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Technical Note

Evaluating potential renewable energy resources in Poultney, Vermont: A GIS-based approach to supporting rural community energy planning

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ABSTRACT

The current electricity infrastructure in the United States relies on a centralized distribution network that carries a heavy carbon footprint and is susceptible to disruption and failure. Rural communities are more susceptible to longer term interruption and should strive towards a local distributed energy model. This transition will require municipalities to engage with and seek input from community stakeholders. This paper describes a possible model for supporting rural community energy projects using a Geographic Information System (GIS), which was used to develop an inventory of energy resource potential in a rural Vermont town for biomass, wind, and solar technologies.

1. Introduction

Household energy consumption for appliances, home heating, and transportation in the United States continues to rely on non-renewable fossil fuels extracted and processed at facilities distant from the end user [1] (Fig. 1). This scenario is problematic for rural communities with low population densities that rely on energy networks utilized by more populous areas and thus susceptible to failure [2–5]. Rural communities may experience lengthy delays to restore the flow of vital energy supplies when critical infrastructure fails. Efforts will focus first on restoring access to energy resources to the most densely populated areas and least costly [6,7]. The situation is analogous to power outages, as those customers at the end of a distribution line are typically the last to have power restored.

Reducing reliance on fossil fuels and minimizing the distance energy is transported into rural areas via power lines, pipelines or vehicles could decrease the production of greenhouse gases (GHG) and other emissions impacts, lower long-term costs and promote greater energy independence [8–16]. Unfortunately, redesigning national energy infrastructures to improve efficiency and reduce GHG emissions will likely take time, economic incentives, and planning [5,17]. However, the transition to a more distributed energy production and delivery system can be facilitated by pursuing local community energy management (CEM) or community energy planning (CEP) strategies [18–21]. Although rising energy prices and the reality of a changing climate are global issues, embracing these locally-based strategies can empower communities to increase energy security, lower GHG emissions, minimize energy losses during transport, lower energy costs over the long-term while buffering market volatility, create local economic development opportunities, and provide independence from increasingly strained energy networks [1,15,19,22].

Many local governments and communities throughout the United States have recognized the value of energy independence and have begun to embrace CEM and local energy committee strategies. In Vermont, State Statute provides explicit authority to municipal governments to appoint an energy coordinator and establish a town energy advisory committee. Approximately 75 towns throughout Vermont have used this authority to formally develop town energy committees, which are supported by the Vermont Climate Action Network (VECAN), a consortium of non-profit organizations dedicated to improving local energy sustainability. VECAN supports a CEM approach to planning and encourages committees to first develop an inventory of local energy demands and potential renewable energy resources [12,19,22,23]. Using these guidelines we initiated the Poultney Community Energy Project (PCEP), a joint effort between Green Mountain College, the town of Poultney, and various community organizations.

The 2005 Poultney Town Plan indicates strong support for energy efficiency and increased use of local, renewable forms of

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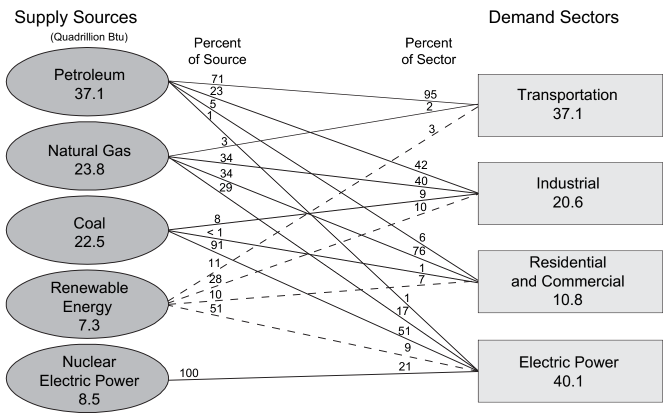

Fig. 1. Diagram illustrating the global dependency on fossil fuels within the overall energy supply sector and where each supply source is primarily consumed adapted from EIA [47].

energy. However, the plan does not specify any mechanisms to promote greater energy efficiency or to encourage the use of renewable energy. To address this challenge, the PCEP was charged with analyzing current energy use patterns within the town and providing a baseline inventory of local, renewable energy resources using a geographic information system (GIS).

GIS-based analyses are used to characterize spatially-related variables within a digital environment and help produce informative visualizations. GIS-based assessments have been used to evaluate renewable energy sources in developing Latin America, China, and Taiwan [24–26], solar radiation potential in rural India and Greece [27,28], community scale solar potential in the UK and California [29,30], characterize site locations for wind farms [31,32], and manage community water resources [33,34].

