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Using the United States Wind Turbine Database to Identify Increasing Turbine Size, Capacity and Other Development Trends

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Abstract

The purpose of this article was to analyze data associated with advances in wind energy across the United States. While governments, academia, and the private sector generally know patterns of wind turbine development (*i.e.* turbine size and capacity growing in recent years), there is no known independent, reliable, and/or updated summary of these variables. Using data collected by the Lawrence Berkeley National Laboratory and partners, this study used descriptive statistics to show turbine development and growth patterns from 1981-2019. The newly created United States Wind Turbine Database (USWTDB) represents the most comprehensive account of wind turbine information and was updated in January 2020. Variables I am interested in here are turbine manufacturer, state of project, turbine and project capacity, and turbine size. Findings provide empirical evidence to support the common, yet previously unrefined statements that wind turbines are growing larger in number, size and capacity. This growth is varied over spatial and temporal scales. I also provide evidence to show patterns of turbine manufacturing, with GE Wind dominating much of the US wind energy landscape today. I hope this work provides a timely resource for those interested in a variety of questions surrounding wind energy development in the United States. Perhaps more importantly, this analysis will hopefully inspire others to use what the USWTDB provides and answer larger questions surrounding wind energy futures.

Keywords

Wind Energy, Wind Turbines, USWTDB, Renewable Energy, Turbine Capacity, Turbine Size

1. Introduction

Responding to intersecting problems including global climate change, air pollution, and domestic energy insecurity, wind energy has emerged as a major source of low-carbon electricity generation. In the United States alone, there are now more than 60,000 utility-scale turbines, representing nearly 100 gigawatts of wind energy capacity and 15% of the global total [1] [2]. Much of this has been introduced over the past decade, and yet up until recently, there was no publicly accessible dataset that described wind turbines and their characteristics (e.g. size, capacity, location). Recognizing this void, researchers across three organizations—the Lawrence Berkeley National Laboratory (LBNL), the United Stated Geological Survey (USGS), and the American Wind Energy Association (AWEA)—came together in 2018 to create such a dataset. Aptly named The US Wind Turbine Database (USWTDB), information is provided on turbines dating back to 1981 and is updated on a quarterly basis. Apart from the USWTDB Viewer [3], which provides a simple and interactive way for anyone to visualize wind turbines across the country, there is no known resource for those who want to understand trends in US wind energy growth. More specifically, the Viewer and any other known resources do not provide any way to understand summarized and/or precise changes to US wind energy landscapes.

In this paper, I use the USWTDB to analyze patterns of US wind energy growth over four decades. For government, this will help those who debate and design policy. In industry, this may help businesses of all sizes understand current (and perhaps future) landscapes of the sector. For academics, I see this paper as providing an important starting-point for discussions around the clustering, size, and growing capacity of wind turbines. Echoing the benefits described by Rand *et al.* [2], this paper may also provide important context for groups interested in: climate change and air quality [4], local health and well-being [5], grid impacts [6], land requirements [7], local surface temperatures [8], sound and noise [9], property values [10] [11], renewable energy potentials [12], and acceptance research [13] [14] [15].

For all of these groups listed above—and more—there is a general understanding that turbines are getting larger in both in size, capacity and overall number. Yet, there is still a need for a study that analyses these trends in a systematic way. I answer what I see is a call for this kind of resource. In doing so, I provide a clear, accessible, and available-to-all report.

2. Methods

2.1. United States Wind Turbine Database

A full description of the USWTDB, including its process of creation, can be found in a recent publication by Rand *et al.* [2]. Here, I simply wish to clarify some important issues that directly relate to the variables used in this analysis. First, for many of the most pertinent variables, the USWTDB authors provide us their level of confidence (0 = not verified; 1 = no confidence; 2 = partial confidence; 3 = full confidence) regarding turbine characteristics (e.g. size, capacity, model, project name) and turbine location (coordinates). Of the total of 63,003 turbines, there was full confidence in turbine characteristics of 81% (9.5% with partial and 9.5% with no confidence). In terms of location, there was full confidence throughout 92.8% of the data (0.6% with partial and 6.5% with no confidence). This leaves us confident in the characteristics of 51,037 turbines and in the location of 58,494 turbines [2].

In most of the analysis here, I include only those turbines/projects with the highest level of confidence. This ensures transparency and should increase the reader's trust in the findings. Exceptions are seen when characteristics of wind turbines are not necessary (*i.e.* total number of turbines). As per the USWTDB, dismantled turbines are not included, but decommissioned turbines are. Residential-scale turbines (usually less than 65 kW and 30 metres in height) are not included in the dataset. Some exceptions to this may include smaller wind turbines built in California before 1990. At the time, these were considered to be utility-scale and thus are retained in the USWTDB.

2.2. Data Analysis

On March 28 2020, the USWTDB data was downloaded and input into SPSS 24 software. Based on Rand *et al.* [2] and verification of the data itself, the USWTDB included all turbines built and constructed by the end of 2019. The oldest wind turbines date back to 1981 (no confidence in turbine characteristics) or 1982 (full confidence in characteristics or any confidence in turbine location).

Before analysis took place, the dataset was cleaned to remove any missing variables. This was done for the variables of project year operational, project capacity, turbine capacity, turbine hub height, turbine rotor diameter, and turbine rotor swept area. I then used simple descriptive statistics to identify trends in the dataset. Based on a combination of what I saw as gaps in the literature, and what the dataset provided, this includes: leading turbine manufacturers, turbine capacity by year, the (physical) growth of wind turbines, and wind energy development by state (by year and decade). Below I present figures and tables that summarize such findings. Complete results of each section (via tables) can be found in the **Appendix A-H** [3].

3. Results

3.1. Wind Turbine Manufacturers

As of the end of 2019, General Electric (GE) Wind was by far the leading manufacturer of wind turbines across the United States (see **Figure 1**). Of the more than 51,000 turbines with full characteristics confidence, the company produced 21,774 (41.5%). Vestas (including Vestas North America; 24.1% or 12,322) produced the next highest number. At 4901 (9.6%), Siemens came in third. Though due to a 2017 merge with Gamesa (which later became Siemens Gamesa Renewable Energy), it may be argued that the new company is actually responsible for a total of 8137 turbines (15.9%) as of 2019. Mitsubishi (5.5%), Gamesa (5.2%), Suzlon (2.6%), Nordex (1.8%), Acciona (1.5%), NEG Micon (1.3%), Clipper (1.3%), Siemens Gamesea Renewable Energy (1.1%), and Repower (1.1%) represent the top 12 and include all those with at least 1% of turbines. A list of all those companies with at least five turbines as of 2019 (0.1% of total) can be found within the **Appendix B**.

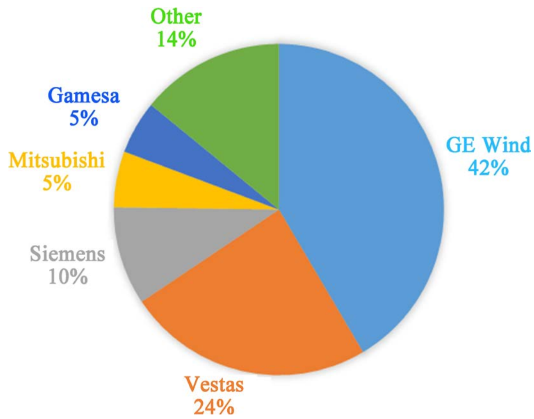
We can also look for recent changes in the above trends. As of 2009, things were much the same. GE Wind was still the leader (36.2%). Vestas was second (22.5%), followed by Mitsubishi (11.6%) and Siemens (6.1%). Going back two decades to 1999, Vestas was the undisputed leader with near a third (32.5%) of all turbines. Enron (20.5%) and NEG Micon (17.6%) followed.

