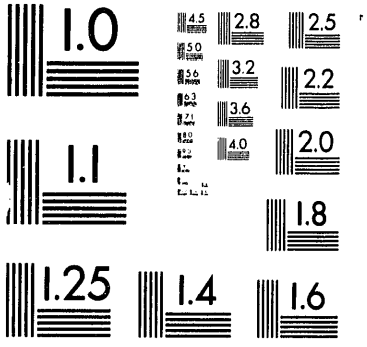
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WIND ENERGY POTENTIAL IN THE UNITED STATES

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WIND ENERGY POTENTIAL IN THE UNITED STATES

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ABSTRACT

Estimates of the electricity that could potentially be generated by wind power and of the land area available for wind energy development have been calculated for the contiguous United States. The estimates are based on published wind resource data and exclude windy lands that are not suitable for development as a result of environmental and land-use considerations. Despite these exclusions, the potential electric power from wind energy is surprisingly large. Good wind areas, which cover 6% of the contiguous U.S. land area, have the potential to supply more than one and a half times the current electricity consumption of the United States. Technology under development today will be capable of producing electricity economically from good wind sites in many regions of the country.

INTRODUCTION

A wind energy resource atlas of the United States [1] shows that areas potentially suitable for wind energy applications are dispersed throughout much of the United States. Estimates of the wind resource in this atlas are expressed in wind power classes ranging from class 1 to class 7, with each class representing a range of mean wind power density or equivalent mean speed at specified heights above the ground (Table 1). Areas designated class 4 or greater are suitable with advanced wind turbine technology under development today. Power class 3 areas may be suitable for future generation technology (year 2000 and beyond). Class 2 areas are marginal and class 1 areas unsuitable for wind energy development. Maps of the areal (percentage of land area) distribution of the wind resource digitized in grid cells of 1/4° latitude by 1/3° longitude (Figures 1 and 2) show that exposed areas with moderate to high wind resource are dispersed throughout much of the contiguous United States.

METHOD OF CALCULATING THE WIND ELECTRIC POTENTIAL

Several factors determine the amount of land area suitable for wind energy development within a particular grid cell in a region of high wind energy potential. The important factors include the percentage of land exposed to the wind resource and land-use and environmental restrictions. The land area exposed to the wind for each grid cell was estimated based on a landform classification and ranged from 90% for relatively flat terrain down to 5% for mountainous terrain. Estimates of land area excluded from wind energy development, in percent per grid cell, were made for various types of land-use (e.g., forest, agricultural, range, and urban lands). Environmental exclusion areas were defined as federal and state lands (including parks, monuments, wilderness areas, wildlife refuges, and other protected areas) where wind energy development would be prohibited or severely restricted. Finally, additional land exclusions were estimated to account for transportation right-of-ways, locally administered park land, privately administered areas, and proposed environmental lands.

The wind electric potential per grid cell was calculated from the available windy land area and the wind power classification assigned to each cell. The amount of potential electricity that can be generated is dependent on several factors, including the spacing between wind turbines, the assumed efficiency of

the machines, the turbine hub height, and the estimated energy losses (caused by wind turbine wakes, blade soiling, etc.). The assumptions used for calculating the wind energy potential per unit of windy land area is given in Table 2. (Estimates of wind turbine efficiency and power losses are based on data from existing turbines. For advanced turbines, efficiency is projected to be 30-35% and power losses 10-15%).

RESULTS

A study in 1991 [2] used a variety of land exclusion scenarios to estimate the available windy land and resultant wind electric potential for several levels of wind resource, both for the contiguous United States as a whole and for each of the 48 contiguous states. Figure 3 shows the overall wind energy potential based on terrain exposure and several land exclusion scenarios. Even under the most restrictive (severe) land exclusion scenario, the wind energy potential for areas with power class 3 and above is greater than total U.S. electricity consumption was in 1990. Figure 4 shows the contribution that the wind energy of each state could make to meet the total electrical needs of the nation, assuming a moderate land exclusion scenario. North Dakota alone has enough potential energy from windy areas of class 4 and higher to supply 36% of the total 1990 electricity consumption of the 48 contiguous states.