Many of the same ideals associated with CEM were integrated into GIS planning practices and helped support the emergence of participatory GIS (PGIS) in the mid-990s [35]. PGIS provides spatially-dependent tools and visualizations that help inform community stakeholders during decision making processes. Jankowski [33] provides an historical summary and describes the current status of PGIS with respect to community-based decision making. Fundamentally, PGIS requires input from local community members to better inform the planning process. This information may be collected using questionnaires tied to paper maps or web-based interfaces [31,33,34,36]. Following these examples, the Poultney Community Energy Project produced baseline visualizations that could be used to solicit information from stakeholders, better inform a town energy committee and support a CEM or PGIS approach to community decision making.

Table 1
Summary of percent in-state and out-of-state energy sources secured electric power utilities in Vermont.

Source of Electricity	Percent of Total	GWh Delivered
In-state Sources (50.2%)		
Vermont Yankee	35.5	2131
Instate Hydro	9.2	554
McNeil Generator	4.9	297
Instate Thermal	0.6	34
Out-of-state Sources (49.8%)		
Hydro Quebec	28.2	1694
Other Purchase	20.4	1226
New York Power Authority	1.2	73

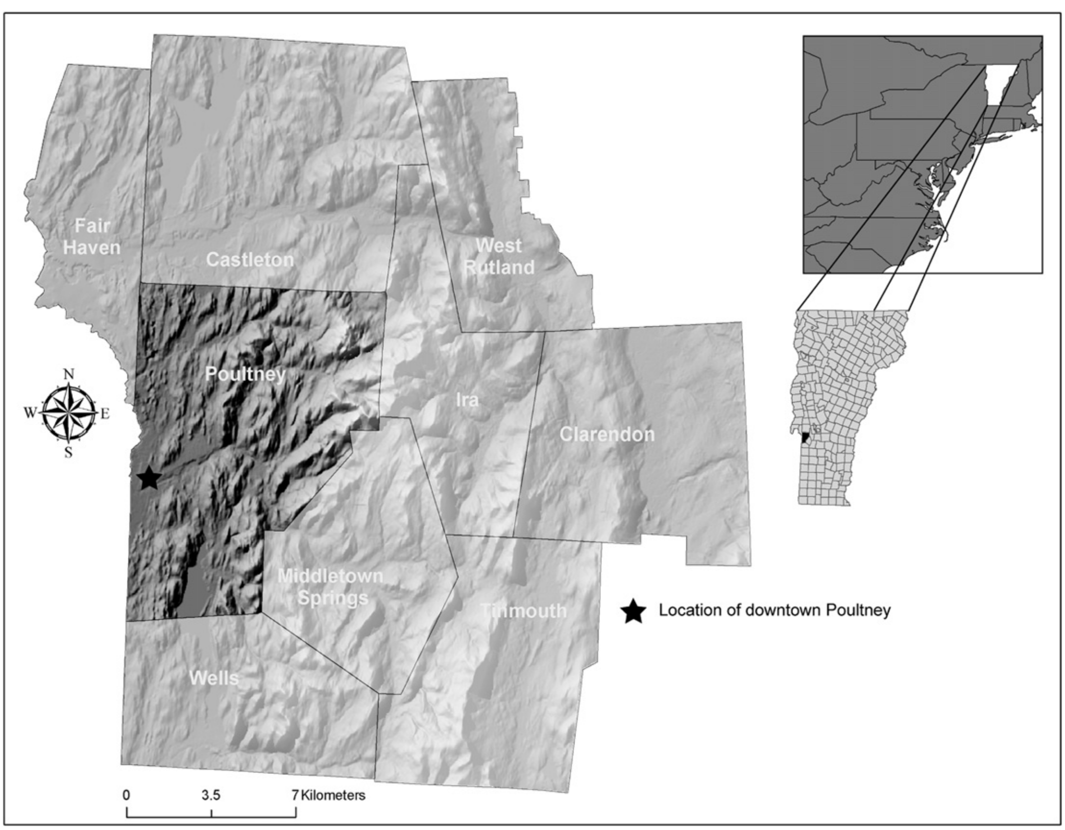

Fig. 2. Shaded relief map depicting location of study area in southwestern Vermont.

