Land Use for Photovoltaic Solar Electric System Siting Rating Metrics

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Definitions

Advanced Power Electronics: The application of solid-state electronics to the control and conversion of electric power that deals with the control, design, and computation of energy-processing electronic systems. These are classified according to their input and output power. (i.e. AC to DC, DC to AC, DC to DC converter, AC to AC converter)

Balance of Systems: Encompasses all components of a photovoltaic system including switches, a mounting system, inverters, wiring, a battery bank, and battery charger. This does not include the photovoltaic panels.

Capacity Factor: The ratio of a power plant's actual output over a period of time to its potential output if it were possible for it to operate at full nameplate capacity continuously over the same period of time.

Ideal System Orientation: The optimum angle and direction at which solar modules should be placed and aligned in order for them to capture the most sun and operate efficiently.

Installed Cost: The cost of the balance of systems, individual photovoltaic panels, labor, permits, and inspection fees that are highly dependent on the type of location where the photovoltaic system is sited.

Module Cost: The costs relative to electrical power output that is often measured by cost per Watt.

NIMBY ("Not In My Backyard"): Opposition to the locating of something considered undesirable in one's neighborhood.

Photovoltaic (PV) Energy: Photons of light exciting electrons into a higher state of energy, allowing them to act as charge carriers for an electric current.

Urban Heat Islanding: A city or metropolitan area that is significantly warmer than its surrounding rural areas primarily due to human activities, the modification of land surface, and waste heat generated by energy usage.

Abstract

Since solar electric power is becoming increasingly popular throughout the United States, there is some concern that this growth can have negative environmental effects associated with the siting of solar modules and land use. Five different locations for siting photovoltaic (PV) systems were evaluated including open lands, brownfields and mine tailings, rooftops and carports, building-integrated photovoltaics (BIPV), and transportation corridors. A ranking system was created to determine which locations are the best for PV systems. The ranking system examined and compared four important metrics including environmental impacts, technological barriers, cost, and social implications. Based on the results of the rating system, rooftops and carports received the highest ranking with a total score of 11 points, BIPV received the second highest score with a total of 10 points, open lands received 9 points, and brownfields and mine tailings and transportation corridors both received a final score of 8 points each.

Introduction

Solar electric power is becoming increasingly popular throughout the United States. According to the United States Energy Information Administration, solar energy use grew by 104% from 2013 to 2014. In comparison, coal grew by 1.4%[1]. There is some concern that this growth can have negative environmental effects. The Union of Concerned Scientists, a group of scientists whose primary focus is on environmental concerns, lists four different categories of environmental impacts associated with solar power. One category of environmental concern is land use, which will be the focus of this research paper[2]. Five different locations for siting solar electric power plants will be compared. These sites will be evaluated and ranked based on technological barriers, social concerns, and environmental impacts.

Solar electric energy, scientifically referred to as photovoltaic (PV) energy, is the ability to convert sunlight directly into electricity, according to Adria Brooks, a PV Research Specialist at the University of Arizona. Solar panels are made up of many photovoltaic solar cells fixed within a thick glass surrounded by a metal frame[3]. They are located in private, residential, and commercial areas including on rooftops and carports, in desert lands, in wasted lands such as old mine lands, transportation corridors such as roadways, and integrated into the infrastructure of buildings. Each of these PV locations has unique advantages and disadvantages.

Technological barriers, social concerns, cost, and environmental impacts are the metrics that this paper will examine. Technological barriers involve the amount of energy produced for a given area, shading systems, the balance of systems including inverters and DC-to-DC converters. Social concerns include NIMBY (Not In My Backyard) attitudes, conflicting desires for limited land usage, and cultural acceptance of solar power production. And environmental concerns include ecological conservation, maintaining plant and animal diversity, water management, land pollution, and excess heating.

The best way to analyze and determine which locations are the best for PV devices is though a serious of methodologies. Some of which include reviewing PV location case studies and technical papers, analyzing PV feasibility studies, site visits, obtaining information from the public such as commentary or responses to PV projects that have already been done, reviewing energy-analysis and cost studies, and analyzing the relationship between PV locations and property values.

