The Alternative to Fossil Fuels: Using Solar Energy to Power the Twin Cities Metro, Minnesota, USA

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Abstract

Using Geographic Information Science (GIS), this study was designed to determine the potential of solar energy collection and areas with the highest production throughout the Twin Cities Metro Area. Results can aid citizens in making decisions relative to the production of green energy on their property or place of business. The study used various data sets including land use, tree cover, slope, and solar insolation along with others to create areas most suitable for placement of future solar gardens and solar energy production.

Introduction

The world faces the dual challenge of fossil fuel depletion and increased carbon dioxide (CO_2) emissions. Most popular solutions for these challenges are coal with carbon capture and storage capabilities (CCS), nuclear and other renewable sources of energy (Fthenakis, Mason, and Zweibel, 2009). Environmental concerns and the demands for energy are strong incentives for further investment and research into renewable forms of energy. Urban areas, due to their high energy consumption, are considered one of the most promising locations for installation of renewable energy technologies (Siraki and Pillay, 2012). The sun has always been a reliable source of energy that the human race and has harnessed via varying methods. In recent years the sun has been harnessed to produce energy and heat through the use of photovoltaic panels. Solar energy capture is expanding faster than any other power source with an average growth rate of 50 percent a year for the past six years. Annual installations of photovoltaic panels increased from a capacity of less than 0.3 gigawatts in 2000 to 45 gigawatts in 2014, which enough to power more than 7.4 million American homes (Pinner and Rogers, 2015).

Purpose

The purpose of this work was to realize the potential of solar energy as it relates to savings on electricity costs and reducing the carbon footprint of individual. This research will allow residents and businesses to better understand how solar insolation can be captured as well as to assist with the determination of the type and number of panels needed to cover a plot of land to produce a desired amount of energy. Communities in the seven-county metro can use the results to evaluate their potential for solar energy

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production and determine if it would be affordable and cost effective. This study can also help local and state governments create legislation and tax incentives to target specific groups of people and to facilitate the transformation of public spaces such as parks and vacant city parcels into small scale solar parks which can also be utilized as examples for wider community use.

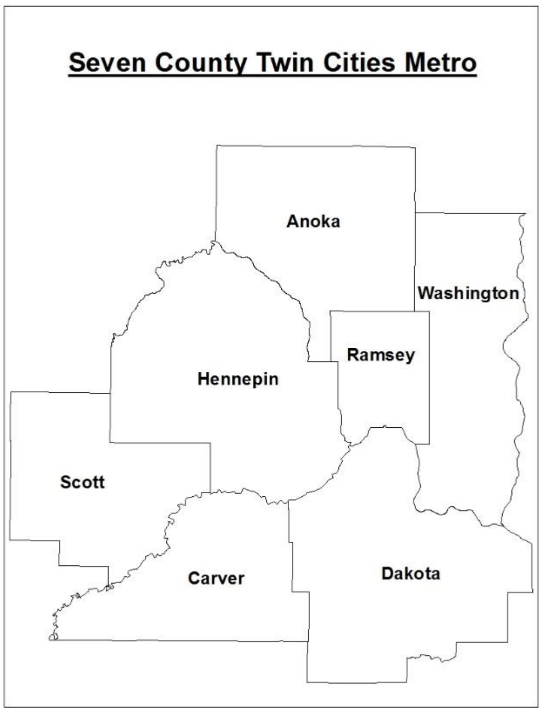

Figure 1. Seven county Twin Cities, USA metro area totaling 2,771 square miles.

The study area of this project was limited to the seven-county Twin Cities metro area of Minnesota, USA (Figure 1). With the metro area of the Twin Cities surpassing three million residents the consumption of energy will rise and production must increase to meet this demand. Alternative energy derived from the sun can transform the way energy is produced and consumed. There are three types of solar panels (monocrystalline polycrystalline silicon, and thin film solar cells) in Figure 2 (Clean Energy Review, n.d.) with countless variations and models

Figure 2. Image displaying the three types of solar panels. Thin film (left), Monocrystalline (center) and Polycrystalline (right).

on today's market, thus it is important to know what type of panel is best for the situation at hand.

