THE POTENTIAL OF UTILITY-SCALE SOLAR AND WIND ENERGY IN CHESTER COUNTY, PENNSYLVANIA

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ABSTRACT: *This study explores the geography of potential sites for installing renewable energy sources in Chester County, one of Pennsylvania's fastest growing counties, twenty-five miles west of Philadelphia. Through a geographic information system (GIS) analysis, we consider utility-scale renewable installations for wind and solar power, and investigate the feasibility of such installations. We also assess the impacts of renewal energy implementation, such as carbon dioxide reduction and job creation. Potential sites were assessed through a constraint-only analysis, and feasibility was calculated through a benchmark analysis using established guidelines for installed capacity at each location. The constraint-only analysis resulted in the definition of potential wind sites of 5,434 acres, or roughly 1% of the county. For photovoltaic devices, 0.02% of the county, or 127 acres, were defined as potential sites. All sites could see a combined installed capacity of 94.9 MW, capable of generating 283.66 GWh a year, accounting for 118% of the county's energy needs in 2020. Furthermore, all sites were found to be economically feasible. Thus, Chester County has great potential for installing wind harvesting devices and solar installations to a lesser degree. Both sources of renewable energy should be incorporated into Chester County's energy mix in order to make it less dependent on fossil fuels, lessen its carbon dioxide emissions, create new jobs, and support its growing population.*

Keywords*: energy planning, GIS constraint analysis, renewable energy, Chester County, Pennsylvania*

INTRODUCTION

In the face of volatile energy prices, an increasing need for energy catalyzed by a growing population, concerns about climate change, and the potential economic benefits of lessening dependence on fossil fuels, there is broad interest in exploring renewable energy options at multiple scales (UNEP 2010, Brown 2009, Liu et al. 2009). Renewable energy has become a viable energy provider when compared to technologies depending on fossil fuels due to declining production costs, technological advancements, and government incentives. Indeed, the world's energy consumption, today as well as in the future, can be entirely met by renewable energy sources as their total available energy far exceeds the actual energy needs (Jacobsen and Delucchi 2011, UNEP 2010, Brown 2009).

Given their enormous benefits, this study investigates the potential of implementing renewable energy sources, specifically utility-scale wind and photovoltaic farm installations, in Chester County, Pennsylvania. The scales addressed in this study—potential utility-scale at the county level—represent the scale at which renewable energy will likely be managed in the study area, thus the problem of a spatial disconnect between the operation, planning, and management of renewable energy systems is minimized (Calvert et al. 2013). We utilize a GIS-based constraint analysis. In spite of its enormous potential to aid in the planning and implementation of renewable energy systems, GIS-based energy analyses remain underutilized in research (Resch et al. 2014). The results of this study can contribute to the planning and decision-making process of wind and solar farms in the local region, and illustrate the application of a finer-scale GIS-based analysis to the investigation of renewable energy potential.

DETERMINING SOLAR AND WIND ENERGY POTENTIAL

The Commonwealth of Pennsylvania has the eighth largest installed solar capacity in the United States, and has one of the largest solar mandates in the nation, requiring the installation of 860 MW solar capacity over the next 15 years (SEIA 2012, Pennsylvania DEP 2011). The state also has a total of 17 wind farms with 420 turbines and 790 MW installed wind capacity, making Pennsylvania the state with the fifteenth highest installed capacity on a national scale (AWEA 2014, Penn Future 2012). Pennsylvania has an Alternative Energy Portfolio Standard in place, which took effect in 2005, setting out annually increasing percentage levels for renewable energy. By 2020, 18% of electricity sold in Pennsylvania has to be derived from alternative energy sources (Pennsylvania Public Utility Commission 2011). However, the commonwealth does not have the authority to decide on wind or solar farm sitings, as the Pennsylvania Municipal Planning Code delegates the police powers of planning and land use to local governments. Thus Pennsylvania's Public Utility Commission also does not have any siting authority. In addition, Pennsylvania is a state characterized by dual authority, requiring local and state permitting authorities. Certain federal agencies also have to be consulted in the planning process. Thus, a plan covering the whole state related to siting issues is non-existent. Instead, Pennsylvania's Department of Environmental Protection (DEP) offers a model ordinance for setbacks, noise, and decommissioning standards for wind turbines, and can be used for guidance in the planning process (DEP 2006).

A number of researchers have utilized GIS to establish the potential of renewable energy sources for a given region by defining a theoretical, geographical, technical, and economic potential (e.g., Freitas et al. 2015, Santos et al. 2014, Grassi et al. 2012, Yagoub 2010, Arnette and Zobel 2010, Wang et al. 2009, Voivontas et al. 1998). The assessment of the potential of renewable energy technologies through such models is an important step in accurately modeling and integrating renewable energy sources (Resch et al. 2014, Wang et al. 2009). Nonetheless, research on GIS-based analysis at local and finer regional scales remains underdeveloped in assessing the potential of renewable energy sources. This represents a critically important gap as analyses of renewable energy potential at broad scales (i.e., national or international scales) incorporate unacceptably high levels of variance unlike fine-scale analyses that can utilize less spatially aggregated data (Calvert et al. 2013).

