Assessing the Viability of Residential Wind Energy in Michigan and the United States

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Program in the Environment Honors Thesis

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Abstract

This study aims to investigate the economic viability of residential wind energy in Michigan and in the United States. In the Michigan analysis, the study examines the cost effectiveness of residential wind turbines in three counties - Leelanau, Huron, and Oakland. The national analysis uses electricity price information for each state along with wind data information to display cost-effective areas for residential wind. The dependent variable is how many years of energy savings from wind turbine usage will it take to pay off the cost of purchasing and maintaining the wind turbine. The independent variables tested are wind speed, electricity prices, turbine prices, and energy usage. The study uses geographic information system (GIS) software to analyze the wind and utility data spatially and to display the results. A small but significant portion of all three counties are shown to be economically advantageous for residential wind, especially under alternative usage and policy scenarios.

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Background

The United States produces 4 trillion kilowatt hours of electricity nationally, of which coal accounts for 39% (EIA 2011). Coal is the largest source of electricity for American homes, and coal mining and combustion are fraught with issues. Using coal for our energy can cause huge damages to public health, natural resources, buildings, and the atmosphere. Coal was originally considered an abundant, cheap source of energy, but research suggests that the cost of coal is much higher for society than its for-sale price shows (Epstein et al. 2011). Coal has health costs to miners and their communities, and to those living around coal power plants. According to Epstein et al. (2011), when the entire cost borne by society is factored in, the cost of coal can double or even triple. In addition, calculations have shown 90% of coal reserves in the western and eastern U.S. will be consumed and unavailable by 2054 and 2084, respectively (Milici et al., 2013).

Coal, petroleum, and natural gas, which account for 67% of Americans' electricity usage (EIA 2011) are fossil fuels, which contribute to climate change. Sources of renewable energy limit the negative externalities associated with energy production. They promote energy security currently and into the future while minimizing harm to the environment. Aside from materials, installation and maintenance, wind power burns no fossil fuels (Kondili and Kaldellis 2012). Of the life cycle CO_2 emissions from wind energy installations, 98% are in the initial building and installation of the turbine (Kondili and Kaldellis 2012). Due to a variety of factors, energy production from wind continues to grow. In the United States, the total installed wind capacity has gone from 4,147 MW in 2001 to 61,327 in 2014, according to the U.S. Wind Industry Market Report (American Wind Energy Association

2014). According to the US Department of Energy, wind is the fastest growing source of power in the United States (Gerrity 2013). Wind is second to hydropower as the largest source of renewable energy in the United States; 4.4% of US electrical energy comes from wind (EIA FAQ 2015).

Over time, the cost of producing energy using wind power has fallen. In some areas, the energy produced per dollar now rivals that of coal, natural gas, and nuclear (Milborrow 2012). This is especially true in the Great Plains, where wind resources are greatest (Caldwell 2014). However, while wind energy cost is decreasing, in areas like Michigan it is unclear yet if, without federal incentives, the cost of wind energy rivals coal.

There is some debate as to when humans first began utilizing wind energy. The first concrete evidence of its usage is in 644 A.D. in the Middle East (Swift-Hook 2012). The first windmills were used for water pumping. Since then, wind mills have evolved over time and developed into what we recognize as wind turbines.

Americans have relied on wind energy since the 1850s, when it was used to pump water, primarily to nourish livestock (Swift-Hook 2012). These pumps were especially important to open up the American West because they were able to reach groundwater. In the 1920s the wind pumps disappeared from the landscape because of cheaper electricity sources and because of the dams that made water more available (Swift-Hook 2012). Small wind turbines were common during the late 1800s and early 1900s, and were used primarily for areas where electricity supplies were unavailable (Swift-Hook 2012).

The Yom Kippur war in 1973 caused a short worldwide oil crisis. The concern that western nations were running out of usable oil fueled a new interest in renewable energy.

Now such interest is primarily fueled by concerns about global climate change (Swift-Hook 2012). In 1978, the Carter administration passed the Public Utility Regulatory Act, which required public utilities to buy renewable energy. California decided to give high tax credits to wind projects, this, coupled with incentives from the federal government to give 50% tax credits to investors in renewable energy, began a huge boom in wind generation, in California in particular. The first wind farm was erected in 1980 by US Windpower. Since then, most of these original incentives have been discontinued, although new ones have risen in their place (Swift-Hook 2012).

Renewable portfolio standards (RPS) are state policies made to encourage renewable energy adoption. Although they differ in terms of program structure, enforcement mechanisms, size and application, they work by mandating and encouraging electricity producers to supply a minimum share of electricity from renewable sources. Thirty states have adopted binding RPS programs (Today in Energy, EIA 2011). Federal and state incentives also exist to reduce the cost of renewable energy for commercial and residential usage.

Net metering is a policy which allows residential generators of energy to “save” the excess electricity that they have produce, by subtracting that energy from their utility meter - hence “net” metering. Any excess electricity not used up by the end of each month is a credit for future bills, and is “rolled over” into the next billing period. Forty three states plus Washington D.C. have net metering policies (Auck et al. 2014). These policies range widely, and have different aspects which can relatively favor or discourage residential electricity generation (Auck et al. 2014). Michigan has a relatively progressive net metering policy (Auck et al. 2014) (MPSC Net Metering 2011) - in this policy, excess electricity credit is “rolled over” into subsequent time periods indefinitely, rather than only lasting a year, as in some other states (MPSC Net Metering 2011). Part of the analysis in the current study uses a term which is referred to here as “perfect net metering”. Perfect net metering refers to a policy in which the utility is required to compensate residential generators at the retail rate in cash, rather than through energy credit. No states currently have such a policy.

The energy market in the United States is changing. Policy changes such as the RPS coupled with technological advances in efficiency and electricity generation are expected to change the energy market.

The current electricity system faces issues with widespread distribution of energy. Firstly, about 6% of electrical power generation is lost in transmission and distribution (EIA FAQ 2014). These transmissions losses increase as the distance from the power plant increases (Benedict et al. 1992). Additionally, as more and more users are tied to power plants, the danger of catastrophic failures increases. One proposed solution to these issues is to localize energy production. This paper discusses several methods to localize wind energy production in Michigan and in the United States through residential installations and community sharing of wind turbines.

In this study I assess economic viability of residential wind turbines in several ways. The first analysis uses local Michigan utility prices and household electricity usage to calculate the payoff periods for wind turbines under the scenario of perfect net metering. The next analysis calculates payoff periods if turbines are shared by several households.

The final analysis estimates the viability of residential wind turbine usage in all fifty states using statewide averages for electricity prices and electricity usage.

General Methods

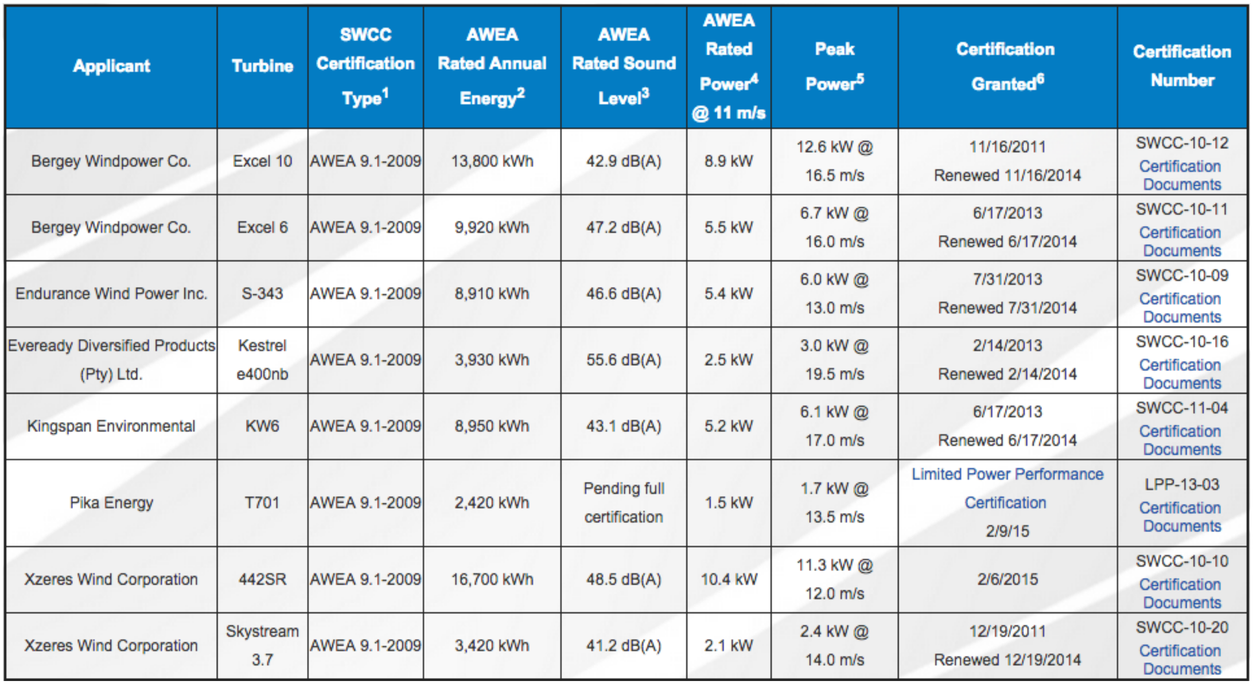
The first two sections of this study focuses on three counties in Michigan, each of which has a different energy provider. The three counties are Huron, Leelanau and Oakland (Figure 1). Huron and Leelanau were chosen because of their high wind resources. Oakland was chosen for comparison as a residential area with relatively low wind resources.

Figure 1: The three counties used in the Michigan analysis - Leelanau, Huron, and Oakland.

In these three regions, the study uses wind speed data to estimate electricity potential. Although zoning for towers can be a major issue with installation of residential wind turbines, that is outside of the scope of this study. This study does not exclude areas in which towers are currently prohibited. Also, because this study is focusing on the economic viability of residential wind turbines, only sites on land are considered; offshore sites are beyond the scope of this study.

Wind Turbine Data

Turbines used for cost analysis were the eight that are currently certified by the Small Wind Certification Council (SWCC). These turbines were chosen because third-party certification is now a prerequisite for eligibility for the IRS - Renewable Energy Tax Credit (Rhoads-Weaver 2015).



Applicant	Turbine	SWCC Certification Type[1]	AWEA Rated Annual Energy[2]	AWEA Rated Sound Level[3]	AWEA Rated Power[4] @ 11 m/s	Peak Power[5]	Certification Granted[6]	Certification Number
Bergey Windpower Co.	Excel 10	AWEA 9.1-2009	13,800 kWh	42.9 dB(A)	8.9 kW	12.6 kW @ 16.5 m/s	11/16/2011 Renewed 11/16/2014	SWCC-10-12 Certification Documents
Bergey Windpower Co.	Excel 6	AWEA 9.1-2009	9,920 kWh	47.2 dB(A)	5.5 kW	6.7 kW @ 16.0 m/s	6/17/2013 Renewed 6/17/2014	SWCC-10-11 Certification Documents
Endurance Wind Power Inc.	S-343	AWEA 9.1-2009	8,910 kWh	46.6 dB(A)	5.4 kW	6.0 kW @ 13.0 m/s	7/31/2013 Renewed 7/31/2014	SWCC-10-09 Certification Documents
Eveready Diversified Products (Pty) Ltd.	Kestrel e400nb	AWEA 9.1-2009	3,930 kWh	55.6 dB(A)	2.5 kW	3.0 kW @ 19.5 m/s	2/14/2013 Renewed 2/14/2014	SWCC-10-16 Certification Documents
Kingspan Environmental	KW6	AWEA 9.1-2009	8,950 kWh	43.1 dB(A)	5.2 kW	6.1 kW @ 17.0 m/s	6/17/2013 Renewed 6/17/2014	SWCC-11-04 Certification Documents
Pika Energy	T701	AWEA 9.1-2009	2,420 kWh	Pending full certification	1.5 kW	1.7 kW @ 13.5 m/s	Limited Power Performance Certification 2/9/15	LPP-13-03 Certification Documents
Xzeres Wind Corporation	442SR	AWEA 9.1-2009	16,700 kWh	48.5 dB(A)	10.4 kW	11.3 kW @ 12.0 m/s	2/6/2015	SWCC-10-10 Certification Documents
Xzeres Wind Corporation	Skystream 3.7	AWEA 9.1-2009	3,420 kWh	41.2 dB(A)	2.1 kW	2.4 kW @ 14.0 m/s	12/19/2011 Renewed 12/19/2014	SWCC-10-20 Certification Documents

Table 1: SWCC certified turbines investigated for the study.

Two of the turbines were excluded - the Endurance S-343, which is no longer sold in the United States, and the Everready Kestrel e400nb, which never responded to cost enquiries. The remaining six turbines still included a sizable range in energy output (from 5,000 kW/yr to 34,000 kW/yr at a 5 m/s wind speed) and cost. The six turbines are the Bergey Excel 10, Bergey Excel 6, Kingspan KW6, Pika T701, Xzeres 442SR, and the Xzeres Skystream 3.7 (Table 1).

Viability in the context of this paper is economic payoff; it answers “yes” to the question: is purchasing the turbine going to save enough money, through offset energy costs, and/or revenue, with the energy it will produce in its lifetime? Since individual turbine prices aren’t readily available, each company was contacted, and a cost estimate was given for turbines and necessary equipment such as inverters. Tower and installation costs were estimated after contacting several installers in the area and averaging estimates. Installation costs can range greatly in price based on labor costs, and equipment rental rates (Table 2). Tower costs can vary orders of magnitude based on height of tower (from 10 m - 42 m) and type (i.e., guyed towers vs. free-standing towers). For the sake of a conservative estimate of turbine economic viability, a high estimate of cost was used. Each turbine price was approximated as if it was installed on a relatively high 30-m free-standing tower. Although turbine lifetime varies, the companies usually advertise a 20+ year lifetime, although some claim to last 30-50 years. Again, for a more conservative estimate, a 20-year lifetime was assumed for each turbine. Each turbine was analyzed as if it was purchased new. According to the 2012 Market Report on Wind Technologies in Distributed Applications, the average cost of a small turbine is about $6,960/kW. Estimates of price in this paper work out to be similar but higher. After the installed cost analysis, the IRS Renewable Energy 30% Federal Tax Credit was applied to the cost.

	Bergey Excel 10	Bergey Excel 6	Kingspan KW6	Pika T701	Xzeres 442SR	Xzeres Skystream 3.7
Turbine Stand-Alone Cost ($)	29,500	19,500	18,000	6,000	50,000	7,000
Turbine Inverter Cost ($)	2,500	2,500	2,500	2,500	2,500	2,500
Turbine Tower Cost ($)	25,000	23,750	19,500	12,600	27,190	13,000
Turbine Installation Costs ($)	15,000	14,250	14,000	7,400	10,310	7,500
Federal Incentive Discount	30% off	30% off	30% off	30% off	30% off	30% off
Yearly Maintenance Costs ($)	600	400	360	120	1,000	140
Lifetime (years)	20	20	20	20	20	20
Turbine Lifetime Cost ($)	62,400	50,000	45,000	22,350	83,000	23,800

Table 2: Turbine cost estimations with Michigan installers and with a 30% federal discount. Turbines highlighted in light grey were used for the spatial analysis.

Estimates of yearly maintenance costs also exhibited a wide range. Although some turbines may have performed more reliably with less maintenance, an estimated yearly cost of 2% of turbine cost was used (Wind Measurement International 2011).

$$T_{LC} = (T_S + T_I + T_T + T_{IC}) * (1 - F_I) + (T_S * M) * L$$

T_{LC} = total lifetime costs:($)
T_S = Turbine Stand-alone cost ($)
T_I = Turbine inverter cost ($)
T_T = Turbine Tower cost ($)
T_{IC} = Turbine installation cost ($)
F_I = Federal incentive discount (%/100)
M = Maintenance costs per year as a percent of turbine cost (%/year)
L = lifetime (years)

The Small Wind Certification Council publishes information on turbine performance and annual energy output for each of the turbines they certify. The following graphs show the annual kWh produced at average wind speeds for each of the analyzed wind turbines (Figure 2).

