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Wind Energy Land Distribution In The United States of America

Office of Energy Policy and New Uses
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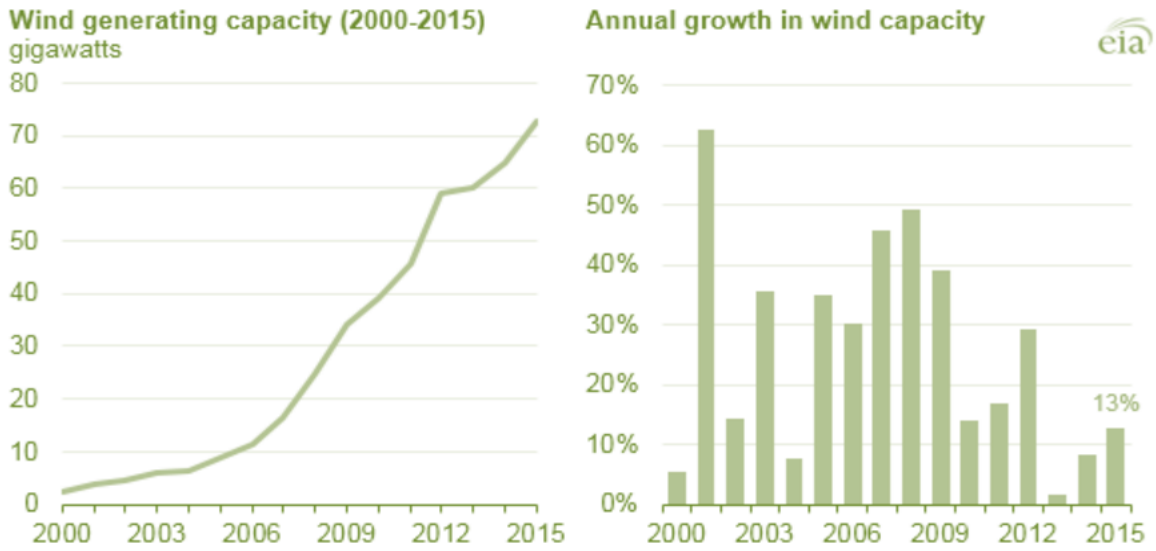
Introduction

The development of utility-scale renewable energy, which has primarily involved wind-power installations, has expanded rapidly in the United States in the last two decades. Installed wind-power capacity increased from approximately five gigawatts (GW) in 2002 to over 69 GW in 2015 (Figure 1) and has accounted for one-third of all U.S. electricity-generating capacity additions since 2007 (U.S. DOE, 2015a; U.S. DOE, 2015b). Specifically in 2015, wind power accounted for 41% of total additions to electricity-generating capacity (Energy Information Administration, 2016a).

Figure 1. Wind-generating capacity (2000-2015)



Source: Energy Information Administration (2016b)

Agricultural producers were early adopters of renewable-power technology because of their remote power needs. Wind turbines, for example, have been used to pump water and for remote electricity generation in the United States since the early 1900s and, in the absence of rural electrification, were widely incorporated in agriculture operations by 1930. At the time, agriculture represented the main market for wind-energy systems (Xiarchos and Lazarus, 2013).

Wind and solar installations are often located on or close to agricultural land, which accounts for 40% of the total U.S. land area, and states with large agricultural sectors are often also leaders in renewable-electricity installations (Xiarchos and Lazarus, 2013). Specifically, over half of the electricity generated in non-hydroelectric renewable-power plants was concentrated in seven states (EIA, 2015)—California (17% of the U.S. total), Texas (15%), Iowa (5%), Oklahoma (5%), Minnesota (4%), Kansas (4%), and Illinois (4%)—a list almost identical to 2015's top seven agricultural producing states (California, Iowa, Texas, Nebraska, Minnesota, Illinois, and Kansas).

The goal of this study is to examine the type of land on which wind turbines are located. While the 2009 On-Farm Renewable Energy Production Survey (OFREPS) from the National Agricultural Statistics Service, U.S. Department of Agriculture (NASS, USDA), was the first national survey of on-farm

renewable-energy generation, it excluded "large wind" systems of 100 kilowatts (KW) or more, which are generally commercial applications and often located on farms but operated by other business entities under wind-rights lease agreements with the farms. This presentation fills the gap by analyzing utility-scale turbines larger than 100 KW. The land data used in the analysis are the 2008, 2010, and 2014 Cropland Data Layers of CropScape available from NASS, USDA. The wind turbine data as of 2015 are from the American Wind Energy Association Market Database Pro. The U.S. Census urban classification data and the Office of Management and Budget metropolitan county classification data are for 2010 and are from the U.S. Census Bureau.

Rural, Regional, and Chronological Wind Turbine Distribution

Most wind turbines are in rural areas. We use two classifications identified by the Economic Research Service, U.S. Department of Agriculture (ERS, 2017). Based on the U.S. Census urban-rural classification system[1], 99.6% of all wind turbines are in rural (non-urban) areas. Based on the Office of Management and Budget metropolitan county classification[2], only 38% of wind turbines are in metro counties, while 62% are in micropolitan or non-core counties. The majority of all wind turbines are located in the Great Plains, California, the Pacific Northwest, and the Northeast. Turbines are noticeably absent in the Southeast and some particularly mountainous areas in the West. The counties with the greatest number of turbines (Figure 1) are in California, which hosts 24% of all turbines, Texas 16%, Iowa 6.5%, Illinois and Minnesota, each about 4%, and Oregon and Oklahoma, approximately 3.5% each. Decommissioned satellites are exclusively located in California, western Texas, and one county in Iowa (Figure 2). Turbines were first installed—from 1981 through 1990—in California (Figures 3 and 4) and began showing up in Iowa counties in the early 1990s (Figure 5). In the late 1990s, turbine location began to disperse around the United States (Figures 6 and 7). A large boom occurred over 10 years (2006 through 2015), in areas including Wyoming, Illinois, Southern Washington and Northern Oregon, and the northeastern states (Figures 8 and 9).

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[1] The Census Bureau's urban areas represent densely developed territory and encompass residential, commercial, and other non-residential urban land uses. Based on the 2010 decennial census, to qualify as an urban area, the territory identified according to criteria must encompass at least 2,500 people, at least 1,500 of whom reside outside institutional group quarters. Urban areas do not always follow municipal boundaries. Most counties contain a combination of urban and rural populations. The Census Bureau identifies two types of urban areas:

- Urbanized Areas (UAs) of 50,000 or more people.
- Urban Clusters (UCs) of at least 2,500 and fewer than 50,000 people.

"Rural" encompasses all people, housing, and territory not included within an urban area. Based on the 2010 decennial census, rural areas comprise open country and settlements with fewer than 2,500 residents.