The feasibility of a renewable energy project has been commonly established through guidelines which are applied to the installed capacity numbers (IRENA 2012ab, NREL 2011, EPA 2010, Wang et al. 2009). These rules are generally drawn from thorough analyses and are helpful in predicting the economic impact of a project, especially as screening-tools for preliminary benefit estimates. It is essential to establish the capital costs of a project (EPA 2010). Capital costs include the construction or installation of the plant, field improvements, such as grading of the land, and equipment costs. The costs for utility-scale wind turbines are currently $1,000 per kW of installed capacity (NREL 2011). Those costs are expected to decline (DOE 2010). The installation costs for wind harvesting devices are 30% of the capital investments costs, and site improvement costs, such as roads and grid extensions are $500 per kWh (NREL 2010, Wang et al. 2010). The benchmark capital costs for utility-scale photovoltaic installations are $4,000 per kW, but can vary drastically between different regions (IRENA 2012a , NREL 2011). The operation and maintenance costs (O&M costs) of the project over its lifetime also need to be factored in to determine a project's feasibility (IRENA 2012ab, NREL 2011, EPA 2010). Those expenses describe the amount of money spent on operating a facility, such as engineering or supervising costs. Maintenance refers to labor cost, and costs to upkeep the facility. The O&M costs for wind turbines are described to be 1.5% of the capital costs (Ragheb 2012). The O&M costs for solar devices are $8.50 per installed kW of solar capacity (NREL 2011). The feasibility of a project is also defined by the revenue of a facility through electricity sales, multiplying the annual kWh output with current energy prices. Applicable incentives, such as the Production Tax Credit or Investment Tax Credit need to be considered in order to estimate a project's feasibility. Finally, the net income of a project is defined as the dollar amount created by revenue and incentives against the added capital and O&M costs (IRENA 2012ab, NREL 2011, EPA 2010, Wang et al. 2009).

STUDY AREA

Chester County is one of Pennsylvania's 67 counties, comprising an area of 750 square miles. The county is located approximately 25 miles west of Philadelphia and is part of the Philadelphia-Camden-Wilmington metropolitan area, one of the most densely populated regions in the U.S. The county is faced with sharply increased energy demands that need to be met in order to support its growing population, which is projected to increase from 498,886 people in 2010 to 538,810 in 2020 and 607,410 people in 2030 (Delaware Valley Regional Planning Commission 2012).

Chester County was chosen as the study site due to the challenges it faces in responding to its increasing energy demands. As the county is expected to gain another 184,000 residents over the next 30 years**,** the energy issue becomes more evident (Chester County Greenhouse Gas Reduction Task Force 2009, DVRPC 2010). Having a sufficient and secure energy supply is vital to a growing population and economy. Thus, it is essential to strategically plan for Chester County's future energy demands, and account for areas that should be reserved for energy production purposes due to their feasibility in generating clean energy. At the same time, Chester County is trying to reduce carbon dioxide equivalent emissions, which were over 8.7 million tons in 2005, in order to improve the county's environment and provide its residents with cleaner air (GHGRTF 2010). West Chester Borough, the county's county seat, had a carbon equivalent emission of 220,000 tons in 2005 (BLUER 2009). Studying the planning and implementation of renewable energy sources at the county level is grounded in the strong local powers granted to municipalities by the state of Pennsylvania (Pennsylvania Municipalities Planning Code, Act of 1968, P.L.805, No.247). Thus, focusing on jurisdictions larger than the county would not be appropriate for this study, as local jurisdictions are in charge of deciding on the location of wind farms, and solar installations. Chester County, being one of Pennsylvania's most prosperous counties, is an appropriate study site for this study as more affluent counties tend to invest more money in renewable energy (Sidiras and Koukios 2004). However, more affluent counties also tend to form stronger opposition to projects as they fear negative impacts on aesthetics, property values, noise pollution and harm to wildlife (Kuzemschak and Okey 2009). Contention can also arise from unequal distribution of costs and benefits, for example individual landowners can financially benefit through leasing their land for a wind farm while the rest of the local community realizes the costs of decreased scenic values and bird mortality.

METHODS

This study utilized a GIS-based constraint-only analysis that was conducted in *ArcMap 10.x* (ESRI 2011). All potential locations were assessed based on criteria that did not meet defined thresholds. Sites were rejected if only one criterion did not meet their respective range of acceptable thresholds.

GIS data was compiled from a variety of sources (Table 1). Data for the annual average wind resource potential at 50m height covering the Mid-Atlantic region, monthly and annual solar resource potential for the contiguous U.S. at 10x10km, and electric grid transmission connectivity for the entire U.S. were obtained from the National Renewable Energy Laboratory (NREL 2003). Urban areas, land cover, national parks, state parks, wetlands, streams, airports, roads, and elevation (derived from 1-meter resolution LIDAR) were downloaded from the Pennsylvania Spatial Data Clearinghouse (PASDA 2013). Land use data based on digitized orthophotography were obtained from the Delaware Valley Regional Planning Commission (DVRPC 2011). Historic structure locations were provided by the Center for GIS and Spatial Analysis (GISSA) at West Chester University (unpublished data).

Table 1. GIS data sources. Data were obtained from the National Renewable Energy Laboratory (NREL 2003), Pennsylvania Spatial Data Clearinghouse (PASDA 2013), the Delaware Valley Regional Planning Commission (DVRPC 2011), and the Center for GIS and Spatial Analysis (GISSA) at West Chester University (unpublished data).