Determining which locations are the best for PV devices is important because it allows people to better understand how solar electric energy works, why PVs exist in certain locations as opposed to others, how feasible they are to install based on location, their technological barriers, social implications, effects on the environment, along with others. This information can be useful to city officials who are looking to lower city energy costs and move towards a more sustainable energy source, or to home and business owners who are interested in converting to using PV energy over electrical grid energy, amongst others as well.

Literary Review

A variety of case studies, technical papers, feasibility studies, and research studies exist on different PV locations, their technological barriers, social implications and responses, and the overall sustainability of each location. However, more studies exist for some locations as opposed to others, and certain locations have more barriers and/or implications than others.

Location-Building Integrated PV Systems (BIPV)

Building Integrated Photovoltaic Systems are exactly what they sound like, which are PV systems that are built directly into building designs as opposed to just placed near or on top of them. Some locations for BIPV systems are building facades, roof panels, and windows. A few architecture projects exist that have incorporated BIPV. The SMA Solar Academy in Niestetal, Germany is an example of a building with solar panels that completely cover the façade (*Photon: The Photovoltaic Magazine*, 48). The project has been a success so far with its PV nominal ratings totaling 151.15 kW of solar capacity from the roof, solar trackers, and the façade. Even the amenities of the building were designed to function efficiently so that they require the use of less of the energy the building produces[4]. Other sources include some pros and cons of BIPVs.

Location-Rooftops/Carports

Rooftops and carports are popular locations for PV systems because they are located above the ground, requiring less space compared to other locations. *Solarworld* is an excellent website that lists where their company has installed rooftop and carport solar power systems, the amount of solar energy that each produces, comments from the customers, and other relevant information. One example from their website is the Burke Solar Pavilion & Solar Canopy in Cincinnati, Ohio. It was custom designed with 1,555 total solar panels generating approximately 380.98 kW of solar energy. According to the website, “This is the largest solar electric system in downtown Cincinnati and the only solar parking canopy system in downtown Cincinnati when installed”[5].

Rooftop solar panels can actually stabilize the grid, according to a *News* journal article in the IEE solar journal collection. Rooftop solar power systems in California generate enough electricity meeting just one percent of the state’s total energy consumption. Smarter and newer solar inverters provide forty percent more PV energy capacity to local power lines, which were first seen in Germany, but are now slowly being applied to homes throughout California and other parts of the U.S.[6].

Location-Waste Lands

Most online websites and scholarly articles address wastelands or brownfield lands as being ideal locations for PV systems since they are essentially recycling land as opposed to taking up rich land that could be used for other development. A few online articles proved to be more bias over others since they only addressed the pros of utilizing brownfields and none of the cons. However, some sites observed and addressed both the pros and cons of doing so. For example, the *National Association of Local Government Environmental Professionals* published a report called, *Cultivating Green Energy on Brownfields*, in which they address the advantages of installing PV systems on brownfield lands as well as some possible public health issues and environmental contaminations. The purpose of the report is to provide local governments that are interested in developing PV sites on brownfields with information about the possible effects of doing so, and not to provide a step-by-step guide to doing so since brownfields can vary depending on site[7].

Location-Roadways/Bikeways

Solar roadways/bikeways are a newer concept that is still being evaluated and tested by PV specialists. One of the most recent solar bikeway projects was done in the Netherlands in November of 2014. It is a bike path with solar panels integrated into parts of it that generates electricity for the national energy grid there. Most information about this project only mentions when and how the project came about, as opposed to the pros and cons of it so far[8].

The co-inventors of the Solar Roadways Indiegogo program first campaigned the idea for solar roadways with their YouTube video, 'Solar FREAKIN' Roadways!' that went viral earlier this year[9]. Since then, critics have been commenting on the reality and feasibility of solar roadways. One critic blogged about the concept on *Worldwatch Institute* quoting that although solar roadways may seem like an extraordinary concept, they may not be quite as feasible as people have hoped. She lists her reasoning for believing this and then proceeds to talk about how solar bikeways may be much more feasible in the near future[10].

Location-Open Lands

Some articles about installing PV systems on open desert lands claim that they are the prime location for them because they are utilizing space that is already preserved and open for the natural environment. Other sources argue that solar panels destroy the natural environment or take up space that could be used for other development. Articles exist for both the pros and cons of installing large PV systems on open desert land.