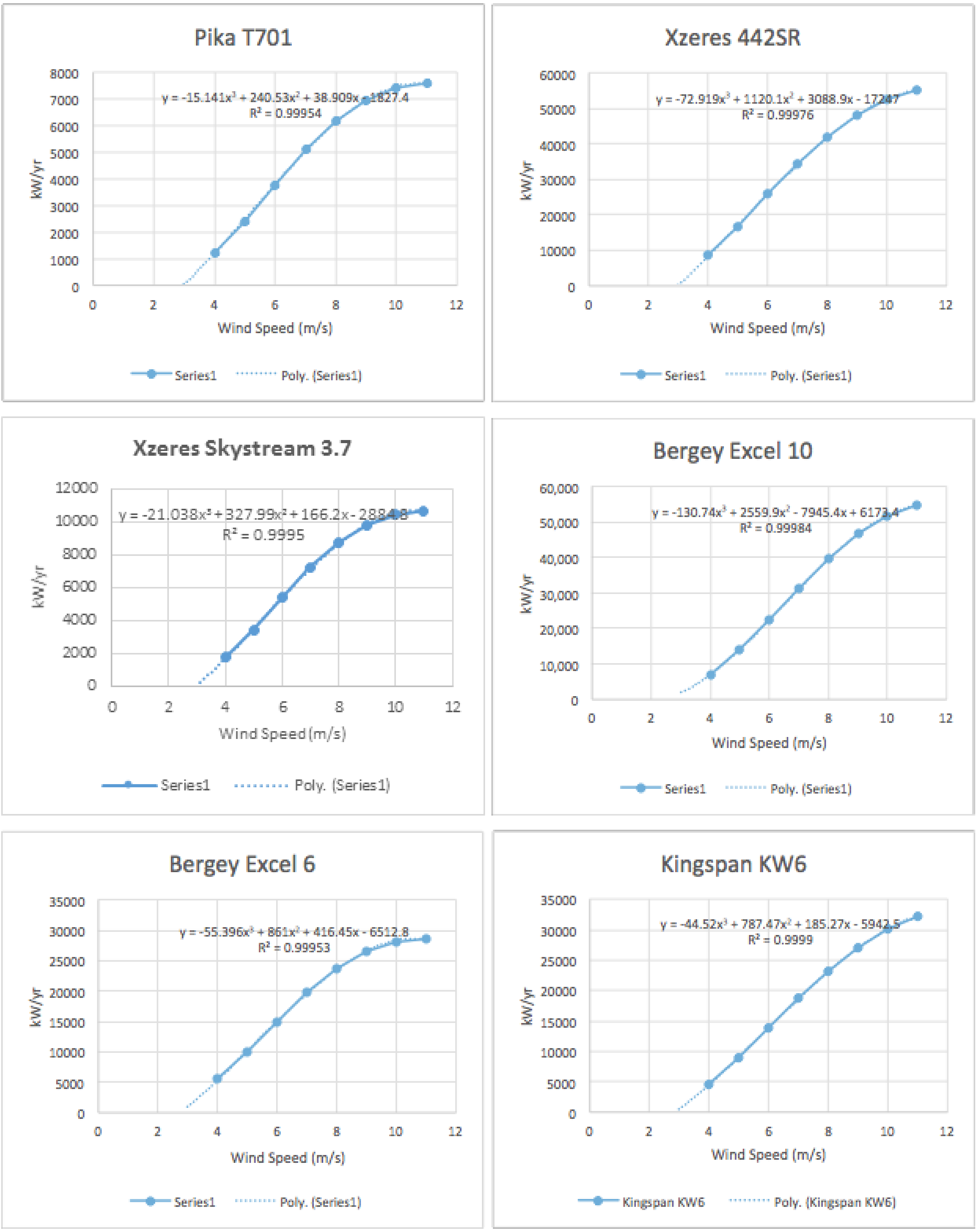


Figure 2: Graphs of annual energy output (kWh/yr) by wind speed (m/s) for of all turbines analyzed. Third degree polynomial trend lines were fitted to the reported values. The formulas for each trendline are given.

Despite periodic variations at wind velocity, wind tends to follow a Rayleigh-distribution over enough time. This distribution was taken into account in the calculations of annual energy output, according to the SWCC. The SWCC only measures output at wind speeds of 4 m/s and above. In order to extrapolate to lower wind speeds, and to retrieve a more precise output for non-integer wind speeds, a 3rd order polynomial trendline was used, then extrapolated to 3 m/s. The resulting formula was used with wind velocity GIS data to yield information on annual energy produced by each turbine.

In order to simplify the results, three of the best-performing turbines were primarily used in the spatial analysis: One turbine was used in each of three categories of energy production. The small category was the Xzeres Skystream, which has a rotor diameter of 3.7 m and produces 3,416 Kw/Yr at 5 m/s wind speed. The medium category was the Kingspan KW6, which has a rotor diameter of 5.6 m and produces 8,429 kW/Yr at 5 m/s wind speed. The large category was the Bergey Excel 10, which has a rotor diameter of 7 m and produces 13,842 kW/Yr at 5 m/s wind speed.

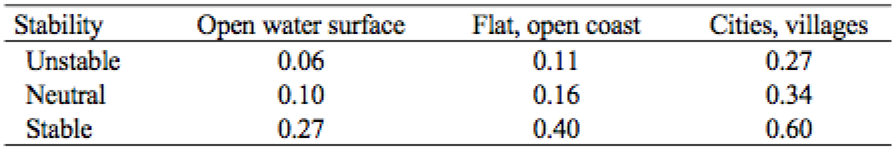
Wind Data

Wind data was obtained from the National Renewable Energy Laboratory (NREL) (Wind Data 2005). The wind data (Figure 3) is classified into six different power classes. The average of each range was used as the wind velocity of each power class. The data measures wind velocity at 50 m above ground. Since the wind data is at 50 m height, the Hellman-Approach formula was used to estimate the wind speed at the lower 30-m tower height used in this study (Kaltschmitt 2007).

$$v_{Wi,h} = v_{Wi,ref}(h/h_{ref})^{\alpha Hell}$$

$v_{Wi,h}$ = mean wind velocity at tower height (m/s).
$v_{Wi,\,ref}$ = wind velocity at reference height (m/s).
h = tower height = 30 m.
h_{ref} = reference height = 50 m.
α_{Hell} = the altitude wind exponent (Hellman-exponent).

A Hellman exponent of 0.16 was used, which corresponds to a flat area with neutral air. So each wind speed was multiplied by 0.9215188.



Stability	Open water surface	Flat, open coast	Cities, villages
Unstable	0.06	0.11	0.27
Neutral	0.10	0.16	0.34
Stable	0.27	0.40	0.60

Table 3: α_{Hell} values for different wind types. (Kaltschmitt 2007)

The wind power classes, after applying the Hellman Exponent Formula, correspond to approximately:

Wind Power Class	1	2	3	4	5	6	7
Median Wind Velocity (m/s)	2.5	5.5	6.2	6.7	7.1	7.7	8.3

Table 4: Calculated wind velocity for each wind power class after applying the Hellman Exponent Formula to account for a tower height of 30 m instead of the reference value of 50 m.

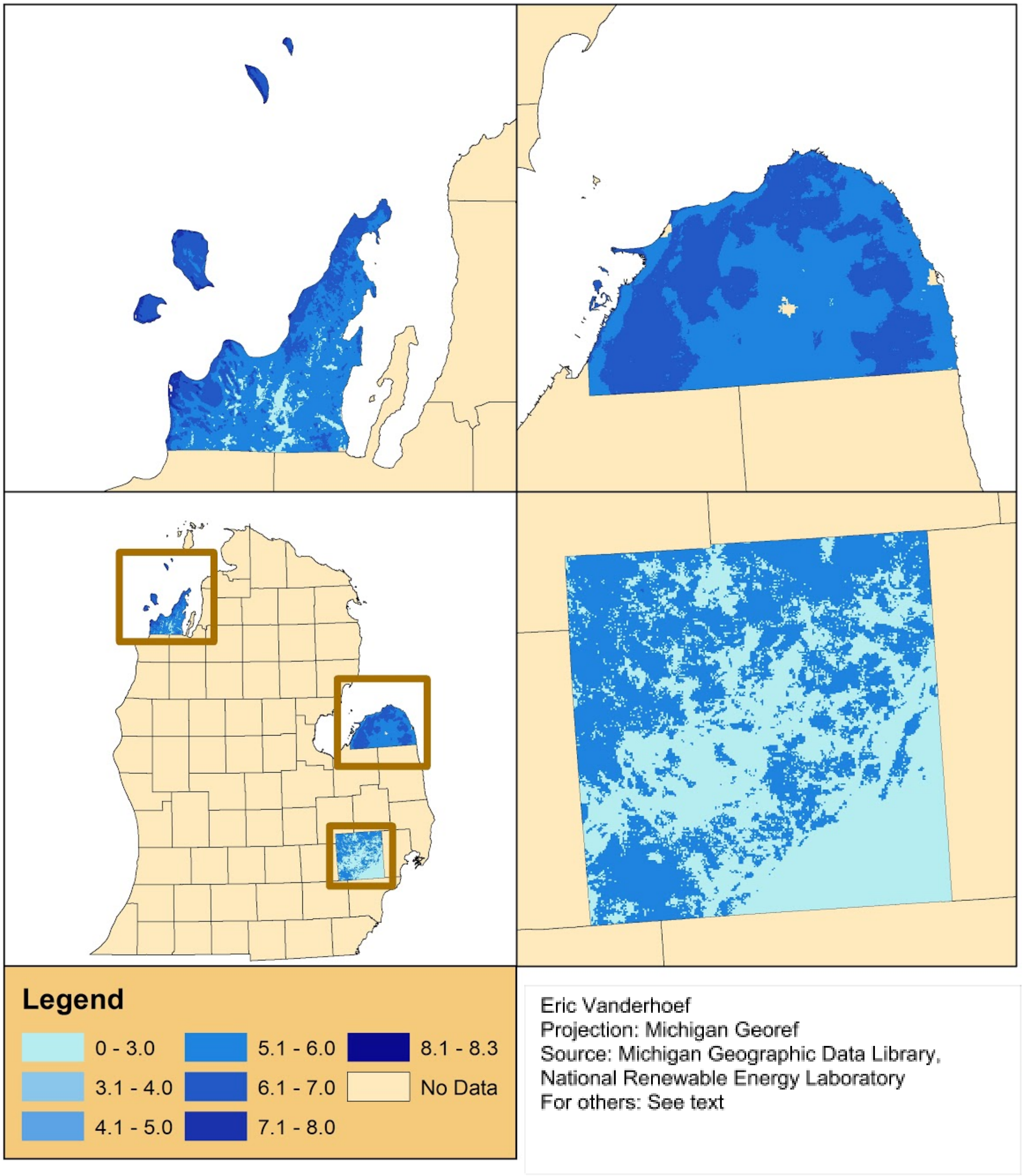


Figure 3: Wind speed in m/s at 30 m above ground level in select counties of Michigan.

Electrical Energy Costs

The economic viability of wind turbines depends in part on the cost of electricity charged by the local electric utility company. Utility prices were obtained for Leelanau, Huron, and Oakland counties. Four utilities service those three counties: Cherryland Electric Cooperative, Thumb Electric Cooperative, DTE Energy, and Consumers' Energy.

1. Cherryland Electric Cooperative (http://cherrylandelectric.coop/wp-content/uploads/2015/01/Sec-D-New-Rates-Feb-20151.pdf)
2. Thumb Electric Cooperative (http://www.tecmi.coop/farm-and-home-rates)
3. DTE Energy (https://www2.dteenergy.com/wps/wcm/connect/e014f02d-957b-4397-b00b-42813ec8319d/electicrateinsert0212.pdf?MOD=AJPERES)
4. Consumers' Energy (http://www.consumersenergy.com/uploadedFiles/CEWEB/SHARED/Rates_and_Rules/electric-rate-book.pdf#page=129)

Each of their pricing schemes was determined, and used to compute the average annual costs a consumer would pay under three different energy use scenarios (Table 5). The low energy use scenario is based on average energy use in Hawaii (low) (EIA RECS 2009). The medium energy use scenario is based on average energy use in Michigan (medium)(EIA RECS 2009). The high energy use scenario is based on average energy use in United States (high)(EIA RECS 2009).

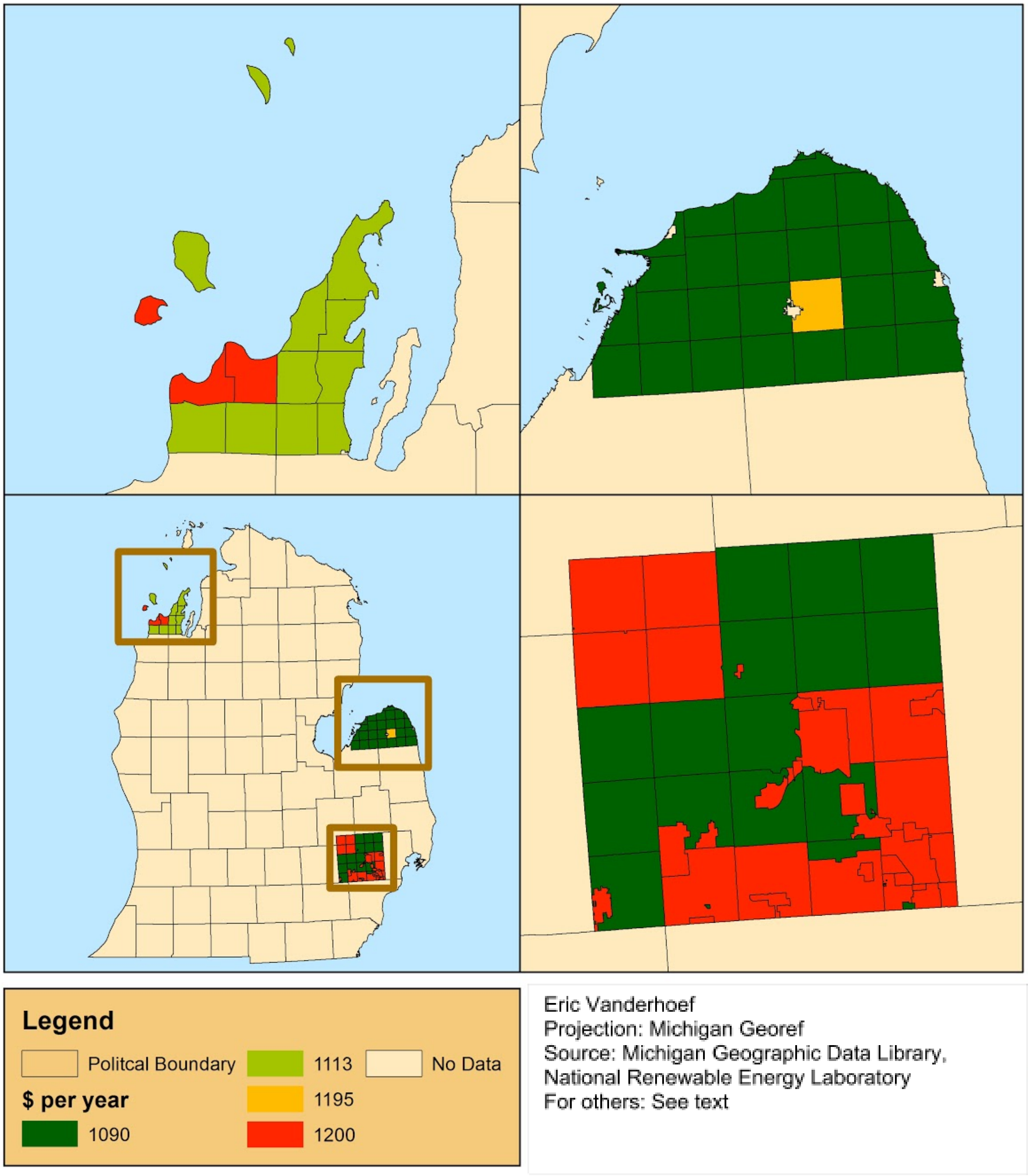
Energy Use Scenario	kWh/Yr
Low: HI Avg. Annual Energy Consumption	6,528
Med: MI Avg. Annual Energy Consumption	8,112
High: US Avg. Annual Energy Consumption	11,280

Table 5: Annual energy use scenarios used in this analysis

Annual Energy Costs ($/Yr)			
	Energy Use Scenario		
Utility	Low	Medium	High
Cherryland	930.61	1112.75	1477.02
Consumers	790.98	1199.74	1668.27
Thumb	989.53	1194.69	1605.02
DTE	876.16	1090.28	1518.53
Average	896.82	1149.37	1567.21

Table 6: Annual energy cost by energy use scenario and Michigan utility provider

This information was joined with township information on ArcGIS to get a more precise mapping of utility providers. The modified 30-m wind data was entered along with turbine costs and energy output.