Data Layer	**Data Preparer (Year of Data)**
Airports	Pennsylvania Department of Transportation (2011)
Chester County Boundary	Delaware Valley Regional Planning Commission (2011)
Chester County Municipalities	Delaware Valley Regional Planning Commission (2011)
Electric Grid	Federal Emergency Management Agency (1993)
Elevation	PAMAP Program (2008)
Historic Structures	GISSA at West Chester University (n.d.)
Land Cover (Barren Land)	U.S. Geological Survey (2001)
Local Roads	Pennsylvania Department of Transportation (2012)
National Parks	ESRI (1996)
Single Family Housing (Land Use)	Delaware Valley Regional Planning Commission (2005)
Solar Resource Potential	National Renewable Energy Laboratory (2011)
State Parks	Pennsylvania Department of Conservation and Natural Resources (2011)
State Roads	Pennsylvania Department of Transportation (2009)
Streams	U.S. Geological Survey (2005)
Urban Area	Pennsylvania Department of Transportation (2011)
Wetlands	U.S. Fish and Wildlife Service (2005)
Wind Speed	National Renewable Energy Laboratory (2003)

GIS ANALYSIS OF WIND ENERGY

Potential sites for wind energy installations in Chester County were evaluated by establishing two potential categories for this form of energy. Both potentials were mapped in a GIS (Figure 1). In a first step the theoretical potential was assessed. This potential was derived from NREL data on the annual average wind resource potential across the mid-Atlantic United States at 50 meter height, represented by polygons providing information on wind power class categories, ranging from power class 1 (poor) to 7 (superb) conditions. Wind speeds at 50 meter height found in Chester County are classified under the second wind power class (2), with wind speeds ranging from 5.6 – 6.4 meters/second. Wind speed was used as the major constraint to determine the theoretical potential as only wind speeds of at least 5.5 meters/second at 80 meter height are needed for wind installations to be viable and cost-effective (EPA 2010). Data on 80 meter wind speeds could not be accessed through NREL, instead, information was only provided in the form of a map document, showing the annual average wind speed in meters/second for Pennsylvania (NREL 2010). The map showed wind speeds between 5.5 and 6.0 meters/second for areas that shared the same geographic boundaries as the polygons of wind speed 2, which were retrieved through the available data on wind speeds at 50 meter height. Thus, data on 50 meter height was used to analyze the theoretical potential.

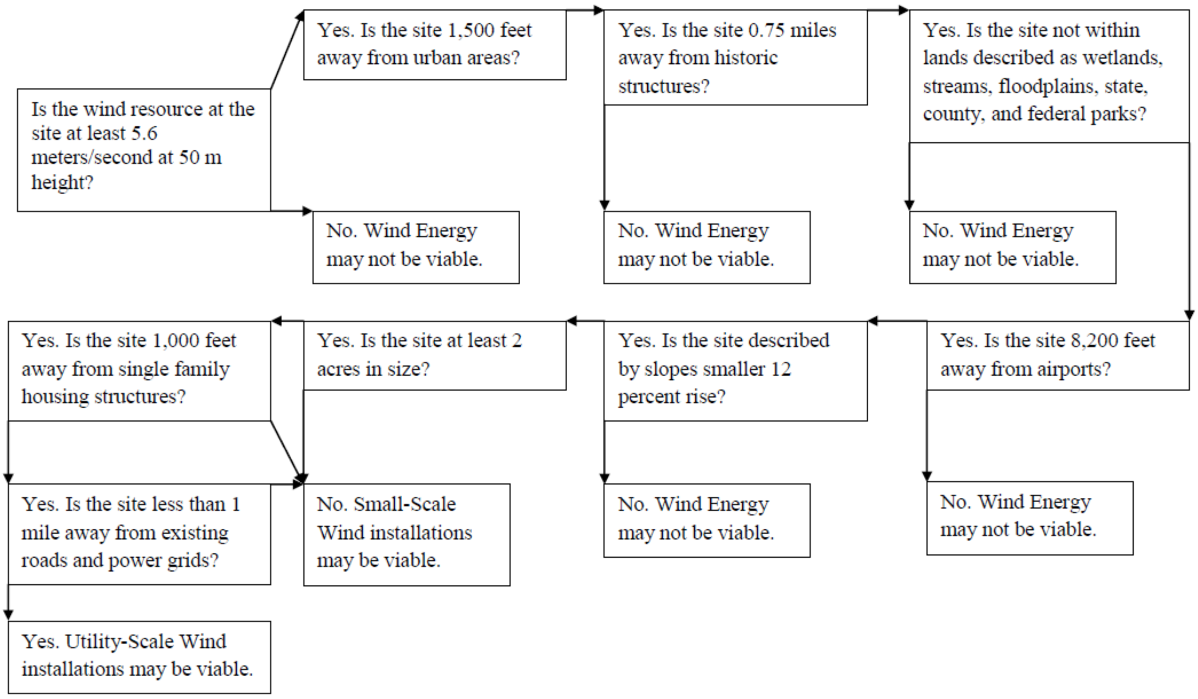

Figure 1. Decision-tree for GIS analysis of utility-scale wind potential in Chester County, Pennsylvania.

