A GIS-based decision making process to optimize the placement of solar PV in geographically constrained regions.

By

Brian A. Jacob

(Under the Direction of David Gattie)

ABSTRACT

A suitability assessment method is presented for the state of Georgia that optimizes regions most appropriate for development of solar PV energy generation technologies. Incorporating economic and geographic constraints in addition to pure solar potential data, this methodology allows for an assessment that mitigates the negative economic externalities often associated with large-scale solar PV by identifying regions that have low economic productivity, are near urban load centers, and consist of land cover more suitable for the installation of utility scale solar PV facilities. Several regions in the state were identified: an area of 3500 square miles south east of Warner Robins, GA and an area of 1600 square miles surrounding Columbus, GA. In the future, using this information, along with additional data such as current land value, existing transmissions lines, and protected land information, more precise assessments can be implemented to isolate parcels of land appropriate for solar PV installations.

INDEX WORDS: solar PV, suitability assessment, Georgia, renewable energy, Clean Power Plan, energy policy

A GIS-based decision making process to optimize the placement of solar PV in geographically constrained regions.

By

BRIAN A JACOB

B.S. Env.E., The University of Georgia, 2013

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2015

A GIS-based decision making process to optimize the placement of solar PV in geographically constrained regions.

By

BRIAN A JACOB

Major Professor: David Gattie

Committee: Jenna Jambeck
John Schramski

Electronic Version Approved:

Julie Coffield
Interim Dean of the Graduate School
The University of Georgia
May 2015

TABLE OF CONTENTS

List of Figures

List of Tables

Introduction:

Mankind consumes tremendous amounts of energy to generate electricity. This electricity is primarily produced by the burning of fossil fuels. According to the International Energy Agency's *Key World Energy Statistics* report, as of 2011, 68% of all the electricity generated in the world was produced by the combustion of fossil fuels. This equates to just over 15,000 TWh of electricity being generated from coal, oil, and natural gas[1]. Making up that 68%, 41% was provided by coal-fired power facilities. Natural gas contributes 22%, followed by oil at 5%. The remainder of the world's electrical needs was met by nuclear at 12%, hydro at 15% and "other" including geothermal, solar, wind, and biofuels at 5% (See Figure 1 below). This burning of fossil fuels leads to the generation of greenhouse gases and, ultimately, climate change. As the issues associated with fossil fuel consumption become more concerning and climate change more problematic, it will be increasingly important to find alternative energy sources to power the world.

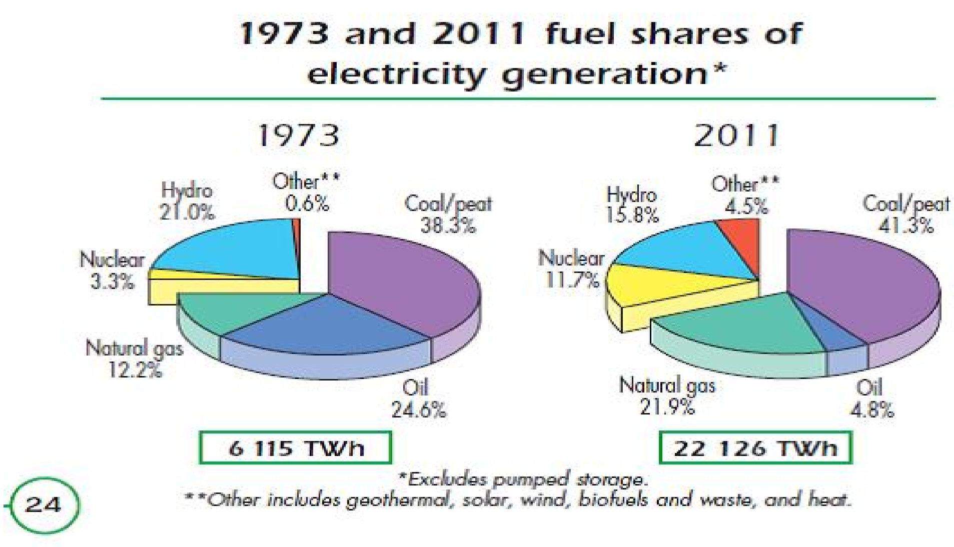


Figure 1: Comparison of fuel mix for power generation between 1973 and 2011[1].