3.2. Growth of New Turbine Capacity and Total Number of Turbines

Figure 2 shows the annual growth of average new turbine capacity and the annual number of new turbines. Because of gaps in data for turbine capacity through the 1980s and 1990s, here I include both the values given with full and partial confidence. The full dataset that makes up Figure 2 can be found within the **Appendix C**.

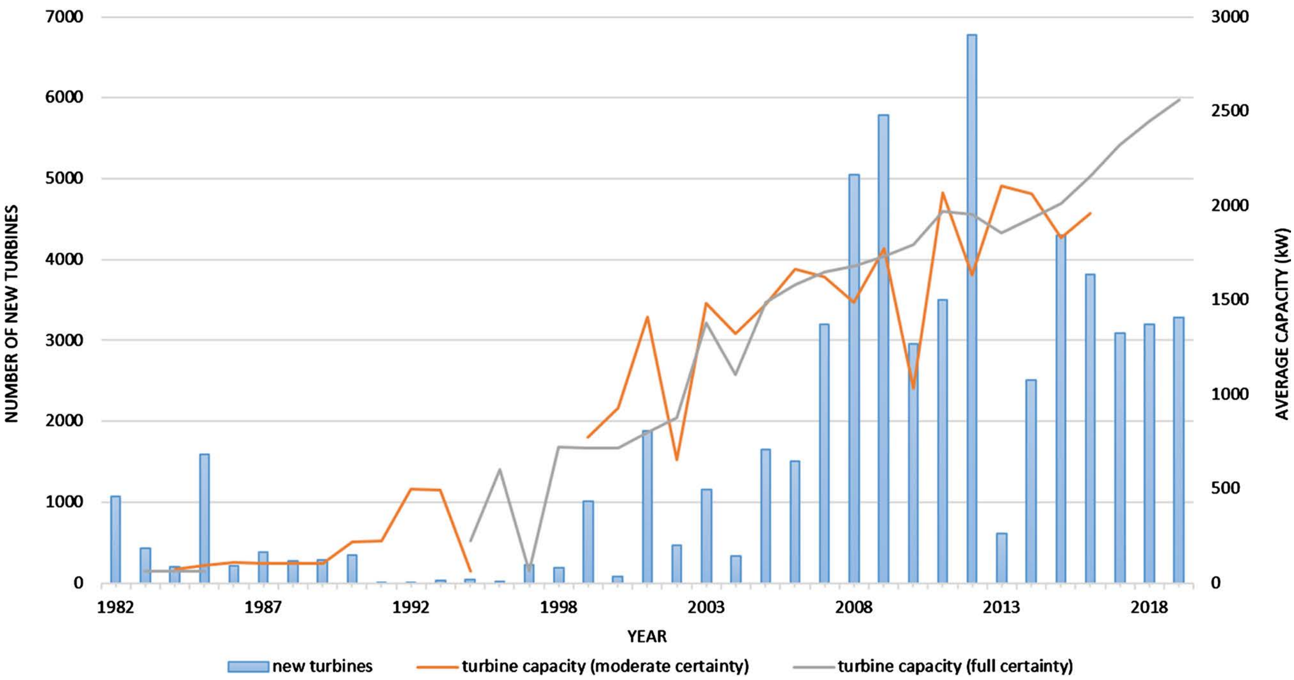
Of the 51,036 turbines with full confidence in capacity, the average (mean) turbine capacity was 1831.85 kW (1.85 MW). Though as the figure shows, this has varied throughout time. In 1990, the average turbine was just 218.16 kW (0.218 MW). In 2005, this reached nearly 1.5 MW. In 2014, this rose to 1.93 MW and finally in 2019, the steady rise continued, with the average turbine having a capacity of 2.56 MW. The turbine with the largest capacity (of all years) became operational in 2016 and had a capacity of 6 MW. It was associated with a five-turbine project called Block Island (Washington County, Rhode Island).

Using an expanded set of all development, we see the number of turbines has generally grown year over year—but with some notable spikes and valleys. Up until 2000, new turbines averaged just under 300 per year. There were just two years in this set of 18 that saw more than 1000 turbines becoming operational—1985 (n = 1596; all of which occurred across 16 wind farms in California), and



*Of the total number of wind turbines as of 2019 (n = 51,036). Though there were 51,037 turbines with full confidence in turbine characteristics, we found one turbine manufacturer as "missing". This may have been caused by a coding error.

Figure 1. Wind Turbines by manufacturer (percent of total*).



*For the year 1989, there was no information about average turbine capacity so I chose to insert a value that is equal to the average of the three preceding years. There were no turbines built in 1993 throughout the entire database, and so that year is not given a value (*i.e.* the year is ignored).

Figure 2. Number of wind turbines and average capacity (by year)*.

1999 (n = 1005; where 33 wind farms were built in 10 states).

From 2001 to 2019, the average number of turbines was 2897/year—though again with great variation. 2001 saw 1876 new turbines—a value that was not exceeded until 2007 when 3200 turbines became operational. This growth would continue until 2010 (n = 5780), when average turbines built from 2010-2011 dropped to just 3232. A recovery in 2012 marked the highest number of turbines ever built (n = 6774). Aside from a severe drop the following year (n = 610), new turbines have been relatively stable in recent history. This includes an average of 3366 turbines from 2014 to 2019.

3.3. Wind Turbine Development by State

Given our understanding of the general growth of wind energy, it is important to recognize the geographic distribution of wind turbine development (*i.e.* by state; see Figure 3 and **Appendix D**). Using the USWTDB's list of all turbines with a state/territory given, there are a few trends that stand out.

First is the dominance of California during the first two decades. From 1981-1991, California accounted for all new wind turbines (n = 4819; not shown). The late 1990s and 2000s brought with them much more diversity across the US energy landscape. By the end of 2009, there were 38 states with at least one turbine. Texas (n = 6094 or 22.2%) was just trailing behind California (n = 6278 or 22.9%) as the nation's leader. Other significant development had taken place in Iowa (9.2%), Minnesota (4.9%), Oregon (4.5%) and Washington state (4.3%).

From 2011-2019 there had been substantial growth in wind energy across the

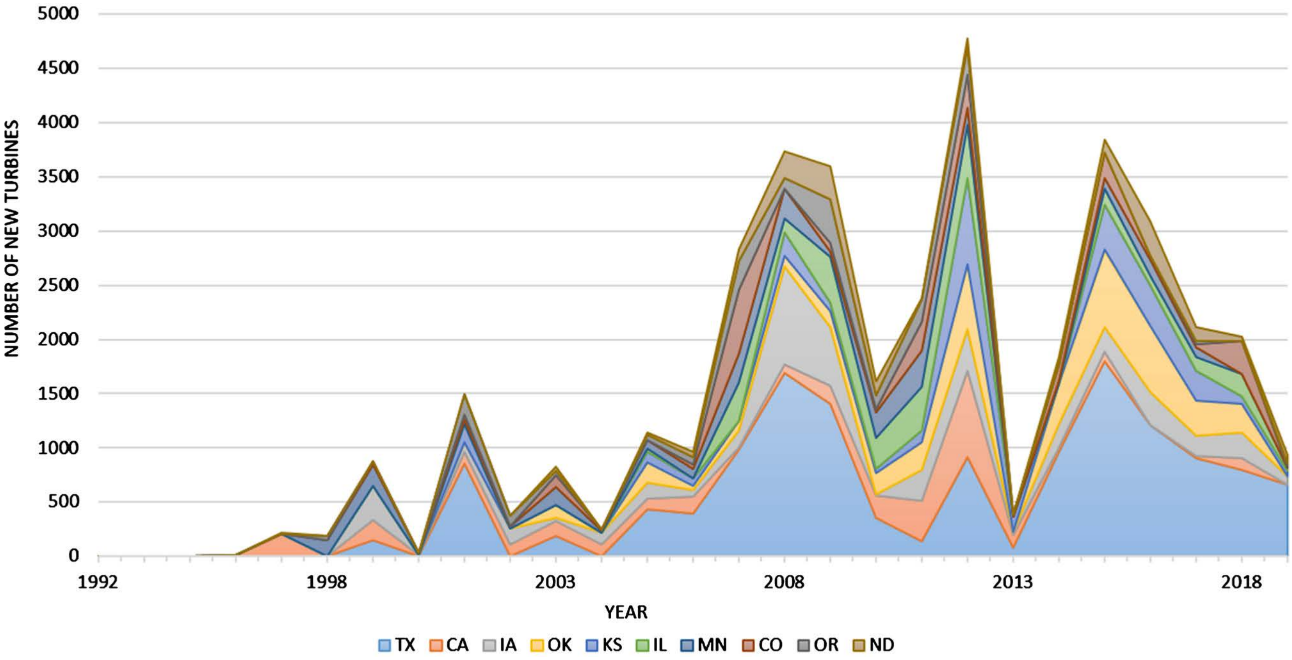


Figure 3. Number of new wind turbines by state and year (1992-2019; Top 10 states as of 2019).