Monocrystalline solar panels (m-Si) have the highest efficiency ratings because the highest grade silicon is used in their manufacture. They are space efficient and have the longest lifespan of all panels. On the other hand, m-Si panels are the most expensive on the market. If partially covered by shade, dirt or snow, the circuit can be broken. They tend to be more efficient in warm weather (Maehlum, 2015). Polycrystalline panels (m-Si) are less costly than m-Si panels but their overall efficiency is lower and they require more space (Maehlum, 2015). Thin film solar cells (TFPV) are the least impacted by shade and high temperatures, they are cheaper to manufacture than m-Si and p-Si panels and they can be made to be flexible but they are not recommended for residential use. They have the lowest space efficiency and have the shortest life span of the panels compared.

Even with the benefits to production of solar energy in Minnesota does have limitations. Limitations depend heavily on the model, the panels, the size of the solar array, each panels' efficiency rating, and overall energy consumption of the household. Solar energy production in the panels, the size of the solar the panels, the size of the solar array, each panels' efficiency rating, and the overall consumption of the household using the power. Solar energy production in Minnesota is most ideal during late spring, and throughout the summer months, as seen in Figure 3 (Deck Monitoring, n.d.).

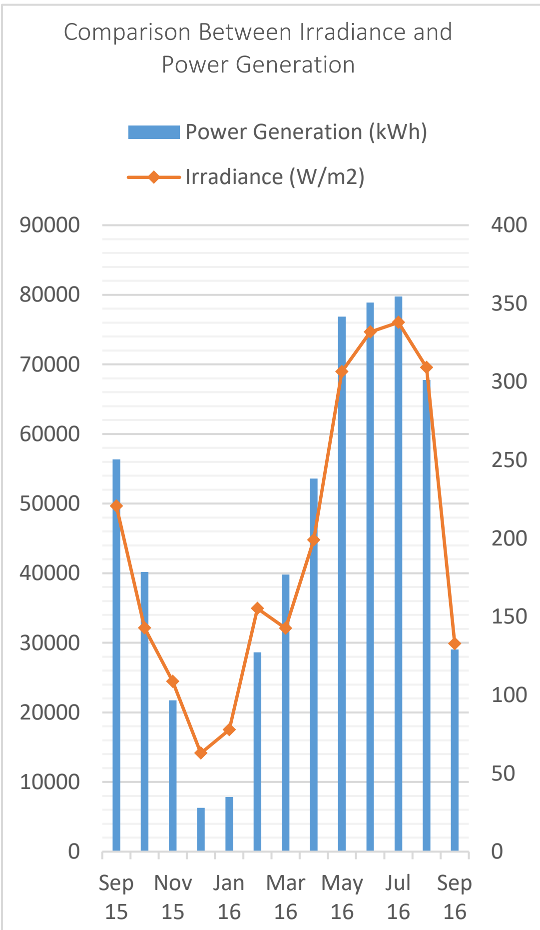

Figure 3. A depiction of the relationship between generated by solar panels (blue bars) and solar insolation (orange line).

Installing solar panels with the goal of producing sufficient energy to power a home or other buildings has upfront costs. These include purchasing and installing the panels, maintenance, and repair. In 2016, the installed cost of solar panels was between \$7-\$9 per watt. A 5 kW system would cost around \$25,000-\$35,000 and a system that costs \$18,000 has a payback period of about 20 years (Solar Power Authority, 2016). The location of the solar array determines the final cost because of the different tax breaks from state to state, incentives from the local utility companies and rebates given by solar panel manufacturers.

Home/business owners who desire to go solar but cannot afford it or do not wish to have panels installed on their property can subscribe to a solar garden, a community or cooperative. Solar gardens can refer to both 'community-owned' or third party-owned panels, where the power generated is distributed by the local utility company to the subscribers of the solar garden. The primary purpose of community solar is to allow members of the community the opportunity to share the benefits of solar (EnergySage, n.d.).

Solar gardens are sites where power is generated and distributed to its many subscribers through the local utility company(ies) at a reduced cost compared to power generated by fossil fuels. More than 300 MW of solar gardens at 80+ locations in Minnesota are currently proceeding through the design and construction process with more expected in the coming months, putting the program on track to become the nation's largest community solar program by the end of the year (Xcel Energy, 2017).