Eric Vanderhoef
Projection: Michigan Georef
Source: Michigan Geographic Data Library,
National Renewable Energy Laboratory
For others: See text

Figure 4: Annual average electricity prices in select Michigan counties based on Michigan average usage and township utility provider.

Section I: Single Home Feasibility:

Methods: Section I: Single Home Feasibility

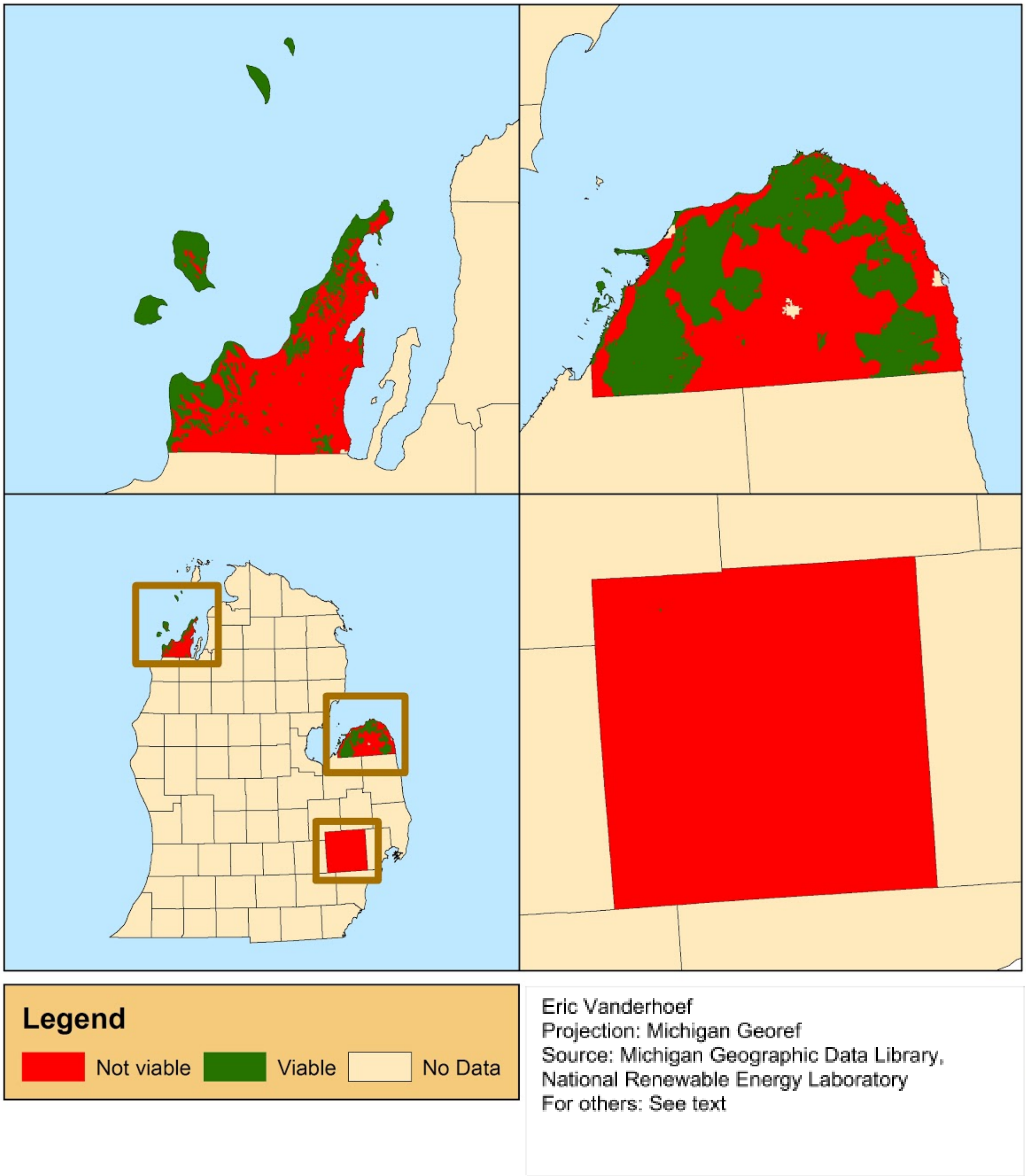
The first analysis determines how economically feasible wind turbines are strictly based on dollars per kilowatt hour. If a wind turbine produces energy cheaper over its lifetime than buying from the grid, the turbine is considered economically viable.

$$T_{LC}/T_O(v_w, T_L) < U_C(U_P, E_S)$$

T_{LC} = Turbine lifetime cost (\$)
T_O = Turbine lifetime output (kWh) as a function of
    v_W = wind velocity (m/s) and
    T_L = Turbine lifetime (20 years)
U_C = Utility cost (\$/kWh) depends on
    U_P = Utility Provider and
    E_S = Energy Use Scenario, in this case, Michigan Average

Results: Section I: Single Home Feasibility

At the medium energy usage of 8112 kWh/year, 33% of Leelanau and 45% of Huron county, along with a very small portion of Oakland County, are shown to be viable under this analysis (Figure 5).



Eric Vanderhoef
Projection: Michigan Georef
Source: Michigan Geographic Data Library,
National Renewable Energy Laboratory
For others: See text

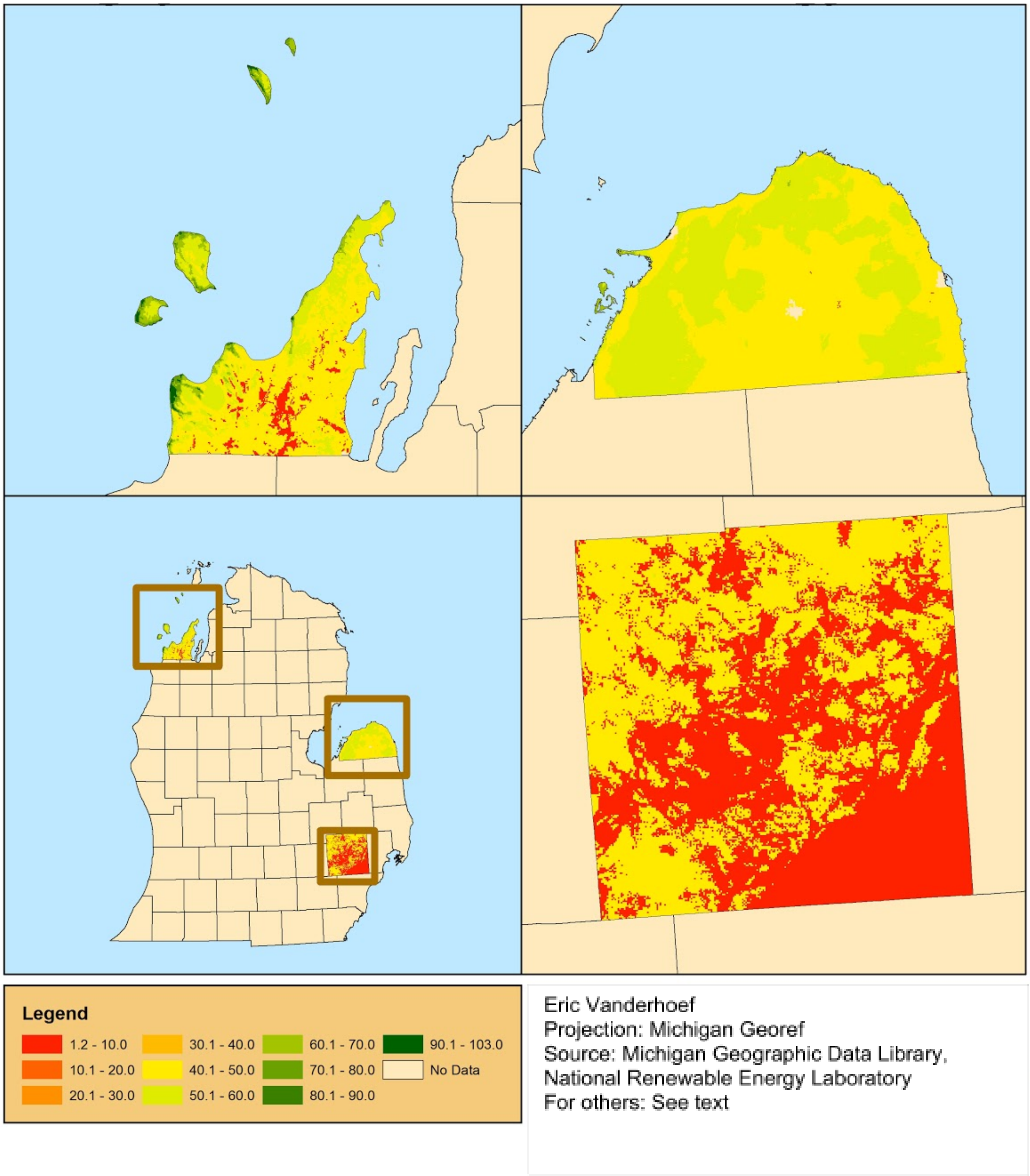
Figure 5: Economic Viability of a large wind turbine (Bergey Excel 10) in three Michigan counties. Analysis assumes a 20-year turbine lifetime and average Michigan household energy usage of 8,112 kWh/y. The spatial variation in average wind speed and variation among provider prices allows viability of wind turbines in 33% of Leelanau County, 45% of Huron County, and less than 0.01% of Oakland County.

Discussion: Section I: Single Home Feasibility

The first analysis determines how economically feasible wind turbines are strictly based on dollars per kilowatt hour - if the wind turbines produce energy cheaper in their lifetime than buying from the grid, it is considered viable.

It is not this simple in reality. It is unusual for all of the energy produced by the turbine to be used to offset energy costs or sold to the utility at retail rates. However, these assumptions hold in several cases. First, the assumptions hold if the energy produced by the turbine is less than the energy used by the household. However, households in which large turbines are viable would have to use huge amounts of energy for this to be true (about three times Michigan's average household electricity consumption, or more than twice the national average).

The second case is under perfect net metering. *Perfect* net metering means that the utility compensates the residential generator for every kWh that the residence produces - regardless of usage. In contrast, *standard* net metering is (usually) formulated so that excess electricity generated by the wind turbine is credited towards the monthly bill - but is NOT redeemable- i.e. the monthly bill is reduced, but households never receive cash for the electricity they generate. This excess electricity is in terms of a monthly basis - if the turbine produces more electricity than is used by the household at the end of the month, the household is credited for that energy, regardless of which point in the month the turbine produced the energy. The "negative balance" of energy is applied to the monthly energy bill, and, depending on the state net metering policy, "rolls over" into following billing periods. This means that perfect net metering compensates households immediately, and standard net metering provides savings to households which last over time. Under standard net metering, savings from the wind turbines will continue to be realized years after the turbine has stopped functioning. An assumption of this paper is that residential wind turbines produce energy for 20 years. What this means is that in viable households in perfect net metering scenarios - the turbine creates revenue equal to the retail rate every time it produces energy and by the end of its 20 year lifetime, has given value to the household greater than its total cost over those 20 years. In standard net metering, a household can still be viable, but the payoff will be much longer than 20 years - because the energy saving credits are still “rolling over.” In other words, households’ electricity credits continue to offset electricity usage after the turbine stops operating. The credits (in kWh) will continue to be credited to the account at the retail rate (in dollars), even as the retail rate changes. In viable households, the energy savings over time (holding retail rates constant) are greater than the lifetime cost of the turbine. The energy produced during the 20 year lifetime of the Bergey Excel 10 can offset a household’s energy needs for 50 or more years, in viable households (Figure 6).



Eric Vanderhoef
Projection: Michigan Georef
Source: Michigan Geographic Data Library,
National Renewable Energy Laboratory
For others: See text

Figure 6: Number of years of energy use for a typical Michigan household (i.e. medium energy scenario: 8,112 kWh/y) that would be offset by a large residential wind turbine (Bergey Excel 10) which was operating for 20 years with standard net metering.

For families to receive these energy credits, in many cases, they must remain in their households for extended periods of time - sometimes up to 40 to 60 years. The Bergey

Excel 10, for example, cost $62,400. Energy costs in Michigan are ~$1200 per year. In viable households, then, the turbine takes 52 years to payoff. There is little information available as to whether or not families can “cash out” if they plan to move from their household after generating energy credits. In Massachusetts, for example, the utilities’ decide whether energy credits can be used to “cash out” when they draft their net metering contracts with customers (Massachusetts Energy and Environmental Affairs 2015). In areas where households can’t cash out, however, the lag in payback time is a big problem - American families stay an average of only 15 years in their house (Emrath, 2009). This means the payoff of the turbine may not be realized by residents in time. For that reason, some households may choose not to invest in a turbine at all.

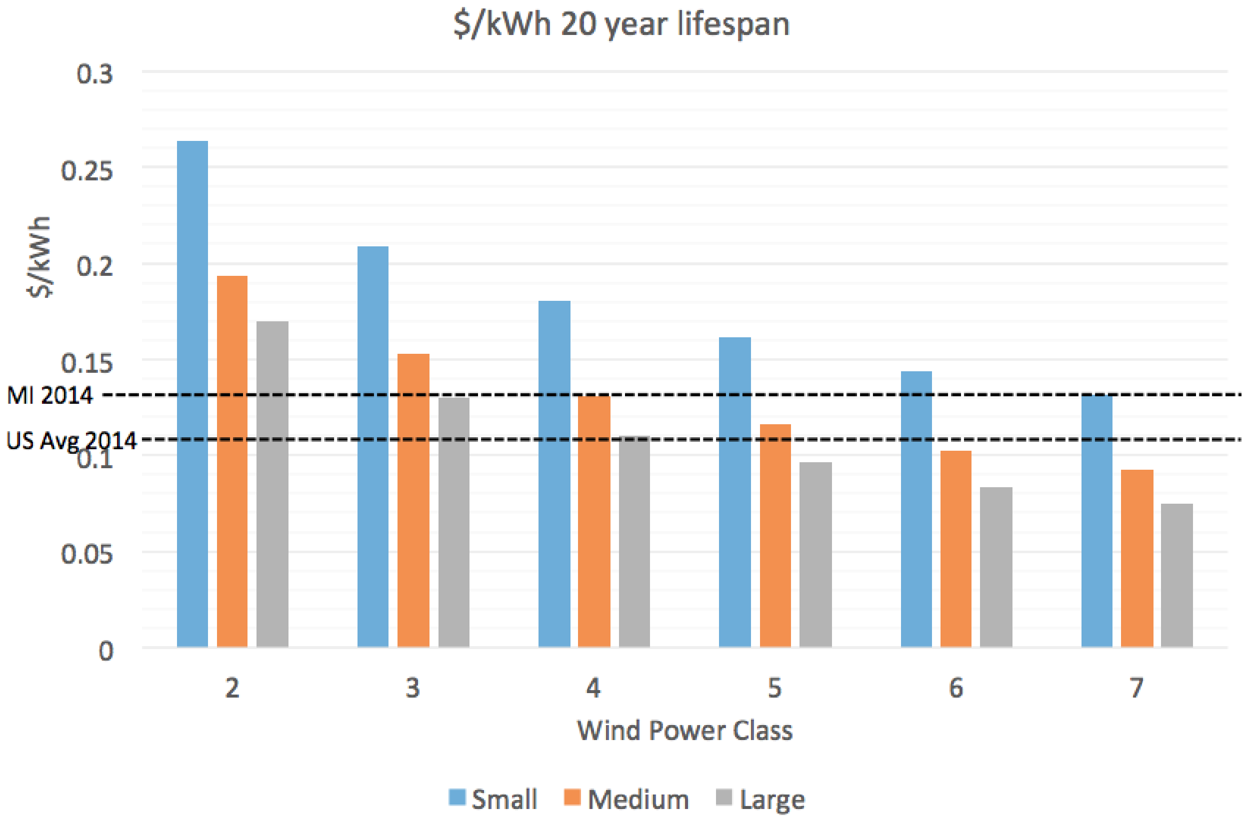


Figure 7: The cost of energy production for turbine use for 20 years, for three sizes of wind turbines. Horizontal dashed lines indicate the average electricity price in Michigan and in the United States. Bars beneath the dashed lines indicate that wind turbines are economically viable with perfect net metering. See **Table 4** for Wind Power Class to wind velocity (m/s) conversion.