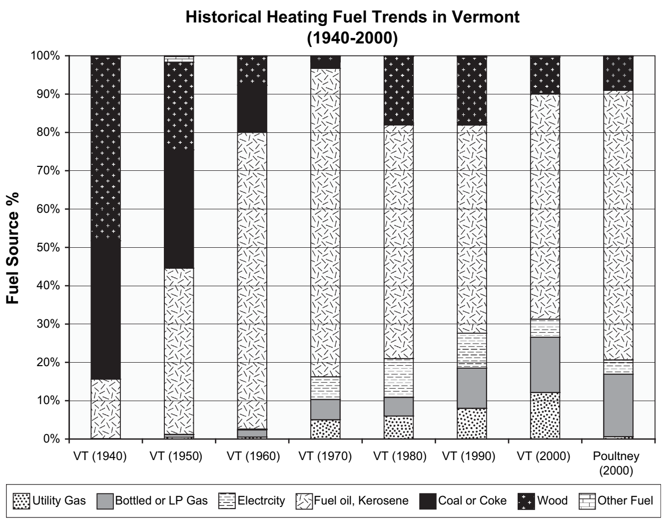

Fig. 3. Temporal variations in fuel sources to provide space heating in Vermont from 1940 to 2000 [44].

Table 2
Estimated annual household energy expenditures for Poultney residents.

Energy Type	Amount Consumed Per Year	Average 2008 Price	Estimated 2008 Costs
Home Heating Oil	779 gallons	$3.50[b]	$2,727
Electricity	6,840 kWh	$0.1432/kWh[c]	$980[a]
Gasoline	810 gallons	$3.26[d]	$2,640
Total			$6,347

[a] Does not include monthly service charge.
[b] Vermont Department of Public Service.
[c] EIA [45].
[d] EIA [46].

2. Study site characterization

2.1. Location and history

The town of Poultney is located in a north-south trending valley of the Taconic Mountains in southwestern Vermont (Fig. 2). It is an historic town that supports a population of approximately 3633 and is characterized by an aging building stock typical of rural New England towns [37]. Of the 1673 housing units in Poultney, 62% were built before 1960 and many of the buildings date to the mid-1800s.

Household energy use can be divided into three categories: electricity, space heating, and transportation. Total energy consumption (in BTUs) in Vermont is highest for electricity (~40%), transportation (~33%), and home heating (~27%) [38]. Electricity is used to provide lighting, power home appliances and to a lesser extent electric heat. Energy used for transportation in rural areas often represents an unavoidable expenditure for households with long commutes to work [39].

2.2. Energy use patterns in Poultney

To meet these demands, residents and business in Vermont are largely dependent on energy sources produced out-of-state. Vermont imports all petroleum-based energy, is one of two states in

Table 4
A summary of data sources, assumptions and reclassification decisions for wind power development.

Wind Potential		
Primary Data: • 30-m U.S. NED DEM[a] • 50-m NREL wind potential[c] • 30-m Canopy Height[d] • E911 building locations[b] • Vermont Town boundaries[b] Derived Data: • Slope	Assumptions: • Slopes should be less than 60° [32] • Elevation is best between 600 and 1050 m [52] • Viewshed calculated using a Clipper Wind power 2.5 MW C96 turbine with a hub height of 80 m • Vegetation height layer accurately represents canopy variations • Viewshed examples assume utilization of areas with best WPC	Wind Power Classification: • None = 0 • Poor = 1 • Marginal = 2 • Fair = 3 • Good = 4 • Excellent = 5 • Outstanding = 6

[a] Obtained from National Elevation Dataset (http://seamless.usgs.gov/index.php).
[b] Obtained from Vermont Center for Geographic Information (http://www.vcgi.org/).
[c] Obtained from National Renewable Laboratory (http://www.nrel.gov/gis/data_analysis.html).
[d] Obtained from National Biomass Carbon Dataset 2000 (http://www.whrc.org/nbcd/index.htm).

Table 3
A summary of data sources, assumptions and reclassification decisions for infrastructure and biomass land development.

Energy Infrastructure and Biomass Potential				
Primary Data:	Assumptions:	Land Use Reclassification Codes	Biomass	Structures
• 30-m U.S. NED[a]	• Land could be used for energy cropsor wood-based products	Brush	3	3
• 30-m U.S. NLCD[b]	• Slopes should be less than 20° forease of cultivation and access	Water	0	0
• VT Town boundaries[c]	• Reclassification indices indicate: 0 = none, 1 = moderate, 2 = best.	Barren Land	2	3
Derived Data:		Residential	1	1
• Slope		Commercial	0	1
		Transportation & Utilities	0	1
		Other Agricultural Land	3	2
		Broadleaf Forest	2	1
		Coniferous Forest	2	1
		Mixed Forest	2	1
		Forested Wetland	0	0
		Non-Forested Wetland	0	0
		Row Crops	3	1
		Hay/Pastures	3	1

[a] Obtained from National Elevation Dataset (http://seamless.usgs.gov/index.php).
[b] Obtained from Multi-Resolution Land Characteristic Consortium (http://www.mrlc.gov/index.php).
[c] Obtained from Vermont Center for Geographic Information (http://www.vcgi.org/).