Over the last 5 years, solar gardens have been seen as the newest form of green energy production in Minnesota because of increased pressure from state legislators on utility companies to source a percentage of electricity to renewable sources. SoCore Energy, one of the nation's leading developers and operators of commercial and distributed solar generation has agreed to acquire equity interests in 22 community solar garden development projects in Minnesota and once constructed, these projects will provide up to 140 megawatts (MW) of solar-generated power to help meet the growing demand for renewable energy in Minnesota (SoCore, 2016).

Methods

Data Gathering

Most of the data used in this study existed as a 30-meter elevation raster for the State of Minnesota. It was obtained from the Minnesota Geospatial Commons, an open source website for geographic and other related data for the State of Minnesota. The elevation raster was interpreted by tools with ArcMap to produce various data sets. Land cover and tree canopy data sets were also obtained from the Minnesota Geospatial Commons.

Land cover provided information on how a parcel was classified, whether it was open/barren land or developed, high intensity. Based on land cover classification, data was used to determine areas in the metro that would be the most suitable for solar arrays. The tree canopy data set provided information on the density of canopy cover throughout the state and was used to determine areas within the metro that did not have heavy canopy cover.

Data Processing

The analysis began with a shapefile of Minnesota. From this, the seven-county metro was selected and a separate shapefile was created. This was used as a mask to select only relevant data from all other layers used in the analysis. Slope and aspect tools, from the spatial analyst toolbox were used to create the slope and aspect rasters from the 30-meter elevation raster. A value field was added to the land cover and tree canopy data sets for the purpose of reclassifying both data sets to facilitate data processing. The reclassify tool, in the spatial analyst tool box, was used on the land cover and tree canopy rasters to alter the data. Developed, high density and deciduous/evergreen forests were combined because the study's goal was to identify areas that did not require the destruction of buildings or clearing of forests to erect solar panels. Areas classified as barren, hay, and cultivated land were combined to represent areas to most likely be candidates for ground mounted solar panels.

Solar insolation data was needed to identify areas receiving higher levels solar energy. However, the first data obtained were in the form of pictures (jpeg and tiff files) with generalized data of solar insolation across the state. The objective was to find state specific raster data on solar insolation, but the data was not available without subscription purchase so the solar insulation was modeled.

The ArcGIS area solar radiation tool was used to produce the data needed to complete the analysis. The tool required 18 different variables to produce a raster that might resemble existing solar insolation calculations. Some of the variables included a z factor used for correcting differences in units, day and time intervals to specify the exact time frame the user desires and transmissivity, which used to specify the amount of solar radiation that will pass through the atmosphere and reach the earth's surface. The tool used the elevation raster provided along with other default or specified criteria to produce a representation of the total amount of solar insolation received across the elevation raster ($W/m^{2)}$. The tool required extensive computing power and the analysis often lasted for hours or days based on the criteria of the model run.

The criteria used to determine suitable locations for solar panels included elevation above 750 feet to avoid low lying areas that could be inundated by changes in water levels. Tree canopies more than 50 percent were eliminated to avoid areas of heavy canopy shading. Slopes greater than 30 degrees were eliminated to avoid installations on steep and uneven surfaces. Aspect facing in a southern direction was chosen to allow the greatest potential for energy collection. Land use that was identified as either barren, hay/pasture, developed (open space) or developed (cultivated crops and shrubs) were selected to indicate areas that appeared to be more conducive to larger arrays installations. Solar insolation greater than 1,000 kw h/m^2 annually was used to indicate areas most likely to produce the greatest amount of energy.

Despite using the criteria mentioned earlier, several iterations using different variables from various rasters were used to cross reference the data and the final outputs. The raster calculator tool in the spatial analyst toolbox was used to produce rasters showing all areas that met the requirements in a simple true or false (1,0) depiction. The model builder was used to construct a model that would only require the user to alter the inputs and a few variables to complete the whole analysis process.

After running the necessary analysis to determine which areas met all criteria, Dakota County was chosen as the case study to evaluate the potential for commercial solar gardens. Dakota county was selected from the seven-metro county shapefile and was used to clip a Minnesota roads shapefile and the final output raster that was mentioned earlier in the previous paragraph. The Minnesota highway geodatabase was obtained from the Minnesota Geospatial Commons website. The raster was converted to a shapefile and the road layer was used to select areas within a half-mile of roads. The significance of the half mile buffer was to select only sites that could be easily accessed by existing road infrastructure. The last portion of this project analyzed the potential solar energy that could be harvested from the roofs of commercial and large residential buildings in Bloomington, MN and Rosemount, MN. This was done to compare the potential production within an urban and suburban city. The shapefiles of both cities were retrieved from the Minnesota Geospatial Commons. Two separate shapefiles were created with on screen digitizing to draw the roofs of relevant buildings. The total area of roofs from both cities and the energy rating of the proposed panels were used to determine a range of solar energy production.