There are two ways to decrease the payback time of turbines in standard net metering scenarios. First is to decrease the price associated with purchasing the turbine. Second is to increase the amount of turbine-generated electricity which is actually used by the households. Wind energy sharing accomplishes both of these tasks - and therefore decreases the payback time of the turbine. Sharing or co-ownership of turbines is discussed in the following section.

Section II: Wind Energy Sharing in Michigan

Methods: Section II: Wind Energy Sharing in Michigan:

In this analysis, wind energy sharing, or neighborhood localized wind generation, refers to multiple households consuming the energy produced by a single residential wind turbine. For example, a larger residential turbine, such as the Bergey Excel 10, can produce double or even triple the amount of energy that is consumed by an average household, in which case it would be advantageous to increase the number of households using the energy produced by the turbine. In order to analyze the economic viability of neighborhood localized wind generation, a cost-sharing formula was used. The formula for cost sharing analyzes the turbine cost using a lifetime cost analysis and payoff. Years until wind turbine payoff with perfect sharing:

$$P_S(T_C,HH,E_C) = (T_C/HH)/(E_C)$$

P_S = Perfect Sharing payoff time (years)
- T_C = total 20-year cost of turbine (\$) = (C_I+C_M*L)
  - C_I = Installed cost (\$)
  - C_M = annual maintenance cost (\$/year)
  - L = lifetime (20 years)
- HH= household = $T_O(v_w)/HH_A(E_S)$
  - T_O = Turbine output (kWh)
    - v_w= wind velocity (m/s)
  - HH_A= Household annual electricity usage (kWh/y)
    - E_S = Energy use scenario
- E_C = Electricity cost (\$/year) = $E_C(U)$
  - U = Utility provider

Location provided the necessary utility provider and wind velocity values. The first three maps (Figures 8, 9, and 10) compare the small, medium, and large turbines with the medium energy use scenario - Michigan's current average consumption of 8,112 kWh/y. The next three maps (Figures 11, 12, and 13) all use the large turbine (Bergey Excel 10) and compare the economic viability under different energy use scenarios: Low - 6,528 kWh/y (average annual household consumption in Hawaii), Medium - 8,112 kWh/y (average annual household consumption in Michigan), and High - 11,280 kWh/y (average annual household consumption in United States).

Results: Section II: Wind Energy Sharing in Michigan

Community sharing of small and medium residential turbines resulted in only a 9.1% feasibility area in Leelanau county (Figures 8, 9). Small and medium turbines fared even worse in Huron County and Oakland County. The small turbine had no viable area in either county (Figure 8). Sharing with the medium turbine resulted in viability in a very small portion (0.3%) of Huron County and no viability in Oakland County (Figure 9). Community sharing using the large turbine was relatively successful, 40.8% of Leelanau, 45.1% of Huron, and 19.3% of Oakland County were viable under this analysis (Figure 10).

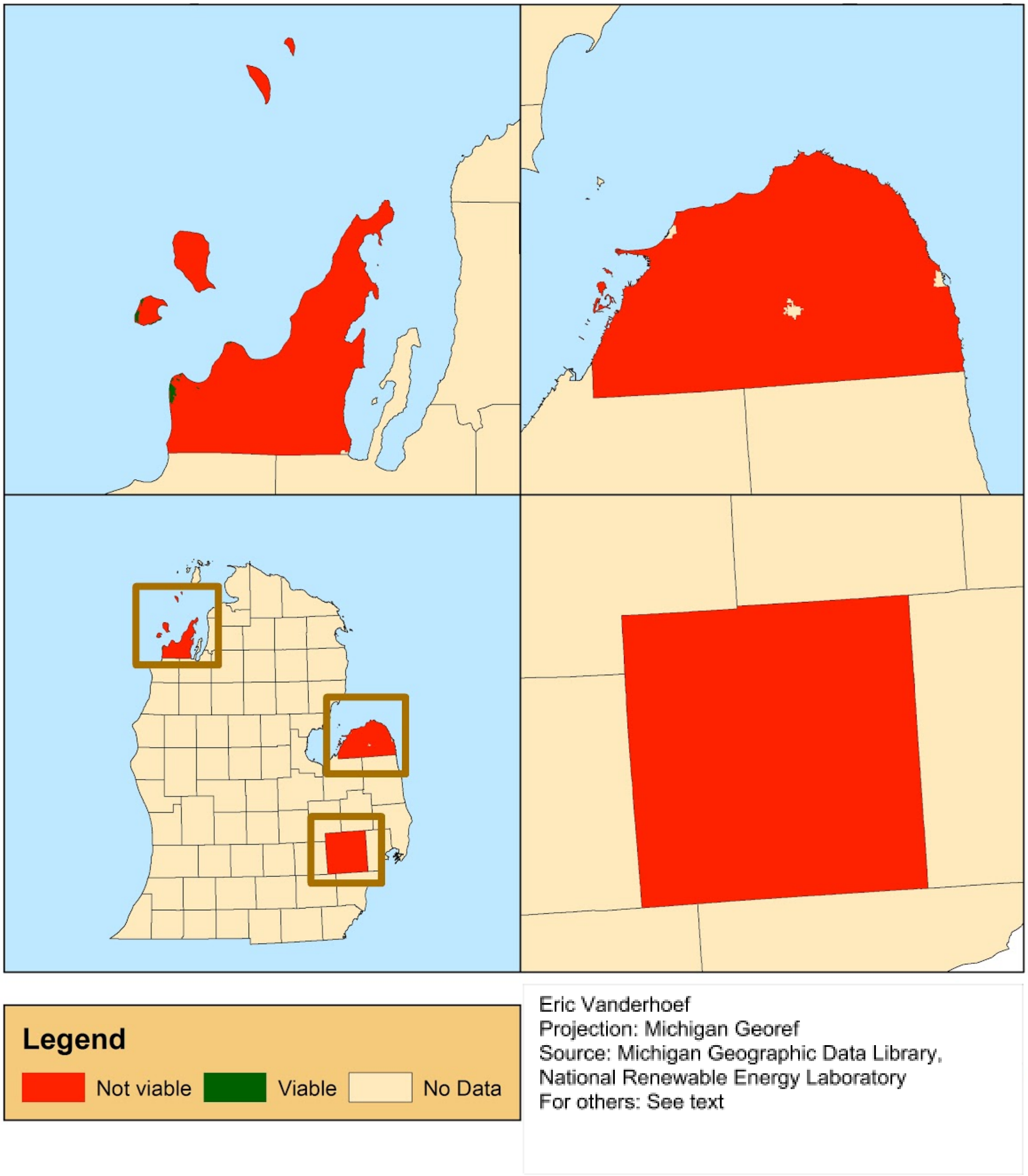
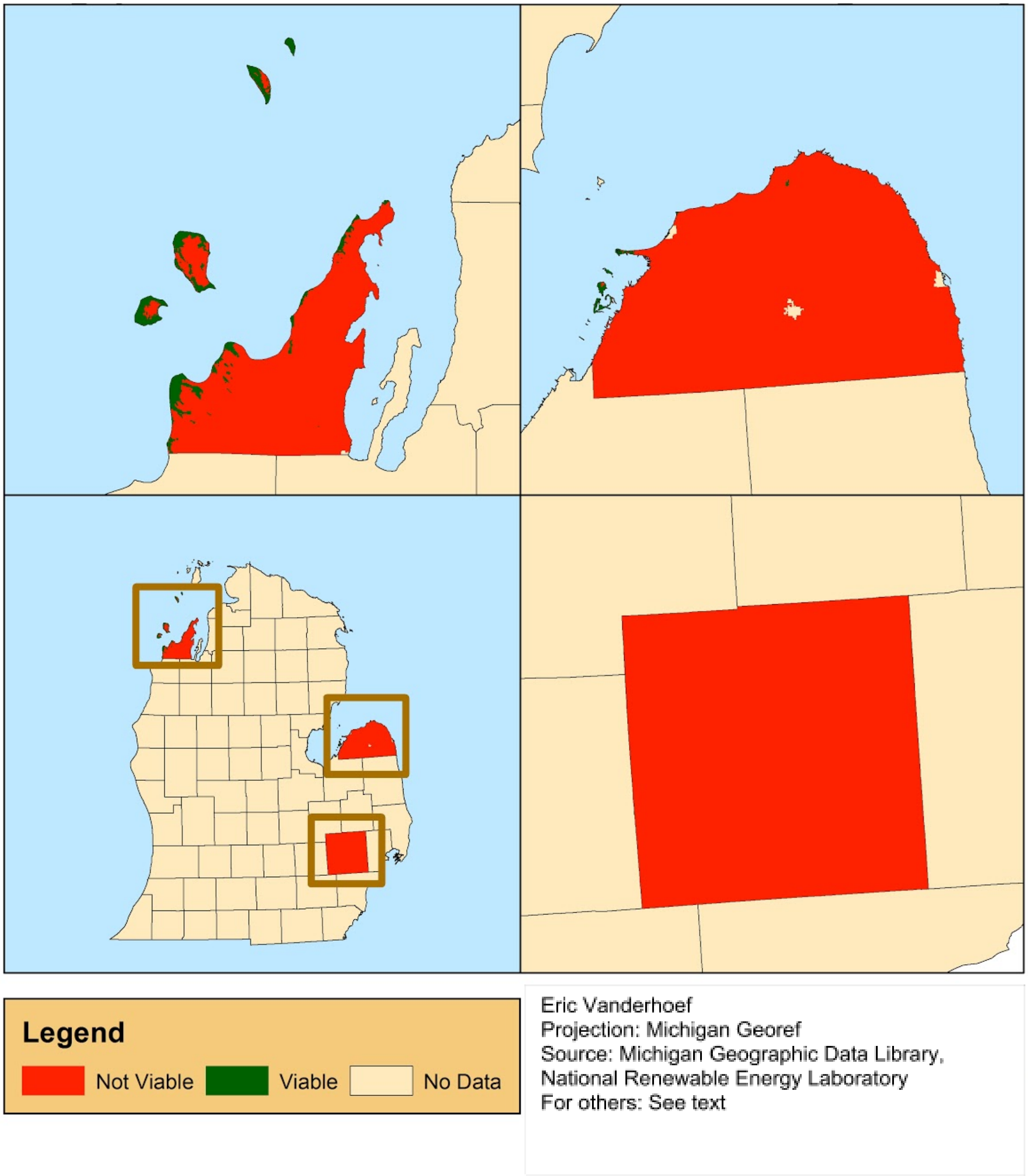


Figure 8: The above map shows economically viable areas in Michigan for community wind sharing of a single small turbine (Xzeres Skystream) in three Michigan counties. Analysis assumes a 20-year turbine lifetime and average Michigan household energy use of 8,112 kWh/y. The spatial variation in average wind speed allows viability of wind turbines in 9.1% of Leelanau County, 0% of Huron and Oakland counties. 1.6% of total area is viable under this analysis.



Eric Vanderhoef
Projection: Michigan Georef
Source: Michigan Geographic Data Library,
National Renewable Energy Laboratory
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Figure 9: The above map shows economically viable areas in Michigan for community wind sharing of a single medium turbine (Kingspan KW6) in three Michigan counties. Analysis assumes a 20-year turbine lifetime and average Michigan household energy usage of 8,112 kWh/y. The spatial variation in average wind speed allows viability of wind turbines in 9.1% of Leelanau County, .3% of Huron and 0% of Oakland county. 1.8% of total area is viable under this analysis.