Table 5
A summary of data sources, assumptions and reclassification decisions for utilizing solar energy.

Solar Potential	
Primary Data: • 30-m U.S. NED DEM[a] • 30-m Canopy Height[c] • 0.5-m Orthophoto[b] • Vermont Town boundaries[b] Derived Data: • Aspect	Assumptions: • Installation area was set to 25% of roof area [26] • Shielding effects of adjacent buildings and vegetation were not quantified • Solar radiation model is realistic representation of insolation

[a] Obtained from National Elevation Dataset (http://seamless.usgs.gov/index.php).
[b] Obtained from Vermont Center for Geographic Information (http://www.vcgi.org/).
[c] Obtained from National Biomass Carbon Dataset 2000 (http://www.whrc.org/nbcd/index.htm).

the U.S. without a coal power plant, and approximately 50% of the electricity consumed in Vermont is generated out-of-state (Table 1) [40]. Vermont is part of the integrated New England power grid managed by a central operator known as the Independent System Operator of New England, based in Holyoke, Massachusetts. The New England grid is a complex system of interconnected plants that delivers power over great distances to regional providers, which then supply households and business throughout the region.

Central Vermont Public Service (CVPS), a regulated monopoly provider, serves the electricity needs of Poultney residents. The CVPS power supply mix is similar to the overall supply mix in Vermont (Table 1). Total electricity consumption in Poultney has not varied significantly over the past five years; the town's average consumption is approximately 20,000 MWh of energy each year. The commercial sector in Poultney, which includes retail businesses, slate quarries, and manufacturing, consumes approximately 20% less electricity than the residential sector. The average household in Poultney consumed approximately 570 kWh per month in 2007, which was slightly higher than the 560 kWh consumed in 2003 based on data provided by CVPS [Personal communication].

The heating season in Vermont spans from September to April, with just over 1200 heating degree days. Poultney residents have a limited number of home heating fuel options: electricity, fuel oil, propane, and wood (either cordwood or pellets). In other regions of Vermont and the United States, natural gas is the preferred choice for home heating. Natural gas is not an option in Poultney because a natural gas pipeline does not service the region. According to the U.S. Census [41], ~70% of Poultney households heated their homes with oil, ~16% used propane and 19% used a wood derivative. Historical data indicate the national trend towards increased consumption of fossil fuels for space heating, which is also reflected in changes over time in Vermont regarding home heating choices (Fig. 3). However, residents have limited fuel options for transportation given the rural nature of the region.

The rural landscape of Vermont and lack of a well-developed public transportation network requires residents to drive private vehicles. Roughly 30% of the total energy consumed in Vermont is related to personal and commercial transportation [38]. The average daily distance driven in Vermont in 2001 was 36 miles and the total average annual distance driven was 12,640 miles [42]. Based on data from the 2000 Census, over 50% of Poultney households reported having two or more vehicles, 76% of workers 16 years of age and older commuted alone to work and just 5% of Poultney workers 16 years of age and older reported they work from their home [43]. The geographic constraints of living in a rural community have tied Poultney residents to the whim of rising energy prices associated with household energy consumption.