Results and Discussion

After analyzing the data, areas ideal for the installation of solar panels were identified. Figure 4 displays areas that

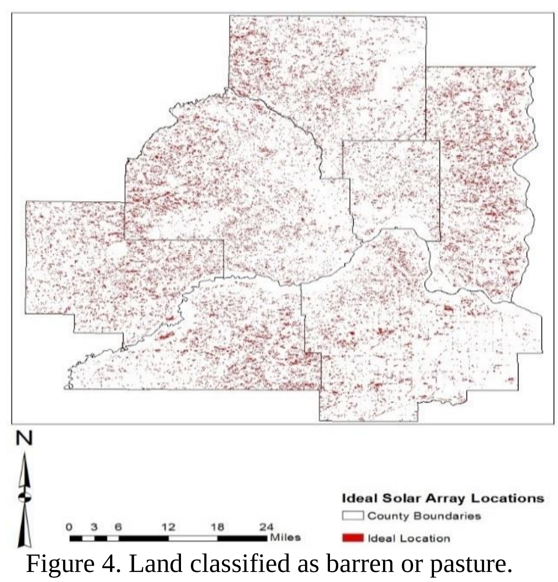

Figure 4. Land classified as barren or pasture.

were above 750 feet in elevation, had a southerly facing aspect, tree canopy cover less than 50 percent, land use classified as barren, hay/pasture and “Developed” (open space) and solar insolation greater than 1000 kw h/m^2 annually. The areas highlighted in Figure 4 totaled 7,746 hectares and has the potential to produce more than 1 terawatt of electricity if fixed tilted photovoltaics panels are installed on every hectare.

Figure 5 shows areas above 750 feet in elevation, slope less than 30 degrees, tree canopy less than 50 percent, southerly facing surfaces, land use classified as developed (low intensity), shrubs, cultivated land and herbaceous plants, and solar insolation greater than 1000 kw h/m^2 annually. The areas that are highlighted in Figure 5 amount to 9,876 hectares of land.

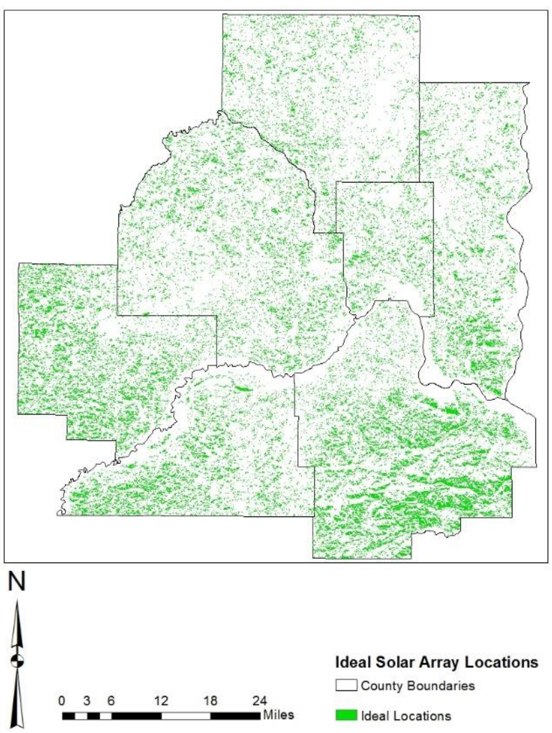

Figure 5. Areas in the metro that met all the criteria which includes land classified as developed (low intensity), shrubs, cultivated land, and herbaceous plants.

To test effectiveness of the data, existing and proposed solar projects throughout the metro were examined to determine if the data intersected locations with the proposed solar array installation projects. Figure 6 shows an area in Coon Rapids, Minnesota and in the yellow highlighted box is the Anoka-Ramsey County Community College where ground and roof top solar panels are to be installed to offset energy demands of the community college. Within the yellow box, there are areas on campus grounds that would be suitable for solar panels installation. The proposed areas for ground mounted panels to be installed were not specified in the project’s proposal but there are areas on school property which are highlighted that indicates the criteria chosen for this study are valid because of the intersection of the proposed project and the data from the analysis.