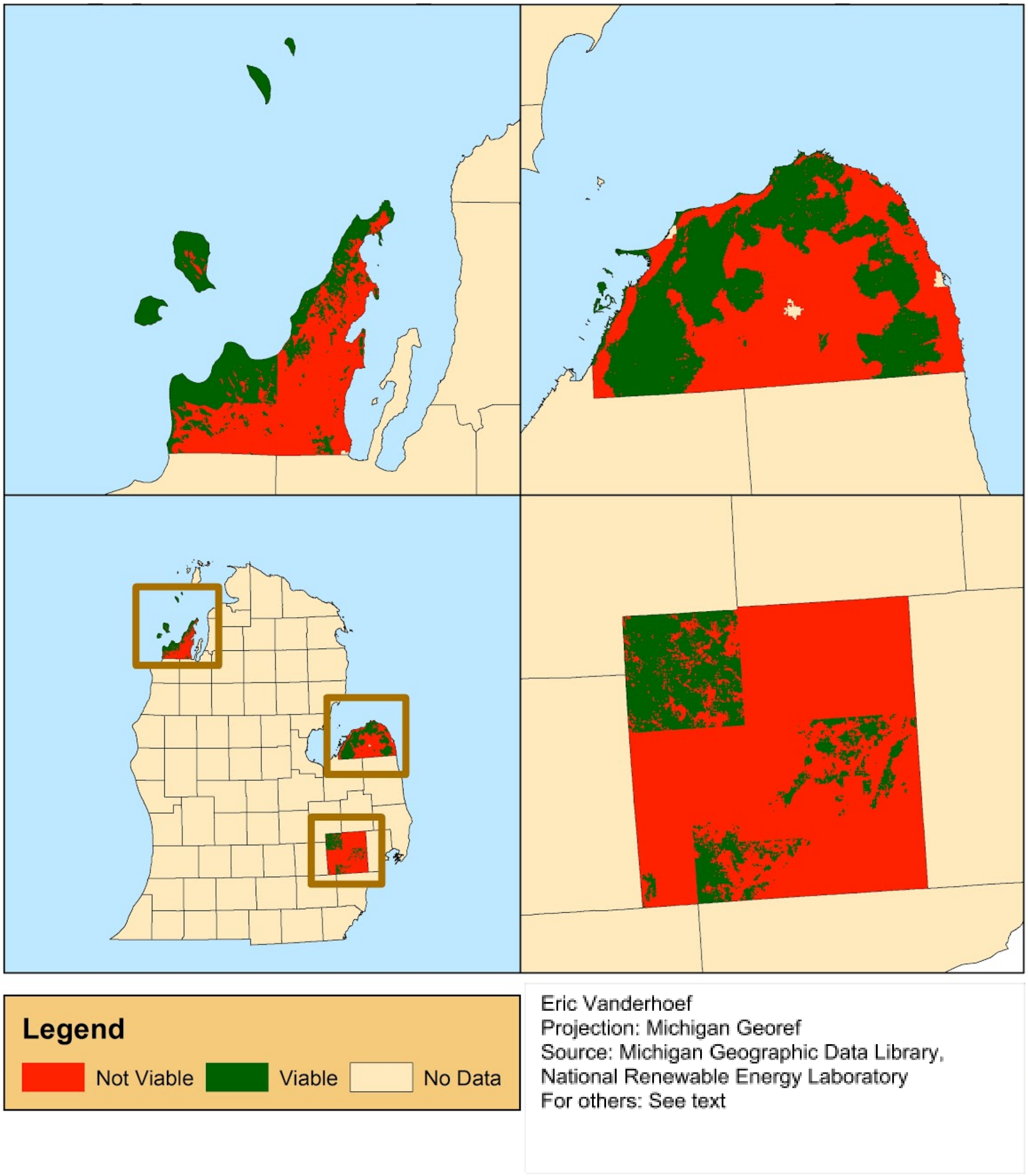

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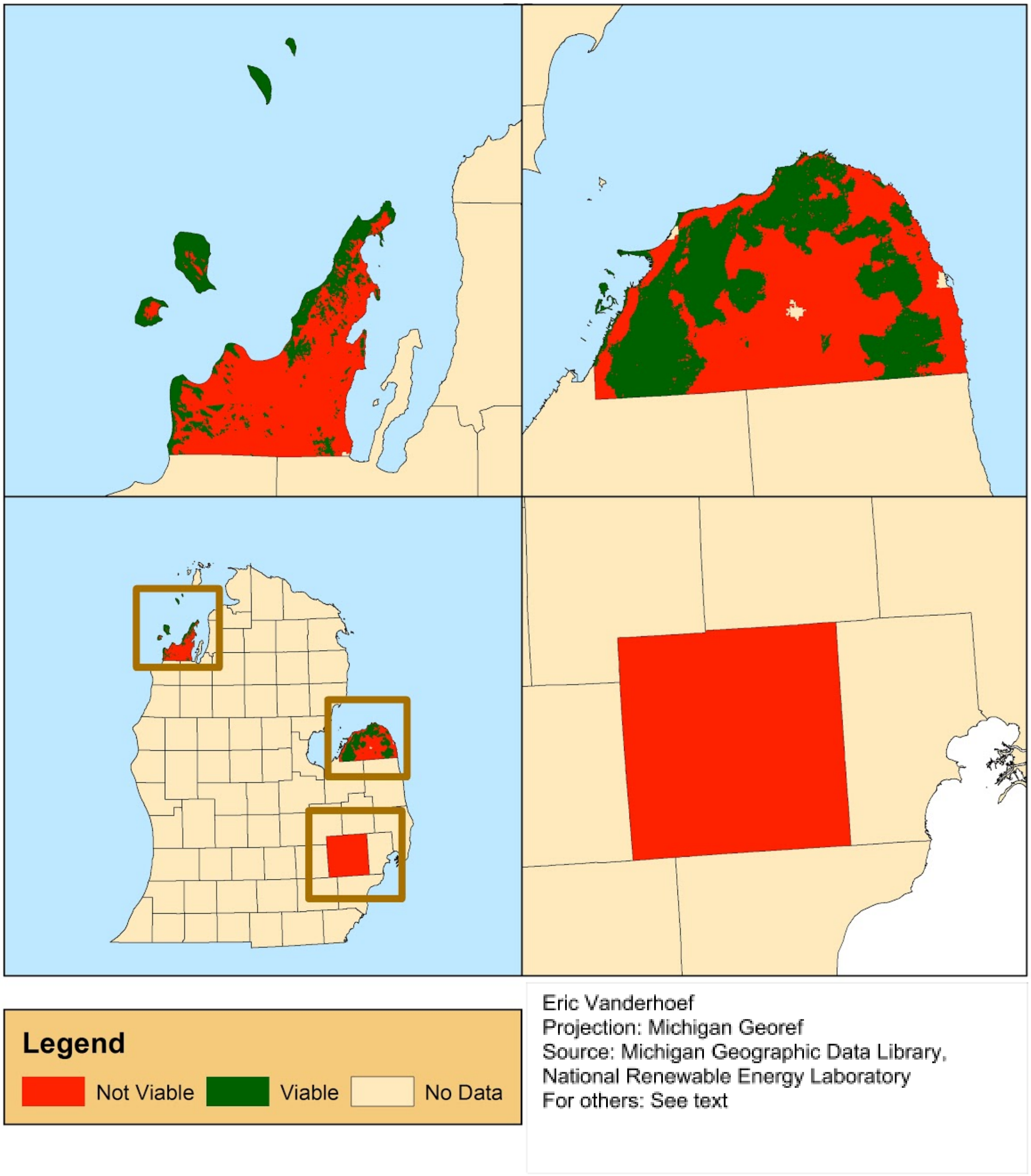
Figure 10: The above map shows viable areas in Michigan for community wind sharing of a single large residential turbine (Bergey Excel 10) in three Michigan counties. Analysis assumes a 20-year turbine lifetime and average Michigan household energy usage of 8,112 kWh/y. The spatial variation in average wind speed allows viability of wind turbines in 40.8% of Leelanau, 45.1% of Huron and less than 19.3% of Oakland County. 33.3% of total area is viable under this analysis.

Wind Turbine	County	Percent of area viable
Small (3.7 m rotor diameter) (Figure 8)	**Leelanau**	**9.1**
	Huron	**0.0**
	Oakland	**0.0**
	Total	**1.6**
Medium (5.6 m rotor diameter) (Figure 9)	**Leelanau**	**9.1**
	Huron	**0.3**
	Oakland	**0.0**
	Total	**1.8**
Large (7 m rotor diameter) (Figure 10)	**Leelanau**	**40.8**
	Huron	**45.1**
	Oakland	**19.3**
	Total	**33.3**

Table 7: Percentage of area in which residential wind turbines are economically viable under the medium energy usage scenario (MI current average: 8112 kWh/y). Analysis varies turbine size and demonstrates strong economies of scale related to increasing turbine size.

The next three maps use the large Bergey Excel 10 turbine to determine how viability changes under low (6,528 kWh/year), medium (8,112 kWh/year), and high (11,280 kWh/year) energy usage scenarios. Varying energy usage with large turbine sharing resulted in highest viability under medium energy usage (Figure 11, 12, 13 and Table 8). Energy scenario was especially important in Oakland county. Low and high usage resulted in no viable area in Oakland County (Figure 11, 13). Medium energy usage resulted in 19.3% viability in Oakland (Figure 12).



Eric Vanderhoef
Projection: Michigan Georef
Source: Michigan Geographic Data Library,
National Renewable Energy Laboratory
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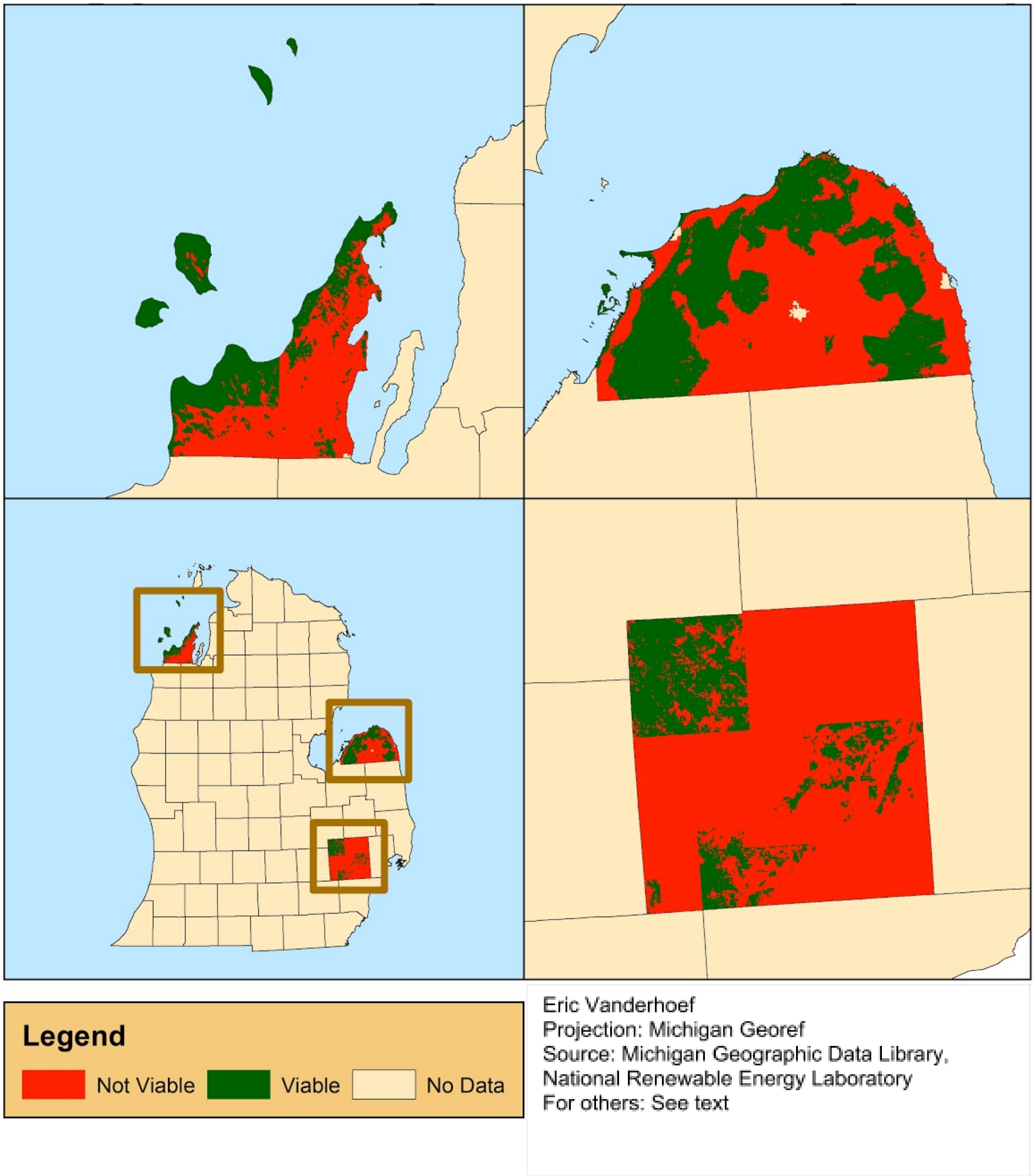
Figure 11:The above map shows viable areas in Michigan for community wind sharing of a single large residential turbine (Bergey Excel 10) in three Michigan counties. Analysis assumes a 20-year turbine lifetime at a low household usage scenario of 6,528 kWh/y. The spatial variation in average wind speed allows viability of wind turbines in 27.9% of Leelanau County, 45.1% of Huron and 0% of Oakland county. 22.7% of total area is viable under this analysis.



Eric Vanderhoef
Projection: Michigan Georef
Source: Michigan Geographic Data Library,
National Renewable Energy Laboratory
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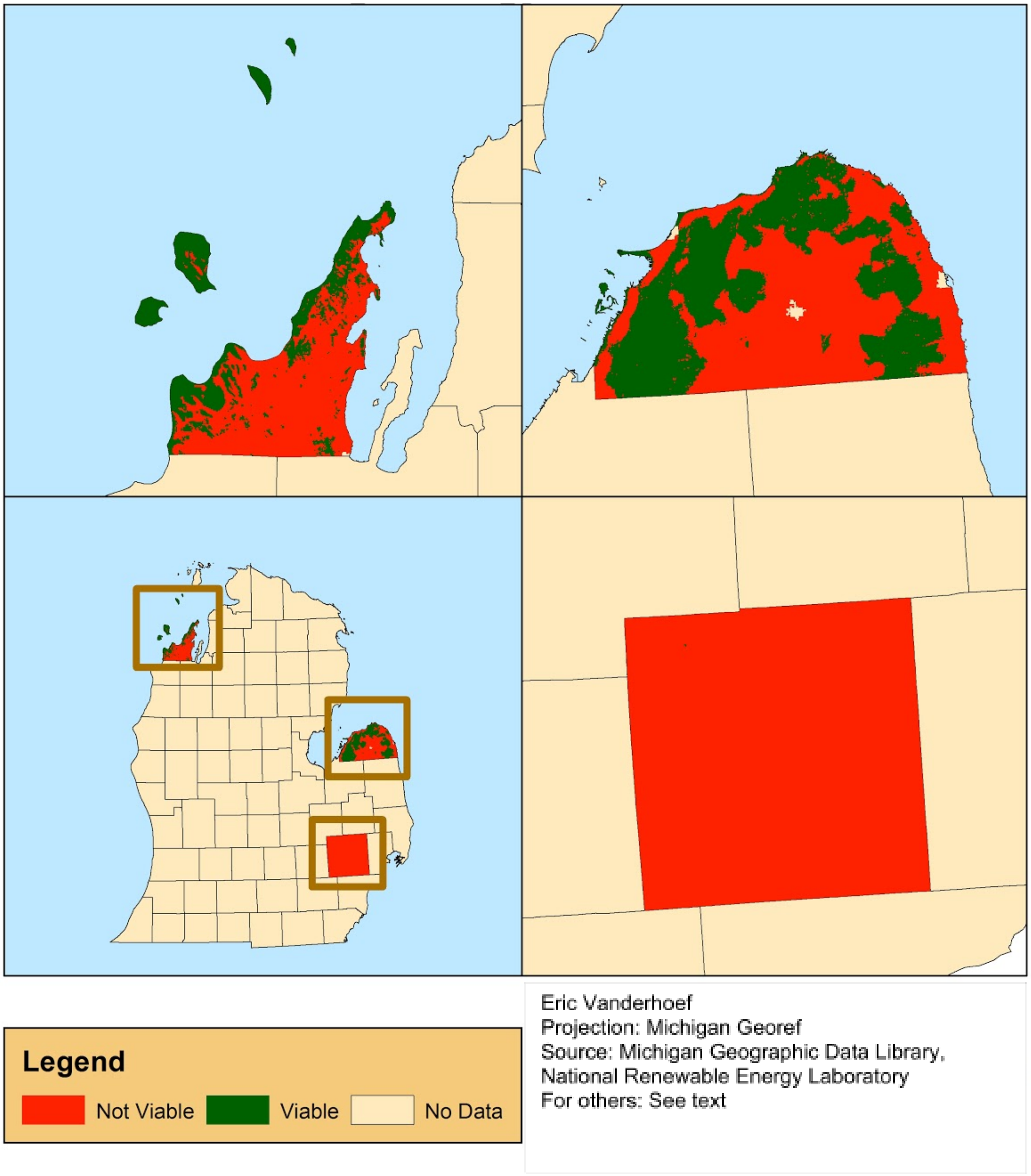
Figure 12: The above map shows viable areas in Michigan for community wind sharing of a single large residential turbine (Bergey Excel 10) in three Michigan counties.. Analysis assumes a 20-year turbine lifetime at a medium household usage scenario of 8,112 kWh/y, which is the current average Michigan household usage. The spatial variation in average wind speed allows viability of wind turbines in 40.8% of Leelanau County, 45.1% of Huron and 19.3% of Oakland county. 33.3% of total area is viable under this analysis.



Eric Vanderhoef
Projection: Michigan Georef
Source: Michigan Geographic Data Library,
National Renewable Energy Laboratory
For others: See text

Figure 13: The above map shows viable areas in Michigan for community wind sharing of a single large residential turbine (Bergey Excel 10) in three Michigan counties. Analysis assumes a 20-year turbine lifetime at a medium household usage scenario of 11,280 kWh/y, which is the current average United States household usage. The spatial variation in average wind speed allows viability of wind turbines in 32.8% of Leelanau County, 45.1% of Huron and less than .1% of Oakland county. 23.6% of total area is viable under this analysis.