In a second step, the geographical potential was established, which took several restraining factors, and thresholds into account. Further constraints were included, as potential sites were not to fall within urban areas, historic sites, state parks, county parks, federal parks, wetlands, streams, floodplains, and airports. Urban areas were eliminated due to safety reasons and the minimization of visual impacts. For that purpose, 1,500 feet buffers were created to account for setbacks from the most outlying urban areas (after EPA 2011b). To minimize the visual impact on historical structures, setback requirements of 0.75 miles were established. This setback requirement was derived for wind turbines with the current average total height of 363 feet based on setbacks required for cell phone towers by the EPA. Wetlands, streams, floodplains, state, county, and federal parks were also excluded from the geographical potential due to legal reasons (Elliot and Schwartz 1993). Airports were included as a constraint due to safety concerns, requiring a buffer distance of 8,200 feet from wind farms (Voivontas et al. 1998). To account for slopes, a database containing LIDAR data was created. LIDAR data was used to determine slopes too steep for implementing wind energy generating technologies. Based on Voivontas et al. (1998) and EPA (2011) slopes were not to exceed the maximum rise of 12%, as higher percentages would result in access difficulties. Following this step, only areas larger than two acres were selected as possible sites, resulting in the overall geographic potential for only small-scale wind installations in Chester County, PA (EPA 2011b). To determine the geographic potential for utility-scale wind installations, the land use map for Chester County was used for a final overlay analysis using dwellings not included in the urban area shapefile. In order to eliminate areas not feasible for generating wind energy, a 1,000 feet buffer around single family housing was used. Finally, existing roads and power grids were added to determine possible locations based on 1 mile distance (EPA 2011b).

GIS ANALYSIS OF SOLAR ENERGY

Potential sites for large-scale installations generating electricity through solar energy were assessed through establishing two potentials: the theoretical and geographical potential of solar photovoltaic installations (Figure 2). The theoretical potential was derived from NREL data on the annual and monthly average of solar irradiation for the lower 48 states of the United States. The geographic potential was evaluated in a second step. There are no constraints to the annual amount of solar insulation as NREL classifies all values feasible as they are greater 3.5 kWh per m² per day (EPA 2011a). LIDAR data was used to calculate slope and aspect for Chester

County. The combination of slope and aspect was considered as the major constraint in this analysis. Slopes smaller than 2.5% rise were accepted with any aspect as solar panels can be easily adjusted to have a southern exposure when installed on lands with lower steepness. Aspect was the determining factor for potential sites on lands with slopes between 2.5%-15% rise. For slopes in that range of steepness a southern exposure was required in order to be considered feasible for solar farm installations (Arnette and Zobel 2010). Land use obtained from NLCD put another constraint on the geographical potential. Only land classified as barren land was accepted for potential sites as solar farms require large areas of land. Wetlands, streams, floodplains, airports, state, county, and federal parks were excluded from the geographical potential. For the purpose of determining potential solar farm sites, buffer requirements regarding urban land were not needed as there are no major political issuses involved due to missing noise emissions and aesthetic concerns when compared to wind installations (Arnette and Zobel 2011). Only single family housing structures were omitted from the theoretical potential as to make sure that no dwelling would accidentally fall into lands classified as barren. Finally, only areas larger 2 acres were selected as potential sites (EPA 2011a).

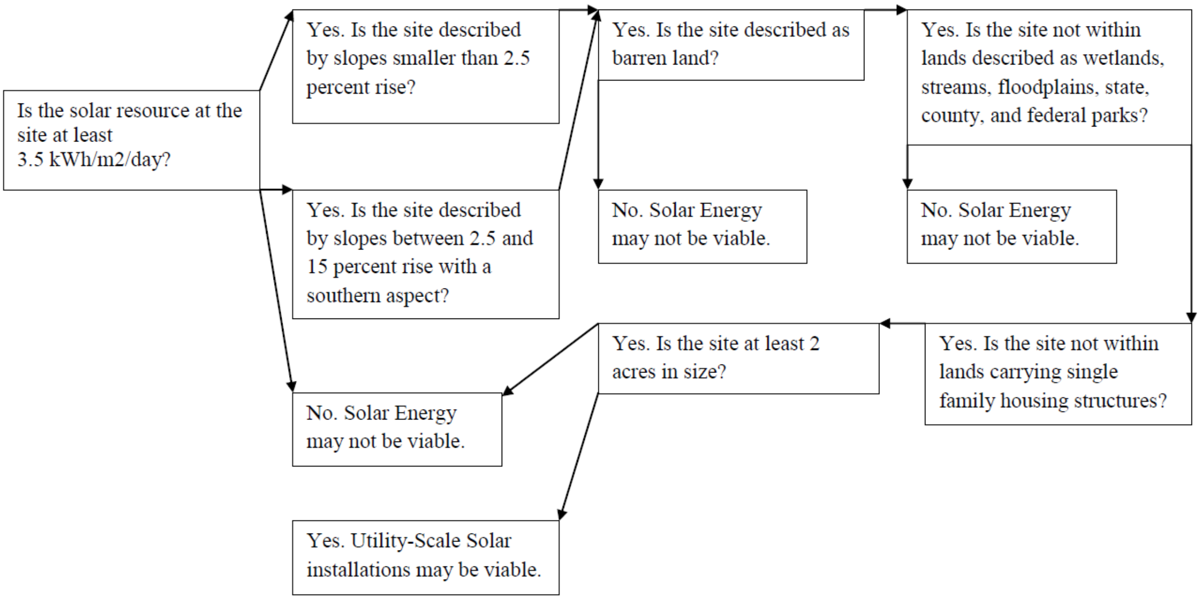

Figure 2. Decision-tree for GIS analysis of solar energy potential in Chester County, Pennsylvania.