Metric-Technological

Some technological issues that exist with PV system locations are shading issues that limit the amount of energy produced for a given area. One source, *Sargosis Solar & Electric PV Solar Specialists*, provide diagrams on their website depicting how solar cells are affected by shade with models and charts. Newer PV system models exist that function better than others when exposed to shaded environments, but it all depends on the system configurations and models[11].

Metric-Social

Social metrics that exist regarding PV locations include the Not In My Backyard (NIMBY) phenomenon, which is a type of social non-acceptance to certain PV system locations. These people are commonly concerned that solar power plants will present as eye sores if they are located near people's homes and neighborhoods. The scholarly article, *Social Acceptance of Renewable Energy Innovation: An Introduction to the Concept*, informs how the public can gain a better understanding and acceptance of new sustainable technologies[12].

Metric-Ecological

PV system locations can cause some environmental concerns. Some of which include, compromising natural desert habitats, harming various plant and animal diversity, land pollution, and excess heating. Many pros and cons exist regarding the ecological impacts of solar power plants. For instance, one solar power advocacy group argued that solar technology has the smallest environmental impact compared to other existing renewable energy sources, and that the only negatives associated with them are the chemicals and other toxins used in their production making. While on the other hand, a Senior Fellow with the Committee for a Constructive

Tomorrow, argues that solar fields take up approximately 1,000 acres to produce the same amount of electricity that gas fired electric plants can produce on only 5 acres of land[13]. Multiple other pros and cons exist regarding PV location issues and the environment.

Metric-Economic

Economic constraints include the cost of installing PV systems and the cost of maintaining them. The more complex the system is, the higher the installation costs will be because of installation fees, and of course, the cost of purchasing the systems in general. Just like with any high-order good, the higher the quality, the more expensive the product tends to be. Maintenance costs depends on how well PV systems work in particular locations, along with a variety of other implications. If a PV system needs to be repaired, the parts must be ordered directly from the company that distributed it because manufacturers can build them in multiple different ways that require the use of different parts and accessories. Even though they all have the same function, some can be far more complex than others.

Energy production is another economic metric because some PV systems produce more energy than others. It all depends on how well the system functions based on its use and location. PV systems that have the most direct contact wit sunlight throughout the day will produce more energy than systems that do not receive direct sunlight as often.

Methodology

For years, quantitative data has been the dominant type of data gathered when experimenting with scientific research theories and practices. This type of data was especially associated with the sciences and mathematics as Egon Guba and Yvonna Lincoln refer to in their book, *The Sage Handbook of Qualitative Research Third Edition,* as the "'queen of sciences'" (105). But it was not until recently that quantitative data came about as an accepted means of gathering, recording, comparing, and researching data, especially regarding fields such as biology and the social sciences, which are constantly changing with time. According to Guba and Yvonna's, *The Sage Handbook of Qualitative Research Third Edition*, qualitative data provides contextual information about "Human behavior," and that "unlike that of physical objects, cannot be understood without reference to the meanings and purposes attached by human actors to their activities"…and it "can provide rich insight into human behavior" (Guba & Lincoln 106)[14]. In general, qualitative data focuses more on the concept of doing research based on information that already exists that can be obtained by textual or digital sources, by talking to specialists in the desired field(s) of interest, or by physically experimenting with subjects relating to the area(s) of interest, in which quantitative data cannot feasibly be obtained. Qualitative data in some cases also allows the researcher to form a more personal bond with whomever he or she is working with or interviewing, as opposed to quantitative data, which is typically done independently as a means to prove or disprove already existing data and theories.

Qualitative research will be the most beneficial approach to better understanding PV system locations for this report because it will allow the researcher to gain information on research that has already been done on solar technology, which can then be applied to the ranking system based on the specific criteria. The researcher will also gain an exceptional perspective of the research information using a qualitative approach as opposed to a quantitative approach in which the researcher would be required to physically conduct his or her own field studies with PV systems at each desired location and analyze their function and efficiency. By combining quantitative and qualitative research on existing and proposed projects throughout the United States, the research will provide a much more extensive analysis of different locations than could be possible by conducting new field studies at a few locations in the Tucson region.