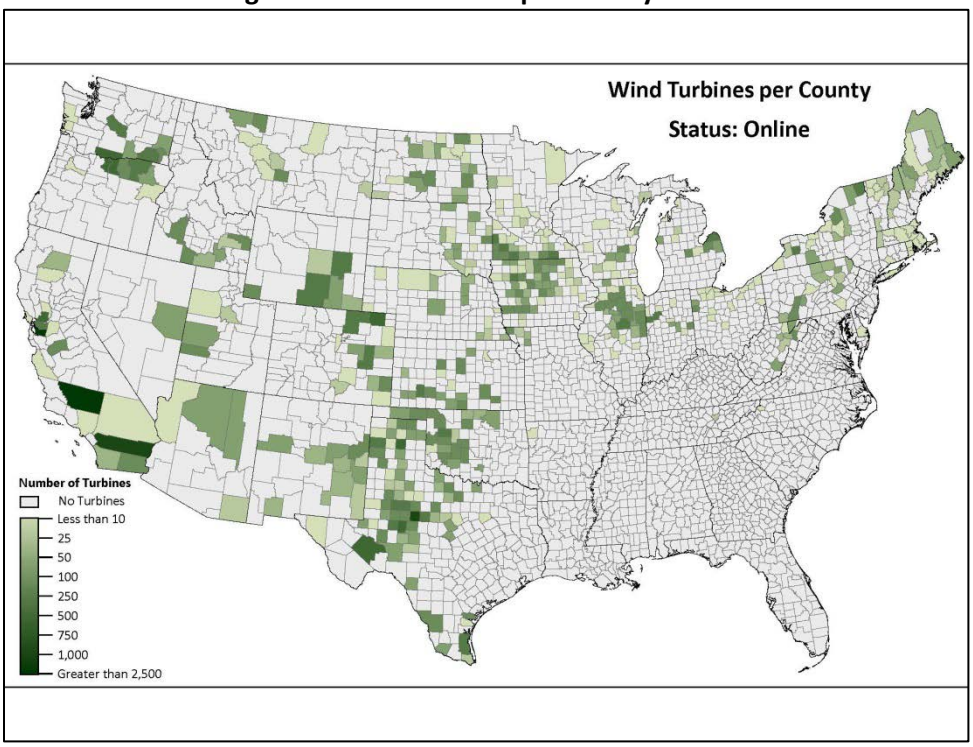
[2] OMB defines metropolitan (metro) areas as broad labor-market areas that include:

- Central counties with one or more urbanized areas (with 50,000 or more people).
- Outlying counties that are economically tied to the core counties as measured by labor-force commuting. Outlying counties are included if 25% of workers living in the county commute to the central counties, or if 25% of the employment in the county consists of workers coming out from the central counties—the so-called "reverse" commuting pattern.

Non-metro counties include rural areas defined as:

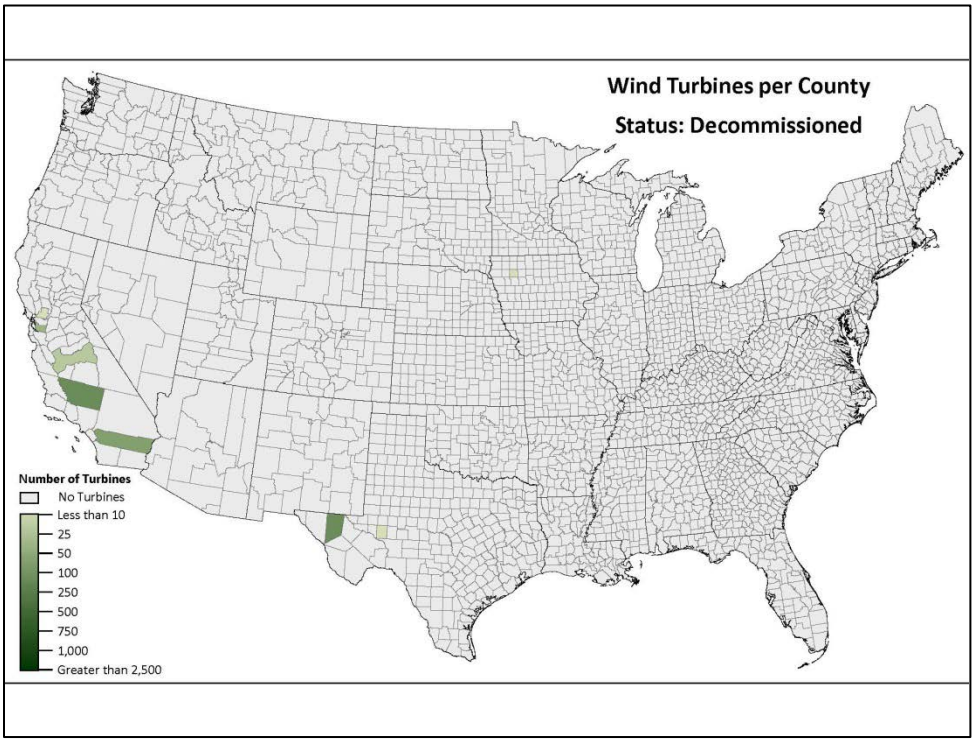
- Micropolitan (micro) areas, which are non-metro labor-market areas centered on urban clusters of 10,000-49,999 people and defined with the same criteria used to define metro areas.
- All remaining counties.

Figure 2. Wind Turbines per County: Online



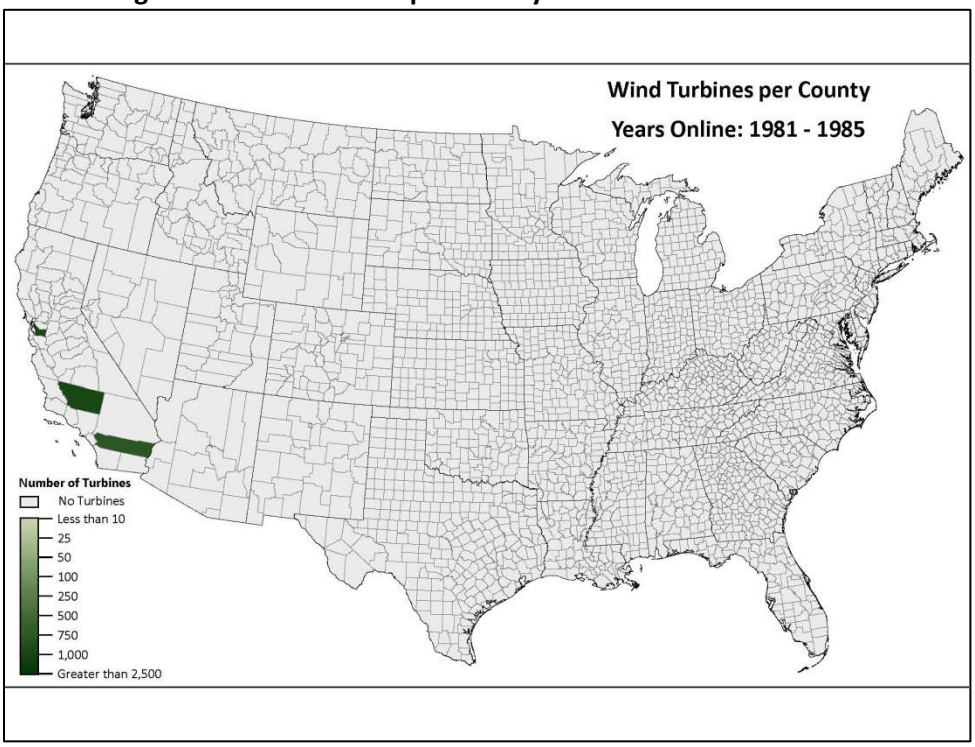
The data are sourced from the American Wind Energy Association Market Database Pro, and the map is prepared by Avery Sandborn in the Spatial Analysis Research Section of the National Agricultural Statistics Service.