United States. Again, when using the dataset of all turbines, there is a 2.24x increase in wind turbines from 2009 to 2019—strongly aided by "spikes" in 2012 and 2015. By the end of 2019, Texas was the leader in wind turbines (n = 14,852 or 24.2%) while California was a distant second (13%). Iowa was in third (8.7%) and Oklahoma moved to fourth (6.6%). As of 2019, there were 22 states with at least 1% of all turbines. There were 40 states and 2 territories (Puerto Rico and Guam) with at least one turbine.

3.4. Total Wind Energy Capacity by State

While the growth in number of turbines tells us something about the way wind energy development has taken place over the United States (Figure 3 and **Appendix D**), it is also helpful to understand the geographic distribution of wind energy capacity as well (Figure 4). That is because especially valuable given that more recently built turbines have capacities 5-6× larger than those from the 1980s (see Figure 2). Figures 4-6 below show the top 10 leading states in terms of total wind energy capacity—as well as total turbines and average turbine capacities—built in the 1990s, 2000s, and 2010s. The full dataset can be found in **Appendix E**.

Due to a concentration of new wind farms in Minnesota and Iowa in the late 1990s, both states overtook California by 2000. While still behind in total number of turbines, advancements in wind energy technology (re: capacity) allowed for this to happen. In line with Figure 3, from 2010 onwards Texas also became the undisputed leader in terms of capacity—with nearly 8000 MW in 2010 and nearly 25,000 MW by the end of 2019. Other notable states to emerge as wind energy leaders over the past decade include Oklahoma (n = 7033.33 MW) and

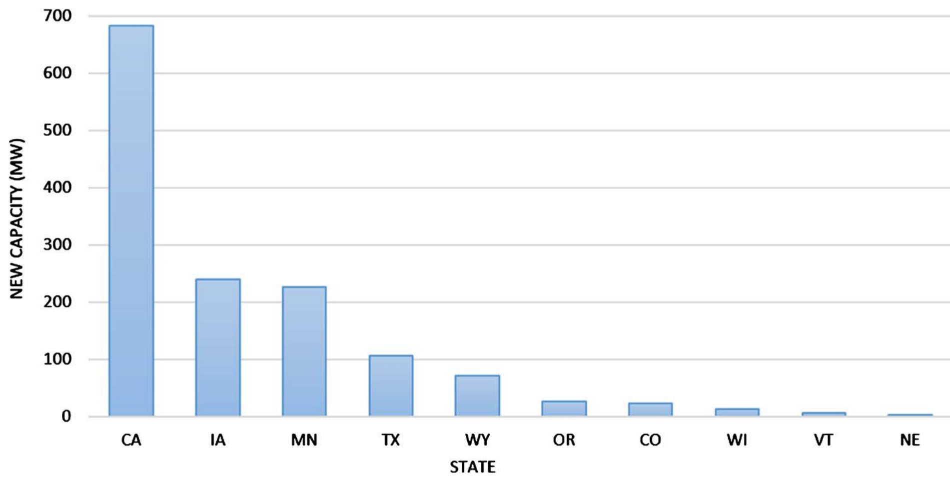


Figure 4. Total new wind energy capacity in the 1990s by state (Top 10 states in the 1990s).

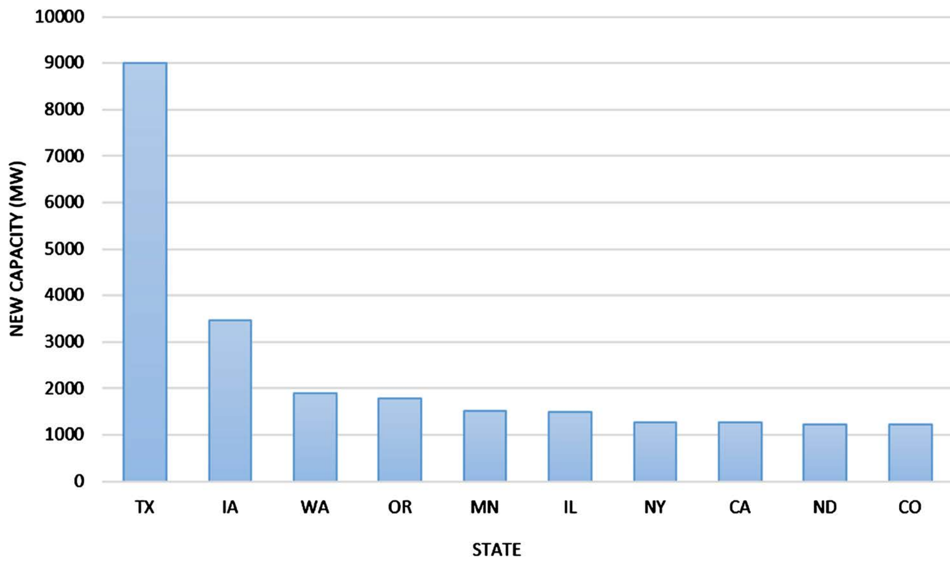


Figure 5. Total new wind energy capacity in the 2000s by state (Top 10 states in the 2000s).

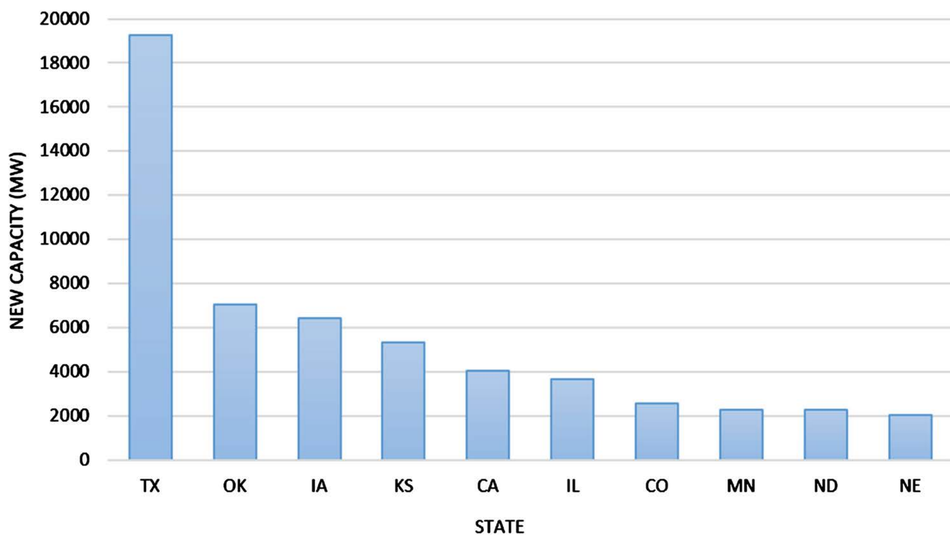


Figure 6. Total new wind energy capacity in the 2010s by state (Top 10 states in the 2010s).