To begin a transition towards alternative energy sources, there will need to be a push for the implementation of renewable energy technologies on a global scale. The United States has a particularly diverse range of renewable energy opportunities that can be leveraged. However, while there have been some localized renewable energy initiatives, in general the United States has a relatively small fraction of renewable energy sources contributing to the national fuel mix (6% in 2013)[2]. For this to change, the country needs to evaluate the renewable sources available and determine the most effective way to utilize them. The National Renewable Energy Laboratory conducted a thorough analysis of the renewable energy technical potential across the continental U.S in 2012. They examined wind energy, solar PV, solar thermal, biomass, hydroelectric, and geothermal technical potential. For their report, NREL defined renewable energy technical potential as "the achievable energy generation of a particular technology given system performance, topographic limitations, environmental, and land-use constraints"[3]. It is important to note that technical potential is one of several types of potential, each with an increasingly narrow scope (See Figure 2 for more detail). Technical potential does not include

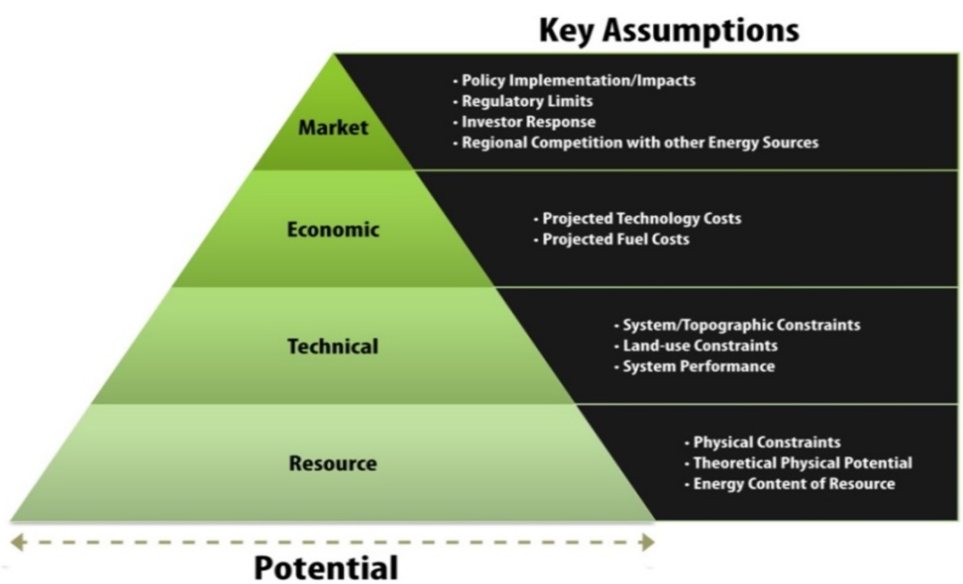


Figure 2: Key Assumptions used for different levels of analysis in NREL report [3].

economic or market constraints. Specifically, the NREL report provides an upper-boundary estimate of renewable potential. Also, by taking geographic and topographic constraints into consideration, the maps generated by NREL provide an initial estimation of geographic areas with the best potential for development of renewable energy sources.