Figure 3. Wind Turbines per County: Decommissioned



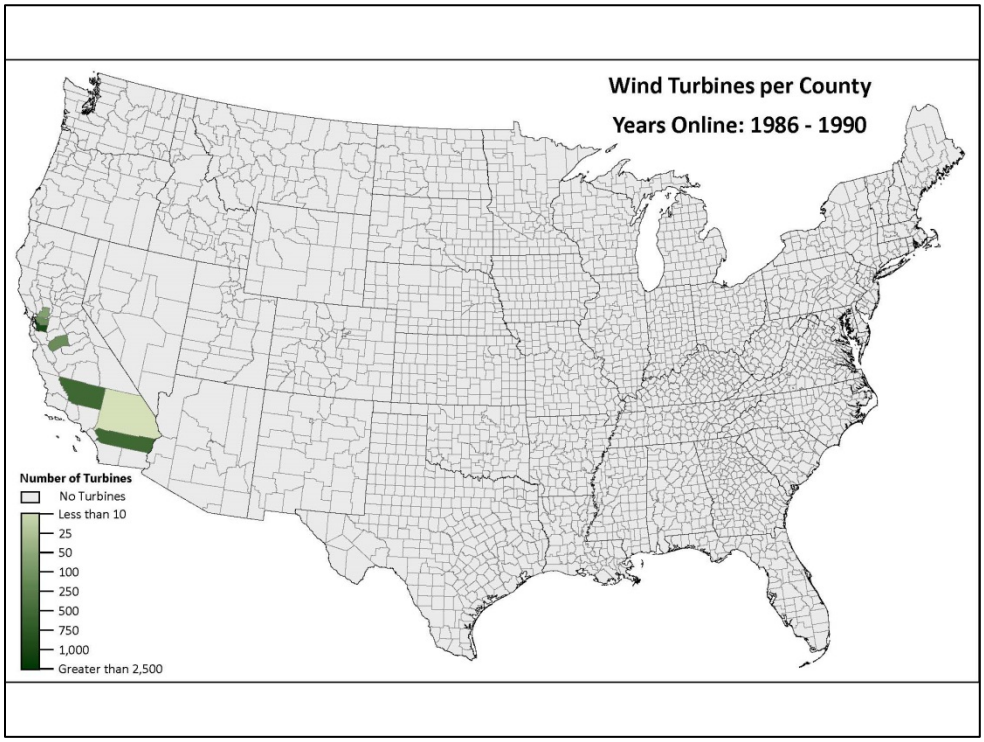
The data are sourced from the American Wind Energy Association Market Database Pro, and the map is prepared by Avery Sandborn in the Spatial Analysis Research Section of the National Agricultural Statistics Service.

Figure 4. Wind Turbines per County: Years Online 1981 - 1985



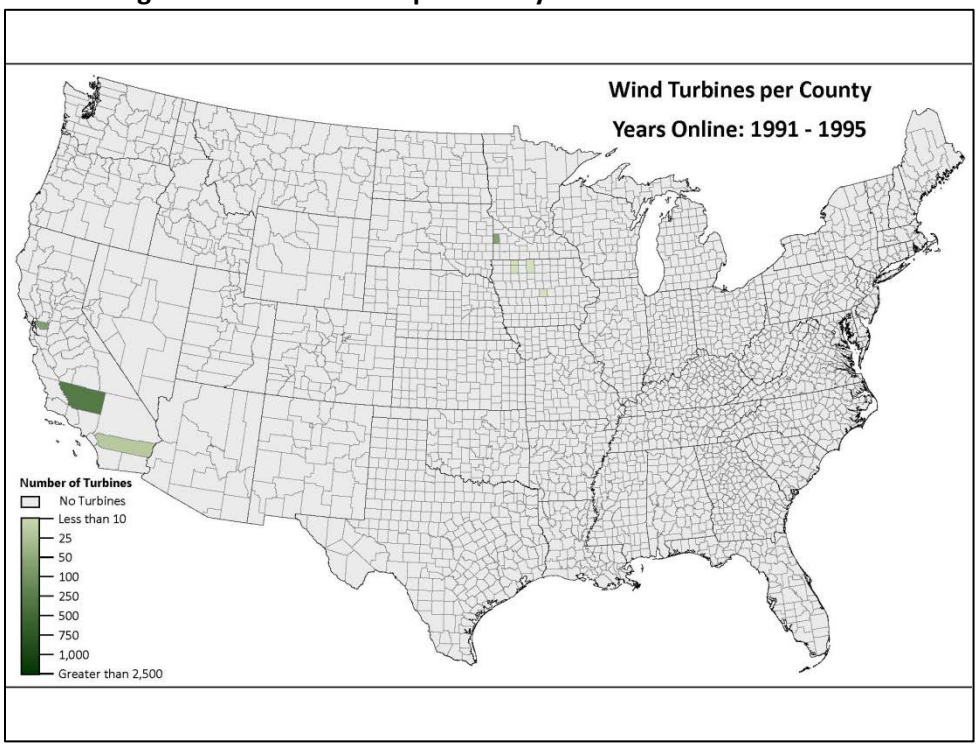
The data are sourced from the American Wind Energy Association Market Database Pro, and the map is prepared by Avery Sandborn in the Spatial Analysis Research Section of the National Agricultural Statistics Service.

Figure 5. Wind Turbines per County: Years Online 1986 - 1990



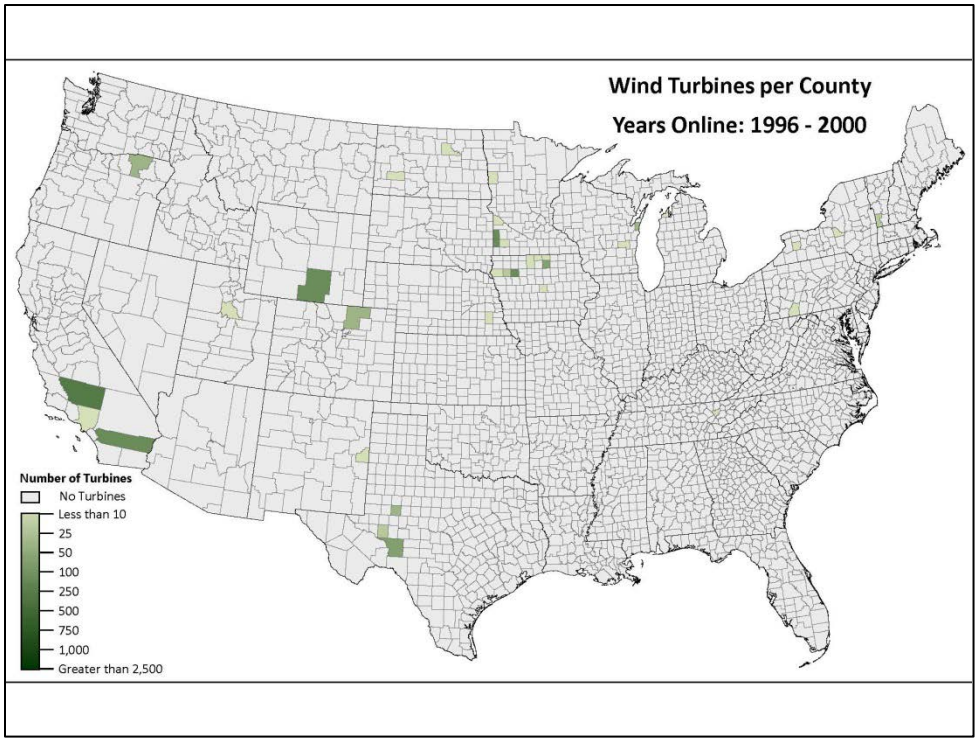
The data are sourced from the American Wind Energy Association Market Database Pro, and the map is prepared by Avery Sandborn in the Spatial Analysis Research Section of the National Agricultural Statistics Service.