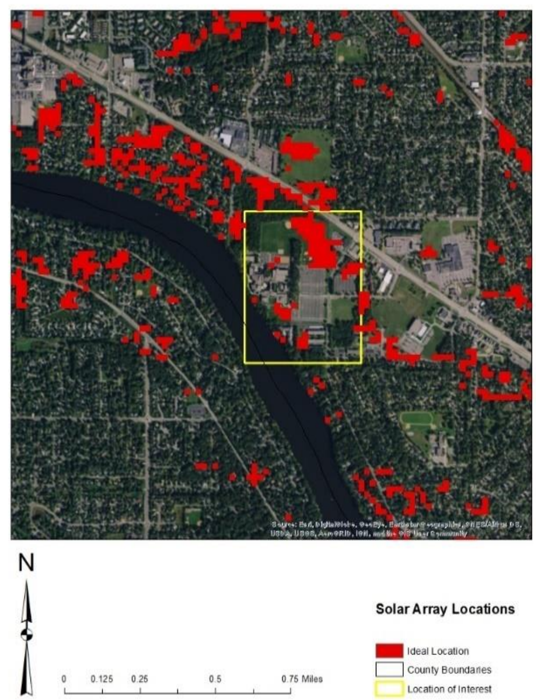

Figure 6. The area within the yellow box is the Anoka-Ramsey County Community College campus where a solar array is being planned for construction.

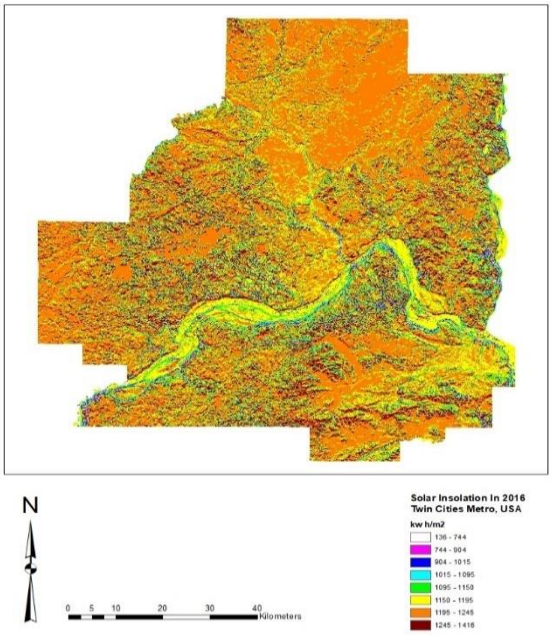

Figure 7. Solar insolation (measured in kw h/m^2) of the seven county metro for the year 2016. Higher values of solar insolation increases energy production.

Figure 7 represents the modeled solar insolation received in the metro during 2016. The locations that were chosen from the analysis match areas where solar insolation was greater than 1150 kw h/m^2. Areas highlighted in tan and dark brown represent areas of interest to this study. Solar insolation was a crucial component of the analysis because it allows citizens of the metro to have a general idea of how much solar insolation could be collected in their neighborhood.

Solar Gardens in Dakota County

Solar gardens are becoming popular in Minnesota as a result of changes in policies, the overall cost effectiveness of solar panels and its increase in popularity throughout the country. Table 1 contains information on 11 solar gardens of various sizes and energy outputs in towns such as Farmington, Rosemount, and Northfield. Ten of the eleven gardens are no longer accepting new subscribers (Xcel Energy, 2017).

Table 1. Solar gardens currently in operation or under construction in Dakota County as of February, 2017.

Operator	**Name of Solar Garden**	**Address**	**Maximum Output**	**Garden Status**	**Subscription Status**
BHE Renewables	Ursa Community Solar Garden	1650 190th St. W., Farmington	5 Megawatts	In Operation	Filled
BHE Renewables	Northfield Community Solar Garden	2300 North Ave., Northfield	5 Megawatts	In Operation	Filled
BHE Renewables	Rosemount Community Solar Garden	2505 160th St. E., Rosemount	5 Megawatts	In Operation	Filled
Oak Leaf Solar XV	Met Council Empire	2540 197th St., Farmington	5 Megawatts	In Operation	Filled
Solar Stone Partners	Waterford	N/A	1 Megawatt	In Operation	Accepting
Solar Stone Partners	Waterford	N/A	1 Megawatt	Construction	Filled
SunEdison	SunEdison Farmington	N/A	5 Megawatts	Construction	Filled
SunEdison	SunEdison Castle Rock	3330 225th St. W., Farmington	5 Megawatts	Construction	Filled
SunEdison	SunEdison Northfield	N/A	N/A	Construction	Filled
SunEdison	SunEdison Coates	N/A	N/A	Construction	Filled
SunEdison	Cannon Falls	N/A	N/A	Construction	Filled