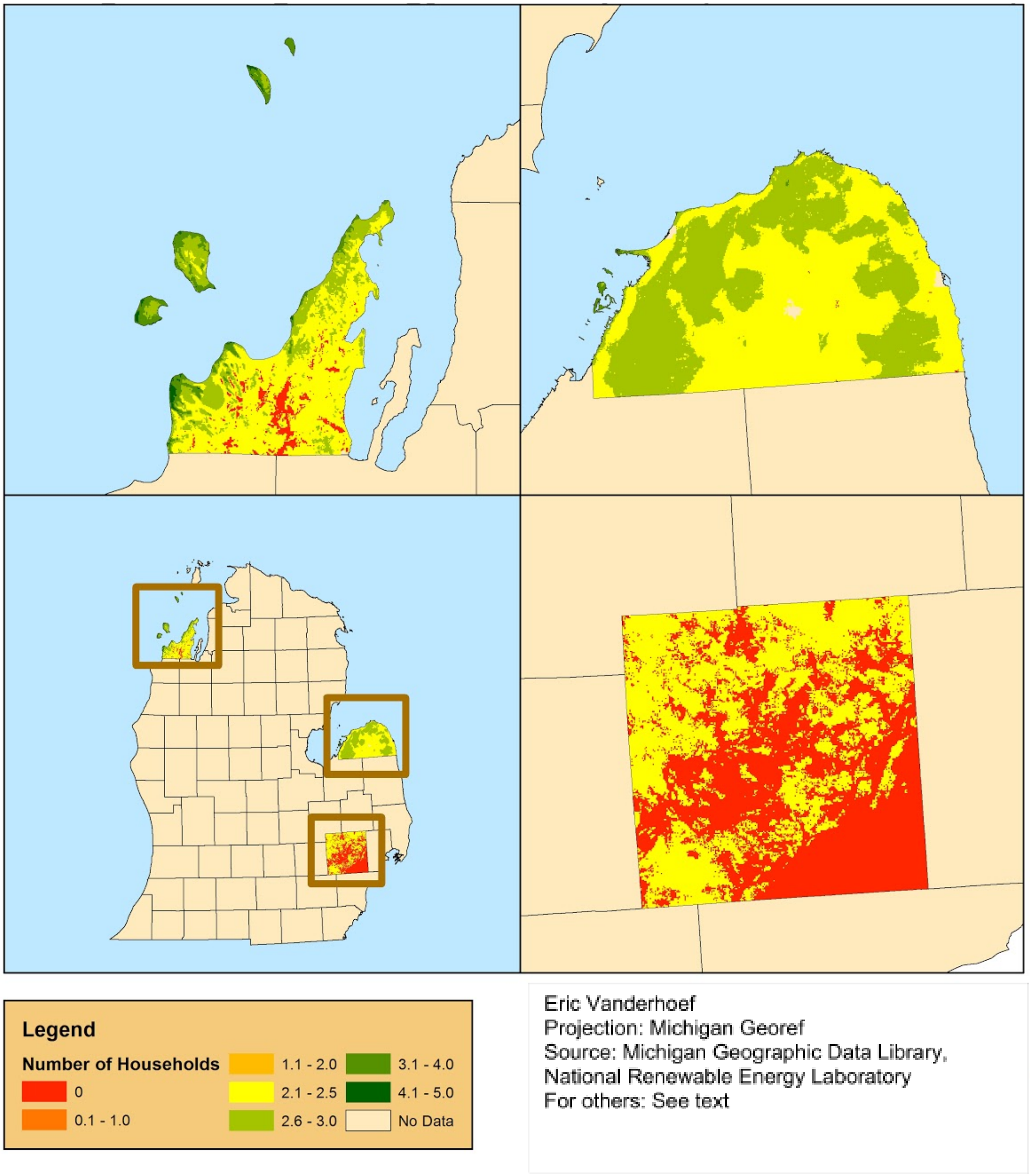


Figure 14: The above map shows number of households with Michigan's current average electricity consumption - i.e. medium energy use scenario - whose total energy consumption can be offset with the energy produced using the large turbine - the Bergey Excel 10.

Household Energy Use Scenario	County	Percent of Area Viable
Low (6,528 kWh/year) (Figure 11)	**Leelanau**	**27.9**
	Huron	**45.1**
	Oakland	**0.0**
	Total	**22.7**
Medium (8,112 kWh/year) (Figure 12)	**Leelanau**	**40.8**
	Huron	**45.1**
	Oakland	**19.3**
	Total	**33.3**
High (11,280 kWh/year) (Figure 13)	**Leelanau**	**32.8**
	Huron	**45.1**
	Oakland	**<0.1**
	Total	**23.6**

Table 8: The economically viable area of different counties as a percent of total area. Compares different energy use scenarios with the large turbine, the Bergey Excel 10.

Discussion: Section II: Wind Energy Sharing in Michigan

Economies of scale, at least theoretically, are hugely important to wind power production, as demonstrated in Table 7. This is why the Bergey Excel 10 has the largest area of economic viability - it produces energy at a cheaper cost than do the other turbines, due primarily to its larger rotor diameter (see table 7). As rotor diameter increases, wind swept area increases. Wind swept area refers to the total area over which the turbine rotors spin. Calculating the wind swept area is the same as calculating the area of a circle:

$A = \pi * (r)^2$

A = Wind swept area (m^2)
r = rotor radius (m)

So, doubling the radius of a wind turbine rotor quadruples the wind swept area, and, therefore, the power that the turbine can theoretically extract. Since increasing the turbine rotor area is less expensive in general than quadrupling the price, larger turbines tend to produce energy at a lower dollars per kilowatt hour. The importance of the wind swept area to power extraction is shown in this formula:

The power extraction by a rotor, according to Zafirikis et al. (2012) is

$P_r = ½ * d * V^3 * A * C_P$

P_r is power extraction by the rotor (W)
d is given air density
V is the wind velocity (m/s)
A is the wind swept area (m^2)
C_p is the aerodynamic coefficient.

Of this wind power function, only the aerodynamic coefficient and wind swept area can be manipulated by turbine design and rotor size (not including location of the turbine and tower height). The aerodynamic coefficient is a measure of the losses from the theoretical maximum power available from the wind, including friction losses and turbulence losses (Zafirikis et al. 2012). The aerodynamic coefficient usually ranges from approximately 0.35 to 0.45 (Zafirikis et al. 2012). While the aerodynamic coefficient does depend on turbine design, the turbines in this analysis have relatively similar aerodynamic coefficients, and size is the main factor in determining the wind energy output from each turbine.

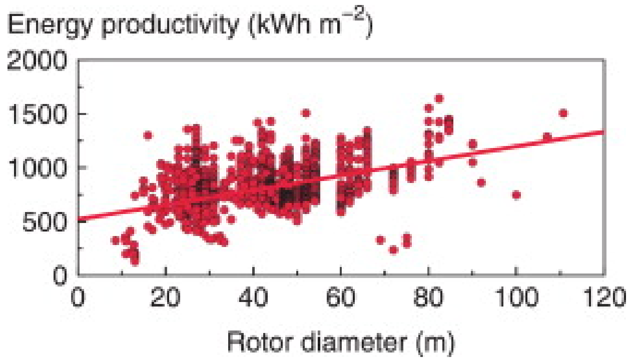


Figure 15: Demonstrates the effect of rotor diameter on energy productivity. Data are from operating turbines in a variety of locations, from the Danish Environment Ministry. (Milborrow 2012)

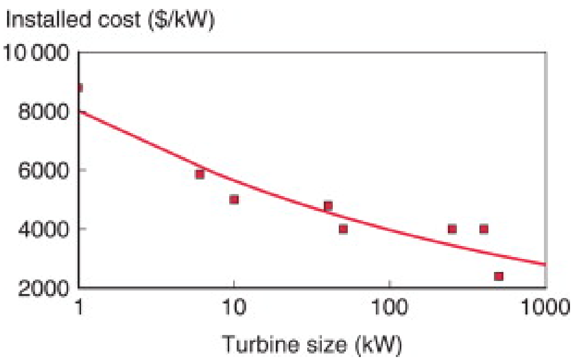


Figure 16: Demonstrates the effect of increased turbine size on reducing cost per kilowatt.

This explains why it is more economically efficient to use a larger, yet more expensive turbine and create a surplus of energy rather than using a smaller, less expensive turbine to produce less energy. Wind turbine sharing can help minimize the cost per household of installing and maintaining a turbine, while maximizing the amount of energy which is actually used by the turbine.

The next three maps, Figure 11, 12, 13, show how the viability area is affected by energy usage. As shown in Table 8, the viability of residential wind is maximized at the medium energy use scenario, rather than at either the low or the high energy use scenarios. This means that the energy provided by the utility in terms of dollars per kilowatt-hour is highest for the middle usage scenario, since the same turbine (Bergey Excel 10) is used for all values of Table 8. This is an unexpected result. One would expect the viability to be mostly uniform across the board, or to peak at either the low or the high ends of usage. After perusing the information on usage and price information, given in Table 6, I hypothesize this result is due to two factors - both relating to the complicated electricity pricing schemes used by the utility. First, the low energy scenario has a lower dollars per kilowatt-hour than the medium energy scenario because of the staggered pricing schemes used by several of the utility providers - as energy usage increases, so does the price. For example, for one aspect of the pricing scheme, Consumer's Energy charges $0.08/kWh for the first 600 kWh/month used during June-September, but increases the charge to $0.11/kWh after the initial 600 kWh. This decreases the relative cost of electricity for low energy users, which thereby decreases the viability of turbines for low energy users. This hypothesis is corroborated somewhat by showing that the two utility providers that use this graduated pricing scheme are Consumer's Energy and DTE, both of which service Oakland County, which is the county which sees the greatest change in viability under different energy scenarios. This argument, however, would predict that the high usage scenario would have the highest energy costs by far - since the amount of energy used on the "high grade" (in the Consumer's Energy example, over 600 kWh/month) is highest for the high energy scenario. The most likely explanation for why this isn't the case is because of the fixed costs associated with utility pricing. For example, DTE has $14/month of fixed costs regardless of usage. This increases the overall dollars per kilowatt-hour price of electricity for lower usage than for higher usage, which could explain why the medium energy users face a higher dollars per kilowatt-hour utility pricing than do the high energy users.

The largest assumption that the turbine sharing analysis rests on is the assumption of perfect turbine sharing. Perfect turbine sharing refers to the ability to share turbines fractionally in order to reduce costs as much as possible. For example, if a given wind turbine had an output of 20,000 kWh/yr and each household used 8,000 kWh/yr the analysis would be generated as if 2.5 households could share that one turbine to offset their annual energy needs and would split the price of the turbine 2.5 ways. This is only a fair assumption under two scenarios: First, the fractional-sharing household realizes only their fraction of energy offset and are only responsible for that same fraction of total turbine cost (in the case of this example, 20% = .5/2.5). Second, if turbine sharing became prolific, in which case households could share in many clusters - such as 5 households sharing 2 turbines rather than 2.5 households sharing 1 turbine. In this case, all households have all of their energy accounted for. If there are areas where these scenarios exist, this model of turbine sharing provides a much more viable option than do models with standard net-metering models and single-households.

Wind turbine sharing is not a new concept (Lantz and Tegen 2009). In fact, several studies have investigated the economic impacts of larger-scale (commercial, not residential) wind turbine sharing, i.e., community sharing of a local wind farm. Empirical analysis by Lantz and Tegen of the National Renewable Energy Laboratory on existing wind turbine sharing communities has shown that sharing of wind energy on a local scale has increased jobs and economic development both during the construction and maintenance of the wind power plants. The wind sharing operations in their study also exhibited a substantial return on investment. These positive effects increase with greater community ownership in wind energy sharing operations.

Local energy production also may reduce the risk of large-scale blackouts. According to Pourbeik et al. (2006), blackouts primarily occur when single events (such as failing equipment, line trips due to tree contact, overload, relay misoperation, etc.) initiate a sequence of events that, if not contained, can cause catastrophic outages across the entire grid. Such outages have occurred in the United States before. For example, the second worst blackout in history occurred in the Northeast United States in 2003, when a tree limb caused a short circuit in one part of the energy grid (Walsh 2013). Issues such as these are usually locally contained, but due to some system malfunction and human error, the blackout reached a critical mass; 50 million people lost power in 8 states and part of Ontario (Walsh 2013). The blackout lasted two days and caused at least 11 deaths and cost the economy $10 billion (Walsh 2013).

Widespread community wind energy sharing would reduce the strain on our energy grid, reducing the probability of blackouts from system overload. They also offer redundancies in the event of a failure - namely, they would still continue to power the homes in the area despite the grid collapse. In the event of a failure within the wind-sharing community, the grid would act as a backup so those homes wouldn’t be without power.

Section III: United States

After doing the Michigan analysis, I was curious how the rest of the nation compared in terms of viability of wind turbines. So, a similar analysis was conducted using information on the average energy price in each state and the wind resources in those states.

Methods: Section III: United States

The methodology for this section differs from the methodology used previously in several limited ways. These differences are addressed in the following paragraphs. See Section I for methodology related to turbine pricing, turbine energy output, and energy consumption scenarios.

Wind data at 50 m height was retrieved from the Natural Resource Energy Library (Wind Data 2005) for the contiguous United States. This data was then adjusted using the Hellman exponent formula to compute wind speed data at a 30 m level. This wind data was used with the best performing turbine in terms of lifetime dollars per kilowatt hour at each different wind power class. In this case, the Bergey Excel 10 performed the best at each speed. Each wind power class yielded a different dollar value per kilowatt hour for the lifetime of the turbine.

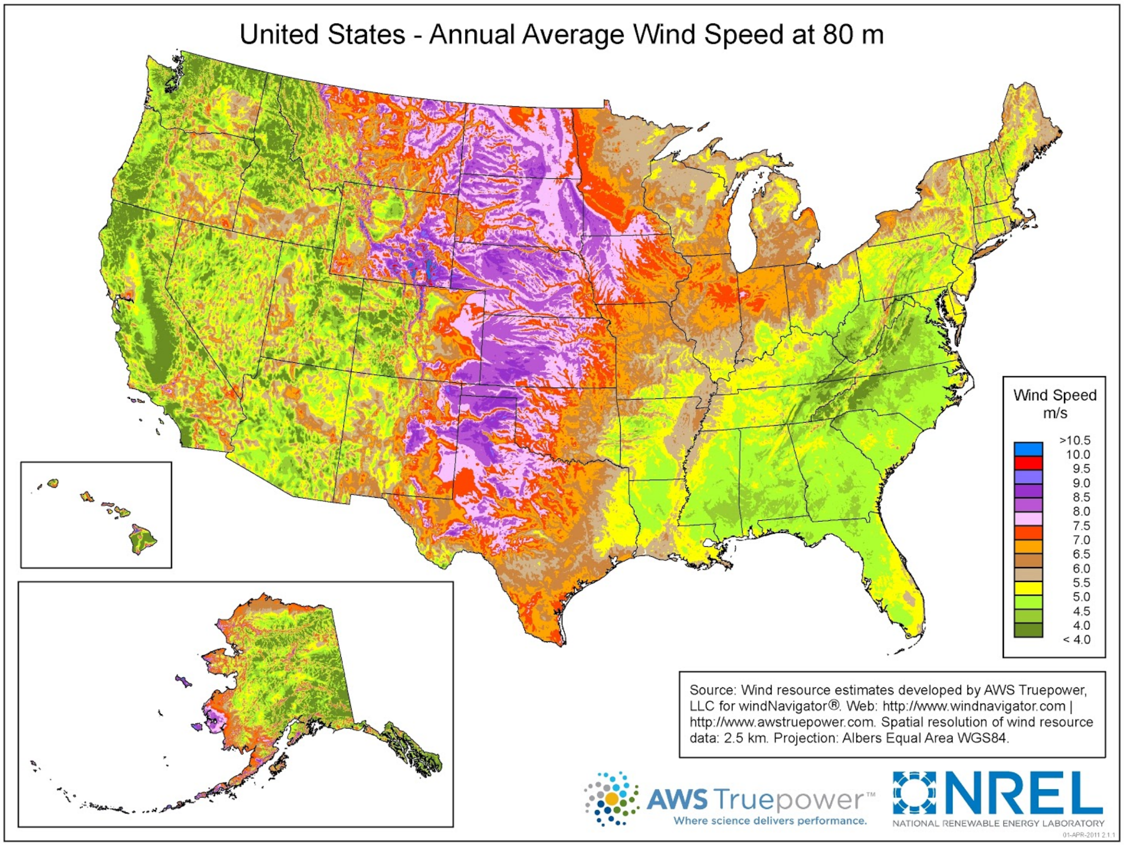


Figure 17: United States wind speed map at 80 m above ground level from NREL 2015.

Average energy prices per kWh were then found for each state and mapped (EIA, 2011). The price map and the wind resource map were then compared - areas where energy is produced more cheaply using single-home perfect-net-metering residential wind are mapped in green, and areas where energy is more cheaply produced from a power plant are mapped in red (Figure 19).