Figure 6. Wind Turbines per County: Years Online 1991 - 1995



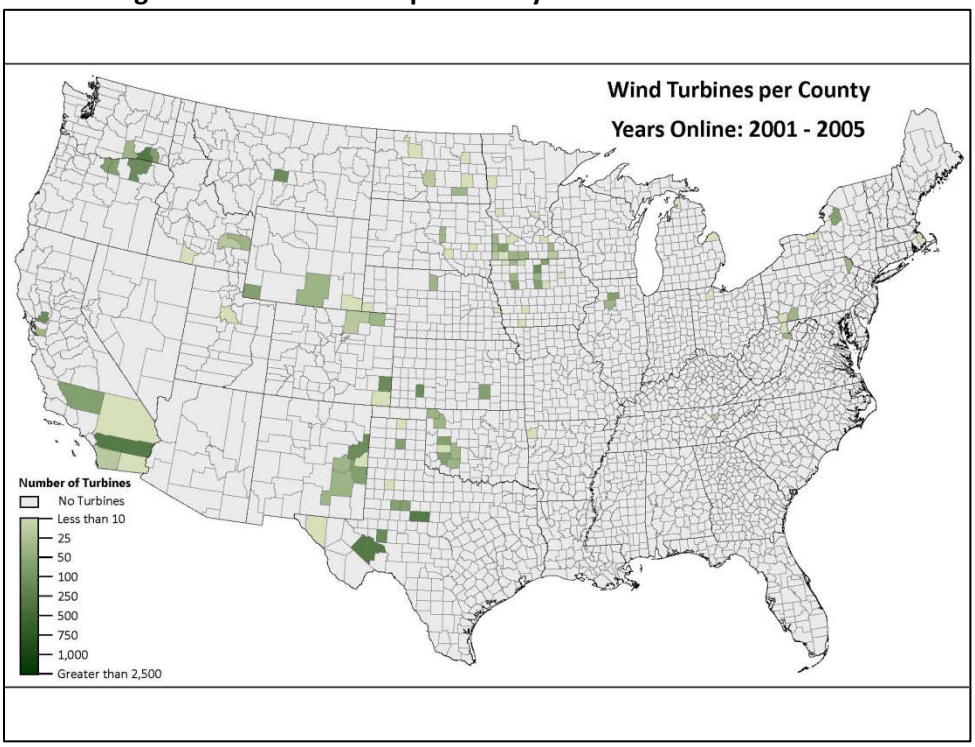
The data are sourced from the American Wind Energy Association Market Database Pro, and the map is prepared by Avery Sandborn in the Spatial Analysis Research Section of the National Agricultural Statistics Service.

Figure 7. Wind Turbines per County: Years Online 1996 - 2000



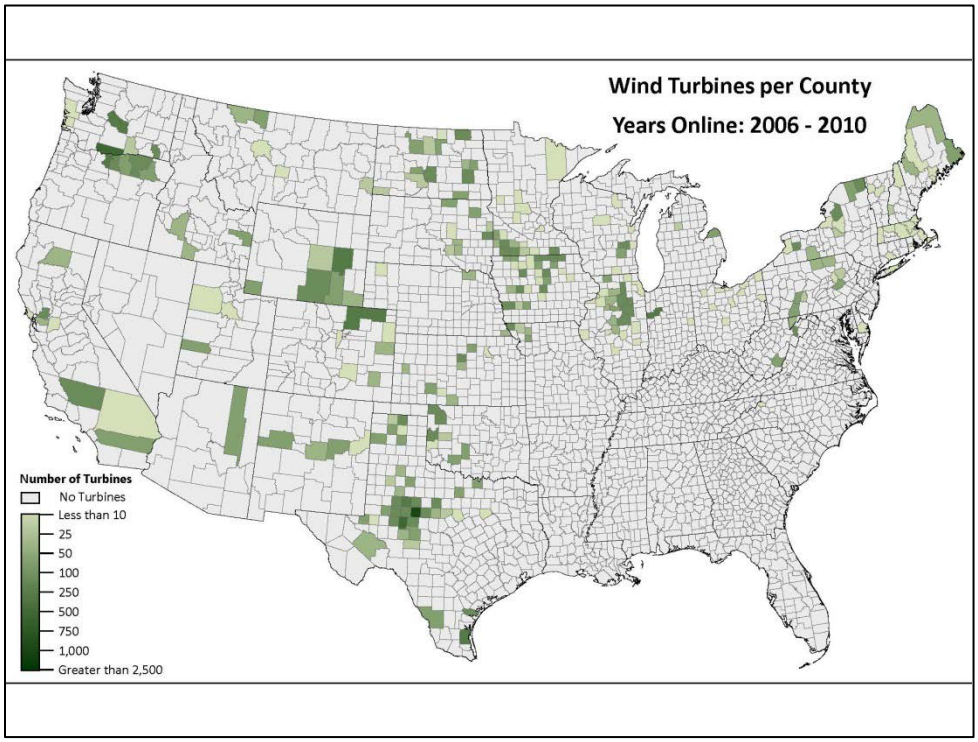
The data are sourced from the American Wind Energy Association Market Database Pro, and the map is prepared by Avery Sandborn in the Spatial Analysis Research Section of the National Agricultural Statistics Service.

Figure 8. Wind Turbines per County: Years Online 2001 - 2005



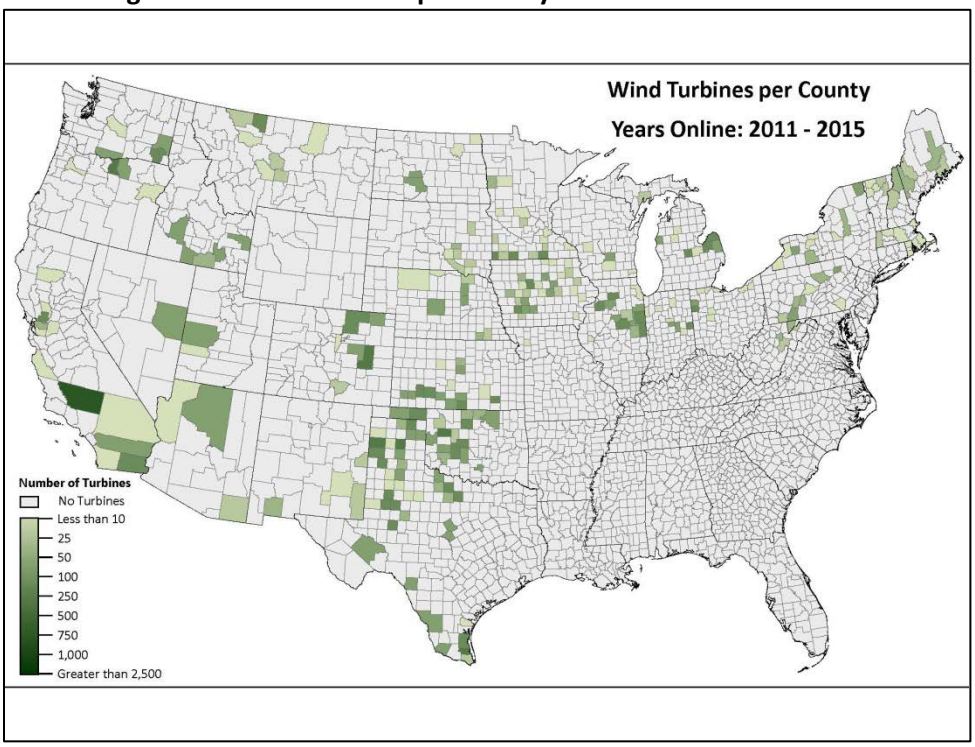
The data are sourced from the American Wind Energy Association Market Database Pro, and the map is prepared by Avery Sandborn in the Spatial Analysis Research Section of the National Agricultural Statistics Service.

Figure 9. Wind Turbines per County: Years Online 2006 - 2010



The data are sourced from the American Wind Energy Association Market Database Pro, and the map is prepared by Avery Sandborn in the Spatial Analysis Research Section of the National Agricultural Statistics Service.

Figure 10. Wind Turbines per County: Years Online 2011 - 2015



The data are sourced from the American Wind Energy Association Market Database Pro, and the map is prepared by Avery Sandborn in the Spatial Analysis Research Section of the National Agricultural Statistics Service.

Land Cover Wind Turbine Distribution

According to the 2014 CDL, the majority of all online turbines are located in rangeland (over 50%), followed by cropland (about 39%). On rangeland, online turbines are evenly divided between shrubland and grass/pastureland[3]. However, over 90% of decommissioned turbines are on rangeland, most of it scrubland (Table 1). For cropland, online turbines are mostly located in corn, soybean, and winter wheat fields in the respective order. 3.65% of online turbines are on fallow/idle cropland, and just 1.83% are on barren land. Deciduous forest accounts for 3.50% of turbine land cover[4].