The best approach as to determine which locations are the most ideal for photovoltaic (PV) systems is to rank each location based on the following criteria: technological barriers, social implications, and environmental impacts. The PV system locations that will be researched and compared are Building-Integrated Photovoltaic systems (BIPV) , transportation corridors, rooftops, desert lands, and brownfields. The best way to determine the rankings for the above criteria is to learn about each location's feasibility, solar potential, cost, energy-analysis, social and cultural acceptance, and the overall environmental impacts. This approach uses qualitative data in a mixed method approach, combining case studies with construct.

The researcher will review case studies on existing PV system installations, feasibility studies on proposed PV system installations, technical papers on PV operation, attend or review public comment periods, and do site visits to obtain the desired qualitative research. The researcher may also work together with solar technicians, specialists, or any other related participants to understand what locations are the most ideal based on rankings. Technical limitations to solar installation and cost-energy analysis will provide data for this part of the research.

Results

Land Use for Photovoltaic Solar Electric System Siting
Rating Metrics

	Ecological Impacts	*Technological Barriers*	*Cost*	*Social Implications*	*Total*
Open Lands	1	3	3	2	9
Brownfields / Mine Tailings	1	1	3	3	8
Rooftops / Carports	3	3	3	2	11
BIPV	3	2	2	3	10
Transportation Corridors	3	1	1	3	8

Metric Descriptions

Ecological Impacts

Excellent (3):

- Does not damage existing vegetation or wildlife corridors
- Does not create heat islanding effect[1]
- Does not release or introduce soil/water toxins
- Does not cause erosion or divert water drainages

Good (2):

- Minimal/reversible damage to existing vegetation or wildlife corridors
- Does cause heat island effect, but does not raise local temperatures by more than 2°F[1]
- Does release or introduce environmentally safe soil/water toxins
- Minimal/reversible erosion or divert water drainages

Poor (1):

- Significant/irreversible damage to existing vegetation or wildlife corridors
- Does cause heat island effect, and raises local temperatures by more than 2°F[1]
- Does release or introduce soil/water non-environmentally safe toxins
- Significant/irreversible erosion or divert water drainages

Technological Barriers

Excellent (3):

- If system is meant for commercial or residential use; PV system is large enough to offset 100% energy use

[1] 2°F temperature rise results in 3%-4% increase electricity use by people using air conditioners. (http://www.epa.gov/heatislands/impacts/index.htm)

- PV system location faces the sun directly (either at the optimal fixed tilt angle or uses tracking) to obtain full potential of sunlight daily, and the system is sited so as to receive <5% average shade per year.
- System mounting is trivial and does not require specialized equipment.
- Modules and balance of systems equipment used are off the shelf and not specialized.
- Existing power distribution or transmission already on site and can support variable-resource generation.
- Capacity factor of about 0.3 and higher

Good (2):

- If system is meant for commercial or residential use, PV system is large enough to offset between 75%-99% energy use
- PV system receives an average annual shading of <25%, or advanced power electronics are used to minimize the power loss due to shade.
- System is not sited at optimal orientation, and has an associated power reduction of <25%.
- System mounting is complicated and requires specialized equipment and labor.
- Modules and balance of systems equipment used are off the shelf and not specialized.
- Power distribution or transmission must be brought to location, but grid can support variable-resource generation.
- Capacity factor of about 0.2 to 0.3

Poor (1):

- If system is meant for commercial or residential use, PV system is large enough to offset less than 75% energy use.
- PV system may receive >25% average annual shading and no attempt is made to minimize power loss.
- System is not sited at optimal orientation, and has an associated power reduction of <25%.
- System mounting is complicated are requires specialized equipment and labor.
- Modules and balance of systems equipment are site-specific and must be custom-designed.
- Power distribution or transmission must be brought to location and local grid must be further supported in order to connect variable-resource generation.
- Capacity factor of less than 0.2

Installed System Cost

Excellent (3): ≤ $3 / Watt
Good (2): $3.01 - $8 / Watt
Poor (1): ≥ $8.01 / Watt

Social Implications

Excellent (3):

- Location does not provoke NIMBY attitude to surrounding residents
- PV installation creates job opportunities throughout the community
- On-site, on-going community education outreach opportunities

Good (2):

- Location may provoke NIMBY attitude to few surrounding residents, but is accepted by majority of community members
- PV installation requires few workers and provides minimal job opportunities throughout the community
- Pre-installation site-specific outreach

