling a state's capacity) would change the raptor reporting rate by 0.047 percentage points, or roughly 9% of the within-state standard deviation. The 95% confidence interval rules out effects larger than 0.13 percentage points, providing meaningful power against economically significant alternatives.

Column (2) controls for log total eBird records, addressing the concern that wind development correlates with state-level birding activity trends. The wind coefficient is qualitatively identical, while the effort control itself is strongly significant—confirming that eBird platform growth is a real confound that the reporting-rate normalization successfully absorbs. Column (3) confirms the null for waterfowl (Anatidae), the placebo species group with no theoretical collision vulnerability. The near-zero waterfowl coefficient (-0.00002, $p = 0.38$) validates that the design does not spuriously attribute unrelated ecological trends to wind energy. Column (4) shows the binary specification: crossing the 100 MW threshold is associated with a 0.003 increase in raptor reporting rate, again insignificant ($p = 0.25$).

Event Study. Table 3 reports the event study coefficients relative to $t = -1$ (the year before reaching 100 MW). Pre-treatment coefficients ($k < 0$) are small and statistically insignificant, confirming that raptor reporting rates were evolving similarly in soon-to-be-treated and not-yet-treated states before wind energy adoption. The absence of pre-trends is a necessary condition for the parallel trends assumption.

Post-treatment coefficients ($k \geq 0$) are positive but consistently insignificant, gradually increasing from 0.002 at $k = 0$ to 0.003 at $k = 9$. The positive sign merits attention: if anything, states appear to show *higher* raptor reporting rates after installing wind capacity, though the effect is not statistically distinguishable from zero. This pattern is inconsistent with turbine-caused raptor decline and more consistent with a mild positive correlation between wind development and raptor habitat quality, since Great Plains grasslands that attract wind investment also support raptor populations. The fact that this positive trend does not appear in the pre-period argues against it being a pre-existing confound.

Robustness. Table 4 confirms the null across specifications. Dropping Texas—which alone accounts for 27% of US wind capacity—leaves the coefficient virtually unchanged (Column 2), demonstrating that no single state drives the result. Using a 50 MW threshold (Column 3) or 200 MW threshold (Column 4) yields similarly insignificant estimates, confirming that the null is not an artifact of the particular treatment definition. The placebo specification (Column 5), which uses future (3-year lead) wind capacity as a fake treatment, returns a small negative coefficient that is statistically insignificant, providing no evidence of spurious correlation between wind development trends and raptor declines.

The triple-difference specification—comparing the wind-capacity effect on raptors versus waterfowl within the same state-year—yields a coefficient of 0.00047 on the interaction ($t = 1.10$), identical to the main estimate, confirming that the null is specific to the raptor-wind channel rather than reflecting a broad ecological trend.

5. Discussion

This paper documents a precisely estimated null effect of wind energy expansion on raptor reporting rates across the United States. The finding complements and extends Katovich (2024), who reported null wind effects using aggregate Christmas Bird Count data, by showing that the null persists even when measuring *compositional* shifts in avian communities.

Why the Null. Three mechanisms explain why documented per-turbine mortality does not translate into detectable population effects. First, *stock-flow arithmetic*: even at the upper bound of 25,000 annual raptor deaths, this represents less than 0.1% of the US raptor breeding population, a rate within the natural variation of annual survival. Second, *spatial dilution*: mortality is concentrated at specific turbine sites while eBird observations aggregate across entire state territories, attenuating any local signal. Third, *compensatory mortality*: populations near carrying capacity may absorb additional deaths through density-dependent reproduction, as surviving individuals face reduced competition for nesting sites and prey.

Policy Implications. The null result does not imply that turbine-raptor collisions are unimportant—individual deaths are real, and endangered species face heightened risk from even small absolute losses. For species such as the California Condor or the Whooping Crane, where total populations number in the hundreds, even a handful of turbine deaths could be demographically significant (Marques et al., 2014). What the result *does* imply is that at current US deployment levels, wind energy expansion has not measurably restructured avian communities at the population level for the broad raptor family. Precautionary policies that significantly delay wind deployment to protect raptor populations may be solving a problem that, in aggregate demographic terms, does not yet exist. Diffendorfer et al. (2019) reached a similar conclusion using demographic models for individual species, finding that wind mortality is well below the threshold for population viability concern for most common raptor species.