Turbine installations on developed land are characteristically low[5], showcasing the important role of farm and rangeland in wind-energy development. The only turbine owner types with substantial installations on developed land are industrial, commercial, and government. These types also have more installations on forest land. However, they represent only 0.50% of total wind turbines. Most wind turbines (almost 88%) are owned by independent power producers (IPP) that generate electricity for sale to utilities and end users, followed by 12% owned by utilities. While 58% of IPP-owned turbines are on rangeland, 67% of utility-owned turbines are on cropland (Table 2). Similarly based on power purchasing type, industrial purchasers are supplied more heavily by wind turbines on developed land,

[3] Rangeland contains shrubland, grass, and pasture.
[4] Forest consists of deciduous, evergreen, and mixed forest.
[5] Developed land cover contains low-, medium-, and high-intensity developed land and developed open space.

and commercial purchasers are associated with more installations on forest and developed land. Turbines supplying the open market and utilities represent over 90% of the market and follow the online distribution closely (Table 3).

Table 1. Wind Turbine Distribution by Land Cover Type: Online and Decommissioned

Land Cover Type	Status: Online Based on 2014 CDL		Status: Decommissioned Based on 2014 CDL	
Total	**Number**	**Percent**	**Number**	**Percent**
All Land Cover	49,048	100.00%	406	100.00%
General Categories	**Number**	**Percent**	**Number**	**Percent**
Cropland	19,192	39.13%	16	3.94%
Rangeland	26,547	54.12%	372	91.63%
Forest	1,960	4.00%	1	0.25%
Wetland	117	0.24%	0	--
Barren	892	1.82%	12	2.96%
Open Water	2	0.00%	0	--
Developed	338	0.69%	5	1.23%
Detailed Categories	**Number**	**Percent**	**Number**	**Percent**
Corn	5,855	11.94%	1	0.25%
Cotton	1,319	2.69%	0	--
Sorghum	575	1.17%	0	--
Soybeans	4,570	9.32%	0	--
Spring Wheat	415	0.85%	0	--
Winter Wheat	2,977	6.07%	0	--
Alfalfa	390	0.80%	13	3.20%
Other Hay/Non-Alfalfa	331	0.67%	0	--
Fallow/Idle Cropland	1,788	3.65%	0	--
Developed/Open Space	223	0.45%	5	1.23%
Developed/Low Intensity	54	0.11%	0	--
Developed/Med Intensity	46	0.09%	0	--
Developed/High Intensity	15	0.03%	0	--
Barren	892	1.82%	12	2.96%
Deciduous Forest	1,728	3.52%	0	--
Evergreen Forest	181	0.37%	1	0.25%
Mixed Forest	51	0.10%	0	--
Shrubland	12,498	25.48%	326	80.30%
Grass/Pasture	14,049	28.64%	46	11.33%
Triticale	46	0.09%	2	0.49%

Note: Selected land cover categories presented may not add up to 100%.

Table 2. Wind Turbine Distribution by Land Cover Type: Owner Type

Land Cover Type	Total		Commercial		Government		Industrial		IPP		Utility	
Total	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
All Land Cover	49,454	100.00%	184	0.37%	48	0.10%	15	0.03%	43,314	87.58%	5,687	11.50%
General Cateogries	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Cropland	19,208	38.84%	73	39.67%	8	16.67%	0	--	15,215	35.13%	3,825	67.26%
Rangeland	26,919	54.43%	38	20.65%	17	35.42%	11	73.33%	24,956	57.62%	1,785	31.39%
Forest	1,961	3.97%	19	10.33%	9	18.75%	1	6.67%	1,867	4.31%	62	1.09%
Wetland	117	0.24%	5	2.72%	2	4.17%	0	--	104	0.24%	6	0.11%
Barren	904	1.83%	4	2.17%	1	2.08%	0	--	897	2.07%	1	0.02%
Open Water	2	0.00%	1	0.54%	0	--	0	--	1	0.00%	0	--
Developed	343	0.69%	44	23.91%	11	22.92%	3	20.00%	274	0.63%	8	0.14%

Note: Selected land cover categories presented may not add up to 100%.

Table 3. Wind Turbine Distribution by Land Cover Type: Power Purchaser Type

Land Cover Type	Total		Commercial		Industrial		Open Market		Utility	
Total	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
All Land Cover	49,454	100.00%	374	0.76%	58	0.12%	6,982	14.12%	38,745	78.35%
General Categories	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Cropland	19,208	38.84%	72	19.25%	19	32.76%	2,616	37.47%	14,689	37.91%
Rangeland	26,919	54.43%	154	41.18%	26	44.83%	3,418	48.95%	22,023	56.84%
Forest	1,961	3.97%	69	18.45%	1	1.72%	850	12.17%	905	2.34%
Wetland	117	0.24%	6	1.60%	0	--	5	0.07%	105	0.27%
Barren	904	1.83%	28	7.49%	0	--	40	0.57%	820	2.12%
Open Water	2	0.00%	1	0.27%	0	--	0	--	1	0.00%
Developed	343	0.69%	44	11.76%	12	20.69%	53	0.76%	202	0.52%

Note: Selected land cover categories presented may not add up to 100%.

Turbines commissioned over the past decade show a shift from being built in rangeland to being built in cropland (in the 1980s, over 90% of turbines were built in rangeland, whereas in the last five years, less than 40% were built in rangeland) (Tables 4-6)[6]. While there are more turbines on rangeland than cropland, MW-capacity allocation is equally divided (Table 7). By extrapolation, the average capacity is lower in rangeland compared with cropland (1.2 MW vs. 1.7 MW). After 1990, capacity additions to cropland gradually increased. By 2006, additions to cropland caught up to additions to rangeland, and after 2010, MW additions to cropland surpassed additions to rangeland. While in the 1990s, the average capacity additions were higher in cropland, after 2000, they were proportionate between cropland and rangeland but higher in forest land and, after 2005, on barren land (Tables 8-10).

[6] 924 turbines that contained no data for the years-online attribute were excluded from the time-series portion of the analysis.

Table 4. Wind Turbine Distribution by Land Cover Type: 1981 - 1990

Land Cover Type	Online: 1981 - 1985 Based on 2008 CDL		Online: 1986 - 1990 Based on 2008 CDL	
Total	**Number**	**Percent**	**Number**	**Percent**
All Land Cover	3,989	100.00%	3,047	100.00%
General Categories	**Number**	**Percent**	**Number**	**Percent**
Cropland	1	0.03%	20	0.66%
Rangeland	3,618	90.70%	2,846	93.40%
Forest	5	0.13%	0	--
Wetland	0	--	0	--
Barren	365	9.15%	167	5.48%
Open Water	0	--	0	--
Developed	0	--	14	0.46%
Detailed Categories	**Number**	**Percent**	**Number**	**Percent**
Corn	0	--	0	--
Cotton	0	--	0	--
Sorghum	0	--	0	--
Soybeans	0	--	0	--
Spring Wheat	0	--	0	--
Winter Wheat	1	0.03%	20	0.66%
Alfalfa	0	--	0	--
Fallow/Idle Cropland	0	--	0	--
Developed/Open Space	0	--	14	0.46%
Developed/Low Intensity	0	--	0	--
Developed/Med Intensity	0	--	0	--
Developed/High Intensity	0	--	0	--
Barren	365	9.15%	167	5.48%
Deciduous Forest	0	--	0	--
Evergreen Forest	4	0.10%	0	--
Mixed Forest	1	0.03%	0	--
Shrubland	1,725	43.24%	929	30.49%
Grass/Pasture	1,893	47.46%	1,917	62.91%
Triticale	0	--	0	--

Note: Selected land cover categories presented may not add up to 100%.