ECONOMIC FEASIBILITY, ENVIRONMENTAL IMPACTS AND BENEFITS, AND GROWING ENERGY DEMAND

For the purpose of estimating the total possible amount of installed capacity for all potential wind turbine sites in Chester County, the size of each site was used to determine the power of the turbine. Based on the reported average number for acres required per installed MW from AWEA (2011), areas smaller 60 acres were assumed to be feasible for the installation of 100 kW turbines. Sites larger 60 acres and smaller 90 acres were used as possible locations for installing 1 MW turbine devices. Sites between 90 acres and smaller 120 acres were accounted for 1.5 MW turbines, and sites larger 120 acres were set out for the installation of 2 MW wind devices. The annual electricity generation was based on the installed capacity and multiplied by a capacity factor of 40%.

To determine the economic feasibility of a wind project, it was necessary to establish the capital and installation costs. Capital costs amount to $1,000 per kW of installed capacity (NREL 2011). The installation costs for wind harvesting devices were expressed as 30% of the capital investments costs (Wang et al. 2009). Site improvements, such as roads and grid extensions are $500 per kWh (NREL 2010). Thus, the total investment for a turbine was the sum of its installation costs, capital costs, and site improvement costs (Ragheb 2012). The O&M costs of the project over its lifetime were calculated by multiplying the capital costs by 0.015, as those expenditures are described to be 1.5% of the capital costs (Ragheb 2012).

The projected revenue was calculated by multiplying the annual kWh output by $0.102, the price of electricity PECO Energy was charging per kWh, and then multiplying it by 20, which is the expected lifetime of the project (PECO 2012). As electricity prices are expected to rise, those numbers only represent an estimate based on current prices and are subject to increase. Possible incentives, such as the Production Tax Credit had to be accounted for as another form of income for wind energy. The Production Tax Credit was 2.2 cents per kWh and is paid for the first 10 years of the projects lifetime (DSIRE 2011). Thus, the total revenue of the turbine was assessed by the sum of the revenue of electricity sales over 20 years, and the Production Tax Credit for the first ten years (Ragheb 2012). Finally, the annual net income over 20 years was calculated by subtracting the total revenue from the investment costs and operation and maintenance costs over 20 years (Ragheb 2012). In addition, property owners could generate $42,500 per year per installed MW (NREL 2012b). Furthermore, the county's tax revenue would see an increase through $75,000 in local property taxes per year per installed MW of wind capacity (NREL 2012b).

The installed capacity of solar energy was based on the annual average kW/m² for every potential site and multiplied by the acreage of the site, while accounting for shading by removing 25% of the land. This value was multiplied by an efficiency factor of 14% and a conversion factor of 0.77 to receive the electricity generated per year (after Arnette and Zobel 2010). The capital costs for photovoltaic installations were $4,000 per kW (NREL 2011). To calculate those costs, the installed capacity of solar devices was multiplied by 4,000. O&M costs were $8.50 per installed kW of solar capacity, over the 25 year lifetime of a solar installation (NREL 2011). The project's revenue was calculated by multiplying the annual kWh output by PECO Energy's current price for 1kWh of electricity. Incentives such as the Alternative Energy Credit of $0.12 and the 30% Investment Tax Credit also needed to be included (DSIRE 2012). Finally, to gain the net income of the project, the capital costs and O&M costs over 25 years were added, and then subtracted by the revenue of incentives and electricity sales.

The installation of wind turbines and ground-mounted photovoltaic devices will disturb natural habitat. The average permanent direct impact area for wind turbines ranges from 0.1 to 0.6 hectares per one MW of installed wind capacity (Denholm et al. 2009). The temporary impact area is described to be between 0.1 and 1.3 hectares per one MW of capacity (Denholm et al. 2009). To account for the area for solar modules needed to provide the installed MW amount, the installed capacity was divided by the efficiency factor of 14% and then multiplied by 1,000 (Fthenakis et al. 2009).

Emissions from fossil fuels are removed by wind turbines at the following levels: 6.5 tons of sulfur dioxide (acid rain), 3.2 tons of nitrogen oxide, and 1,500 tons of carbon dioxide from one MW installed capacity (Pennsylvania Wind Working Group n.d.). Photovoltaic devices reduce emissions such as carbon dioxide, sulfur dioxide, and nitrogen oxide by 1,400 pounds, eight pounds, and five pounds per 1,000 kWh of electricity, respectively (NREL 2004).

Census information was used to estimate the additional amount of energy needed to sustain the county's growing population (Census 2010). The number of new households added was needed in order to approximate the overall increase in electricity consumption. The 2010 owner and renter-occupied housing profile was assumed to stay the same until 2040. Thus, 76% of all households were classified as owner-occupied versus 24% that were described as renter-occupied tenure. Owner-occupied housing accounts for an average household size of 2.77, renter-occupied units have an average household size of 2.28 people in 2010. The number of new households for 2020 was calculated by splitting the total increase of 39,924 people in owner and renter-occupied units. The figure for each tenure type was multiplied with its corresponding average household number. Finally, both figures were added to account for the total number of new households. For the year 2020 a total of 19,357 new households would be added to Chester County at a predicted average annual growth rate of 0.93% (DVRPC 2000). This number was then multiplied by the average use of electricity per household in Pennsylvania, which was 35,500,000 BTU (10,400 kWh) per household per year (EIA 2012c), resulting in additional energy needs of 201,312,800 kWh a year, or 201.3 GWh. The same calculation was undertaken for the year 2030, resulting in an increased energy need of 428.4 GWh a year for the additional 108,524 people in Chester County.