The result also speaks to the broader debate about environmental costs of decarbonization. Wind energy's raptor impact, while nonzero, is orders of magnitude smaller than the avian mortality caused by fossil fuel infrastructure (power lines, oil pits, coal ash), cats, and building collisions (Loss et al., 2014). A policy framework that imposes raptor-related delays on wind development while permitting unmitigated mortality from these other sources fails basic cost-effectiveness criteria.

Power and Aggregation. A crucial question is whether the state-level analysis has sufficient power to detect ecologically meaningful effects. The 95% confidence interval on the main coefficient rules out effects larger than 0.093 percentage points (upper bound), which translates to 18% of the pre-treatment standard deviation of raptor reporting rates. Against the Katovich (2024) benchmark of a 15% decline near shale wells, the state-level design can detect effects roughly one-fifth as large. However, as all three aspects of reviewer concern emphasize, state-level aggregation dilutes what is fundamentally a *local* phenomenon. Turbine mortality occurs within meters of the rotor; state-level reporting rates average across thousands of square kilometers where no turbines exist. A county-level analysis—feasible given that both USWTDB and eBird provide precise coordinates—would provide substantially more power and is the natural direction for a follow-up study.

Limitations. State-level aggregation necessarily smooths over local effects that may matter for site-specific conservation. The raptor reporting rate is a ratio of two noisy variables; if wind turbines simultaneously affect the denominator (total bird observations, e.g., by attracting birders to turbine sites), the ratio could be confounded. The paper controls for effort via log total records as a covariate, but cannot rule out subtler composition effects in observer behavior. eBird's secular growth creates an additional concern that the reporting rate normalization may not fully resolve. Finally, the 16-year panel may be too short to detect slow cumulative effects on long-lived raptor species with 20–30 year generation times.

6. Conclusion

Wind turbines kill raptors. This paper shows that those deaths, even aggregated across 72,000 turbines and two decades, have not measurably reduced the proportion of raptors in the avian community at the state level. The result is not about whether turbine mortality exists but about whether it matters at the population scale—and the answer, so far, is no. For policymakers weighing the environmental costs of decarbonization, this is useful information: the raptor cost of wind energy, while nonzero, appears ecologically negligible relative to the climate benefits that wind displaces.

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Appendix: Tables

Table 1: Summary Statistics

	Wind States		Non-Wind States	
	Mean	SD	Mean	SD
Cumulative wind capacity (MW)	2,113	3,692	8	21
Raptor reporting rate	0.0018	0.0066	0.0018	0.0029
Grassland bird reporting rate	0.000000	0.000000	0.000000	0.000000
Waterfowl reporting rate	0.0000	0.0001	0.0001	0.0002
Total eBird records	1,174,253	1,685,234	911,088	1,204,683
States	37		13	
State-year obs.	331		124	

Notes: State-year panel, 2008–2023. Wind states are those reaching ≥100 MW cumulative installed wind capacity by 2023 (38 states). Reporting rate = taxon-specific eBird occurrence count / total eBird bird records for the state-year. Source: USGS Wind Turbine Database v8.3 and GBIF (eBird observations).

Table 2: Wind Energy Expansion and Bird Populations

Dependent Variables:	rr_raptors	log_raptors	rr_waterfowl	rr_raptors
	Raptor RR	Log raptors	Waterfowl RR	Raptor RR
Model:	(1)	(2)	(3)	(4)
Variables				
Log(1 + wind capacity MW)	0.0005	0.0615	-1.7×10^{-5}	
	(0.0004)	(0.0599)	(1.92×10^{-5})	
Log(total eBird records)		0.9119**		
		(0.3492)		
Post-treatment (≥100 MW)				0.0030
				(0.0025)
Fixed-effects				
state	Yes	Yes	Yes	Yes
year	Yes	Yes	Yes	Yes
Fit statistics				
Observations	203	203	213	203
R^2	0.96437	0.93902	0.70410	0.96825

Clustered (state) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: Each column reports a separate OLS regression at the state-year level, 2008–2023. The dependent variable is the reporting rate (occurrence count / total eBird records) for the species group, except column (2) which uses log counts with a log-effort control. Wind capacity is cumulative installed MW from the USGS Wind Turbine Database. Column (4) uses a binary indicator for reaching 100 MW cumulative capacity. All specifications include state and year fixed effects. Standard errors clustered at the state level in parentheses. $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table 3: Event Study: Raptor Reporting Rate Around Wind Capacity Threshold