Table 5. Wind Turbine Distribution by Land Cover Type: 1991 - 2000

Land Cover Type	Online: 1991 - 1995 Based on 2008 CDL		Online: 1996 - 2000 Based on 2008 CDL	
Total	**Number**	**Percent**	**Number**	**Percent**
All Land Cover	1,144	100.00%	1,680	100.00%1
General Categories	**Number**	**Percent**	**Number**	**Percent**
Cropland	60	5.24%	590	35.12%
Rangeland	1,062	92.83%	1,024	60.95%
Forest	0	--	15	0.89%
Wetland	0	--	0	--
Barren	20	1.75%	46	2.74%
Open Water	0	--	0	--
Developed	2	0.17%	5	0.30%
Detailed Categories	**Number**	**Percent**	**Number**	**Percent**
Corn	47	4.11%	247	14.70%
Cotton	0	--	0	--
Sorghum	0	--	0	--
Soybeans	7	0.61%	248	14.76%
Spring Wheat	3	0.26%	19	1.13%
Winter Wheat	2	0.17%	4	0.24%
Alfalfa	0	--	29	1.73%
Fallow/Idle Cropland	0	--	27	1.61%
Developed/Open Space	2	0.17%	3	0.18%
Developed/Low Intensity	0	--	2	0.12%
Developed/Med Intensity	0	--	0	--
Developed/High Intensity	0	--	0	--
Barren	20	1.75%	46	2.74%
Deciduous Forest	0	--	8	0.48%
Evergreen Forest	0	--	4	0.24%
Mixed Forest	0	--	3	0.18%
Shrubland	360	31.47%	740	44.05%
Grass/Pasture	702	61.36%	284	16.90%
Triticale	0	--	0	--

Note: Selected land cover categories presented may not add up to 100%.

Table 6. Wind Turbine Distribution by Land Cover Type: 2001 - 2015

Land Cover Type	Online: 2001 - 2005 Based on 2008 CDL		Online: 2006 - 2010 Based on 2010 CDL		Online: 2011 - 2015 Based on 2014 CDL	
Total	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
All Land Cover	5,443	100.00%	18,386	100.00%	14,841	100.00%
General Categories	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Cropland	1,789	32.87%	8,565	46.58%	7,872	53.04%
Rangeland	3,366	61.84%	8,573	46.63%	5,902	39.77%
Forest	261	4.80%	1,017	5.53%	816	5.50%
Wetland	0	--	30	0.16%	8	0.05%
Barren	16	0.29%	156	0.85%	184	1.24%
Open Water	0	--	1	0.01%	0	--
Developed	10	0.18%	43	0.23%	59	0.40%
Detailed Categories	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Corn	595	10.93%	2,997	16.30%	1,927	12.98%
Cotton	1	0.02%	694	3.77%	512	3.45%
Sorghum	57	1.05%	173	0.94%	348	2.34%
Soybeans	361	6.63%	2,317	12.60%	1,566	10.55%
Spring Wheat	48	0.88%	290	1.58%	141	0.95%
Winter Wheat	470	8.63%	956	5.20%	1,674	11.28%
Rye	0	--	21	0.11%	83	0.56%
Alfalfa	10	0.18%	143	0.78%	104	0.70%
Other Hay/Non-Alfalfa	42	0.77%	171	0.93%	120	0.81%
Sugarbeets	0	--	11	0.06%	97	0.65%
Dry Beans	0	--	36	0.20%	182	1.23%
Fallow/Idle Cropland	189	3.47%	608	3.31%	889	5.99%
Developed/Open Space	6	0.11%	14	0.08%	24	0.16%
Developed/Low Intensity	3	0.06%	10	0.05%	14	0.09%
Developed/Med Intensity	1	0.02%	12	0.07%	13	0.09%
Developed/High Intensity	0	--	7	0.04%	8	0.05%
Barren	16	0.29%	156	0.85%	184	1.24%
Deciduous Forest	164	3.01%	868	4.72%	689	4.64%
Evergreen Forest	97	1.78%	101	0.55%	90	0.61%
Mixed Forest	0	--	48	0.26%	37	0.25%
Shrubland	2,075	38.12%	4,089	22.24%	1,936	13.04%
Grass/Pasture	1,291	23.72%	4,484	24.39%	3,966	26.72%
Triticale	0	--	1	0.01%	6	0.04%

Note: Selected land cover categories presented may not add up to 100%.

Table 7. Wind Turbine Distribution by Land Cover Type: MW Capacity

Land Cover Type	All Turbines Based on 2014 CDL			
Total	**Number**	**Average**	**Sum**	**Percent**
All Land Cover	49,454	1.40	69,074	100.00%
General Categories	**Number**	**Average**	**Sum**	**Percent**
Cropland	19,208	1.68	32,210	46.63%
Rangeland	26,919	1.19	31,906	46.19%
Forest	1,961	1.85	3,626	5.25%
Wetland	117	0.47	55	0.08%
Barren	904	0.80	723	1.05%
Open Water	2	1.30	3	0.00%
Developed	343	1.61	552	0.80%
Detailed Categories	**Number**	**Average**	**Sum**	**Percent**
Corn	5,856	1.62	9,487	13.73%
Cotton	1,319	1.63	2,152	3.12%
Sorghum	575	1.89	1,089	1.58%
Soybeans	4,570	1.65	7,562	10.95%
Spring Wheat	415	1.84	765	1.11%
Winter Wheat	2,977	1.77	5,258	7.61%
Alfalfa	403	1.56	629	0.91%
Other Hay/Non-Alfalfa	331	1.81	599	0.87%
Fallow/Idle Cropland	1,788	1.69	3,017	4.37%
Developed/Open Space	228	1.58	361	0.52%
Developed/Low Intensity	54	1.74	94	0.14%
Developed/Med Intensity	46	1.76	81	0.12%
Developed/High Intensity	15	1.07	16	0.02%
Barren	904	0.80	723	1.05%
Deciduous Forest	1,728	1.83	3,160	4.57%
Evergreen Forest	182	2.01	365	0.53%
Mixed Forest	51	1.99	101	0.15%
Shrubland	12,824	1.21	15,466	22.39%
Grass/Pasture	14,095	1.17	16,441	23.80%
Triticale	48	1.83	88	0.13%

Note: Selected land cover categories presented may not add up to 100%.

Table 8. Wind Turbine Distribution by Land Cover Type: MW Capacity, 1981 - 1990

Land Cover Type	Years Online: 1981 - 1985 Based on 2008 CDL				Years Online: 1986 - 1990 Based on 2008 CDL			
Total	**Number**	**Average**	**Sum**	**Percent**	**Number**	**Average**	**Sum**	**Percent**
All Land Cover	3,989	0.09	360.38	8.07%	3,047	0.12	372.12	6.16%
General Categories	**Number**	**Average**	**Sum**	**Percent**	**Number**	**Average**	**Sum**	**Percent**
Cropland	1	0.07	0.07	0.02%	20	0.10	2.00	0.54%
Rangeland	3,618	0.09	320.08	88.82%	2,846	0.12	350.31	94.14%
Forest	5	0.09	0.43	0.12%	0	--	--	--
Wetland	0	--	--	--	0	--	--	--
Barren	365	0.11	39.81	11.05%	167	0.10	17.52	4.71%
Open Water	0	--	--	--	0	--	--	--
Developed	0	--	--	--	14	0.16	2.28	0.61%
Detailed Categories	**Number**	**Average**	**Sum**	**Percent**	**Number**	**Average**	**Sum**	**Percent**
Corn	0	--	--	--	0	--	--	--
Cotton	0	--	--	--	0	--	--	--
Sorghum	0	--	--	--	0	--	--	--
Soybeans	0	--	--	--	0	--	--	--
Spring Wheat	0	--	--	--	0	--	--	--
Winter Wheat	1	0.07	0.07	0.02%	20	0.10	2.00	0.54%
Alfalfa	0	--	--	--	0	--	--	--
Other Hay/Non-Alfalfa	0	--	--	--	0	--	--	--
Fallow/Idle Cropland	0	--	--	--	0	--	--	--
Developed/Open Space	0	--	--	--	14	0.16	2.28	0.61%
Developed/Low Intensity	0	--	--	--	0	--	--	--
Developed/Med Intensity	0	--	--	--	0	--	--	--
Developed/High Intensity	0	--	--	--	0	--	--	--
Barren	365	0.11	39.82	11.05%	167	0.10	17.52	4.71%
Deciduous Forest	0	--	--	--	0	--	--	--
Evergreen Forest	4	0.09	0.36	0.10%	0	--	--	--
Mixed Forest	1	0.07	0.07	0.02%	0	--	--	--
Shrubland	1,725	0.09	151.21	41.96%	929	0.17	155.73	41.85%
Grass/Pasture	1,893	0.09	168.87	46.86%	1,917	0.10	194.58	52.29%
Triticale	0	--	--	--	0	--	--	--

Note: Selected land cover categories presented may not add up to 100%.