When examining the Southeastern U.S. it can be determined that overall renewable potentials are low by comparison, which means when implemented, output will be less. However, of the available resources, the best potential for development is associated with solar photovoltaics. There is some potential for biomass-based power as well as offshore wind potential; however solar PV provides the best option for the region from a pure potential perspective. Figure 3 shows the NREL map of the United States focusing on total solar PV

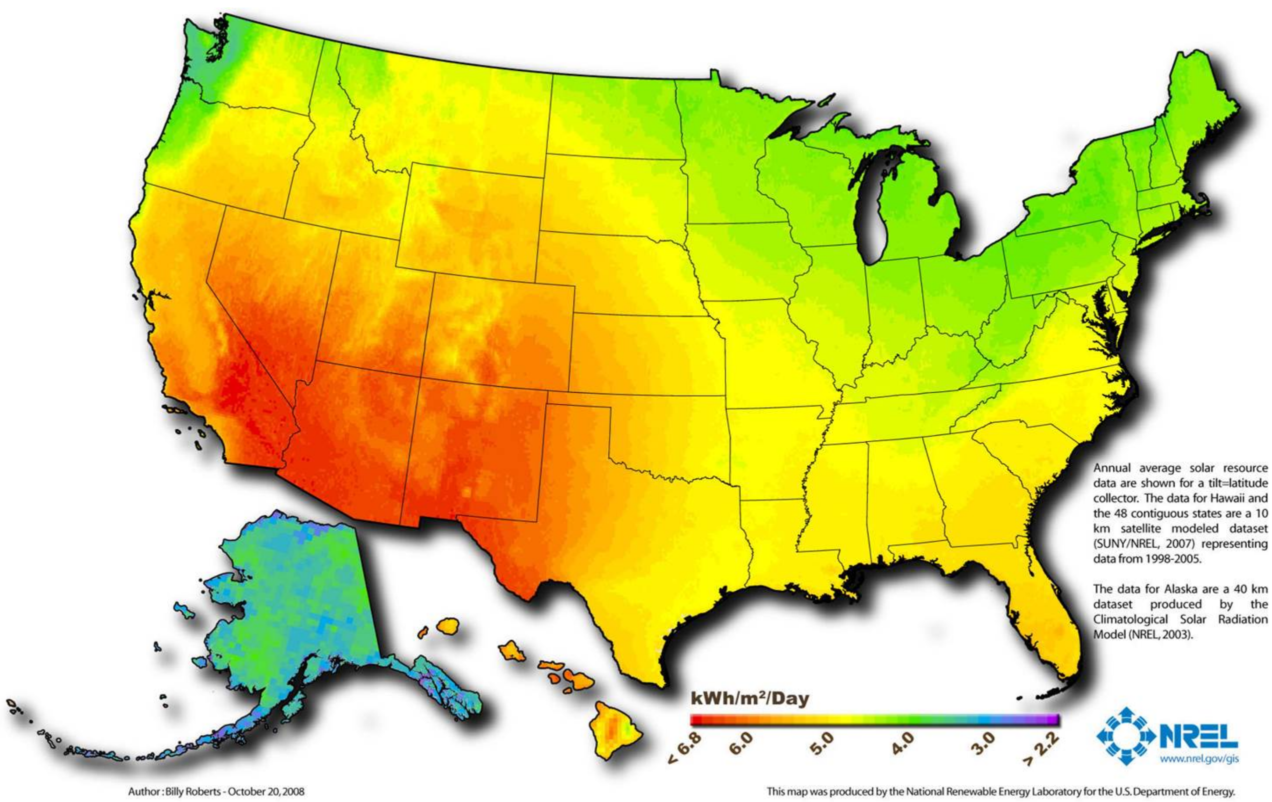


Figure 3: NREL map of solar technical potential across United States [3].

potential. In the Southeast, Georgia, Florida, and parts of Alabama have the greatest potential for development. Additionally, each state was assessed for different forms of the technology (e.g., rooftop PV, utility-scale, concentrating solar thermal, etc.). Within these categories, due to its more developed nature, Florida has the greatest potential for rooftop solar (49 GW), Georgia has the greatest potential for rural utility scale solar PV (3100 GW) and no state in the region had any notable potential for concentrating solar power (CSP)[3].