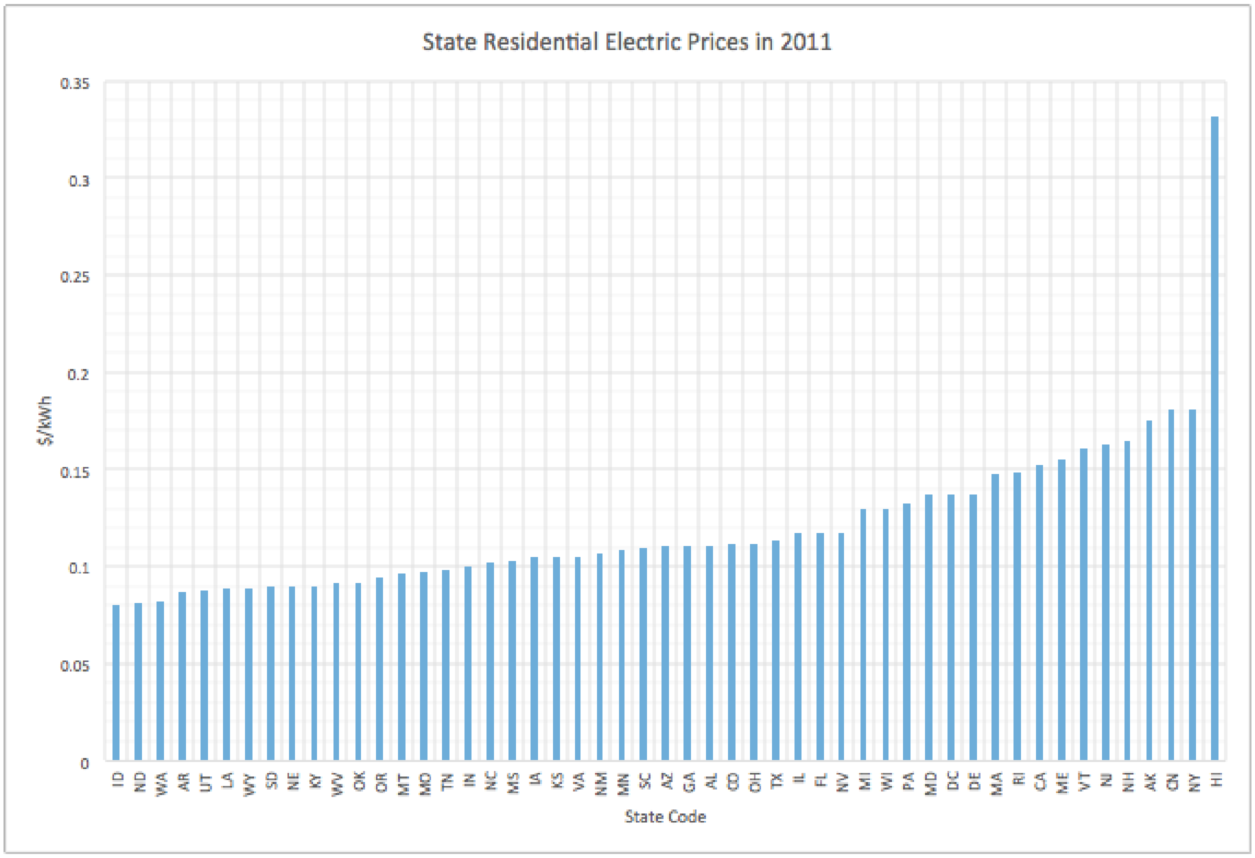
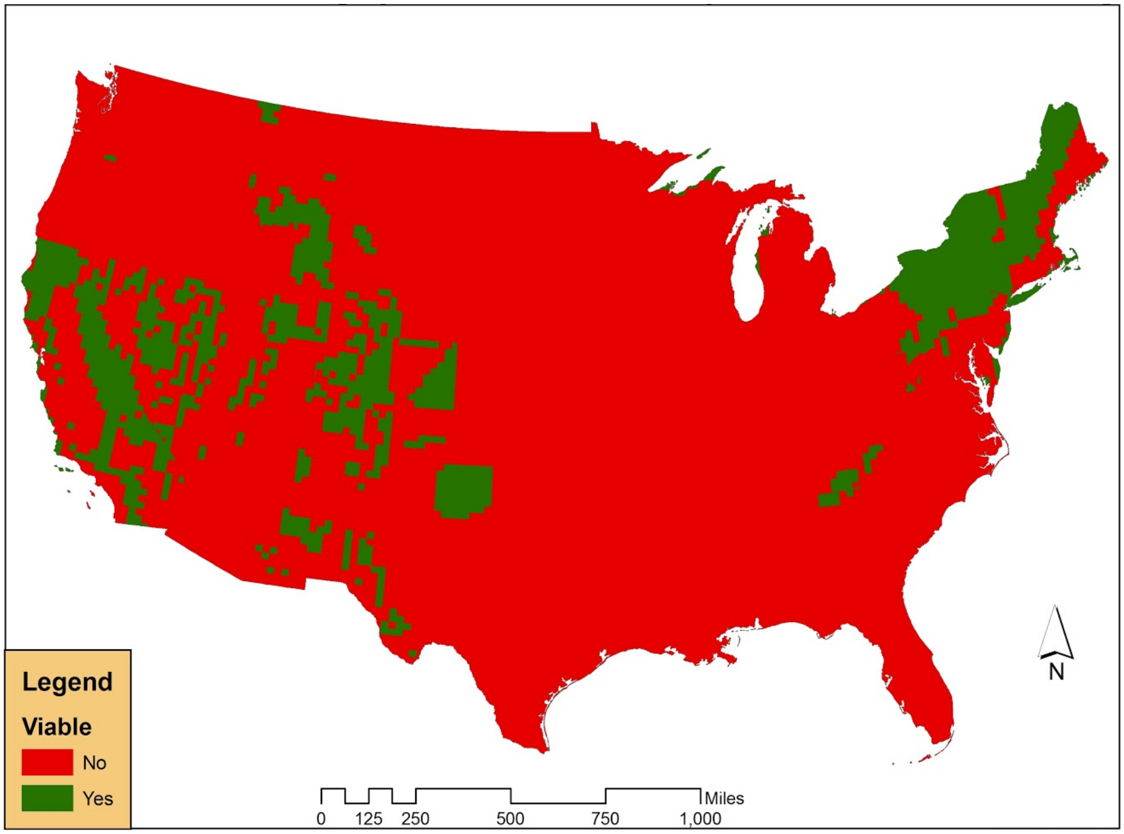


Figure 18: State electricity prices in dollars per kilowatt hour, according to EIA 2011. Michigan ranks 17th in electricity price.

Results: Section III: United States

This analysis shows large wind turbines are viable in about 13.6% of the United States (Figure 19).



Projection: NAD 1983 Contiguous USA Albers.
Source: Energy Information Administration 2011, National Renewable Energy Laboratory 2005.

Figure 19: The above map shows the economic viability of the Bergey Excel 10 in the United States based on state utility prices and wind resources. According to this analysis, 13.6% of land is economically viable for turbine use with perfect net metering.

Discussion: Section III: United States

This analysis shows the importance of energy prices to economic viability of turbines. This is especially obvious in New York. The average energy cost is the second highest in the nation (about $0.18/kWh). Even though New York's wind resources are relatively mediocre, almost the entire state is considered economically viable for wind turbines. It’s also interesting to consider the importance of price on states in the middle part of the country - from North Dakota down through the western part of Oklahoma and Texas. According to Figure 17, the best wind resources in the entire contiguous United States occur in this region. Despite all that, as shown in Figure 19, only a small portion of that area is viable, because of the low cost of energy in this part of the country. This highlights the importance of future energy prices on the viability of wind turbines. The U.S. Energy Information Administration (2015) predicts a substantial increase (~20%) in residential electricity prices in the next 25 years.

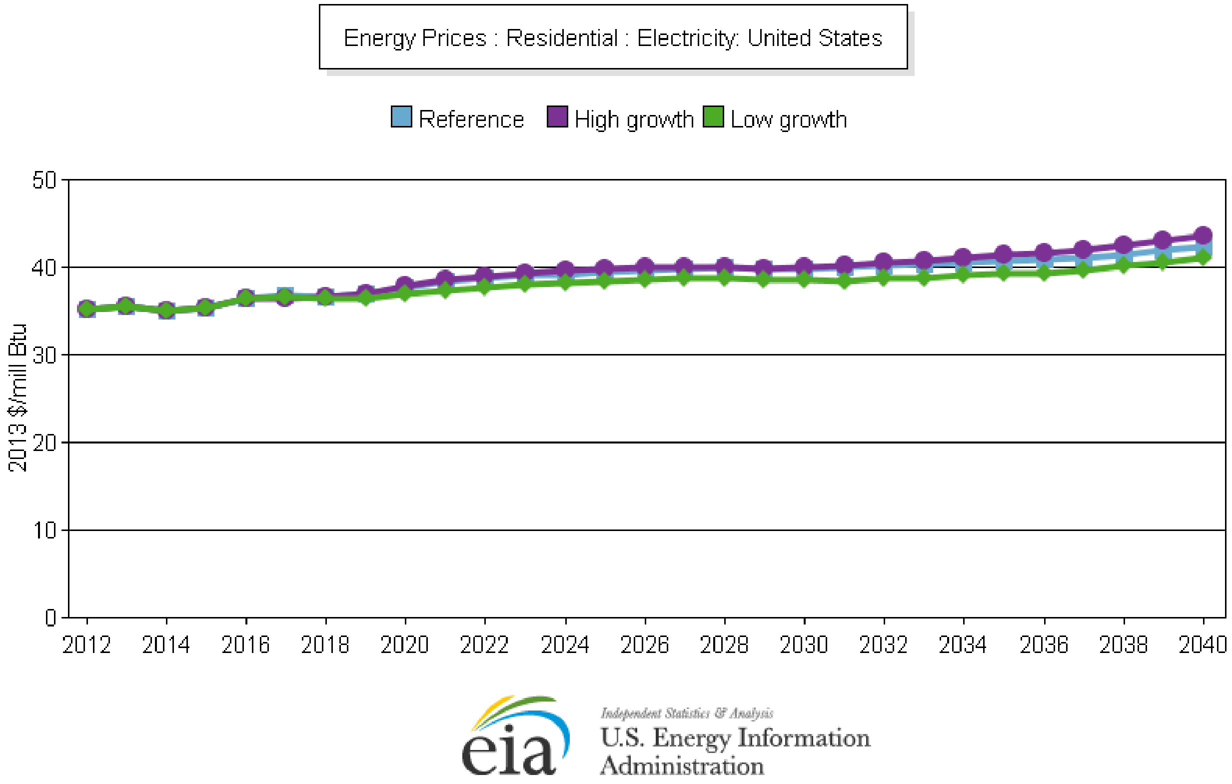


Figure 20: Shows increasing projected energy prices in the United States for residential customers. The Reference case is a projection based on a growth in real gross domestic product (rGDP) of 2.4% from 2013- 2040, with laws and regulations remaining relatively stable. The high growth scenario is if the rGDP grows instead by 2.9%. The low growth scenario is if rGDP instead grows by 1.8%.

The section III analysis hinges on several issues. First, the household average dollars per kilowatt-hour isn't uniformly distributed across the state. Several areas are isolated from the power grid or in areas where electricity generation are abnormally high - in these regions turbines may be a more viable option. At the same time, the cost analysis of turbines is very location dependent. The turbine cost and installation analysis was computed based on Michigan installation prices. However, costs can differ greatly depending on location, and remote areas are likely to be more expensive, and could therefore be less economically viable. On the other hand, if a remote area is off the grid, a wind turbine could be more economically viable than connecting to the grid. This model also uses rates set at current levels. The analysis only included the Bergey Excel 10, which was the best performing turbine in the Michigan analysis in terms of dollars per kilowatt hour over a 20-year lifespan. This analysis, however, only compared the eight turbines certified by the Small Wind Certification Council, which is only a fraction of available small wind turbines available in the market. This analysis compares price per kilowatt-hour from the wind turbine to the price per kilowatt-hour from the utility provider. As stated in the first section's discussion, this isn't usually the case.

Another shortcoming of this national analysis is that it fails to investigate state energy incentives. The only incentive included in the analysis is a 30% federal tax incentive of residential renewable energy installations. Since the turbine cost analysis was performed in Michigan, at the time of the study no incentives existed to promote wind generation at non-farming, non-small-business residences in Michigan. So, any additional state incentives would increase the area in which residential wind generation is economically viable.

General Discussion

There are several interesting results from this study. Due to the wind turbines' economies of scale, at least theoretically, bigger is better- which is why the Bergey Excel 10, the largest turbine used in the spatial analysis, was the best performer in terms of dollars per kilowatt-hour. The second is that utility pricing schemes can make medium energy consumers pay the most per kilowatt-hour compared to those households which consume more or less than they do. This causes the economic viability to peak in those medium use households, holding all else equal. The third is that the price of electricity is a hugely important part of the economic viability analysis, and, in some areas, is a more important factor than the wind resources. These findings should inform future efforts to increase the usage and improve the economic viability of wind generation.

Climate Change Legislation

Policy makers in the United States have been largely unsuccessful in the regulation of greenhouse gas emissions (GHGs). Congress has failed to pass any comprehensive climate change legislation (Plater et al. 2010). However, in the 2007 case *Massachusetts* v. EPA, the Supreme Court has ruled that the Environmental Protection Agency has the statutory authority to regulate climate-change-inducing Greenhouse Gas Emissions (Plater et al. 2010). In 2009, the EPA found that GHG emissions constituted an endangerment to public health and welfare (Plater et al. 2010). Despite passing several proposals for the reduction of GHG emissions from power plants, the EPA has yet to enforce a lasting comprehensive plan which regulates the emissions of greenhouse gases (Plater et al. 2010). When they, or some other policy makers do, however, we will likely see huge increases in the economic viability of residential energy systems, as shown in this analysis. New regulation will increase the cost of energy to a level where, as seen in the United States analysis, it will be cheaper in many places to produce energy from a home wind turbine installation than to purchase energy from an electric grid which overarchingly depends on GHG-emitting fossil fuel combustion.

Renewable Portfolio Standards and Net Metering

The following map shows the 30 states which have adopted renewable portfolio standards.

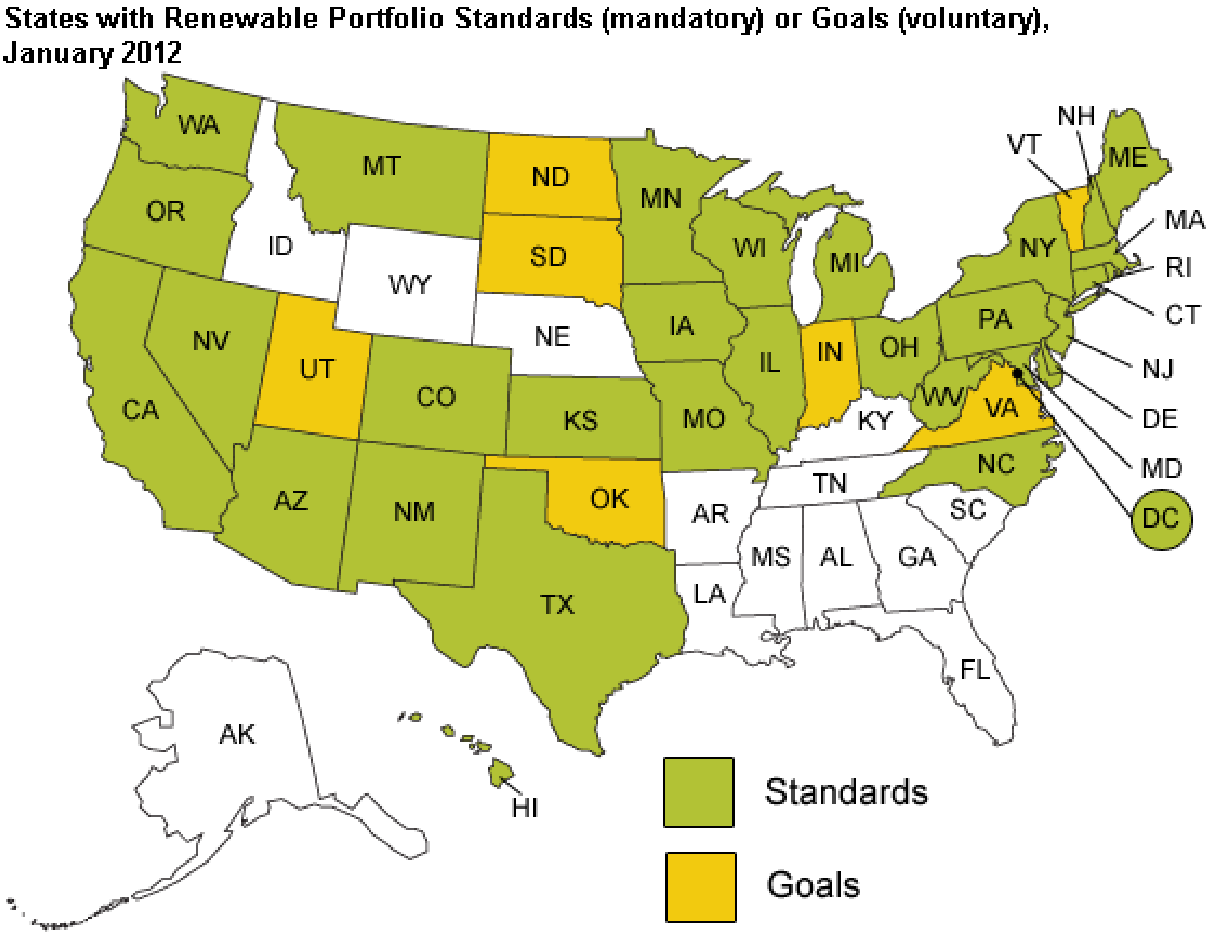


Figure 21: Renewable Portfolio map from EIA (2012). Thirty States and the District of Columbia have mandated renewable portfolio standards and another seven states have set goals for renewable energy adoption in their state.