A study in 1992 [3] recalculated estimates of windy land area and wind electric potential based on a more accurate mapping of environmental exclusion areas and a moderate land exclusion scenario. These new estimates were about 1 to 2% higher than the preliminary estimates made in 1991 based on the same land exclusion scenario. Overall, even with land being excluded from wind energy development for environmental and land-use considerations, the amount of windy land available and potential electric power from wind energy is surprisingly large. The amount of windy land available for power class 4 and above is approximately 460,000 square kilometers, or about 6.0% of the total land area in the contiguous United States. The potential average power from areas with class 4 and higher, which are suitable for development with advanced wind turbine technology, is estimated at 500,000 MW. If future generation technology is utilized to take advantage of areas with wind resource class 3 and higher, than the amount of windy land available is over 1,000,000 square kilometers, or almost 14% of the land area in the contiguous United States. Moreover, the estimates show that a group of 12 states in the midsection of the country have enough wind energy potential to produce nearly four times the amount of electricity consumed by the nation in 1990.

Although the nation's wind potential is very large, only part of it can be exploited economically. The economic viability of wind power will vary from utility to utility. Important factors not addressed in this study that influence land availability and wind electric potential include production/demand match (seasonal and daily), transmission and access constraints, public acceptance, and other technological and institutional constraints.

To provide 20% of the nation's electricity, only about 0.6% of the land of the lower 48 states would have to be developed with wind turbines. Furthermore, less than 5% of this land would be occupied by wind turbines, electrical equipment, and access roads. Most existing land use, such as farming and ranching, could remain as it is now.

CONCLUSION

The considerable wind electric potential has not been tapped before because the wind turbine technology was not able to utilize this resource. However, during the past decade, increased knowledge of wind turbine behavior has led to more cost-effective wind turbines that are more efficient in producing electricity. The price of the electricity produced from wind by these advanced turbines is estimated to be competitive with conventional sources of power, including fossil fuels. Because of the increasing competitiveness of wind energy, wind resource assessment will become essential in incorporating wind energy into the nation's energy mix. For example, the 1992 study [3] also produced gridded maps of wind electric potential and windy land area for the 48 contiguous states that show the distribution of these features within individual states, thus enabling utilities and wind energy developers to identify promising areas for wind energy. The importance of accurate wind resource assessment is also recognized in other parts of the world.

Detailed wind resource assessments have been proposed or are being considered as part of a plan to increase the use of wind energy in Europe, Asia, Latin America, and other regions. The decreasing cost of wind power and the growing interest in renewable energy sources should ensure that wind power will become a viable energy source in the United States and worldwide.

ACKNOWLEDGMENTS

We wish to thank Gene Gower for his efforts on the development of the computer software for the project. This work was supported by the U.S. Department of Energy (DOE) under Contract DE-AC06-76RLO 1830 at the Pacific Northwest Laboratory, which is operated for DOE by Battelle Memorial Institute.

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TABLE 1: CLASSES OF WIND POWER DENSITY

Wind Power Class	10 m (33 ft)[a]		30 m (98 ft)[a]		50 m (164 ft)[a]	
	Wind Power Density, W/m²	Speed[b], m/s (mph)	Wind Power Density, W/m²	Speed[b], m/s (mph)	Wind Power Density, W/m²	Speed[b], m/s (mph)
1	0	0	0	0	0	0
2	100	4.4 (9.8)	160	5.1 (11.4)	200	5.6 (12.5)
3	150	5.1 (11.5)	240	5.9 (13.2)	300	6.4 (14.3)
4	200	5.6 (12.5)	320	6.5 (14.6)	400	7.0 (15.7)
5	250	6.0 (13.4)	400	7.0 (15.7)	500	7.5 (16.8)
6	300	6.4 (14.3)	480	7.4 (16.6)	600	8.0 (17.9)
7	400	7.0 (15.7)	640	8.2 (18.3)	800	8.8 (19.7)
	1000	9.4 (21.1)	1600	11.0 (24.7)	2000	11.9 (26.6)

[a]Vertical extrapolation of wind power density and wind speed are based on the 1/7 power law.
[b]Mean wind speed is estimated assuming a Rayleigh distribution of wind speeds and standard sea-level air density. The actual mean wind speed may differ from these estimated values by as much as 20%, depending on the actual wind speed distribution and elevation above sea level.