By evaluating the estimated potentials, it can be determined that Georgia is left with rural utility-scale solar PV as the best option for incorporating renewable energy generation technologies. NREL defines rural utility scale solar PV as large scale (greater than 1MW) PV systems deployed outside of urban areas. Since a significant percentage of the state is comprised of rural land, it is reasonable the state's best option for development of renewable resources would be that of rural utility-scale solar PV systems. The addition of new nuclear capacity in the form of the two reactors currently under construction at Plant Vogtle near Augusta, GA can help to provide the state with reliable and clean power in the future. However, as effects of climate change become more apparent, it will be increasingly important to begin the transition away from fossil-fuel based electric generation. Currently Georgia is entirely dependent on coal and gas from other regions in the country; the state has no fossil-fuel reserves of its own. However, if the solar potential within the state can be utilized effectively in conjunction with large scale energy storage systems and other alternative generation methods, over time Georgia can break free of its dependency on outside support for electricity as well as become a major producer of renewable energy.

Despite these opportunities, the solar PV industry has little traction within the state or the country for that matter. This is largely due to the costs associated with solar energy technology. However, these costs have been drastically decreasing in recent years, partly due to government subsidizes but also because of groundbreaking improvements in solar PV technology. Furthermore, as the market for photovoltaic technology grows, costs will be further driven down by the free market economy.

In addition to decreasing costs and increasing relevance of renewable energy technologies in light of climate change concerns, another potentially even more pressing motivation for a solar power transition in Georgia is the recent E.P.A regulation, known as the Clean Power Plan, which places a mandate on all states to reduce their CO_2 emission rates to an individually set amount by 2030. This regulation, while still under review, would represent the first governmental attempt at regulating CO_2, the gas most closely associated with climate change and global warming[4]. If passed, the Clean Power Plan would require that each state provide an implementation policy by 2016 that would detail their independent plans to achieve their unique mandated CO_2 emission limit.

For Georgia to meet this goal, it is likely that this implementation plan will include the addition of significant solar PV installations. An important consideration, however, is that these utility-scale solar PV arrays are placed in locations that maximize the potential gain in electrical output and minimize the cost, economic and ecological. It would be beneficial for the state if the solar arrays are located such that they are in areas of prime solar potential with minimal effects on economic gain for the region. For example, it would not be economically prudent if viable farm land was replaced with a utility-scale solar farm if the potential benefit from the farmland outweighs the gains from the solar PV facility. In order to understand these situations, a GIS-based decision-making process will be developed in order to determine the most effective way to implement renewable technologies (specifically, utility-scale solar PV) in relatively low solar potential areas and to mitigate the associated economic costs. By using a geographic information system (GIS) approach, this study will determine the prime real estate within Georgia for the installation of large scale solar PV arrays, taking into consideration the geographically diverse solar PV potential across the state, the inherent economic value of the displaced land, and the position relative to centers of electrical demand (residential, industrial, and commercial).

Background and Literature Review:

There is little debate in the scientific community on the existence of climate change. The Intergovernmental Panel on Climate Change (IPCC) recently released sections of their 5th Assessment Report in which the Summary for Policymakers directly stated that climate change is an unequivocal fact[4]. IPCC is an international effort to compile a clear scientific perspective on the current knowledge regarding climate change. Created in 1988 as a collaboration between the World Meteorological Organization and the United Nations Environment Program, the initial task of IPCC was to "prepare a comprehensive review with respect to the state of knowledge of the science of climate change" as well as the economic impact and potential response strategies for the governments of the world[5]. Today, 195 countries serve as active members of the IPCC. This intergovernmental nature allows IPCC to provide unbiased information to the world policy makers.

Throughout its history, IPCC has been well received. The 2nd Assessment Report published by IPCC played a critical role in the adoption of the Kyoto Protocol in 1997. Furthermore, IPCC received a Nobel Peace Prize for the 4th Assessment Report in 2007. While the 5th Assessment Report (AR5) has not been officially released (at the time of this report), several sections of it have been made available including much of the physical evidence analysis used when assessing the current status of climate change around the globe.

It is also well documented that climate change is in part caused by the increase of greenhouse gases in the atmosphere. IPCC has concluded the 40% increase in CO_2 emissions when compared to pre-industrial times is primarily caused by the combustion of fossil fuels[4]. The question remains that if CO_2 emissions are causing climate change, how can the United States reduce its dependency and eventually transition away from fossil fuels?