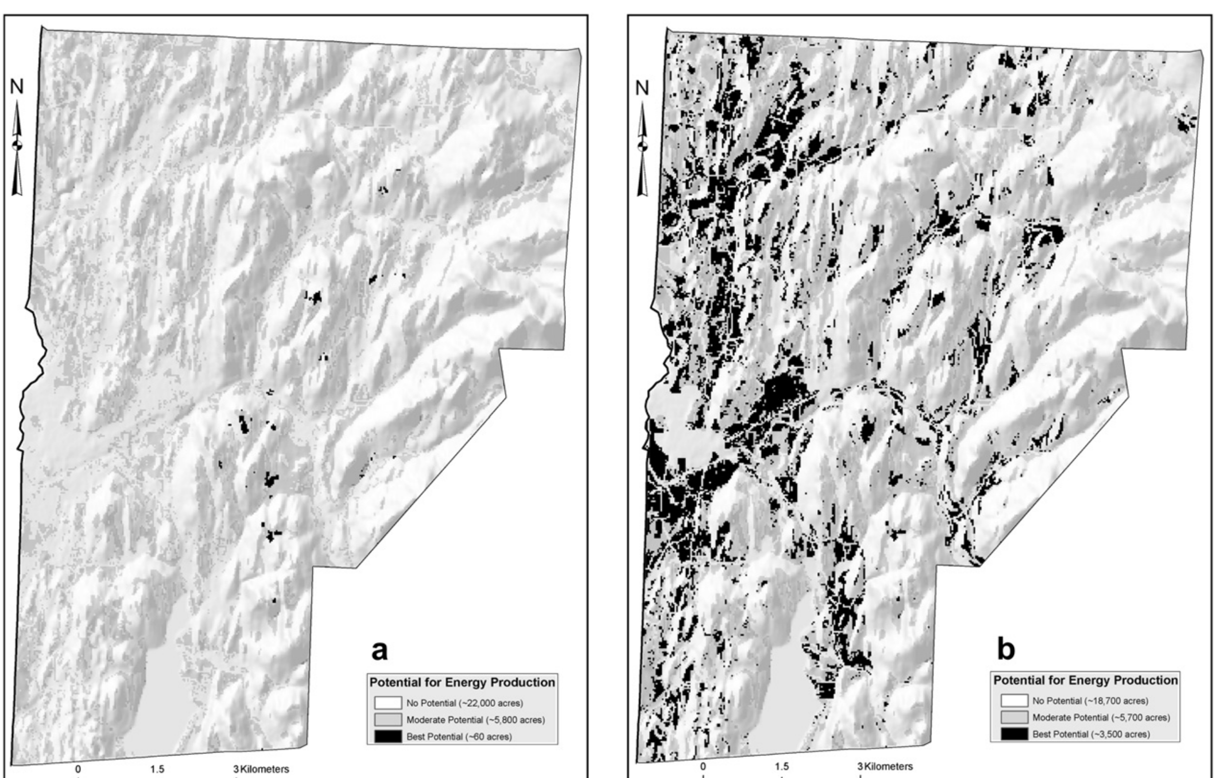

Fig. 4. Comparison of land use potential for general infrastructure construction (a) and biomass-based energy cultivation (b).

Table 6
A summary of the range in visual impact for idealized turbines sited in the areas with best wind potential evaluated with and without vegetation correction. The corrected for vegetation column summarizes data from analyses that incorporate tree canopy data and provide a minimum for visual impact and those in the no vegetation correction assumed a bare earth scenario resulting in an overestimate of visual impact.

Turbine	Corrected For Vegetation		No Vegetation Correction	
	Area Impacted (Acres)	# Homes	Area Impacted (Acres)	# Homes
1	44,560	2460	54,350	3898
2	42,130	2301	51,930	3789
3	31,320	1829	39,180	3010
4	30,260	1798	37,835	2951
5	32,480	1491	43,800	3313
6	28,800	1332	38,073	2836

2.3. Economic implications

The price of gasoline and heating oil has steadily increased over the last two decades with a sharp increase during the 2007–2008 heating season [44]. These dramatic increases placed economic strain on families, municipal government, non-profit organizations, and local businesses. Average household expenditures on energy for a typical Poultney household are presented in Table 2. These estimates assume the average household: (1) consumes 779 gallons of heating fuel per year; the average for New England households in 2005 [47], (2) uses 570 kWh per month, and (3) drives two vehicles with an average fuel efficiency of 31.2 mpg, the average annual distance of 12,640 miles, consuming approximately 810 gallons of gasoline [41,42]. According to the US Census [43], the mean household income in Poultney was $31,711. Thus, a typical Poultney household could spend approximately 20% of its annual income on energy.

It is likely consumption will increase and energy costs will continue to rise in all three categories. However, identifying, managing and utilizing locally-derived energy sources could help offset rising costs [11].

3. Methodology

To help support the development of a local energy committee, we used ESRI ArcView 9.2 GIS software to assess the potential for utilizing biomass, wind and solar resources in Poultney, Vermont. Using the highest-resolution data available, we created energy potential maps for each of these categories to provide visualizations that could be used to solicit input from community stakeholders and better inform an energy committee to promote a participatory approach to local energy planning [33,48,49]. Therefore we modeled the theoretical potential for all three categories because community input will likely provide many of the restrictions needed to model the actual on-the-ground potential [32]. The assumptions we used to reclassify existing datasets and create binary and ordinal maps for each energy option are summarized in Tables 3–5.