Dakota County was chosen to further investigate the possibility of solar energy production because of the large tracts of land under cultivation, its flat land surfaces and little tree cover. These conditions make Dakota County an ideal location for solar gardens.

Figure 8 depicts areas in Dakota county that would be most suited to the installation of solar gardens. The areas highlighted in tan shows 22,717 hectares of land, from which more than 6 GW of energy could potentially be produced.

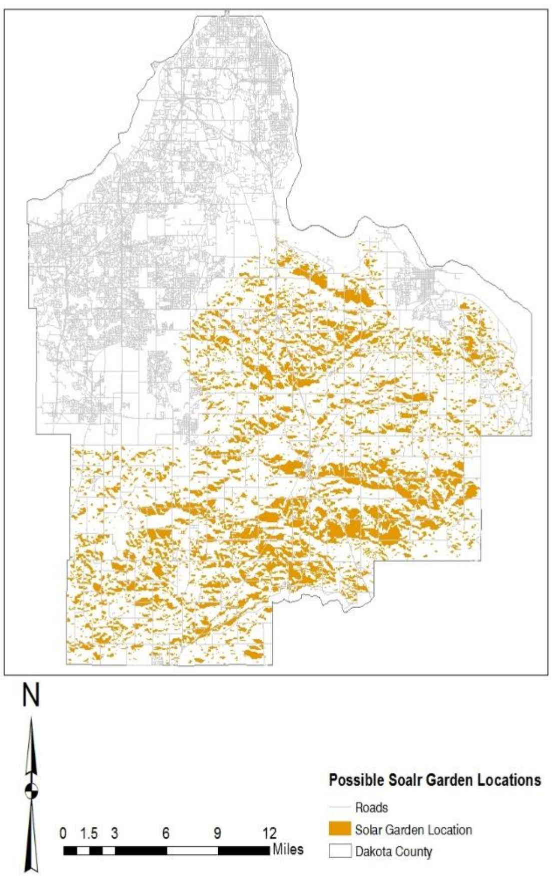

Figure 8. The areas highlighted in tan are potential areas that would be conducive to the installation of larger commercial scale solar gardens/farms in Dakota County.

Most of the land highlighted in Figure 8 is classified as farm land which is largely used for corn production. Farm land is ideal for photovoltaic systems because it is mostly void of mature tree, buildings that produce shading problems, and it is mostly flat. The U.S. cultivates more than 90 million acres (36,421,708 hectares) of land planted to corn, with the majority of the crop grown in the Heartland region (refers to Midwestern states of the United States) where most of the crop is a main food source for livestock (USDA, 2017). With such a large quantity of land being used for corn production, farmers might consider leasing a portion of their land in Dakota County. This would not only help other American enjoys green energy but also make more money per hectare of their land.

Commercial solar installers are now actively looking for farm land to lease and farmers in Dakota County can benefit greatly. Innovative Solar Systems, based out of Ashville, North Carolina, is currently involved in solar farm land lease programs that have been deemed by many as some of the best in the solar industry. Owners of qualifying farm land tracts can make good profits by entering into 20 to 30-year land lease with the company. At the time of this study, it is paying rates in the range $500-$750 per acre per year (Innovative Solar Systems, n.d.).

As of March 18, 2017, the current price of corn per bushel stood at $3.67 per bushel and currently farmers in America can produce up to 200 bushels of corn per acre (USDA, 2017). This would yield a gross income per acre of $724 before the costs of production, which are substantial. With a solar lease, a farmer can lease his/her land for 30 years and earn a substantial income with minimal land maintenance costs.

Roof Top Solar Gardens

Ground mounted solar gardens do not have to be the only way panels are erected. Roof top solar gardens are an alternative not affecting the overall aesthetics of the

Table 2. Top 5 largest commercial roofs in the cities of Bloomington and Rosemount and potential energy production.