Table 9. Wind Turbine Distribution by Land Cover Type: MW Capacity, 1991 - 2000

Land Cover Type	Years Online: 1991 - 1995 Based on 2008 CDL				Years Online: 1996 – 2000 Based on 2008 CDL			
Total	**Number**	**Average**	**Sum**	**Percent**	**Number**	**Average**	**Sum**	**Percent**
All Land Cover	1,144	0.17	192.34	2.31%	1,680	0.63	1,052.01	3.40%
General Categories	**Number**	**Average**	**Sum**	**Percent**	**Number**	**Average**	**Sum**	**Percent**
Cropland	60	0.35	21.04	10.94%	590	0.75	441.42	41.96%
Rangeland	1,062	0.15	160.97	83.69%	1,024	0.55	566.15	53.82%
Forest	0	--	--	--	15	0.71	10.67	1.01%
Wetland	0	--	--	--	0	--	--	--
Barren	20	0.50	10.00	5.20%	46	0.70	32.20	3.06%
Open Water	0	--	--	--	0	--	--	--
Developed	2	0.16	0.33	0.17%	5	0.32	1.58	0.15%
Detailed Categories	**Number**	**Average**	**Sum**	**Percent**	**Number**	**Average**	**Sum**	**Percent**
Corn	47	0.35	16.36	8.51%	247	0.75	185.85	17.67%
Cotton	0	--	--	--	0	--	--	--
Sorghum	0	--	--	--	0	--	--	--
Soybeans	7	0.36	2.52	1.31%	248	0.74	183.12	17.41%
Spring Wheat	3	0.36	1.08	0.56%	19	0.72	13.62	1.29%
Winter Wheat	2	0.36	0.72	0.37%	4	0.71	2.82	0.27%
Alfalfa	0	--	--	--	29	0.68	19.83	1.88%
Other Hay/Non-Alfalfa	0	--	--	--	15	1.14	17.06	1.62%
Fallow/Idle Cropland	0	--	--	--	27	0.68	18.46	1.75%
Developed/Open Space	2	0.16	0.33	0.17%	3	0.37	1.10	0.10%
Developed/Low Intensity	0	--	--	--	2	0.24	0.48	0.05%
Developed/Med Intensity	0	--	--	--	0	--	--	--
Developed/High Intensity	0	--	--	--	0	--	--	--
Barren	20	0.50	10.00	5.20%	46	0.70	32.20	3.06%
Deciduous Forest	0	--	--	--	8	0.85	6.82	0.65%
Evergreen Forest	0	--	--	--	4	0.55	2.20	0.21%
Mixed Forest	0	--	--	--	3	0.55	1.65	0.16%
Shrubland	360	0.24	85.73	44.57%	740	0.50	366.63	34.85%
Grass/Pasture	702	0.11	75.25	39.12%	284	0.70	199.52	18.97%
Triticale	0	--	--	--	0	--	--	--

Note: Selected land cover categories presented may not add up to 100%.

Table 10. Wind Turbine Distribution by Land Cover Type: MW Capacity, 2001 - 2015

Land Cover Type	Years Online: 2001 - 2005 Based on 2008 CDL				Years Online: 2006 - 2010 Based on 2010 CDL				Years Online: 2011 - 2015 Based on 2014 CDL			
Total	**Number**	**Average**	**Sum**	**Percent**	**Number**	**Average**	**Sum**	**Percent**	**Number**	**Average**	**Sum**	**Percent**
All Land Cover	5,448	1.19	6,456	11.02%	18,386	1.70	31,218	37.18%	14,841	1.94	28,847	30.01%
General Categories	**Number**	**Average**	**Sum**	**Percent**	**Number**	**Average**	**Sum**	**Percent**	**Number**	**Average**	**Sum**	**Percent**
Cropland	1,789	1.13	2,028	31.42%	8,565	1.67	14,342	45.94%	7,872	1.90	14,946	51.81%
Rangeland	3,366	1.18	3,987	61.77%	8,573	1.71	14,638	46.89%	5,902	1.99	11,737	40.69%
Forest	261	1.58	413	6.39%	1,017	1.79	1,820	5.83%	816	2.08	1,697	5.88%
Wetland	0	--	--	--	30	1.73	52	0.17%	8	2.16	17	0.06%
Barren	16	0.68	11	0.17%	156	2.11	330	1.06%	184	2.02	371	1.29%
Open Water	0	--	--	--	1	0.10	0	0.00%	0	--	--	--
Developed	10	0.87	9	0.14%	43	0.83	35	0.11%	59	1.33	79	0.27%
Detailed Categories	**Number**	**Average**	**Sum**	**Percent**	**Number**	**Average**	**Sum**	**Percent**	**Number**	**Average**	**Sum**	**Percent**
Corn	595	1.16	689	10.67%	2,997	1.67	5,018	16.07%	1,927	1.84	3,551	12.31%
Cotton	1	1.00	1	0.02%	694	1.45	1,004	3.22%	512	1.94	996	3.45%
Sorghum	57	0.75	43	0.67%	173	1.91	330	1.06%	348	2.03	705	2.44%
Soybeans	361	1.22	441	6.83%	2,317	1.68	3,894	12.47%	1,566	1.87	2,924	10.14%
Spring Wheat	48	1.36	65	1.01%	290	1.58	459	1.47%	141	2.34	330	1.14%
Winter Wheat	470	1.09	512	7.93%	956	1.72	1,645	5.27%	1,674	1.91	3,203	11.11%
Alfalfa	10	1.54	15	0.24%	143	1.67	239	0.76%	104	1.90	197	0.68%
Other Hay/Non-Alfalfa	42	1.61	68	1.05%	171	1.63	279	0.89%	120	2.15	258	0.89%
Fallow/Idle Cropland	189	0.89	168	2.61%	608	1.82	1,105	3.54%	889	1.93	1,715	5.94%
Developed/Open Space	6	1.27	8	0.12%	14	1.00	14	0.04%	24	1.48	36	0.12%
Developed/Low Intensity	3	0.34	1	0.02%	10	0.57	6	0.02%	14	1.46	20	0.07%
Developed/Med Intensity	1	0.10	0	0.00%	12	0.75	9	0.03%	13	1.01	13	0.05%
Developed/High Intensity	0	--	--	--	7	0.97	7	0.02%	8	1.19	10	0.03%
Barren	16	0.68	11	0.17%	156	2.11	330	1.06%	184	2.02	371	1.29%
Deciduous Forest	164	1.55	255	3.95%	868	1.75	1,520	4.87%	689	2.04	1,408	4.88%
Evergreen Forest	97	1.63	158	2.44%	101	2.22	224	0.72%	90	2.33	210	0.73%
Mixed Forest	0	--	--	--	48	1.57	76	0.24%	37	2.12	78	0.27%
Shrubland	2,075	1.10	2,273	35.20%	4,089	1.73	7,094	22.72%	1,936	2.16	4,186	14.51%
Grass/Pasture	1,291	1.33	1,715	26.56%	4,484	1.68	7,544	24.17%	3,966	1.90	7,550	26.17%
Triticale	0	--	--	--	1	2.30	2	0.01%	6	2.13	13	0.04%

Note: Selected land cover categories presented may not add up to 100%.