3.1. Land use

To define those areas best suited for building infrastructure (e.g. – solar arrays, fuel processing plant, etc) and those areas best suited to support biomass energy derivatives, we ESRI's Spatial Analyst to reclassify the National Land Cover Dataset [50] based on the assumptions summarized in Table 3. We used an ordinal ranking

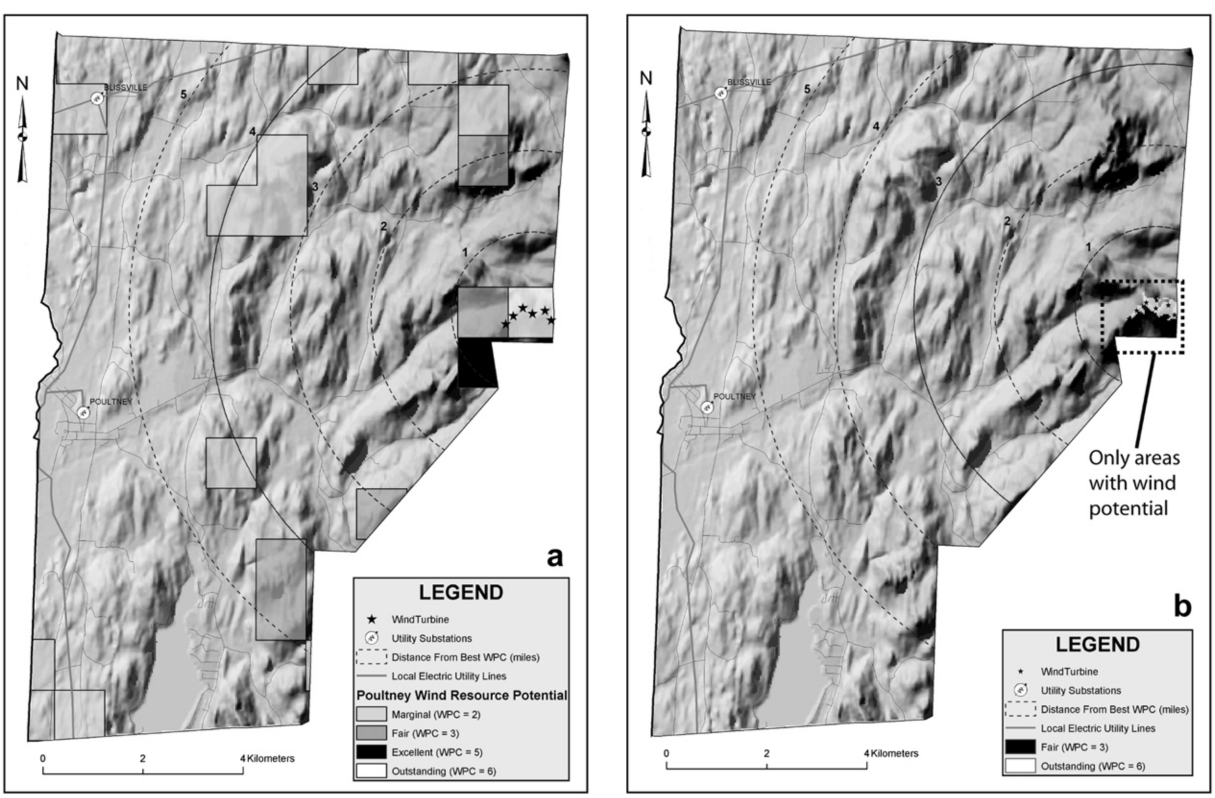

Fig. 5. A comparison of wind potential before (a) and after (b) landscape restrictions were included in the analysis. After restrictions were included in the analyses, the only area with wind potential was located within the dashed rectangle. The dashed lines radiating away from the turbines indicate distance to the nearest utility line capable of transferring wind energy into the electrical grid.