Bloomington				
	Building	**Address**	**Size(ha)**	**Potential Output**
	Mall of America	60 E Broadway	47.34	52.6 – 78.9 MW
	Best Buy Shipping	6203 W 111th St.	16.48	14.9 – 22.4 MW
	Progressive Rail	2001 W 94th St.	13.47	14.9 – 22.4 MW
	Thermo King Corporation	314 W 90th St	10.94	12.2 – 18.2 MW
	Sight Path Medical	5775 W Old Shakopee Road 90	9.33	10.4 – 15.6 MW
Rosemount				
	Dakota County Technical College	1300 145th St. E.	6.12	6.8 – 10.2 MW
	Rosemount High School	3335 142nd St. W.	4.78	5.3 – 7.9 MW
	El Dorado Packing, Inc.	2750 145th St. W.	3.72	4.1 – 6.2 MW
	Rosemount Middle School	3135 143rd St. W.	3.09	3.4 – 5.1 MW
	Cub Foods	3784 150th St. W.	1.89	2.1 – 3.2 MW

installation site or displacement of crops or families.

The best option would be to partner with existing businesses, such as those mentioned in Table 2, that have large, flat roof spaces being under-utilized for energy production. One example of this can be seen with the IKEA store (Figure 9) located in Bloomington, Minnesota. In 2012, had the largest photovoltaic layout in the state and can be seen as an example to other businesses interested in self-sufficiency. The 1.36 hectare PV array consists of a 1,014-kW system, built with 4,316 panels. IKEA Bloomington program will produce approximately 1,161,328 kWh of clean electricity annually (Business Wire, 2012). The second option would be to acquire grants from state and/or federal programs that would allow communities to purchase abandoned or non-productive properties and install smaller scale solar gardens or seek out companies who would invest in such a project.

Figure 9. IKEA building in Bloomington, MN with solar panels installed on the roof. Image provided by BusinessWire, 2012.

A case study was conducted to compare the amount of potential solar energy that could be produced on the roofs of commercial and residential buildings in a rural and urban areas. Two metro municipalities were selected, Bloomington to represent the dense urban environments, and Rosemount to represent the less developed rural environment.

After digitizing the roofs in each city, Bloomington had 186 hectares of available roof space among 226 buildings.

Rosemount had 13 hectares from 45 buildings. The difference in the amount of available roof space is largely because of the difference in population density between the two cities. The roofs in Bloomington have the potential to produce between 206,666 to 310,000 kilowatts annually. The roofs in Rosemount could produce between 1,444 to 2,166 kilowatts. In both instances, there would be negligible disruption of the aesthetics of the area and no land would be removed from agricultural production.

Conclusions

The alternative energy sector is growing and green energy production is at the fore-front like never before. Solar panels can be used in Minnesota, but they do have limits as to the amount of electricity produced and where they can be placed to produce energy in the most efficient way. This study has shown the potential for the production of solar energy is significant in Minnesota, and the various figures produced illustrate areas most suitable.

Despite not being constantly showered in solar insolation as compared to states such as Florida, Texas, Arizona, etc., the solar revolution has taken hold in Minnesota and legislation and incentives will be key to the continuing growth of green energy. There are already solar arrays set up throughout the state which produces energy for homes, business and schools. Saint John's University in Collegeville, Minnesota is an excellent example where solar panels are used to offset the university's demand for energy.

Farm leasing of land to solar companies is also a viable option to help prevent farmers from the stresses of crop production relating to yield, production costs and commodity pricing. If more farmers leased their land, it would cause a major shift in the way energy is produced in Twin Cities metro area most of which is presently sourced from coal-fired power plants.

For farmers and other individuals who are against the introduction of commercial solar gardens to produce energy on agricultural lands, the roofs of commercial and large residential buildings within densely populated areas are also an option for energy production. Here, tax incentives for owners of such buildings to install roof top solar garden would be an ideal way to introduce the concept.

Limitations and Issues

The solar insolation data that was used in the study was simulated data which was good, but actual solar data throughout the seven county metro would have been the ideal. Another limitation was not having data to analyze the electrical grid in Dakota County to determine if existing infrastructure was capable of redistributing the potential energy produced from solar gardens at proposed sites in Figure 8.

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