Poor (1):

- Location provokes NIMBY attitude to majority of surrounding residents
- PV installation does not provide new job opportunities throughout the community
- No attempts at community outreach/education

PV Siting Location Scoring

Open Lands / Desert

Ecological Impacts

- Poor because irreversible land damage[2] and heat islanding increase local temperatures by 5F[1]
- Poor because destroys vegetation and can disrupt wildlife habitats[2]

Technological Barriers

- Excellent rating because PV systems can still produce efficient amounts of electricity when some panels are shaded[3], are typically on land areas that are large enough to produce efficient amounts of electricity, and receive full sunlight exposure potential (field observations)

Cost

- Excellent rating because $1.50 / Watt[4]

Social Implications[2]

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[1] Green roofs increase local temperatures minimally (based on Fig. 10b) (http://www.sciencedirect.com/science/article/pii/S0360132311001843)

[2] Utility-scale solar energy systems can cause both direct and indirect irreversible damage to soil, water resources, & biodiversity. (http://www.sciencedirect.com/science/article/pii/S1364032113005819)

[3] Solar cells that are connected in a series circuit have higher efficiency when a part of the series is shaded. (http://sargosis.com/articles/science/how-shade-affects-a-solar-array/)

[4] Solar modules cost roughly between $1 or less per watt being the cheapest to $10 and up being the more expensive modules. (http://www.wholesalesolar.com/grid-tie-packages#SolarEdgeAstronergyGridtie)

- Excellent rating because open land solar energy facilities create numerous jobs throughout communities with manufacturing, operations, and installations & can help stimulate the economy[5]
- Poor because many environmental groups do not approve of bulldozing the desert for PV installation.
- Excellent because does not invoke NIMBY

Brownfields / Mine Tailings

Ecological Impacts

- Good rating because utilizing recycled land with redevelopment (i.e. does not damage much existing vegetation or wildlife corridors since the land was previously developed on)[6]
- Poor because disruption of the land could disturb or release soil/water toxins [6]

Technological Barriers

- Poor rating because electric power transmission lines do not always exist on site already[7]
- Excellent because no public or private lands need to be reformed for utility-scale power[7]
- Good because has a capacity factor between 20% & 30%[8]
- Poor because of necessary technical equipment and specialized labor[18]

Cost

- Good rating because cost ranges to about $4/Watt[7]

Social Implications

- Excellent rating because location does not cause a lot of NIMBYism[9]
- Excellent because installation of utility-scale PV systems on brownfields/mine tailings can create community job opportunities[10]

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[5] Solar projects often help create numerous jobs throughout communities (http://www.ehow.com/info_8704232_social-impacts-solar-energy.html)
[6] Location addresses current constraints on land redevelopment
[6] Potential contaminants: lead (paints), arsenic, PCBs, metals, pesticides, asbestos, & hydrocarbons (http://www.sciencedirect.com/science/article/pii/S0301421510005513)
[7] The major cost of transmission infrastructure need not be reinstalled
[7] The tailings area is large enough to accommodate present and medium term future demands
[7] The entire installation can cost up to $2,000 per kilowatt ($2 per watt) (http://www.azrise.org/wp-content/uploads/2013/07/Tailing-Ponds.pdf)
[8] Capacity factor of about 0.25 (http://www.nrel.gov/analysis/tech_cap_factor.html)
[18] A popular form of non-penetrating mounting of PV modules are used on polluted sites (http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6317669&tag=1)
[9]Development already constrained by commercial & industrial property demand and diminished housing (https://auth.elsevier.com/SHIRE/Login?SAMLDS=1&entityID=urn%3Amace%3Aincommon%3Aarizona.edu)
[10] Many new jobs can be fulfilled by workers as a result of a community using solar energy (http://www.ehow.com/info_8704232_social-impacts-solar-energy.html)
[1](http://www.epa.gov/heatislands/impacts/index.htm)

Rooftops / Carports

Ecological Impacts

- Excellent rating because location does not damage existing biodiversity since modules are applied to existing structures
- Good/Poor rating depending on specific locations of rooftops/carports because modules can cause heat island effect and can potentially raise local temperatures by 2°F or more[1]

Technological Barriers

- Excellent rating because rooftop/carport modules are less susceptible to shade since they are residential and several modules are connected in a series[11]
- Good/Poor because capacity factor varies depending on location

Cost

- Excellent rating because rooftop/carport PV system installment fees can cost between $3 to $8 per Watt depending on quantity & type[12]

Social Implications

- Excellent rating because installation of PV units can create local job opportunities[13]
- Good, not excellent because many homeowner's associations do not allow them to be installed
- Excellent because PV requires homeowners to engage more actively with their electricity usage, helping to educate homeowners on their energy consumption habits.