RESULTS

WIND ENERGY POTENTIAL, FEASIBILITY, AND ENVIRONMENTAL IMPACT

The geographical potential of large-scale wind installations was found to be 5,430 acres, or 1.1% of the county (Figure 3). The majority of potential sites were located in municipalities with the lowest population densities of the county. Based on the reported average number for acres required per installed MW from AWEA (2011), and the constraints set out in the GIS analysis, these sites could support the installation of 200 turbines with a combined installed capacity of 75.8 MW (Table 2). The county could see the installation of 37 turbines with a capacity greater than 1 MW, consisting of nineteen 2 MW, seven 1.5 MW, and eleven 1 MW turbines. Taking an efficiency factor of 40% into account (NREL 2011), the 75.8 MW of installed wind capacity could generate 265,603,200 kWh of energy annually. The installation of wind turbines in Chester County could generate 34 long-term jobs, and 56 temporary jobs. The 75.8 MW of installed capacity would translate to a total of 363.8 job years.

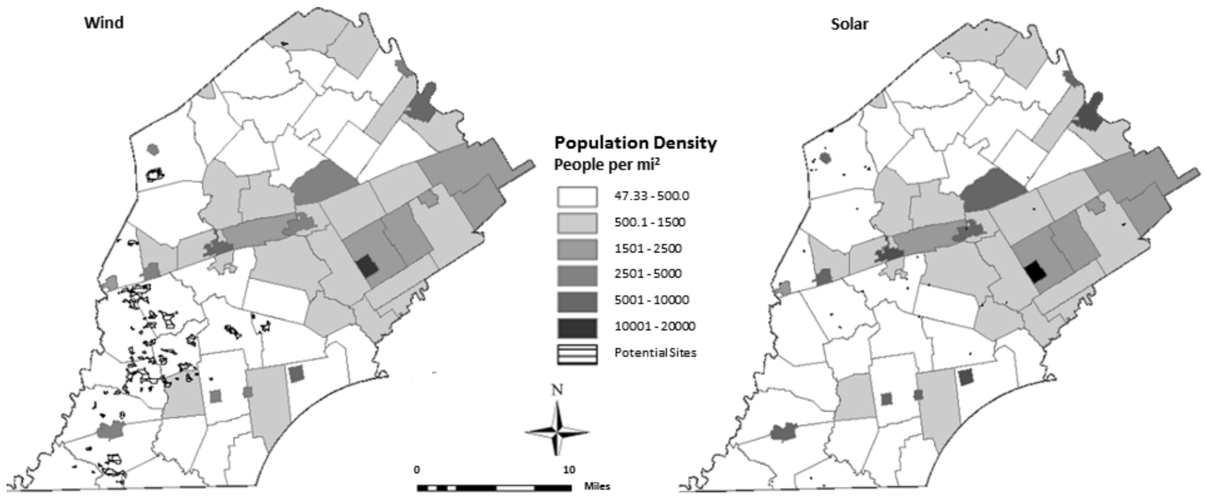

Figure 3. Potential sites for utility-scale wind (left) and solar (right) power with corresponding population densities in Chester County, PA, 2000 Census Tracts. Note that the western third of the county, home to the lowest population densities, proved to be the most favorable for potential sites.

The installation costs for all 200 turbines in Chester County would amass to $75.8 million (Table 3). Site improvement and installation costs would account for $37.9 and $22.74 million, respectively. Thus, the total investment costs for wind power in Chester County would be $136.4 million. The O&M costs of the project over its lifetime would amass to $22.74 million, while the revenue from electricity sales over 20 years would be $541.83 million. The Production Tax Credit would account for an income of $58.43 million over 10 years. All potential sites were found to be economically feasible, and would have a combined net income of $429.7 million. Through leasing agreements, the property owner could generate another form of income. A total of $32.2 million in lease revenue could be generated annually in Chester County. Furthermore, the county could increase its tax base by $56.85 million per year.

Chester County would see a total direct impact area imposed by the installation of wind turbines ranging from 18.7 to 243.49 acres of which up to 112.38 acres would be permanently impacted. Installing wind turbines in Chester County would displace dangerous emissions from fossil fuels, as a total of 113,700 tons of carbon dioxide, 492.7 tons of sulfur dioxide, and 242.56 tons of nitrogen oxide will be removed if all wind turbines are installed (Table 4).

SOLAR ENERGY POTENTIAL, FEASBILITY, AND ENVIRONMENTAL IMPACT

The geographical potential of large-scale solar installations comprised 127 acres, ranging from 2.06 to 11.97 acres in size. Potential sites were spread out across the county, with a small clustering in the county's center, and generally fell into municipalities with the lowest population densities. Five potential locations could be ranked as priority-1 sites as they were larger than 5 acres (EPA 2011a). Those sites have a total area of 42.91 acres. The remaining 84.53 acres, 30 locations, were classified as priority-2 sites. Utilizing all sites could see a total installed capacity of 19.1 MW of solar power (see Table 2). The installed capacity of 19.1 MW of solar power could generate 18,065,938.97 kWh of electricity annually. Five acres are required per 1 MW of installed solar capacity (EPA 2011a), resulting in 200 kW per acre. Thus, only three sites had the potential of employing photovoltaic devices with a capacity greater 1MW. The installation of solar capacity in Chester County would result in 618 temporary, 7 long-term jobs and 18.17 job years.