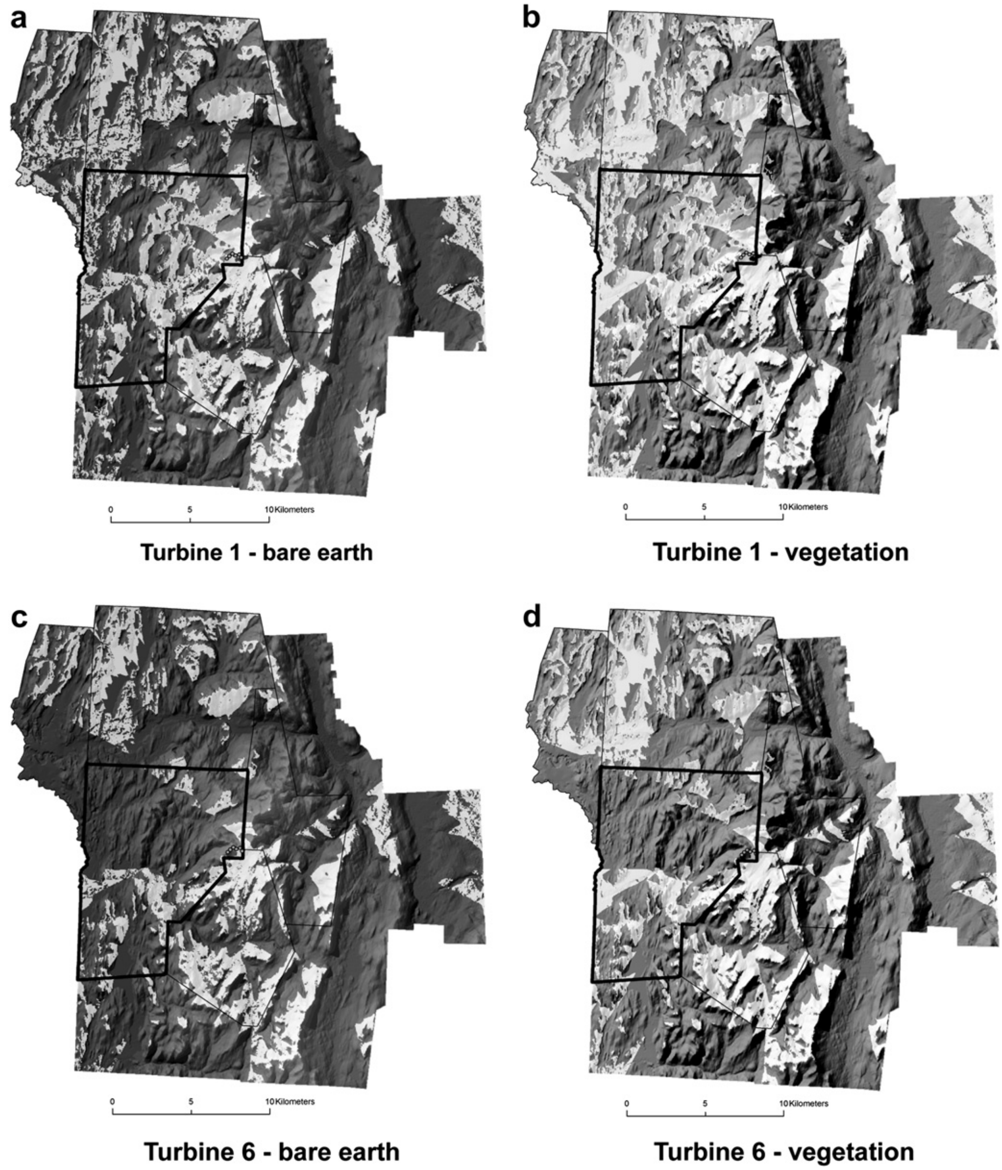

Fig. 6. A comparison between potential viewshed impacts for turbines 1 and 6 under bare earth conditions and after incorporating the effects of vegetation shielding.

from 0 to 3 where 0 indicates the lowest potential for supporting infrastructure or biomass production and 3 indicates the highest potential. For example, we assumed that brush could be cleared and posed no further limitations to development and it would be impossible to build or support crops in areas of open water. A 30-m digital elevation model (DEM) was obtained from the National Elevation Dataset (NED) and used to create a shaded relief map to illustrate the variations in energy potential relative to topography.

3.2. Wind potential

Similarly, wind potential was characterized by reclassifying the National Renewable Energy Laboratory wind class dataset for Vermont, based on the assumptions summarized in Table 4, and overlaid on a shaded relief map. Landscape restrictions were used to further refine wind potential by excluding slopes greater than 60° and only using areas that fall within an elevation range of 600–1050 m. Once the areas of highest potential were identified, we established 6 possible turbine sites and calculated Viewshed to evaluate the visual impact of each turbine on surrounding towns. We calculated Viewshed under bare earth conditions (i.e. – only taking topography into consideration) and also using an approximate tree canopy height obtained from the 2000 National Biomass Carbon Dataset in an attempt to account for shielding by vegetation. These two calculations were necessary to provide a minimum and maximum visual impact assessment since high resolution canopy height data is currently unavailable in Vermont. The number of towns and buildings impacted by each turbine was also estimated using town boundaries and E911 building locations.