TABLE 2: WIND ENERGY POTENTIAL PER SQUARE KILOMETER OF LAND AREA

Assumptions: 50-m hub height, 10 D x 5 D spacing, 25% efficiency, and 25% power losses

Power Class	Wind Power Density, W/m^2	Average Power Intercepted, MW/km^2	Average Power Output, MW/km^2	Annual Energy Production million kWh/km^2
3	350	5.50	1.03	9.02
4	450	7.07	1.33	11.65
5	550	8.64	1.62	14.19
6	700	11.00	2.06	18.04
7	900	14.14	2.65	23.21

FIGURE 1: PERCENTAGE OF LAND AREA WITH CLASS 4 OR HIGHER WIND RESOURCE

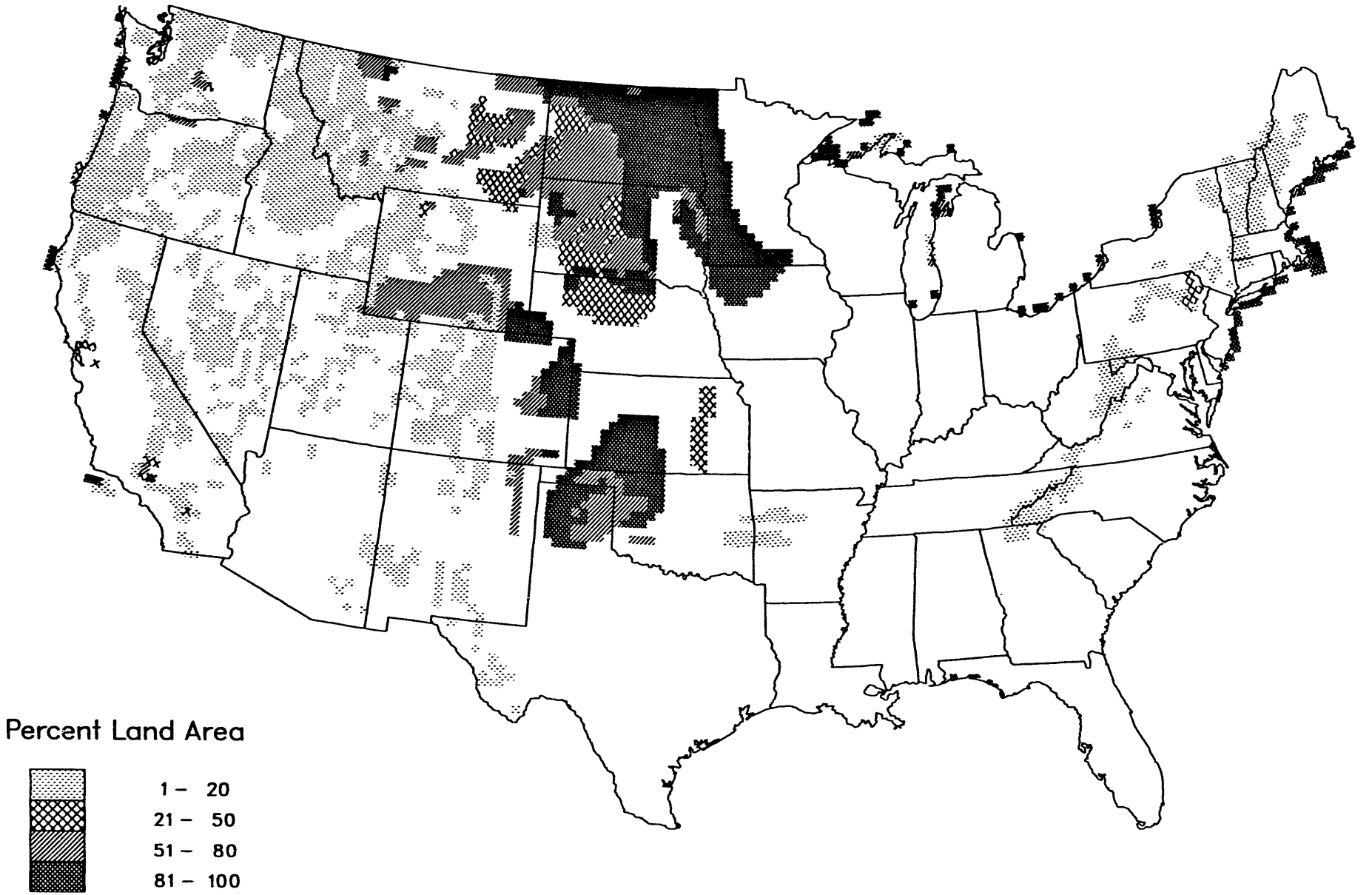