BIPV

Ecological Impacts

- Excellent because BIPV is installed on or into existing infrastructure and does not require land clearing

Technological Barriers

- Good rating because shade can reduce BIPV annual energy production by approximately 20% or more[15]
- Good because power electronics are used to minimize energy loss due to shade

Cost

- Good rating because the total cost of BIPV installation can range between $5 to $8 per Watt depending on building specific factors[16]

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[11] Rooftop/Carport modules are more susceptible to hard and soft shade, also depending on the type of connection between them (http://sargosis.com/articles/science/how-shade-affects-a-solar-array/)

[12] Rooftop/Carport modules vary by price, falling between $3 & $8 / Watt (http://www.wholesalesolar.com/solar-panels)

[13] Social Impacts of Solar Energy (http://www.ehow.com/info_8704232_social-impacts-solar-energy.html)

[15] Shading is the primary critical aspect of technical barriers for BIPV during the planning and design stage (http://www.arcom.ac.uk/-docs/proceedings/ar2010-1407-1415_Ikedi_et_al.pdf)

[16] BIPV prices can often be lower than traditional residential PV systems (Figure ES-2) (http://www.nrel.gov/docs/fy12osti/53103.pdf)

Social Implications

- Excellent rating because BIPV is installed on or into existing infrastructure and does not require land clearing
- Excellent because BIPV systems have the capacity to generate about 8% of the electrical power required depending on building size, location, and integration[15]

Transportation Corridors

Ecological Impacts

- Excellent rating because does not damage existing vegetation or wildlife corridors only when applied to existing corridors
- Excellent because solar transportation corridors do not contribute to heat islanding effect when installed on existing infrastructure

Technological Barriers

- Poor because fast and slow-moving shade can reduce solar corridor efficiency[17]
- Poor because installation on transportation corridors are in the early stages of development and fraught with technological barriers[19]

Cost

- Poor rating because it would cost approximately $56 trillion to replace all U.S. highways with solar panels[18]
- Poor because the installed cost for roadways would be greater than or equivalent to about $8 per Watt[18]

Social Implications

- Excellent because installation of solar corridors can create community job opportunities

Discussion

The rating system for photovoltaic land use was created to help determine which locations are the most ideal for solar panels. Four different rating metrics are used to compare the five possible PV siting locations. The metrics include ecological impacts, technological barriers, installation costs, and social implications. Each PV location could earn one of three scores within

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[17] The shade effects due to vehicles moving over the panel is considered to play a significant role photovoltaic energy generation (http://ir.lib.uwo.ca/cgi/viewcontent.cgi?article=2220&context=etd)

[19] Cost and safety are the primary issues preventing Solar Roadways from being installed (http://www.greentechmedia.com/articles/read/Department-of-Transportation-Official-Discusses-Solar-Roadways)

[18] It would take about 5.6 billion solar panels to cover the estimated 800 billion square feet of U.S. roads that could potentially be covered by solar modules (http://singularityhub.com/2010/08/08/solar-roadways-crackpot-idea-or-ingenious-concept-video/)

each metric criteria: *Excellent* worth three points, *Good* worth two points, and *Poor* worth one point to give each location a numerical value. The rating system is designed on a scale from one being the least beneficial to three being the most, and is based on a series of general criteria that are to be taken into consideration when determining the effects of installing PV systems in different locations. The highest total score any location could have received is 12 points, a perfect score for the most ideal location, while the lowest total score any location could have received is 4 points, the least desirable location for PV modules. Each section contains a few specific criteria describing what each numerical section pertains in order for the PV locations to earn points for one section of each metric. Whichever numerical section contains the majority of the criteria met for a particular PV location, determines the numerical rating for that criteria. After all of the locations are given rankings for each of the criteria, the numbers are then added together to create a final total ranking score for each location. The location with the highest total is determined to be the most ideal location for PV systems according to this rating system.