Kansas (n = 5331.98 MW).

3.5. Turbine Size by Year

Finally, and corresponding to the growing capacity of wind developments, new turbines have grown in physical size since the 1980s. When using looking at hub height (*i.e.* the distance from the ground to the nacelle or centre of the wind turbine) there has been a 3.7× increase from 1985 (24.4 metres) to 2019 (90.3 metres). In looking at Figure 7 below (see also **Appendix F**), this rise has also been relatively constant, especially over the past 20 years. Again, due to inconsistencies in the data, I use turbine hub height data with full (n = 51,032) and partial (n = 4168) confidence.

Using only those turbines with full confidence in hub heights, as of 2019 the largest onshore wind turbine has a hub height of 130 metres and is single turbine part of the UL Advanced Wind Turbine Test Facility (built in 2018 in Randall County, Texas). This is a 1.6× increase since the early to mid-2000s, where the largest hub heights were 80 metres (see Figure 8 below). Today, there are 1482 turbines with a hub height of 100 metres or more. The multi-turbine wind development with the largest hub heights is the Hancock Wind Farm (Hancock County, Maine), which has 17, 116.5-metre turbines. More information on tallest turbines (per year), can be found in **Appendix G**.

Although it is the most common approach, hub height is just one way to measure turbine size. Rotor diameter and turbine rotor swept area, which is the total area covered through one full rotation of turbine blades, are also used. Looking at only those turbines with full characteristics confidence, we can see the rise of both of these values over the past two decades (see Figure 9 and **Appendix H**).

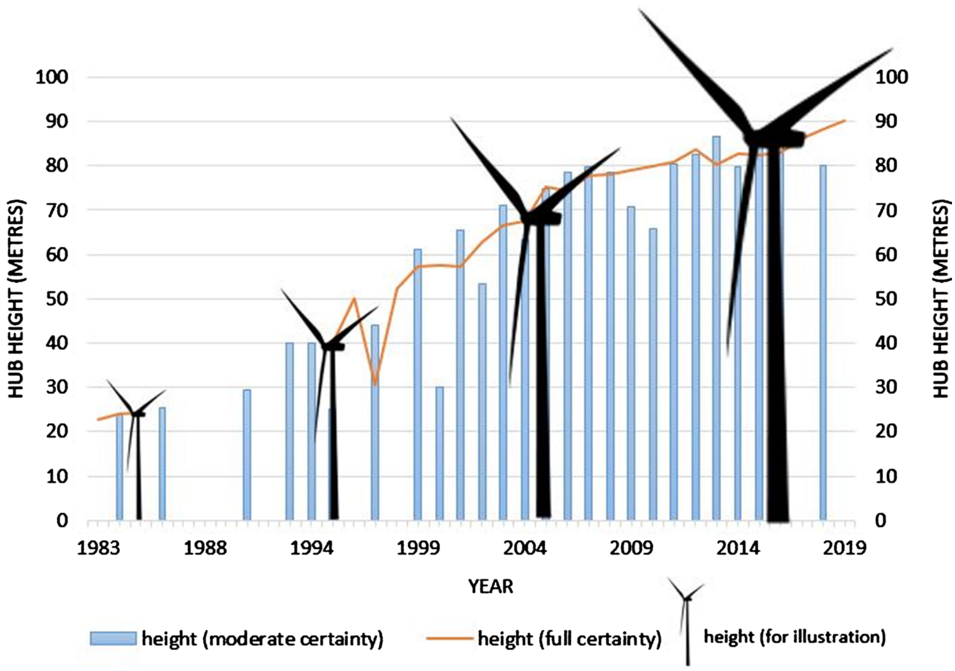


Figure 7. New turbine hub height (average) by year.

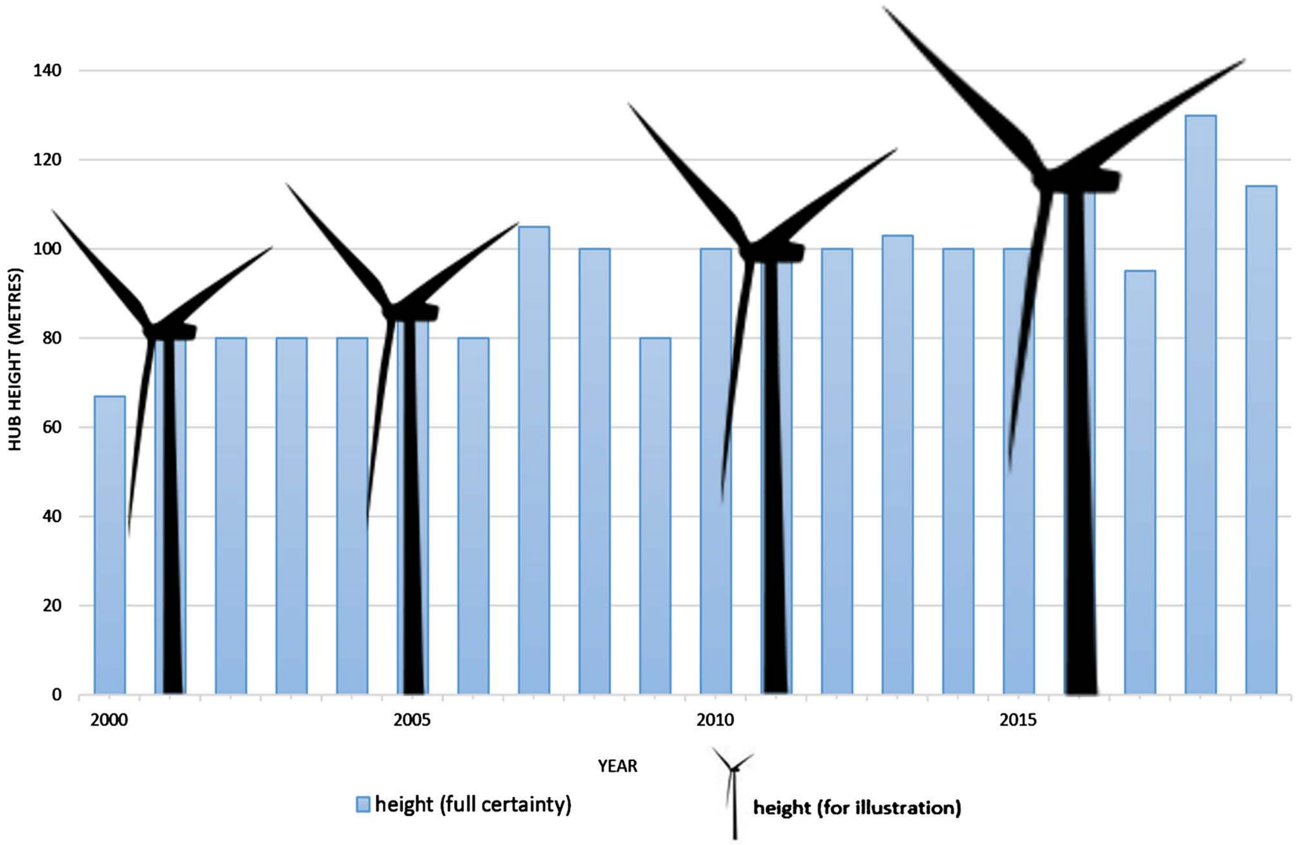


Figure 8. Largest turbine hub height (by year).