There is a plethora of scientists and engineers working on this problem every day. The energy industry has made significant breakthroughs in renewable energy generation in the last few decades. According to Richard Swanson, the founder of SunPower Corp., a leading manufacturer of silicon based photovoltaic cells, as of 2011 solar PV technology was selling at a price of $1.32/watt. For comparison, in 1979, when solar PV technology was introduced outside of a laboratory, the price was approximately $33/watt [6] (See Figure 4 for more information). A common method to judge the improvements within a certain technology is via a graph known as an experience curve, or a learning curve. Essentially an experience curve is a visualization of a mathematical relationship first observed in 1936 by T.P Wright on an American Air Force Base. Wright noticed that every time the total aircraft production doubled, the amount of labor required decreased 10-15%[7]. In later years other industries noticed a similar relationship, but typically had a different percentage reduction. In the 1960s the relationship was modeled mathematically and has since been used to judge the effectiveness of production. The percent decrease in cost is determined by a complex relationship between labor efficiency, changes of resources, technology driven learning, and several more components[8]. In regard to renewable energies, the experience curve approach has been used several times [9-11]. In his presentation, Swanson discussed the solar PV experience curve, stating that overall the solar industry has an experience factor of 81%. In terms of experience curves, the lower this number, the better. This means that every time the total production output of solar PV doubles, the price ($$/watt) decreases by 19%[6]. Similar studies into the experience curves of solar PV have generated comparable results with the average percent decrease ranging between 19-22%[12]. Primarily, these cost declines have been caused by technological improvements. Today solar PV is made with fewer, cheaper materials, has a higher cell efficiency, and due to economies of scale, there has been a 96% reduction in cost since 1979.