Based on the results of the rating system, the PV location with the highest total metric value is the Rooftops/Carports location with a final score of 11 points, followed by BIPV scoring a total of 10 points, followed by Open Lands with a total of 9 points, and finally a tie between Brownfields/Mine Tailings and Transportation Corridors, each accumulating a score of 8 points. The results of this ranking system are somewhat expected based on the case studies, reference materials, and site visits examined prior to the creation of the rating system.

Rooftops/Carports scored the highest score of 11 points, which is not surprising because rooftops and carports are prime locations for solar panels, especially here in the southwest where there is an abundance of sunlight exposure. Many people find them to be desirable and convenient because they can be installed directly onto the roofs of existing infrastructure and take up underutilized rooftop space. This location did not receive a perfect score because of the social implications associated with it including how certain homeowner's associations do not allow the installation of them because of cost and NIMBY attitudes.

BIPV location scored the second highest ranking of 10 points, which is somewhat surprising considering that BIPV is not as popular as some of the locations that scored lower than it. BIPV systems are built directly into the infrastructure of buildings and designed to function as elements of buildings such as BIPV roof panels, cladding, and windows. There are a few technological barriers and high installation costs associated with BIPV, which earned BIPV only a Good rating as opposed to an Excellent rating for those criteria.

Open Lands scored the third highest ranking of 9 points. PV systems that are located in open lands are typically designed as rows of interconnected modules filling open, undeveloped land. It is not surprising that this location scored the third highest ranking because of the social implications and especially the ecological impacts that are often correlated with them. A primary social implication is that many environmental advocates do not always approve of bulldozing open land for the installation of PV modules because of the habitat and biodiversity loss it entails, while others simply find it to be a waste of space that could otherwise be used for other development. The primary ecological impacts associated with open desert lands is that the installation can cause irreversible damage to the land as well as escalate urban heat island effect.

Brownfields/Mine Tailings and Transportation Corridors both tied with the lowest total ranking score of 8 points each, which is not entirely surprising based on the case studies and reference materials. Brownfields and mine tailings are areas of land that previously had commercial or industrial use that entail perceived or actual environmental hazards and/or contamination. Since these lands have strict regulations for land use and development due to the potential hazards associated with them, there are not many development options for these locations. This is why they are prime locations for the placement of specific solar panels that are designed to rest on top of the soil to avoid disturbing it. However, specific technical equipment and specialized labor is necessary for the installation of PV modules on these sites, which are adverse technological barriers.

Solar transportation corridors are not as common as the other locations studied in this rating system because there are so few that exist. Because of there lack of continuation, there are few case studies on them that discuss and analyze their efficiency, feasibility, and other implications. However, there are potential ecological impacts, technological barriers, social implications, and cost estimations that researchers and engineers have made based off of the limited information and solar corridor projects that do exist, which were beneficial for the creation of this rating system.

Although Brownfields/Mine Tailings and Transportation Corridors both earned the same final rankings based on the criteria of this rating system, both locations entail separate distinct measures for each of the criteria since the locations themselves are very different.

Finally, although this rating system is beneficial in helping to determine the most ideal locations for solar modules based on the given metrics of ecological impacts, technological barriers, cost, and social implications, it is a very broad rating system that compares locations that are exclusive from one another. Some are residential locations while others are commercial, some can accommodate more PV modules than others, some systems work better than others, and some locations such as Open Lands, Brownfields/Mine Tailings, and Transportation Corridors generate solar energy on a utility level scale, while the other locations generate it on an individual scale. Assigning numeric values to this rating system makes it easier to compare the PV siting locations.

Conclusion

As discussed, where photovoltaic solar systems are sited is a growing environmental and technological concern. The primary concern with PV system placement is the potential adverse affects of solar modules associated with land use. Locating PV systems in a way that maximizes potential energy production and minimizes environmental impact is key. Through this research, a rating system for comparing different possible system locations was developed to help compare the most ideal locations for PV system placement based on land use.