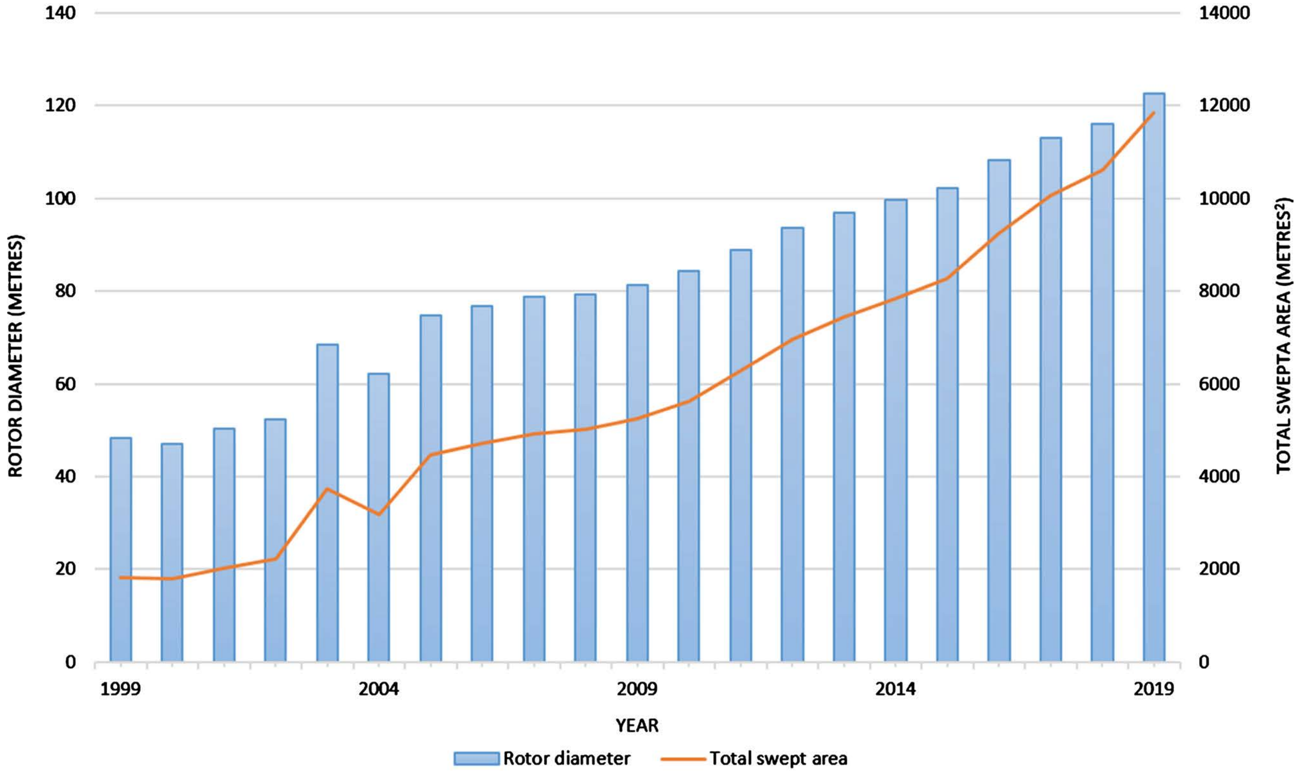


Figure 9. Average rotor diameter and total swept area by year.

Average rotor diameter increased from 48.22 metres in 1999 to 122.63 metres in 2019. The largest diameters during this same period ranged from 66 metres in 1999 to 150 metres (GE Haliade 150-6) in 2016.

Total swept area is a direct function of turbine diameter and thus why we see a perfect association between the two values in **Figure 9**. The total swept area is calculated by dividing the rotor diameter by two (*i.e.* to get radius/blade length), multiplying that value by itself, and then multiplying by the value of Pi (approx. 3.14159). It is represented through the following equation:

$$\text{Total swept area} = \pi * (\text{rotor diameter}/2)^2 \tag{1}$$

4. Discussion and Conclusions

Here I have presented a paper that has highlighted some major trends related to wind energy development across the United States. This was enabled by the newly-published United States Wind Turbine Database—an important, yet previously unsynthesized resource.

I have begun this important work here, quantifying patterns of wind energy growth in terms of variables such as total number of turbines, capacity, geographic distribution, and size. In existing literatures, these factors are often written about as assumptions. That is, phrases like "as turbines grow larger in size"—without quantification or citation—are increasingly common. I attempt to help move past the tendency to write in this way. More specifically, I show that in terms of manufacturing, and with 42% of the total, GE Wind is the undisputed leader as of 2019. Despite some significant peaks and valleys, the number of US turbines has generally increased year over year—with an average of over 3300 from 2014-2019. Average turbine capacity has also increased over the past four decades, and is now at just over 2.5 MW. In terms of geographic distribution, California may be labelled as the "early adopter" of wind energy, dominating all (small turbine) developments throughout the 1980s and much of the 1990s. Since then, Texas—and states like Iowa, Oklahoma and Kansas to smaller degree—have challenged and surpassed the "Golden State" in terms of both number of turbines and/or total capacity. Finally, I confirm the popular refrain of turbines getting physically larger since the 1980s. Growth of hub heights, rotor diameters and (thus) total swept areas, have seen very consistent growth over nearly 40 years. The largest turbines are now more than twice as tall (up to 130 metres) as they were just 20 years ago. Turbine rotor (blade) diameters have risen from approximately 50 metres in the early 2000s to just over 120 meters in 2019.

There are a few clear limitations of this study, some of which provide opportunities for further research. First, regarding the USWTDB itself, it included turbines that had been decommissioned. It would have been ideal if the dataset only included operational turbines, however even when not "spinning", there is an impact living near these structures. I suggest the USWTDB is edited to allow for analysis that identifies operational turbines, so that certain research questions would benefit as such. Second, and despite their best efforts [2], there were still some significant gaps in data throughout the USWTDB. These were especially prevalent throughout the 1980s and 1990s, so future research that depends on precise trends may want to focus on the past two decades only. Lastly, because the data only covered one country—albeit an important one in terms of global wind energy capacity—the results here are really only relevant to studies or reports that happen within the US. That said, and assuming there are similar datasets elsewhere, I hope this analysis inspires others to summarize the major trends in their jurisdiction.

All of these findings shared here should support a wide variety of actors—including governments, industry, and researchers—across an even wider area of inquiry. Given my expertise in the social acceptance of wind energy research [13] [14] [15], I see particular value to researchers here. I also want to highlight the opportunity for this research, and indeed the rich USWTDB as a whole, to help provide important context for a range of quantitative and qualitative studies. In the former, the dataset could be combined with other survey work. Fruitful research in this area could include health surveys and/or real estate sales data. In the qualitative realm, this data can also provide important context for case study research. For example, it may offer some important wind-farm specific characteristics that can help shape a common understanding of local development.

Acknowledgements

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Appendix

A. State and Territories: Abbreviations

STATE	Abbreviation
Alabama	AL
Alaska	AK
Arizona	AZ
Arkansas	AR
California	CA
Colorado	CO
Connecticut	CT
Delaware	DE
District of Columbia	DC
Florida	FL
Georgia	GA
Guam	GU
Hawaii	HI
Idaho	ID
Illinois	IL
Indiana	IN
Iowa	IA
Kansas	KS
Kentucky	KY
Louisiana	LA
Maine	ME
Maryland	MD
Massachusetts	MA
Michigan	MI
Minnesota	MN
Mississippi	MS
Missouri	MO
Montana	MT
Nebraska	NE
Nevada	NV
New Hampshire	NH
New Jersey	NJ
New Mexico	NM
New York	NY
North Carolina	NC

Continued

North Dakota	ND
Ohio	OH
Oklahoma	OK
Oregon	OR
Pennsylvania	PA
Puerto Rico	PR
Rhode Island	RI
South Carolina	SC
South Dakota	SD
Tennessee	TN
Texas	TX
Utah	UT
Vermont	VT
Virgin Islands	VI
Virginia	VA
Washington	WA
West Virginia	WV
Wisconsin	WI
Wyoming	WY