3.3. Solar potential

The potential for utilizing photovoltaic and solar thermal technologies was modeled using a 30-m DEM and ESRI's Solar Analyst [51]. We calculated the average annual solar radiation received within the town of Poultney and estimated the useable area for building footprints by digitizing the roofs of 475 structures in the downtown business sector. The total area was then halved because only south-facing roofs would likely be utilized and then halved again because the eaves of many homes face east–west, decreasing

Table 7
A summary of the estimated average annual solar radiation available to Poultney and the approximate area that could be used to utilize this energy.

Modeled Average Annual Solar Radiation (kWh/m2)			Approximate Useable Roof Area (m2)	
High	Low	Daily Total	Total	25%
1429.98	776.14	5.05	97,464.59	24,366.15

the area of the roof facing south. This rationale for estimating useable area is equivalent to multiplying total area by 25% suggested by Yue and Wang [26]. The assumptions and datasets used to perform these analyses are summarized in Table 5.

4. Results

4.1. Land use

The areas with the best potential to support energy development requiring physical infrastructure (e.g. – large scale solar array) and those areas that could support biomass-based energy cultivation are depicted in Fig. 4. These areas have difficult access and are all at least 4 miles away from the closest electrical substation and downtown Poultney. Almost all the areas with the best potential for biomass-based energy production are currently in use for agricultural production or pasture. Many areas with moderate potential also have difficult access. These analyses indicate limited potential for physical infrastructure and moderate potential for biomass development.

4.2. Wind potential

Regional data indicates areas with fair, excellent and outstanding wind power potential. After incorporating the restrictions described in Table 6, six sites were selected as possible locations for wind turbines on Spruce Knob in the northeast corner of the town (Fig. 5). Visual impact was calculated under a bare earth scenario providing an overestimate of impact and by attempting to correct for vegetation obstruction to provide an underestimate of visual impact (Fig. 6). The data used to correct for vegetation was extracted from the 2000 National Biomass Carbon Dataset and provides estimates for canopy heights. However these estimates are for 30 m grid cells and assume each grid cell is a uniform height, which is an unrealistic representation of canopy diversity. Table 7 summarizes the estimated area and number of homes impacted by each turbine. These analyses suggest Spruce Knob is an outstanding location for wind power development but that any siting of turbines will have a considerable impact on all surrounding towns.

4.3. Solar potential

The regions of Poultney with the highest average solar radiation values are located in areas with difficult access and ~4–5 miles from downtown. These regions are primarily higher in elevation and have greater relief; therefore they experience less topographic shielding than downtown Poultney. Fig. 7 illustrates the spatial variations in solar insolation within the town and Table 7 summarizes the potential for utilizing solar technologies. These values are similar to those provided by the National Renewable Energy Laboratory following Perez et al. [53]. These results suggest moderate potential for utilizing building specific solar technologies and poor potential, under current land use scenarios, for developing a larger-scale array close to downtown, which consumes the most energy.

5. Discussion

This project illustrates the usefulness of GIS analyses used to support CEM by providing visualizations used to identify areas with

Fig. 7. The spatial variation in annual average solar radiation within the town of Poultney (a) and rooftops that could be used to utilize photovoltaic or thermal solar within the downtown area (b).

the greatest potential for alternative energy production in the town of Poultney. However, with the exception of wind class potential, our approach is not limited to rural communities or the United States; the factors limiting the usefulness of the analyses will be data availability and resolution. The economic and environmental costs associated with electricity production, transportation and home heating are of global concern and will be best addressed by an informed community.

As energy prices continue to rise, more communities and municipal governments will embrace community energy planning focused on lowering carbon emissions and reducing operational costs. We suggest these committees will be best informed through GIS-based analyses of local energy resource potential and will make the most democratic decisions by employing PGIS throughout the decision making process.

Role of the funding source

We received funding from an anonymous Trustee of Green Mountain College. The award made no stipulations regarding the study design, data collection, analysis, interpretation or in the writing and submission of this article. This award only provided stipends for faculty, student research assistants and field equipment.

Conflict of interest

We do not believe that any conflict of interest exists between our institution, persons or the research we are presenting in this paper.

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