The rating system was created by analyzing, researching, and evaluating five different land use locations for siting solar electric power plants on both utility and residential scales. The locations are Open Lands, Brownfields/Mine Tailings, Rooftops/Carports, BIPV, and Transportation Corridors. Note, however, the locations were not limited to just the southwest and arid lands. Instead the locations were based broadly on land uses found throughout the United States. The developed metrics used to rank each PV location are Ecological Impacts, Technological Barriers, Installed System Cost, and Social Implications. After the analysis was preformed, Rooftops/Carports scored the highest rating with a total of 11 points. This result was not too surprising given the ease of installation and how the surfaces can perform both the functions of a rooftop and that of a flat or angled space fit for PV module placement. BIPV was second with a total of 10 points, followed by Open Lands totaling a score of 9 points. Surprisingly, Open Lands did not score lower given the ecological impacts PV can have in some areas. Again, the broadness of the scale makes it difficult to specify what type of open land entails less ecological impacts as opposed to others. In addition, the value of the land and other potential uses was not considered and should be included in future refined models. Finally, Brownfields, Mine Tailings, and Transportation Corridors each totaled an equal score of 8 points. This was perhaps the most surprising result of the study given the generally negative connotations placed on these land uses. It is not immediately clear why these locations scored so low, except for distance from cities, which could be a factor in driving up the cost of delivering the power. This research found that rooftops are the most ideal location to install PV and both brownfields and transportation corridors are considered to be the least ideal for PV system placement compared to the other locations in this rating system.

Limitations

There are some limitations acknowledged in this research project that may have impacted the results. For instance, the data and information researched prior to the creation of the rating system included case studies, technical papers, feasibility studies, and site visits, which are all forms of qualitative data. There was no experimental quantitative approach taken to achieve direct experimental results. If that were the case, then the results of this study would possibly vary, or even be inconclusive due to the diversity of the land uses.

Although this rating system is beneficial in helping to determine the most ideal locations for solar modules based on the given metrics of ecological impacts, technological barriers, cost, and social implications; the broadness of the rating system is both beneficial and poses as another limitation recognized in this research project because it compares locations that are exclusive from one another. Some are residential locations while others are commercial, some can accommodate more PV modules than others, some systems work better than others, and some locations such as Open Lands, Brownfields/Mine Tailings, and Transportation Corridors generate solar energy on a utility level scale, while the other locations generate it on an individual scale. This is beneficial because the rating system has the ability to compare these diverse subjects on a single rating system, however, the broadness and diversity of the system must also be recognized when utilizing this rating system to help determine PV installation locations.

Another limitation recognized in this study is that the locations that were examined are only located in the United States, so different environmental, social, and cultural aspects to locations that are not in the United States were not taken into consideration when creating this rating system. If they were, then the scores for each location would most likely vary depending on different location types. For instance, rooftop designs in other regions may be distinctive from those in the United States, or specific regulations in other regions may restrict PV module placement on open lands, brownfields, or even rooftops that may not have been addressed in the criteria of this rating system.

Also, it must be considered that this rating system is based on a numeric scale of 1 to 3. A perfect score for the most ideal location would be 12 points, while the lowest total score for the least desirable location for PV modules would be 4 points. All four metric categories received the same score values based on the scale of 1 to 3, with no weights applied. This evokes potential user discretion depending on who uses the scale. For instance, a capitalist businessperson may appreciate the economic values associated with a PV installation location as opposed to the ecological impacts, and assign an *Excellent* economic score of 6 points and an *Excellent* ecological score of only 3 points, whereas an environmentalist may be more likely to value and assign the opposite values for PV locations. This should be taken into consideration when using this rating system for its purpose of determining locations for PV modules because it helps users better determine the values of each location in comparison to each other.

Recommendations

The numeric rating system presented here compares different land uses for photovoltaic solar electric siting based on four metrics. There are future research opportunities that would be beneficial in extending the comparisons of each location. For example, a quantitative experimental approach could be taken to analyze each location more in depth. Each location could be analyzed in a controlled environment, where the PV modules are individually tested with the same criteria of Ecological Impacts, Technological Barriers, Cost, and Social Implications, as opposed to the qualitative approach used to create this rating system.

Another future opportunity to further analyze the locations of open lands, brownfields/mine tailings, rooftops/carports, BIPV, and transportation corridors, would be to research additional metrics such as real estate values, region specific location values, or economic incentive values to examine and compare the locations for PV system siting. These additional metrics and values could change the results of this rating system.

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