B. US Wind Turbines by Manufacturer (As of 2019)

COMPANY	NUMBER OF WIND TURBINES[a]	PERCENTAGE OF TOTAL (%)
GE Wind	21,174	41.5
Vestas (and Vestas North America)	12,322	24.1
Siemens	4901	9.6
Mitsubishi	2796	5.5
Gamesa	2654	5.2
Suzlon	1306	2.6
Nordex	929	1.8
Acciona	758	1.5
NEG Micon	680	1.3
Clipper	676	1.3
Siemens Gamesa Renewable Energy	582	1.1
REpower	548	1.1
Bonus	404	0.8
Enron	396	0.8

Continued

Goldwind	186	0.4
Zond	156	0.3
Danwin	115	0.2
Nordtank	90	0.2
DeWind	84	0.2
Vensys	28	0.1
Northern Power Systems	26	0.1
Alstom	24	<0.1
Fuhrlander	19	<0.1
China Creative Wind Energy	17	<0.1
Sany	17	<0.1
Entegrity	16	<0.1
HZ Windpower	16	<0.1
NedWind	13	<0.1
EWT	11	<0.1
Vergnet	9	<0.1
Seaforth Energy	8	<0.1
PowerWind	7	<0.1
Guodian	6	<0.1
Windmatic	5	<0.1
Aeronautica	5	<0.1
RRB	5	<0.1
TOTAL	51,037	100.0

[a]Here I include only those wind turbines with full confidence in characteristics (n = 51,037) and those manufacturers with at least five turbines as of 2019. I thus exclude 22 manufacturers.

C. Turbine Capacity by Year

YEAR	NUMBER OF NEW WIND TURBINES[a]	MEAN TURBINE CAPACITY[b] (full certainty)	STANDARD DEVIATION	MEAN TURBINE CAPACITY[c] (moderate certainty)	STANDARD DEVIATION
1981	10	n/a	n/a	n/a	n/a
1982	1073	n/a	n/a	221.98	87.16
1983	432	65	0.00	n/a	n/a
1984	196	65	0.00	70.40	10.35
1985	1596	65	0.00	95.41	45.32
1986	212	n/a	n/a	107.50	90.19
1987	387	n/a	n/a	101.45	6.51
1988	277	160	0.00	105	.

Continued

1989	288	n/a	n/a	n/a	n/a
1990	347	n/a	n/a	218.16	30.02
1991	1	n/a	n/a	225	.
1992	2	250	.	500	.
1994	30	n/a	n/a	490	20.34
1995	44	225	0.00	65	.
1996	14	600	.	n/a	n/a
1997	231	65	0.00	561.43	181.34
1998	189	722.38	65.25	n/a	n/a
1999	1005	715.33	84.52	771.84	219.07
2000	82	715.92	327.05	929.55	233.67
2001	1876	798.19	254.30	1408.06	281.61
2002	462	875	351.89	652.00	678.54
2003	1153	1377.18	340.39	1482.65	133.48
2004	328	1101.77	418.19	1321.88	244.12
2005	1653	1488.19	300.88	1475.27	193.54
2006	1506	1578.32	413.67	1664.01	398.67
2007	3 200	1646.23	420.28	1619.85	284.39
2008	5046	1680.19	459.26	1488.81	219.71
2009	5780	1732.86	412.07	1770.12	806.20
2010	2960	1792.39	394.02	1033.80	858.73
2011	3504	1969.19	459.62	2065.00	536.99
2012	6774	1952	444.24	1630.35	353.79
2013	610	1853.66	373.50	2105.56	592.82
2014	2512	1933.34	358.33	2061.81	280.92
2015	4300	2012.99	329.81	1828.24	479.47
2016	3810	2157.08	442.62	1957.26	387.08
2017	3090	2321.77	411.27	n/a	n/a
2018	3200	2443.37	483.59	1525	1096.02
2019	3283	2558.96	491.23	n/a	n/a
TOTAL/AVERAGE	61463	1831.93*	604.28	1027.21	768.90

[a]Based on all turbines regardless of turbine characteristic or location confidence (n = 61,463). [b]I include all turbines with full confidence values in turbine capacity (n = 51,036). [c]I include all turbines with partial confidence values in turbine capacity (n = 6007).

D. New Turbines by State and Year (Decade)

1981-1989[a,b]

STATE	1981	1982	1983	1984	1985	1986	1987	1988	1989	1980s TOTAL
CA	10	1073	432	196	1596	212	387	277	288	4471

[a]I include all turbines, regardless of confidence of level, that provide a state/territory of each turbine (n = 4471). [b]All other states/territories with zero turbines in the 1980s are excluded within this table.

1990-1999[a,b]

STATE	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	1990s TOTAL
CA	347	1	1	0	30	42	13	207	2	187	830
MN	0	0	0	0	0	0	0	1	142	192	335
IA	0	0	1	0	0	2	0	2	3	312	320
TX	0	0	0	0	0	0	0	0	0	151	151
WY	0	0	0	0	0	0	0	0	2	108	110
OR	0	0	0	0	0	0	0	0	38	0	38
CO	0	0	0	0	0	0	0	0	0	29	29
WI	0	0	0	0	0	0	0	0	0	18	18
AK	0	0	0	0	0	0	6	0	6	0	12
VT	0	0	0	0	0	0	0	12	0	0	12
NE	0	0	0	0	0	0	0	0	2	1	3
ND	0	0	0	0	0	0	0	2	0	0	2
IL	0	0	0	0	0	0	0	1	0	0	1
MI	0	0	0	0	0	0	1	0	0	0	1
NM	0	0	0	0	0	0	0	0	0	1	1

[a]I include all turbines, regardless of confidence of level, that provide a state/territory of each (n = 1863). [b]All other states/territories with zero turbines in the 1990s are excluded within this table.

2000-2009[a,b]

STATE	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2000s TOTAL
TX	0	852	0	186	0	434	395	980	1694	1402	5943
IA	0	91	150	32	108	152	67	161	912	534	2207
OR	0	181	102	41	0	50	67	260	102	403	1206
WA	0	270	37	12	0	83	260	165	104	243	1174
MN	18	41	18	165	28	77	81	263	269	41	1001
CA	10	108	104	141	104	93	152	21	71	173	977
IL	0	0	0	0	1	34	0	358	129	430	952
CO	0	48	0	108	5	1	40	591	1	83	877
NY	17	19	1	0	0	82	112	31	188	345	795
ND	0	1	3	41	0	22	50	111	247	301	776
OK	0	1	0	113	0	182	40	85	91	154	666
WY	31	49	0	80	0	2	0	0	226	274	662

Continued

KS	0	170	0	0	0	100	68	0	222	73	633
IN	0	0	0	0	0	0	0	0	88	529	617
NM	0	0	0	138	60	140	90	0	1	40	469
PA	0	16	0	63	0	0	25	65	32	211	412
MT	0	0	0	0	0	108	6	8	83	69	274
WI	0	20	0	0	1	0	0	0	216	37	274
SD	0	4	2	28	0	0	0	36	59	68	197
WV	0	0	44	0	0	0	0	0	132	0	176
MO	0	0	0	0	0	0	0	27	51	73	151
UT	1	0	0	0	0	1	0	0	9	98	109
ME	0	0	0	0	0	0	7	21	3	64	95
MI	0	2	0	0	0	0	0	0	80	7	89
ID	0	0	0	0	0	50	0	0	0	34	84
NE	0	1	0	0	0	36	0	0	0	27	64
AK	2	1	1	2	4	0	6	2	21	14	53
HI	0	0	0	0	0	0	36	14	0	0	50
AZ	0	0	0	0	0	0	0	0	0	30	30
MA	0	1	0	0	0	1	2	1	3	13	21
TN	3	0	0	0	15	0	0	0	0	0	18
NH	0	0	0	0	0	0	0	0	12	1	13
OH	0	0	0	2	2	0	1	0	0	4	9
NJ	0	0	0	0	0	5	0	0	0	0	5
RI	0	0	0	0	0	0	1	0	0	2	3
VT	0	0	0	0	0	0	0	0	0	2	2
AR	0	0	0	1	0	0	0	0	0	0	1
NC	0	0	0	0	0	0	0	0	0	1	1

[a]I include all turbines, regardless of confidence of level, that provide a state/territory of each (n = 21,086).
[b]All other states/territories with zero turbines in the 2000s are excluded within this table.