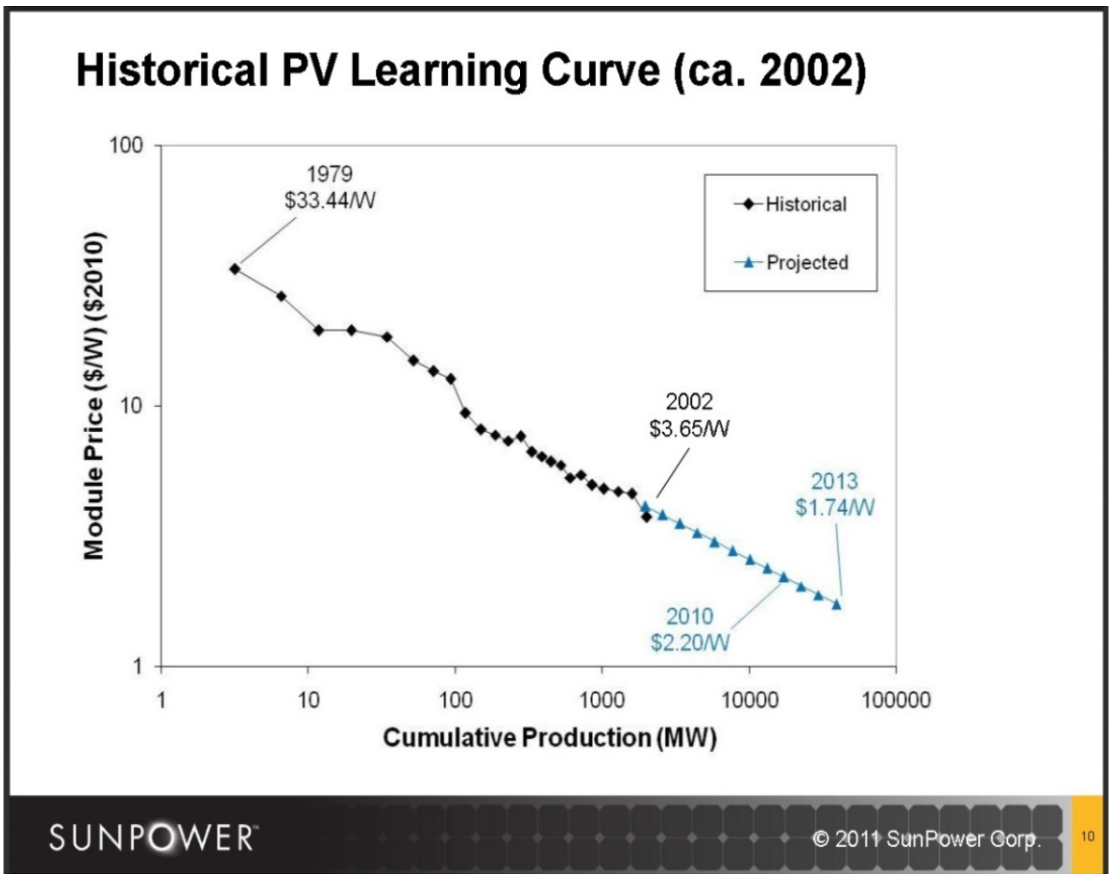


Figure 4: Historical and projected price decrease for manufacture of PV modules [6].

Increases in solar PV cell efficiency have been significant in the last twenty years. Average efficiencies of 7-9% in the 1990s have improved to averages between 14-18% today with a maximum recorded efficiency of 41% under laboratory conditions[6]. Most important, the levelized cost of electricity (LCOE) is approaching price parity levels, meaning the price of solar PV is becoming comparable to that of traditional fossil fuel based electricity generation[13]. LCOE is used to judge this relationship because it provides the best estimate of the value of the electricity generated through various technologies whether they are renewable or fossil fuel based systems. It provides the best basis of comparison for different methods of generating electricity.

It is important to note the technology being discussed is that of utility-scale, ground mounted solar PV as opposed to roof-top solar PV. This is an important distinction because several factors affect roof-top PV systems that can impact the price of these systems. In addition, many societal, economic, and technological constraints are unique to roof-top based PV. Therefore the primary solar PV technology discussed in this report will be that of utility-scale ground mounted PV systems.

According to a joint study by the Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL), the LCOE for solar PV has been steadily declining. In 2010 the national average for total system LCOE was at 21.4 cents per kilowatt hour (or $214/MWh). However, three years later in 2013, LCOE was down to 11.2 cents per kWh, or $112/MWh[13] with some independent reports even lower at 8 cents per kWh[12]. While this remains higher than conventional coal at $96/MWh or natural gas combined cycle technology at $66/MWh[14], it is notable that the LCOE of solar PV is approaching equilibrium with fossil fuel energy and still steadily decreasing. A crucial consideration to keep in mind is that LCOE is not universally agreed upon. There have been numerous studies on the LCOE for solar PV as compared to conventional coal and natural gas. One of the most recent studies, completed by Lazard in September of 2014, lists an LCOE of solar PV at $60-86/MWh with conventional coal at $66-151/MWh and natural gas combined cycle at $61-87/MWh[15]. However, EIA's Annual Energy Outlook (AEO) Report for 2014 places the total system LCOE for solar PV at $130/MWh[14] which is down from their AEO 2013 report which placed the value at $144/MWh[16]. Further analysis done by NREL in 2010 claims that the utility-scale solar PV levelized cost of electricity ranges between $90-120/MWh in the continental U.S[17]. The NREL report goes on to discuss how variable LCOE values can be and that they are extremely dependent on solar insolation as well as the type of solar PV being implemented. Solar insolation (the amount of solar energy striking the surface of the Earth) is dependent on geographic location. A study conducted by the European Photovoltaic Industry Association (EPIA) in 2011 estimated the global average for the LCOE of large scale, fixed axis ground mounted solar PV was $160-380 per MWh. This high variability is due to solar insolation. For example, according to EPIA, Northern Europe receives 1,000 kWh/m^2 of solar energy and has an LCOE of $380/MWh while Southern Europe receives 1,900 kWh/m^2 and has a corresponding LCOE of $200/MWh. Finally, the Middle East has much higher solar exposure and receives about 2,200 kWh/m^2 yielding an LCOE of $160/MWh as of 2010[18]. Even within the U.S there is significant variability in solar insolation and therefore in LCOE data as well. Cities such as Seattle, WA have higher LCOE values (>$120/MWh) while desert cities such as Phoenix, AZ are at the low end of the spectrum (<$90/MWh)[17].