The widespread adoption of these standards highlights the commitment many states have made to renewable energy. Still, no states currently have an energy policy which repays residential electric producers for all their energy production at the retail rate. In the absence of this perfect net metering, the payback time for wind turbines increases substantially, considerably decreasing the incentive to buy a wind turbine. Different states have different policies regarding excess electricity produced by residences. These different policies are laid out in the following table.

Number of States	Restrictions on Net Metering Rollover
10	Allow lifetime rollover at retail rates
10	annual rollover paybacks at wholesale rates
14	rollover for 12 months then all excess is donated back to the utility
10	monthly pay back at discounted rate
6	no statewide policy on rollover restriction

Table 9: Net metering rollover policy by state, from Auck et al. (2014).

There are equity issues with net metering. The issue of net metering has been debated hotly, and will continue as residential energy systems become more and more viable (Satchwell et al. 2014). Net metering has been criticized as placing an unfair burden on utility customers who aren't participating in net metering. The argument is that utilities are responsible for maintaining and increasing the size of the electricity grid, and that net metering customers benefit from the grid without having to pay their share, leaving other customers to pick up the tab. One study, by Satchwell et al. (2014) used a financial model to investigate net metering equity issues under different market penetration rates of solar panels. He found that a 2.5% market penetration by residential solar causes a price increase of about .1% for utility customers. If that market penetration increases to 10%, the customers have to pay about 2.5% more. Although the price increases are moderate, these results taken superficially do seem to support the claims made by critics of net metering. However, the market penetration modeled in Satchwell et al. (2014) is much higher than current levels - about .2% market penetration in the United States. In Michigan, two of the largest utility providers - Consumers Energy and DTE, net metering capacity is 0.014% (as in 14/100,000) and 0.06% of total capacity, respectively (Net Metering and Solar Energy Report 2014). The capacity of net metering pales in comparison to the utility's electric capacity. If the results from Satchwell et al. (2014) can be applied, the increases in price for non-net-metering customers would be incredibly small. Further, increasing residential energy production reduces the strain on the energy grid, which decreases the likelihood of blackouts for **all** consumers (Pourbeik et al. 2006). It also reduces the need to invest in new power plants.

In addition, even if the issues associated with net metering are unfair to consumers, especially at higher levels of market penetration, they may be necessary. The equity issues associated with current energy production and climate change are far worse.

Residential vs. Commercial Wind Turbines

As time passes, wind energy may become even more viable. According to the 2013 wind market report (Gerrity 2013), commercial wind turbine prices per kilowatt hour have declined dramatically since 2008. The price reductions have been coupled with better turbine technology. If these changes in the commercial wind market are also applicable to small-scale wind, we could expect to see further decreases in turbine price, increasing the economic viability in these areas. Increases in the residential wind turbine market could lead to increased competition among suppliers/ installers/ maintainers of wind turbines, which can increase the viable area by further driving down the lifetime costs of wind turbines. In addition, this analysis was relatively conservative in the cost analysis and lifetime estimates of wind turbines - for example, a 20-year lifespan was used for all turbines, while some advertised 30-50 year lifetimes. A decrease in the price or increase in the lifetime of a wind turbine would substantially increase the viable area.

In addition to the reductions in price per kilowatt hour, since 2012, wind capacity has risen sharply, and is projected to continue growing (Conti and Holtberg 2015) (Figure 22).

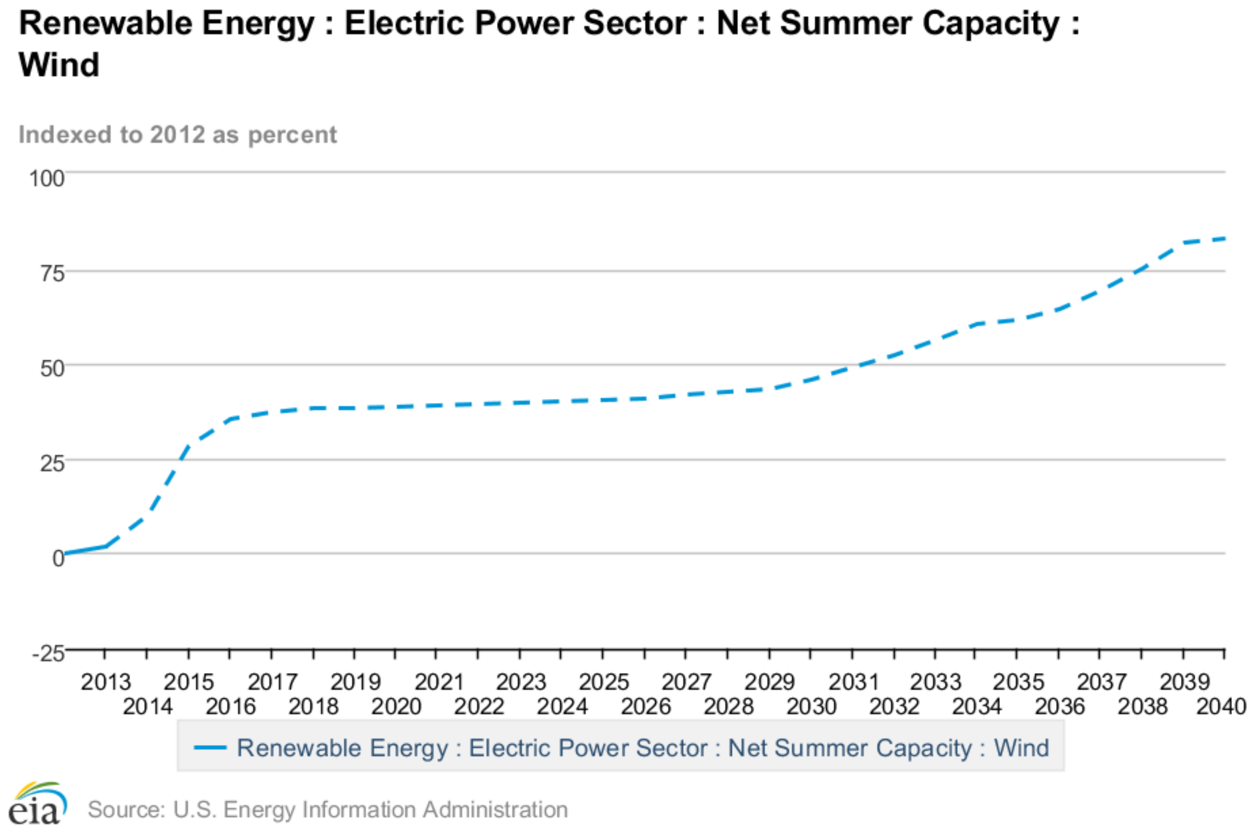


Figure 22: Net capacity of wind is projected to rise in the next 25 years (Conti and Holtberg 2015).

This paper primarily investigated small wind turbines to be used in grid-tied households. However, the benefits of small wind turbines are much greater in many areas, especially areas which are removed from power lines, like farms and islands. In such areas the turbines would no longer be competing with large power plants but instead against household diesel or gas generators. Obviously the cost of generator energy is dependent on the cost of diesel or gas, and especially with rising fuel costs, this could greatly increase the economic viability of small wind turbines.

Wind Leasing

One interesting new program is from United Wind (http://unitedwind.com), it's called a wind lease. The wind lease works by allowing customers to lease a wind turbine from United Wind. United Wind chooses which sites are most fit for residential wind turbines and contacts customers, who then rent the turbine from United Wind. United pays for all costs associated with the turbine, including ongoing maintenance, and only takes rent at a rate lower than household energy savings. The system makes turbine ownership a much more realistic option, especially for users who can't afford the substantial cost of purchasing and installing a new turbine.

Problems with Residential Wind

It's important to remember that there are some significant problems associated with wind power. The main environmental impacts of wind power are noise, visual impacts, and impacts on wildlife (Konili, Kaldellis 2012).

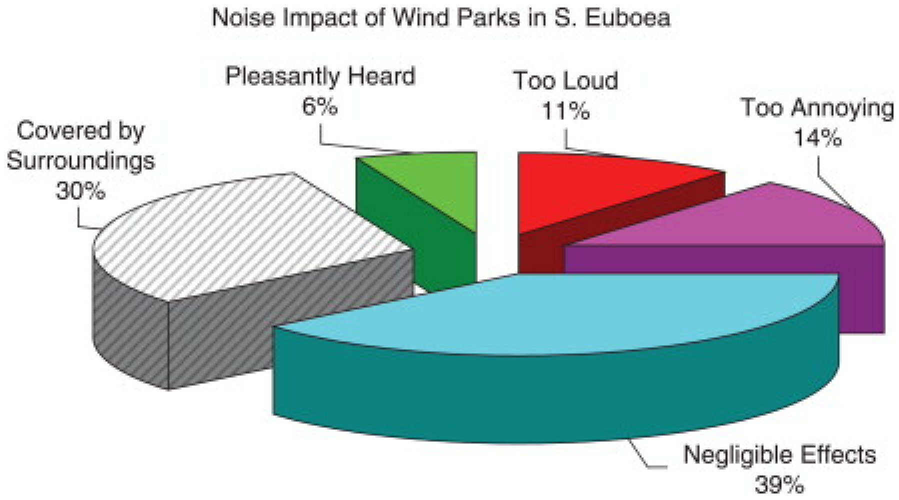


Figure 23: Public opinion about noise impact of commercial-sized wind farms (Konili, Kaldellis 2012).

Noise is one of the most cited concerns about wind energy. However, modern wind turbines create very little noise compared to their predecessors. Unfortunately, there is relatively little research on the subject of small wind turbines noise; most of the literature is instead about large wind farms. One study from Taylor et al. (2012) investigated community perception of noise from wind turbines around small and micro wind turbine installations (like the ones in this study). Taylor et al. found that 54.4 dB of sound were emitted from a 5kW turbine at a 12-m distance - this is about equivalent to being 100 m away from a car traveling at 40 mph (Konili, Kaldellis 2012). She also found that people who have a negative opinion of wind power tend to perceive more noise from the wind turbines near which they live.

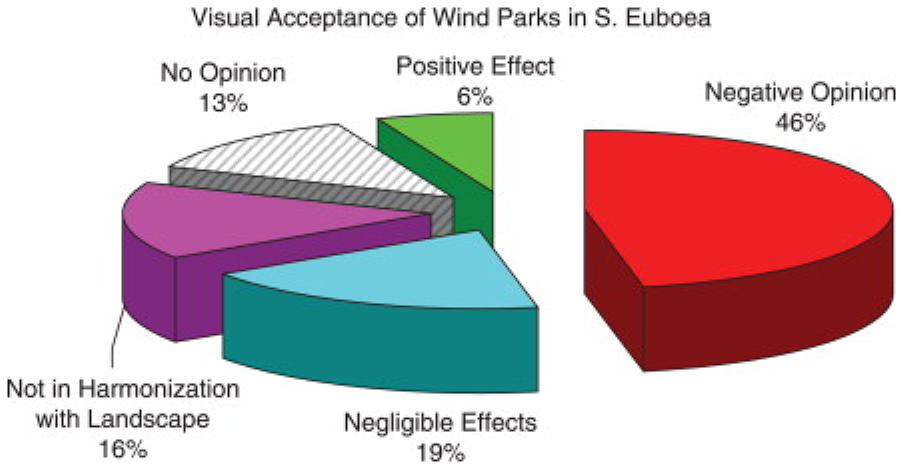


Figure 24: Public opinion on visual impacts of a commercial wind farm (Konili, Kaldellis 2012).

There is very little research on the visual impacts associated with small wind turbines. One concern about larger scale wind installations is the "flicker" caused by the wind turbine blocking sunlight. This flicker can irritate people and can cause detrimental effects to their health. Although small scale wind turbines have a smaller rotor diameter with which to block sunlight, they are typically closer to neighbors than commercial wind farms. This shadow flicker issue can be avoided by changing turbine siting. The sound and visual impacts should be taken into account before any wind installation is built.

There is also some concern of wildlife impacts from wind energy. Again, little research has investigated this issue with small scale wind projects, but larger scale wind projects have been the study of some scientific scrutiny. Konili and Kaldellis point out the issues with criticizing wind energy for bird health when other forms of energy are likely to have a much larger impact on the well being of all species including birds. Wind turbines account for .0003% of all human-related bird deaths (National Academy of Sciences 2007). However, wind turbines are responsible for some bird deaths, and measures should be taken to reduce, as much as possible, the effects of the turbines on the birds, such as avoiding migratory paths.

Recommendations

As stated earlier in the discussion, perfect net metering is equivalent to standard net metering except that perfect net metering compensates households immediately for the electricity they generate, whereas standard net metering compensates (in the form of offset electricity costs) over a long period of time. Under standard net metering, households that are tempted to buy a wind turbine may be discouraged from doing so because they won't realize the full benefit from their purchase unless they stay at their house for many years after their turbine has stopped functioning (because they will still have the electricity credits to use). In addition, the standard net metering system encourages increasing energy consumption in households which produce more energy than they consume, in order to increase their energy savings. In light of Michigan's commitment to renewable energy production demonstrated by their 2008 Renewable Portfolio Standard, which stipulated that Michigan electric providers meet a 10% renewable energy standard by 2015 (Quackenbush 2015), I recommend that states investigate switching from standard net metering policy to perfect net metering and turbine sharing. As mentioned previously, both perfect net metering and turbine sharing encourage residential wind turbine usage by expediting the rate at which energy savings are received by the household. This decreases the portion of an area's energy which comes from fossil fuels while decreasing the stress on the energy grid. A change in net metering policy would also improve the viability of other residential energy generation, such as solar panels. The equity issues of net metering were mentioned briefly in the discussion section.

Conclusion

The energy system in America needs change. Coal energy accounts for 39% of current energy production in the United States. The extraction and combustion of coal causes huge costs to society, which will only increase as we feel more effects of climate change. Large electricity systems increase the risk of catastrophic grid failure, which can lead to billions in damage. Policy makers have the tools to address these issues by facilitating small scale renewable energy systems. Already, small wind turbines are economically viable in a large portion of Michigan and the United States, and there are ways to further encourage their proliferation. Utility pricing is shown in this analysis to have huge effects on the investment potential of turbines - measures should be taken to disincentivize the use of coal and energize the switch to renewable energy.

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