2010-2019[a,b]

STATE	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2010s TOTAL
TX	353	136	920	84	964	1796	1211	946	919	1429	8758
OK	195	257	596	0	369	710	602	323	290	18	3360
IA	5	282	385	26	219	226	304	195	506	690	2838
KS	46	112	802	141	1	413	376	277	210	235	2613
IL	284	405	493	0	0	153	93	139	233	161	1961
CA	212	375	789	115	36	94	3	23	114	6	1767
CO	35	262	308	18	153	232	36	36	300	35	1415
MN	229	332	152	2	32	100	145	100	41	106	1239

Continued

MI	10	121	353	103	207	0	44	101	19	114	1072
ND	128	9	80	1	65	118	311	124	45	145	1026
NE	43	85	73	46	161	47	221	45	232	56	1009
OR	129	209	253	0	0	0	6	25	0	56	678
NM	64	28	14	5	21	134	16	260	22	84	648
IN	184	1	128	1	101	65	0	106	61	0	647
WA	162	158	119	0	117	2	0	0	0	0	558
SD	229	51	0	0	11	98	0	0	18	83	490
ID	134	155	168	0	0	0	0	0	0	0	457
OH	15	58	166	2	1	7	49	34	49	6	387
MO	101	0	1	0	1	0	92	165	0	24	384
NY	2	67	78	52	16	6	40	7	77	1	346
PA	0	21	279	0	0	0	14	0	5	20	339
ME	41	72	19	0	3	57	91	8	0	0	291
MT	8	0	171	1	12	0	13	0	48	1	254
WY	186	0	0	0	0	0	46	0	0	0	232
WV	66	76	8	0	0	0	49	0	0	0	199
WI	11	90	11	1	0	0	0	49	0	0	162
AZ	31	6	62	0	0	15	0	0	0	0	114
NC	0	0	0	0	0	0	0	104	0	0	104
UT	0	68	0	0	0	1	28	0	0	0	97
MD	31	20	0	0	16	12	0	1	0	0	80
AK	13	4	45	4	2	4	0	0	4	1	77
HI	0	12	53	1	0	3	0	5	0	0	74
NH	0	0	57	0	0	5	0	0	0	9	71
MA	9	16	34	2	1	0	4	1	0	3	70
NV	0	0	67	0	3	0	0	0	0	0	70
PR	0	0	58	3	0	0	0	0	0	0	61
VT	2	16	25	1	0	0	0	15	0	0	59
RI	0	0	6	0	0	0	15	1	7	0	29
CT	1	0	0	0	0	2	0	0	0	0	3
DE	1	0	0	0	0	0	0	0	0	0	1
FL	0	0	0	1	0	0	0	0	0	0	1
GU	0	0	0	0	0	0	1	0	0	0	1
NJ	0	0	1	0	0	0	0	0	0	0	1

[a]I include all turbines, regardless of confidence of level, that provide a state/territory of each (n = 34,043).
[b]All other states/territories with zero turbines in the 2010s are excluded within this table.

E. Total Capacity by State and Decade

1981-1989[a]

STATE	1980s TOTAL[b]	AVERAGE TURBINE CAPACITY (kW)[c]	STANDARD DEVIATION	TOTAL NEW CAPACITY (kW)	TOTAL NEW CAPACITY (MW)
CA	4471	79.40	34.08	354,997.40	355

[a]All other states/territories with zero turbines in the 1980s are excluded within this table. [b]I include all turbines, regardless of confidence of level, that provide a state/territory of each (n = 4,471). [c]I include only turbine capacities with full confidence in the 1980s (n = 759).

1990-1999[a]

STATE[a]	1990s TURBINES TOTAL[b]	AVERAGE TURBINE CAPACITY (kW)[c]	SD	TOTAL NEW CAPACITY (kW)	TOTAL NEW CAPACITY (MW)
CA	1177	580.38	212.64	683,107.26	683.11
IA	320	745.82	42.29	238,662.4	238.66
MN	335	675.71	196.54	226,362.85	226.36
TX	151	702.18	119.11	106,029.18	106.03
WY	110	647.73	68.40	71,250.3	71.25
OR	38	660.00	0.00	25,080	25.08
CO	29	750.00	0.00	21,750	21.75
WI	18	660.00	0.00	11,880	11.88
VT[c]	12	545.83	202.77	6549.96	6.55
NE	3	660.00	0.00	1980	1.98
AK	12	74.09	50.59	889.08	0.89
NM[c]	1	660.00	.	660	0.66
MI	1	600.00	.	600	0.60
IL[c]	1	550.00	.	550	0.55
ND[c]	2	100.00	.00	200	0.20

[a]All other states/territories with zero turbines in the 1990s are excluded within this table. [b]I include all turbines, regardless of confidence of level, that provide a state/territory of each (n = 1863). [c]I include only turbine capacities with full confidence (n = 1168).

2000-2009[a]

STATE	2000s TURBINES TOTAL	AVERAGE TURBINE CAPACITY (kW)	STANDARD DEVIATION	TOTAL NEW CAPACITY (kW)	TOTAL NEW CAPACITY (MW)
TX	5943	1515.71	530.75	9,007,864.53	9007.86
IA	2207	1568.76	479.78	3,462,253.32	3462.25
WA	1174	1613.20	598.88	1,893,896.8	1893.90
OR	1206	1485.64	590.58	1,791,681.84	1791.68
MN	1001	1505.24	389.81	1,506,745.24	1506.75
IL	952	1563.88	170.38	1,488,813.76	1488.81
NY	795	1601.16	285.57	1,272,922.2	1272.92

Continued

CA	977	1301.50	637.23	1,271,565.5	1271.57
ND	776	1585.43	224.97	1,230,293.68	1230.29
CO	877	1395.84	360.02	1,224,151.68	1224.15
OK	666	1722.03	307.14	1,146,871.98	1146.87
WY	662	1616.16	364.94	1,069,897.92	1069.90
IN	617	1678.03	261.68	1,035,344.51	1035.34
KS	633	1610.12	823.55	1,019,205.96	1019.21
PA	412	1790.53	309.98	737,698.36	737.70
NM	469	1238.02	460.55	580,631.38	580.63
WI	274	1571.23	119.49	430,517.02	430.52
MT	274	1439.05	289.94	394,299.7	394.30
WV	176	1875.00	217.12	330,000	330.00
SD	197	1620.47	292.99	319,232.59	319.23
MO	151	2029.14	138.13	306,400.14	306.40
UT	109	2084.67	489.21	227,229.03	227.23
ME	95	1837.89	647.94	174,599.55	174.60
ID	84	1742.86	296.28	146,400.24	146.40
MI	89	1607.30	224.18	143,049.7	143.05
NE	64	2204.06	696.25	141,059.84	141.06
AZ	30	2100	.00	63,000	63.00
HI	50	1126.67	423.32	56,333.5	56.33
TN	18	1610.00	437.17	28,980	28.98
NH	13	2000.00	.00	26,000	26.00
MA	21	926.25	597.45	19,451.25	19.45
OH	9	1250.83	852.00	11,257.47	11.26
AK	53	210.94	424.33	11,179.82	11.18
NJ	5	1500.00	.00	7500	7.50
RI	3	380.00	395.98	1140	1.14
VT[d]	2	100.00	.00	200	0.20
AR[d]	1	175.83	330.57	175.83	0.18
NC[e]	1	n/a	n/a	n/a	n/a

[a]All other states/territories with zero turbines in the 2000s are excluded within this table. [b]I include all turbines, regardless of confidence of level, that provide a state/territory of each (n = 21,086). [c]When available, I include only turbine capacities with full confidence (n = 18,045). [d]For these states, I use the average turbine capacities with moderate confidence (n = 2969). [e]There was no turbine capacity data for North Carolina's single turbine.