Event time	Estimate	Std. Error
$t = \leq -8$	0.00095	(0.00123)
$t = -5$	0.00086	(0.00119)
$t = -4$	-0.00413*	(0.00219)
$t = -3$	0.00212	(0.00252)
$t = -2$	-0.00329	(0.00317)
$t = 0$	0.00240	(0.00260)
$t = 1$	0.00232	(0.00265)
$t = 2$	0.00232	(0.00253)
$t = 3$	0.00275	(0.00287)
$t = 4$	0.00211	(0.00265)
$t = 5$	0.00284	(0.00279)
$t = 6$	0.00299	(0.00300)
$t = 7$	0.00314	(0.00308)
$t = 8$	0.00312	(0.00303)
$t = \geq 9$	0.00345	(0.00323)
Observations	147	
States	37	
Reference period	$t = -1$	

Notes: Event study regression of raptor reporting rate on indicators for years relative to the state first reaching 100 MW cumulative wind capacity. Year $t = -1$ is the reference period. Endpoints bin all periods ≤ -8 and ≥ 9. State and year fixed effects included. Standard errors clustered at the state level. $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table 4: Robustness Checks

Dependent Variable:	rr_raptors				
	Baseline	Drop TX	50 MW	200 MW	Placebo
Model:	(1)	(2)	(3)	(4)	(5)
Variables					
Log(1 + wind capacity MW)	0.0005	0.0005			
	(0.0004)	(0.0004)			
Post 50 MW threshold			0.0020		
			(0.0018)		
Post 200 MW threshold				0.0025	
				(0.0022)	
Placebo (future capacity)					-0.0001
					(0.0001)
Fixed-effects					
state	Yes	Yes	Yes	Yes	Yes
year	Yes	Yes	Yes	Yes	Yes
Fit statistics					
Observations	203	201	203	203	130
R^2	0.96437	0.96432	0.96438	0.96688	0.96955

Clustered (state) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: All columns report OLS regressions of raptor reporting rate on wind capacity measures with state and year fixed effects. Column (1): baseline continuous treatment. Column (2): drops Texas. Columns (3)–(4): binary treatment using alternative MW thresholds. Column (5): placebo test using future capacity as fake treatment. Standard errors clustered at the state level. $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Appendix: Standardized Effect Sizes

Table 5: Standardized Effect Sizes

Outcome	$\hat{\beta}$	SE	SD(Y)	SDE	SE(SDE)	Classification
Panel A: Pooled						
Raptor reporting rate	0.00047	0.00043	0.00505	0.30138	0.27435	Large positive
Waterfowl reporting rate (placebo)	-0.00002	0.00002	0.00021	-0.25847	0.29111	Large negative
Log raptor count (effort-controlled)	0.06148	0.05993	2.38298	0.08351	0.08141	Moderate positive
Panel B: Heterogeneous (sample splits)						
Raptors (Great Plains states)	-0.00012	0.00028	NA	NA	NA	Large positive
Raptors (Non-Plains states)	0.00048	0.00044	0.00505	0.30798	0.28117	Large positive

Notes: **Country:** United States. **Research question:** Does wind energy expansion reduce raptor populations relative to other bird species in states that install large-scale wind capacity? **Policy mechanism:** Federal Production Tax Credits and state Renewable Portfolio Standards drove staggered installation of 72,000+ utility-scale wind turbines across 38 states (2000–2023), creating rotating blade hazards that disproportionately kill soaring raptors through collision mortality. **Outcome definition:** Annual raptor (Accipitridae) eBird occurrence count divided by total bird records for the state-year, measuring the proportional representation of raptors in citizen science observations. **Treatment:** Continuous; log(1 + cumulative installed wind capacity in MW) per state-year. **Data:** USGS Wind Turbine Database v8.3 and GBIF eBird occurrence records, 2008–2023, 455 state-year observations across 50 states. **Method:** OLS with state and year fixed effects; standard errors clustered at the state level. **Sample:** All 50 US states; Great Plains subsample includes TX, OK, KS, NE, SD, ND, IA, MN, MT, WY, CO (primary wind corridor). SDE $= \hat{\beta} \times \mathrm{SD}(X)/\mathrm{SD}(Y)$ where SD(X) is the cross-sectional standard deviation of log wind capacity and SD(Y) is the pre-treatment standard deviation of the outcome. Classification refers to magnitude, not statistical significance: Large ($|\mathrm{SDE}| > 0.15$), Moderate (0.05–0.15), Small (0.005–0.05), Null (< 0.005).

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