These are only a few of the reported LCOE values in recent years but the general trend shows the cost of solar PV is steadily decreasing and while it is remains debatable as to when and if solar PV will achieve price parity with conventional fossil fuel-based electricity generation, it is clear that every year the levelized cost of solar goes down and is certainly approaching the LCOE of conventional coal.

While the majority of recent power industry developments in the United States have been in the area of renewable technology, it is important to note that even in the area of non-renewable fuel sources there have been significant advances towards improving the efficiencies of these technologies and mitigating environmentally harmful emissions. Most recently, these advances have been in the area of carbon capture and storage (CCS). Because coal and natural gas combustion are established technologies, there is little improvement to be made in regard to the heat rates of these systems, although large-scale deployment of combined cycle technology still has much to offer. However the primary concern with these technologies is not related to their ability to produce power but instead towards the emissions they release in the process. Carbon dioxide in the upper atmosphere is considered the leading cause of climate change. If these emissions could be captured and repurposed, potentially one of the largest issues with fossil fuel based power systems could be circumvented. However, the technology behind CCS is untested at large scales and is currently an expensive venture. Additionally, the incorporation of CCS technology into the traditional coal or natural gas fired systems causes net efficiency penalties for the conversion of fuel to electricity. According to a report released in 2011 by the International Energy Agency (IEA), CCS technology causes average efficiency penalties of 10% for coal-fired power when compared to the reference case of a pulverized coal facility without CCS. Additionally, IEA estimates that the overnight capital cost of a coal fired CCS facility would be approximately $3800 USD/ kW, which is a 74% increase compared to the reference case. Finally, their report lists the LCOE of coal-fired CCS to be approximately $105 USD/MWh. The IEA report provided similar numbers for natural gas based generation options listing the efficiency penalty at 8%, the overnight capital cost of $1800USD/kW which is 82% higher than the reference case, and the LCOE for a natural gas CCS facility to be $102USD/MWh[19]. An additional report by the National Energy Technology Laboratory (NETL) in 2012 had even higher values. For a coal-fired CCS system NETL determined that the LCOE would be between $143-128/MWh depending on the technology used and the age of the facility[20].

When these data are taken into consideration, there is incentive to deploy economically feasible renewable technologies, along with other technologies such as CCS and nuclear in order to reduce CO_2 emissions. Combined with the inevitability that fossil fuel resources will be depleted over the long-term, along with increasingly expensive environmental regulations, the higher costs that are generally associated with solar PV and other renewable technologies do not seem as severe by comparison; there is little incentive to retain fossil fuel based power generation assuming a goal of reducing global atmospheric CO_2 levels.