Table 2. Wind and solar installation capacity, potential annual electricity generation, and potential job creation

	Installation Capacity	Annual Electricity Generation (GWh)	Long-Term Jobs	Temporary Jobs	Job Years
Wind Energy	75.8 MW	265.6	34	56	363.8
Solar Energy	19.1 MW	18.065	7	618	18.17
Total	94.9 MW	283.66	41	674	381.97

The analysis on capital costs for photovoltaic installations resulted in the total investment cost of $76.5 million for all photovoltaic installations (see Table 3). O&M costs were $8.5 per installed kW of solar capacity, amassing to roughly $4 million over the 25 year lifetime of all projects. The analysis resulted in $46 million in electricity sales for all solar installations over 25 years. The Alternative Energy Credit and 30% tax credit would generate $54.2 million and $53.6 million, respectively. All solar projects would have a total combined net income of $42.6 million over 25 years. Chester County's solar projects would be economically feasible as each of every one generates a positive net income flow. It is important to note, that solar energy projects are feasible only through the income generated through incentives.

Table 3. Wind and solar energy feasibility (in millions of USD rounded to nearest tenth) calculated from total investment costs, operation and maintenance costs (O&M), electricity sales revenue over the project's life time, production tax credit of 2.2 cents per KWh/year, investment tax credit, alternative energy tax credit, and net income

	Investment Costs	O&M Costs	Electricity Sales Revenue	Production Tax Credit	Investment Tax Credit	Alternative Energy Tax Credit	Net Income
Wind Energy	$136.4	$22.7	$541.6	$58.4	-	-	$429.7
Solar Energy	$76.5	$4.0	$46	-	$53.6	$54.2	$42.6
Total	$212.9	$26.7	$587.6	$58.4	$53.6	$54.2	$472.3

The direct impact area of installing all solar devices would amass to a total of 33.8 acres in Chester County, 26% of the size of all locations feasible for installing solar devices. Chester County would see an annual displacement of harmful pollutants, specifically 11,562 tons of carbon dioxide, 65 tons of sulfur dioxide, and 41.5 tons of nitrogen oxide (see Table 4).

Table 4. Environmental benefits of potential wind and solar energy (tons)

	Displacement CO^2	Displacement SO^2	Displacement NO^2
Wind Energy	113,7000	492.7	242.56
Solar Energy	11,5620	65.04	41.55
Total	125,2620	557.74	284.11

COMBINED BENEFITS OF WIND AND SOLAR ENERGY

In sum, the combined environmental benefit of installing 19.1 MW of solar devices and 75.8 MW of wind capacity in Chester County would amount to the displacement of 125,262 tons carbon dioxide annually, or 34,162 tons of carbon equivalent emissions (AWEA 2008) (see Table 4). At the same time 557.74 tons of sulfur dioxide and 284.11 tons of nitrogen oxide would be displaced, while generating a total of 283.66 GWh of clean energy. Wind and solar energy would create 41 long-term, and 674 temporary jobs, while creating a total of 381.97 job years for Chester County (see Table 2). All projects are economical feasible as they are creating a combined revenue of $427.3 million (see Table 3).

DISCUSSION

The potential sites for wind turbines were primarily situated in the county's low density rural areas. Thus, the implementation of wind energy installations would advance the economy of those areas as wind energy would result in revenue through leasing contracts for farmers. Property owners could generate an average of $42,500 per year per installed MW, while continuing farming as only a quarter acre of land is needed to install one wind turbine (Windustry 2005, NREL 2012b). Thus, wind energy can play a vital role in a farmer's revenue base as it represents a comparatively stable form of income through the duration of the lease (GAO 2004). At the same time, farm land will be protected as wind non-obstruction easements will not allow for any buildings on the land interfering with the flow of wind over the land (Windustry 2005, AWEA 2011). The prime agricultural land found in those areas will be preserved for farming purposes. Thus, one of the major reasons for implementing wind energy and realizing the installed capacity possible lies within the potential of offering a way to protect those fertile lands. At the same time, Chester County's rural character would be preserved. Investing in wind farms would help to slow down the annual loss of 5,000 acres of the county's prime agricultural lands. Through the development of wind power, Chester County's agriculture could be protected and enhanced, ensuring that the sector will remain an integral part of the county's economy. A strong agriculture, supported by a growing wind energy sector would result in a stronger Chester County, being able to keep growing food locally and providing clean energy at the same time. Investing in wind energy would also secure American jobs and create new jobs in Chester County.

The installation of wind and solar devices in Chester County could help sustain the county's growing population numbers and reduce its ecological footprint. The energy produced by all photovoltaic and wind installations could provide for 66% of the county's energy needs by 2030. Thus, investing in renewable energy could help the county to be more energy independent, while also decreasing emissions. The installed capacity of wind and solar renewable energy sources would account for a 0.4% reduction in the county's overall carbon dioxide emission. At a more local scale, such as the Borough of West Chester, the significance of this carbon dioxide displacement through the installed wind and solar capacity becomes even more apparent. In 2005, the Borough of West Chester had a carbon equivalent emission of 220,000 tons (BLUER 2009). Thus, the installed renewable capacity in Chester County could offset 15% of the Boroughs emissions, and could nearly displace the total emissions from gas and electricity plants, which are 35,000 tons. The positive impact on the environment is especially important as the county is already trying to reduce its carbon emissions. Thus, the installation of renewable energy would greatly support the county's objectives.