FIGURE 2: PERCENTAGE OF LAND AREA WITH CLASS 3 OR HIGHER WIND RESOURCE

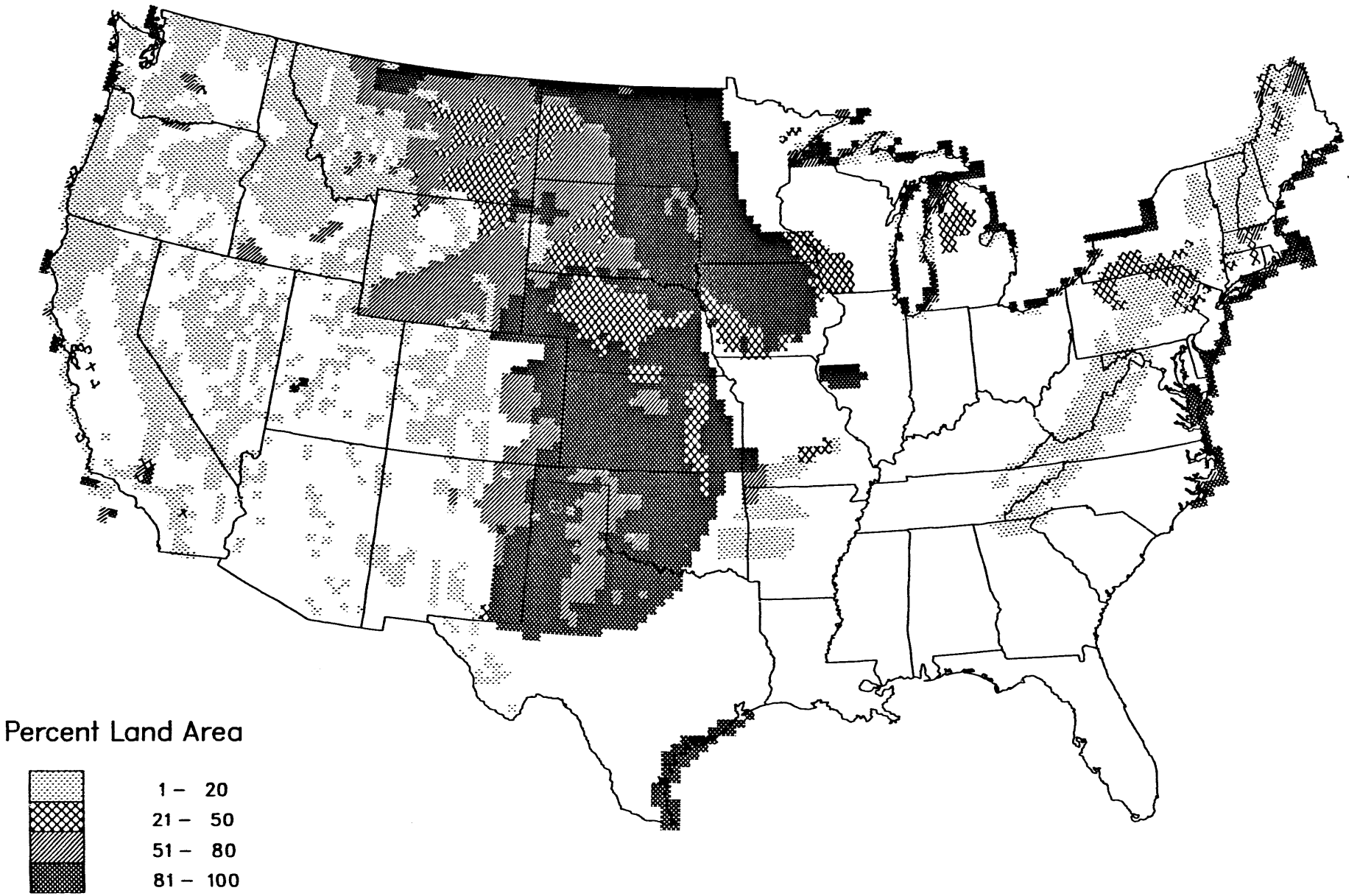


FIGURE 3: WIND ENERGY POTENTIAL OF THE CONTIGUOUS UNITED STATES

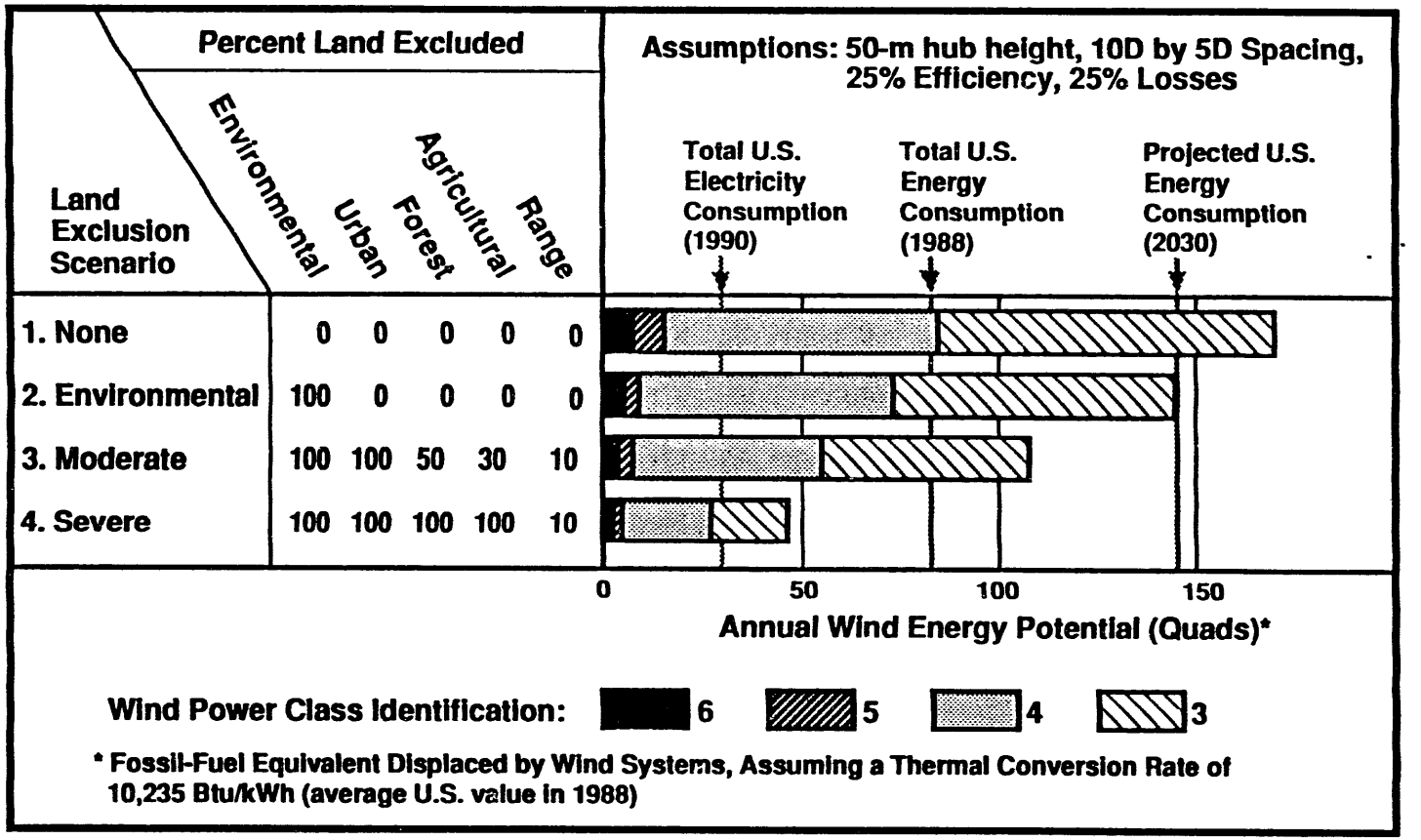
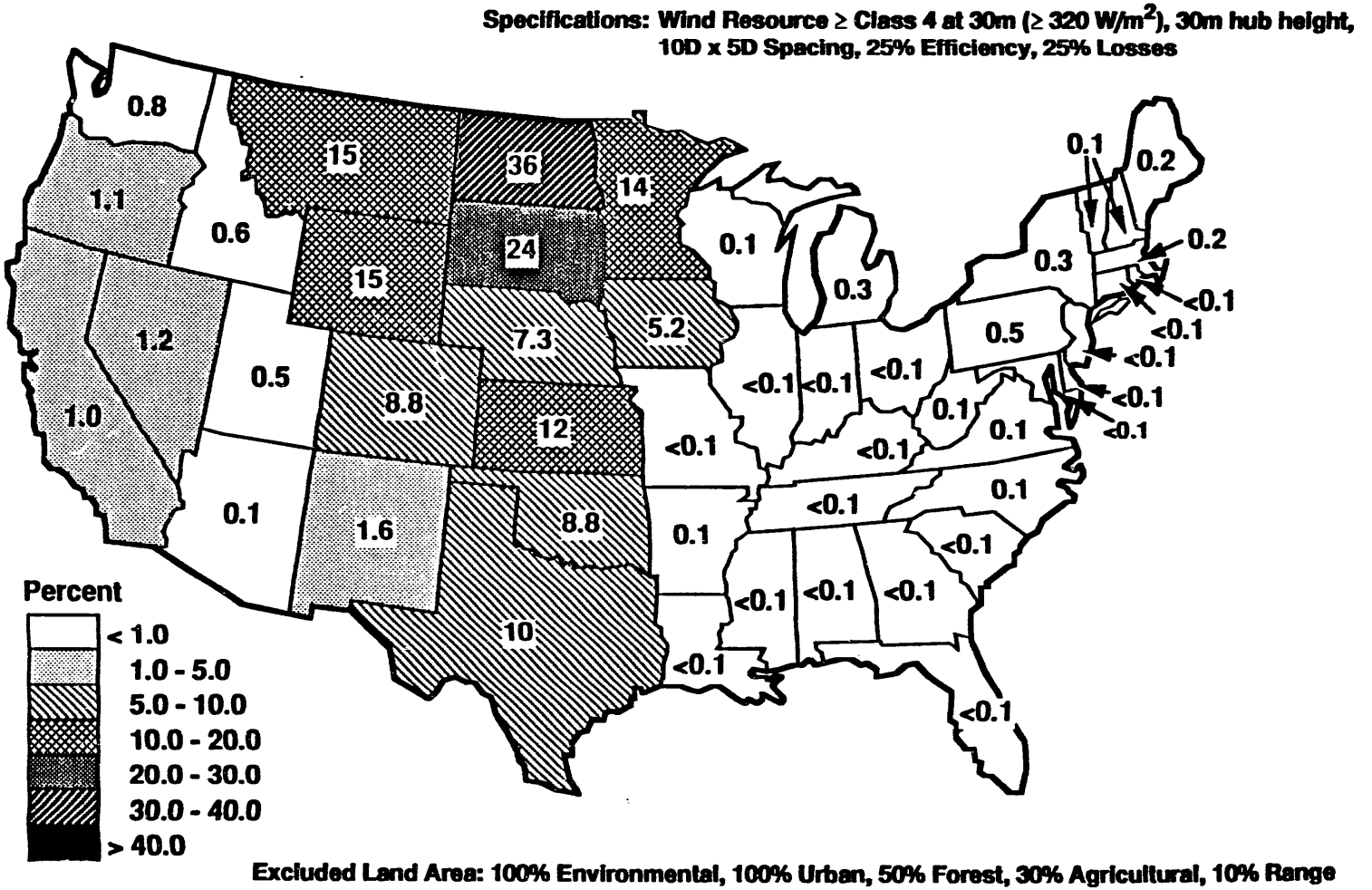


FIGURE 4: PERCENTAGE OF THE TOTAL 1990 ELECTRICITY CONSUMPTION OF THE CONTIGUOUS UNITED STATES THAT EACH STATE COULD PRODUCE (ASSUMPTIONS: AREAS DESIGNATED CLASS 4 AND ABOVE, HUB HEIGHT OF 30 M, MODERATE LAND EXCLUSION SCENARIO)



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