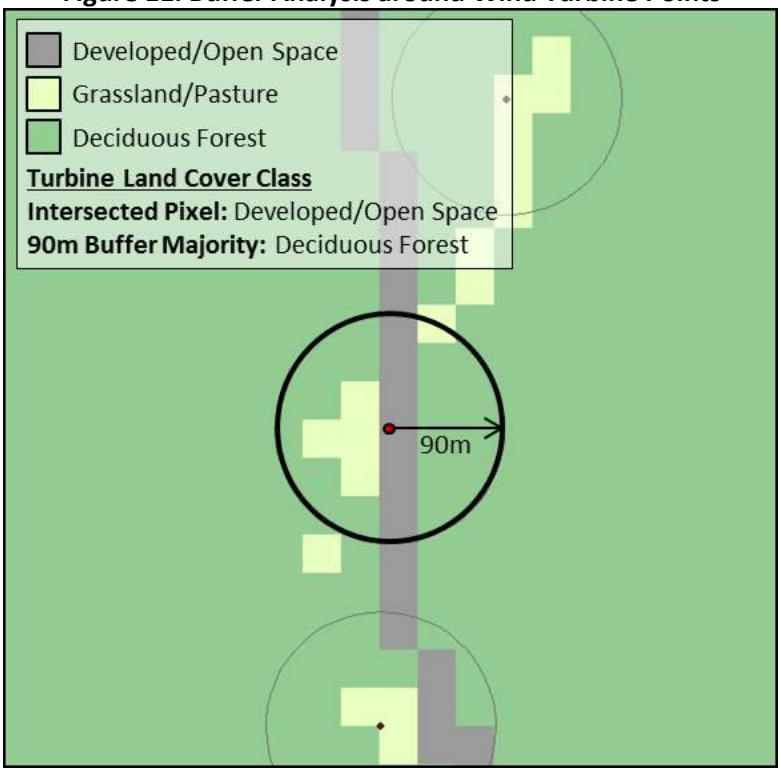
Concluding Remarks

The analysis shows the degree of integration of wind-energy development with rural America and the agricultural sector. Over time, wind development has become more regionally dispersed, yet it remains concentrated in California, the Great Plains, the Pacific Northwest, and the Northeast, specifically in top-producing agricultural states. Rangeland hosted the first wind turbine installations and still hosts the

majority of turbines. Installations on cropland have increased over time—by 2015, cropland hosted almost 40% of turbine installations, and MW capacity was on par with rangeland.

The presented analysis is based on a 90-meter buffer[7] around each wind turbine point because single-pixel analysis could produce misleading interpretations. The buffer zone accounts for single-erroneous-pixel reporting in the land cover classification, as well as for pixels that capture the turbine being on developed land because of land clearing around the installation but that belong to a larger area of land cover. Figure 10 shows that while wind turbines are located on cleared ground and roads provide access to the installation, buffer analysis allows identification of the primary CDL land cover category that characterizes each turbine's location area. Using zonal statistics, the majority CDL land cover within the buffer zone was calculated and then considered the land cover class for that turbine (Figure 10). The buffer analysis provided considerable correction by accounting for surrounding land cover with a significant decrease from the single-pixel analysis in the number of turbines on developed and barren land. The 90-meter buffer analysis led to a decrease in barren land classification, from 2.72% (in the case of single-pixel analysis) to 1.82%, and in developed land classification, from 4.36% (in the case of single-pixel analysis) to 0.69%. As a robustness check, the analysis was also conducted with a 120-meter buffer, but increasing the buffer from 90 meters did not produce significant changes.

Figure 11. Buffer Analysis around Wind Turbine Points



Note: This image shows a turbine located on a pixel classified as developed/open space by the 2014 CDL. However, the majority of pixels in the 90-meter buffer are classified as deciduous forest. The buffer analysis was conducted by Avery Sandborn in the Spatial Analysis Research Section of the National Agricultural Statistics Service.

[7] A 90-meter buffer corresponds to approximately the sum of a typical wind turbine's rotor radius and blade length. This would cover the width of any access roads, which are wide enough for a service truck.

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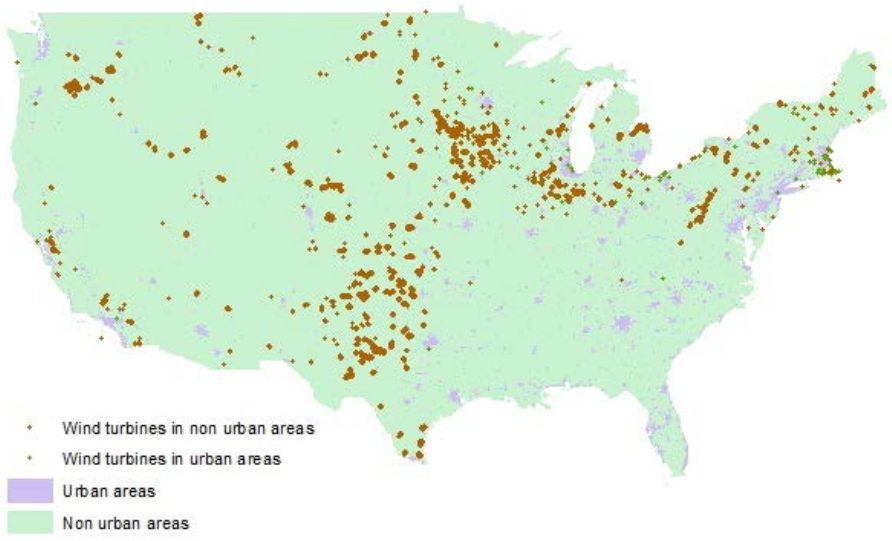
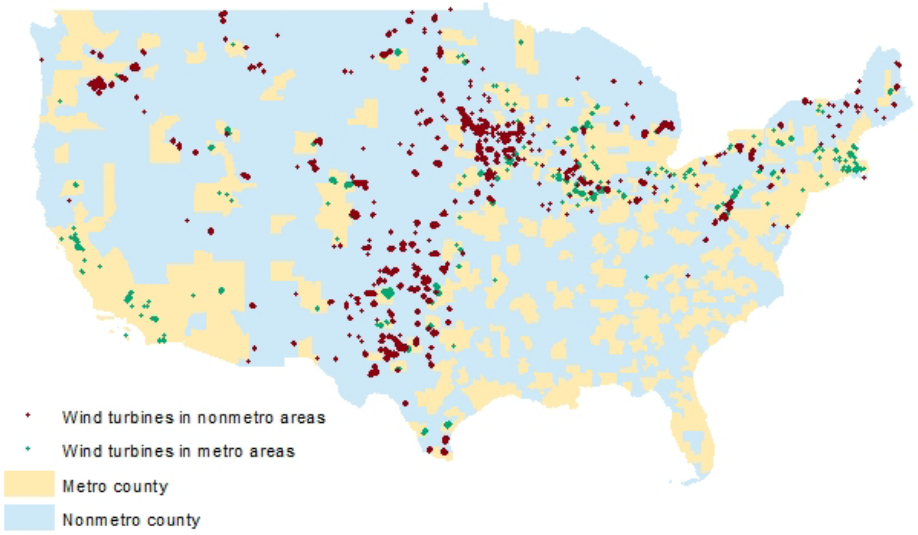
Appendix I

Figure A1. Wind Turbines by Urban Classification



The data is sourced from the American Wind Energy Association Market Database Pro and the U.S. Census Bureau, and the map is prepared by Irene M. Xiarchos in the Office of Energy Policy and New Uses, Office of the Chief Economist in USDA.

Figure A2. Wind Turbines by Metro Classification



The wind data are sourced from the American Wind Energy Association Market Database Pro and the U.S. Census Bureau, and the map is prepared by Irene M. Xiarchos in the Office of Energy Policy and New Uses, Office of the Chief Economist in USDA.