By 2020 the Commonwealth of Pennsylvania requires each electric distribution company and electric generation suppliers to derive 18% of the electricity supplied from renewable energy sources. In 2011 Pennsylvania generated 46% of its electricity from coal, 18% from natural gas, 32% from nuclear power plants, and 4% from other sources, which included 3.3% from renewable energy sources (EIA 2012a). Pennsylvania consumed 148,273 GWh of electricity in 2005, the last year for which state by state electricity consumption numbers are available. Pennsylvania had an average annual electricity consumption increase of 1.5% through 1980 until 2005 (DOE 2008). Pennsylvania will likely see a 22.5% increase in electricity demands from 2005 to 2020, resulting in 33,361 GWh, totaling in 151,634 GWh of consumed electricity for the state in 2020. Thus, 27,294 GWh are required to be derived from renewable energy sources by the end of 2020. In 2010 the state generated 6,577 GWh from renewable energy sources (EIA 2012b). Thus, additional 20,717 GWh of electricity generated from renewable energy are needed to meet the requirements set out in Pennsylvania's renewable energy portfolio. The 284.2 GWh of renewable energy possible to be generated in Chester County would help to reach that goal as it accounts for 1.4% of the electricity required to be generated from renewable energy sources. Also, by generating renewable energy in Chester County, the Commonwealth of Pennsylvania would have to purchase less renewable electricity from other states with renewable energy standards in place, if it failed to meet the 18% threshold in 2020. Thus, not just the county, but the whole state could be more energy independent.

Renewable energy sources, especially wind energy, hold a promising future in Chester County. Wind energy has the greater potential when compared to solar installations with regard to the total area of potential sites and the resulting installable capacity power and actual output. Nonetheless, the potential of photovoltaic installations should be realized in Chester County as it adds to the energy mix, and can help to make the county less dependent on fossil fuels. Most importantly, the installation of photovoltaic devices and wind turbines will sustain Chester County's growing population until 2020, without increasing carbon dioxide emissions through electricity generation from other sources. The realization of such benefits is significant, especially as natural gas has become the biggest competitor for renewable energy sources through an increase in production and cheaper prices. Changing the energy mix to favor natural gas would decrease carbon dioxide emissions, but not as drastically as a change towards using more renewable energy sources would. Also, the negative impacts of generating natural gas as it is polluting fresh water through fracturing techniques need to be accounted for. Thus, it is important to consider installing the maximal capacity of renewable energy at potential sites in Chester County, not only to realize Pennsylvania's goal of providing 18% of electricity created from renewable energy sources by 2020, but to decrease dangerous carbon dioxide equivalents. Indeed, this is the objective of numerous Chester County municipalities and the county itself. In order to diminish those emissions and gain the full amount of benefits from solar and wind energy, it is important to extend and create new incentives, as well as educate the population, in order for natural gas not to outperform the installation of renewables in Chester County, Pennsylvania.

CONCLUSION

This study has demonstrated how a constraint-only GIS analysis can assess the potential of renewable energies, and yield results that can contribute to the planning and decision-making process in wind or solar farm siting procedures. This study established potential sites for utility-scale wind turbines and photovoltaic installations in Chester County, Pennsylvania. The feasibility of such installations was evaluated via a rule of thumb analysis based on capacity numbers possible at each site. Chester County, as one of Pennsylvania's fastest growing counties, is faced with growing energy demands, and the potential of installing 94.9 MW of renewable energy capacity in the county would sustain its growing population until 2020, while helping to attain the county's and numerous municipalities' goal of reducing harmful emissions. At the same time, new jobs would be created and an influx in taxes generated.

Recommendations for further study in establishing potential sites for renewable energy sources in Chester County should include other renewable sources, such as biomass and geothermal. Biomass has a very good potential when used for co-firing purposes at existing coal plants, however it does not negate the emission of carbon dioxide. Geothermal requires large up-front capital costs. In Chester County, West Chester University's investment in an innovative geothermal exchange system is one example of a highly successful conversion from coal to geothermal energy for heating and cooling needs (WCU 2013). Biomass and geothermal energy technologies are listed as recommendations in curbing the county's greenhouse gas emissions in *Chester County Greenhouse Gas Reduction Report*, suggesting the evaluation of the feasibility of these technologies (GHGRTF 2010).

Implementing renewable energy sources in Chester County, Pennsylvania will help make the county less dependent on fossil fuels, while improving the county's environment through the reduction of greenhouse gasses. At the same time, no additional greenhouse gasses will be added in the process of generating electricity as building new power plants using fossil fuels will become obsolete through the installation of renewable capacities. The reduction in greenhouse gasses will greatly benefit the overall health of the county's population and ecosystems. Investing in solar and wind energy will help Chester County to achieve a low-carbon, and resource efficient economy; guiding the county towards a future described by a green economy, a term coined by the *United Nations Environment Programme* (UNEP 2010). In a green economy, Chester County's growing population and economy will be sustained through a growth in environmental quality, through investments that reduce carbon emissions, ensuring that future citizens of the county will have the same or better quality of life. Creating a green economy through the implementation of renewable energy will enable growth of wealth and jobs, while safeguarding and enhancing the qualities of Chester County for many future generations to come.

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