2010-2019[a]					
STATE	2010s TURBINES TOTAL	AVERAGE TURBINE CAPACITY (kW)	STANDARD DEVIATION	TOTAL NEW CAPACITY (kW)	TOTAL NEW CAPACITY (MW)
TX	8758	2200.60	478.76	19,272,854.80	19272.85
OK	3360	2093.37	430.85	7,033,723.20	7033.72
IA	2838	2259.60	303.23	6,412,744.80	6412.74
KS	2613	2040.56	476.51	5,331,983.28	5331.98
CA	1767	2293.76	663.68	4,053,073.92	4053.07
IL	1961	1860.68	315.74	3,648,793.48	3648.79
CO	1415	1795.34	217.23	2,540,406.10	2540.41
MN	1239	1841.12	322.14	2,281,147.68	2281.15
ND	1026	2199.49	541.92	2,256,676.74	2256.68
NE	1009	2015.47	496.39	2,033,609.23	2033.61
MI	1072	1879.77	386.90	2,015,113.44	2015.11
OR	678	2237.86	389.78	1,517,269.08	1517.27
NM	648	2118.89	291.41	1,373,040.72	1373.04
IN	647	1972.26	549.34	1,276,052.22	1276.05
WA	558	2114.46	315.54	1,179,868.68	1179.87
SD	490	1738.42	240.91	851,825.80	851.83
ID	457	1813.14	332.71	828,604.98	828.60
OH	387	1996.03	323.75	772,463.61	772.46
ME	291	2590.31	702.21	753,780.21	753.78
NY	346	2159.73	559.10	747,266.58	747.27
MO	384	1873.27	247.18	719,335.68	719.34
PA	339	2049.00	349.15	694,611	694.61
MT	254	1708.55	377.22	433,971.70	433.97
WY	232	1722.08	312.09	399,522.56	399.52
WV	199	1780.40	324.06	354,299.6	354.30
WI	162	1874.84	276.33	303,724.08	303.72
NC	104	2000.00	.00	208,000	208
AZ	114	1807.96	232.66	206,107.44	206.11
MD	80	2477.27	199.43	198,181.6	198.18
NH	71	2600.81	483.03	184,657.51	184.66
UT	97	1728.02	360.89	167,617.94	167.62
NV	70	2300.00	.00	161,000	161
HI	74	2134.78	605.42	157,973.72	157.97
VT	59	2468.97	599.18	145,669.23	145.67
PR	61	2090.42	467.89	127,515.62	127.52

Continued

MA	70	1593.71	303.61	111,559.70	111.56
AK	77	1173.94	764.05	90,393.38	90.39
RI	29	2552.59	1772.13	74,025.11	74.03
CT	3	2850.00	.00	8550	8.55
DE	1	2000.00	.	2000	2
NJ	1	1500.00	.	1500	1.5
GU	1	275.00	.	275	0.275
FL[d]	1	n/a	n/a	n/a	n/a

[a] All other states/territories with zero turbines in the 2010s are excluded within this table. [b] I include all turbines, regardless of confidence of level, that provide a state/territory of each (n = 34,043). [c] When available, I include only turbine capacities with full confidence (n = 31,031). [d] There was no turbine capacity data for Florida's single turbine.

F. Size of Turbines by Year

YEAR	AVERAGE HUB HEIGHT[a] (metres; full certainty)	STANDARD DEVIATION	AVERAGE HUB HEIGHT[b] (metres; partial certainty)	STANDARD DEVIATION
1983	22.80	0.00	n/a	n/a
1984	24.00	0.00	24	.00
1985	24.39	0.29	n/a	n/a
1986	n/a		25.31	6.80
1987	n/a		n/a	n/a
1988	23.00	.00	n/a	n/a
1989	n/a	n/a	n/a	n/a
1990	n/a	n/a	29.32	2.76
1991	n/a	n/a	n/a	n/a
1992	43.00	.	40	.
1994	n/a	n/a	40	.00
1995	39.77	1.52	25	.
1996	50.00	.	n/a	n/a
1997	30.50	0.00	44.04	6.33
1998	52.29	3.56	n/a	n/a
1999	57.23	7.23	61.05	6.90
2000	57.56	9.29	30.00	.
2001	57.10	7.81	65.41	5.79
2002	62.74	5.83	53.25	37.83
2003	66.70	7.38	70.94	7.56
2004	67.63	9.39	63.32	2.43
2005	75.24	8.06	74.91	9.72

Continued

2006	74.30	9.51	78.67	4.61
2007	77.77	5.16	79.65	2.25
2008	78.14	4.77	78.61	7.45
2009	78.85	3.98	70.71	15.29
2010	79.79	2.25	65.89	21.86
2011	80.89	5.58	80.40	5.91
2012	83.75	9.26	82.61	7.01
2013	80.23	3.55	86.50	9.49
2014	82.85	5.61	79.65	3.81
2015	82.30	5.39	87.71	17.27
2016	82.98	6.02	88.05	18.73
2017	86.01	6.69	n/a	n/a
2018	88.26	5.87	80	.
2019	90.30	6.88	n/a	n/a
TOTAL/ AVERAGE	79	11.72	70.96	17.54

[a]I include all turbines with full confidence values in hub height (n = 51,035). [b]I include all turbines with partial confidence values in hub height turbine (n = 4168).

G. Largest Turbines by Year (Hub Height; 2000-2019)

YEAR	TALLEST TURBINE (HUB HEIGHT; METRES)[a]
2000	67
2001	80
2002	80
2003	80
2004	80
2005	85
2006	80
2007	105
2008	100
2009	80
2010	100
2011	100
2012	100
2013	103
2014	100
2015	100
2016	116.5

Continued

2017	95
2018	130
2019	114
TOTAL/AVERAGE	79

[a]I include all turbines with full confidence values in hub height from 2000-2019 (n = 49,105).

H. Turbine Rotor Diameter and Swept Area (1999-2019)

YEAR	AVERAGE ROTOR DIAMETER (metres; full certainty)[a]	STANDARD DEVIATION	AVERAGE TOTAL SWEPT AREA (metres^2; full certainty)[b]	STANDARD DEVIATION
1999	48.22	3.08	1833.71	195.30
2000	47.15	8.18	1798.27	598.58
2001	50.36	6.35	2023.83	549.64
2002	52.48	8.97	2226.36	813.07
2003	68.36	8.57	3727.21	885.81
2004	62.11	13.89	3170.71	1307.07
2005	74.78	9.33	4460.39	904.72
2006	76.71	10.76	4711.93	1192.97
2007	78.70	9.11	4929.53	1099.01
2008	79.28	9.93	5014.22	1154.89
2009	81.36	8.42	5254.04	1039.99
2010	84.22	7.67	5617.48	1024.65
2011	88.92	8.93	6272.06	1196.47
2012	93.62	10.65	6972.71	1488.44
2013	96.87	9.15	7435.97	1178.05
2014	99.59	7.40	7832.87	1131.63
2015	102.29	7.98	8267.02	1246.57
2016	108.26	7.57	9250.39	1267.75
2017	112.99	7.08	10066.30	1204.18
2018	115.96	8.09	10611.66	1489.73
2019	122.63	7.18	11850.43	1374.05
TOTAL/AVERAGE	90.81	19.14	6764.93	2654.08

[a]I include all turbines with full confidence values in rotor diameter and total swept area (n = 51,035)