One of the greatest challenges facing the nation today in regard to electricity is the immense resistance to change. This is human nature, but in context of this issue, it means that the energy technologies that are being most commonly used today are tried and true. The power industry knows how coal and natural gas combustion works. It is a well-known fact as to how much mass input is required to reach a certain generation output. But primarily, because these technologies have been established for so long, they have become cheap and reliable. And while renewable technologies have the potential to offer so much more, they are still relatively unknown and the costs are still high. This leads to a lot of resistance from the power industry. One suggested explanation for this resistance involves the economic concept of creative destruction. Creative destruction is a term coined by Joseph Schumpeter in his 1942 book *Capitalism, Socialism, and Democracy*. Schumpeter introduced the idea that “the opening of new markets…illustrate the process of industrial mutation” in that the new markets “incessantly revolutionize the economic structure, destroying the old one and creating the new one”[21]. When applied to a modern business structure, this means that the free market promotes innovation and the creation of new technologies and processes. Although these innovations may be better for society in the long term, in order for them to succeed, they must displace the current technology or business process that was fulfilling that need. The internal combustion engine provides an excellent example of this. With its invention, it was quickly realized to provide a superior form of transportation which led to the conception and rapid growth of the automobile industry in the U.S. In the 1920s there were over 260 manufacturers of internal combustion vehicles. However, this economic windfall did not come without costs. In 1900, 109,000 Americans were employed by the carriage and harness making business[22]. With the advent of the internal combustion engine, these people had to switch careers or risk impoverishment as their work lost its value. Creative destruction presents the paradox of progress. In order for progress to be made in our society, some members will inevitably suffer as we continue to innovate. Schumpeter summarized the idea by saying, “The essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process,”[21]. The concept of creative destruction may figure into the challenge of market penetration for the solar and renewable industry. In the long term, renewable technologies can be expected to become responsible for a larger share of the national energy mix. However, this means that the fossil fuel industries will need to either adapt or step aside. Many fall prey to the idea of the "technology mudslide hypothesis," posited by Clayton Christensen in his 1997 book, *The Innovator's Dilemma [23]*. Christensen's hypothesis states that a well-established and successful firm may fail if it does not embrace technological advancements. In terms of the renewable technology industry, these two concepts, that of creative destruction and the Innovator's Dilemma, are becoming increasingly relevant as technological improvements allow solar and wind technology to challenge the traditional methods of electricity generation.

Finally, one important consideration when it comes to the issue of market penetration for renewables is that of resource availability. When examining the distribution of renewable potential across the United States, it is evident that some states are at a distinct disadvantage. California, Texas, and the Southwest have high technical potential for solar and wind capacity compared with states along the eastern seaboard. There is some potential for off-shore wind development, especially in the northern regions, but generally that is considered one of the most expensive options due to the technical problems involved with offshore wind farms. As for solar PV, insolation along the east coast is minimal when compared to the desert states of the southwest region, ranging from 3-4.8 kWh/m^2/day, while southwestern states such as New Mexico and Nevada average over 5 and as high as 6.25 kWh/m^2/day[3]. These issues, in addition to the concepts of Creative Destruction and the Innovator's Dilemma, contribute to the inherent resistance the power industry feels when addressing the transition to renewable technologies for power generation.

Therefore, while technological improvements incentivize the power industry to begin the incorporation of renewables into the energy portfolio, in order for progress to be made there is a need for a comprehensive national energy policy that would motivate the power industry to implement these new technologies and begin a transition towards increased use of renewables. If such a policy existed, it could promote local power providers to introduce renewable energy generation in their networks. In order to mitigate the costs, a viable option is to have a system in place that provided subsidies or some other form of incentive for the power industry to offset the increased capital costs associated with most current renewable technology without directly passing them on to consumers. In order for a renewable transition to be successful, it is important that there be an economic benefit for industry as well as a minimal change in cost of electricity for the consumers. Although there have been several recommendations at a national policy that could achieve this, none have been officially implemented at this time.

In 2010 the nonprofit and nonpartisan organization Resources for the Future (RFF), and the National Energy Policy Institute (NEPI), another independent energy research organization, released a report in which they assessed the options for a new national energy policy[24]. In this report, they considered energy security, climate change, and welfare cost as the key metrics for their analysis. Using these metrics, they designed a series of policies to model, each with slightly different end goals. There were several policies focusing on reducing oil consumption, several on reducing CO_2 emissions, policies for increasing energy efficiency, and even several on the stimulation of research and development of biofuels. They analyzed the impacts of each of these policies by using the National Energy Modeling System (NEMS) developed by the Energy Information Administration (EIA).

NEMS is a computer based energy-economy modeling system of the U.S government and is used by many agencies and independent research groups to model the effects of proposed legislation related to the power industry and existing generation network. NEMS not only considers the production, import, conversion, and price of energy, but also analyzes the impact of macroeconomic and financial factors, world energy markets, resource availability and cost, and performance characteristics of energy technologies[25].

The study by RFF used several policy options for reduction of CO_2 levels including several variants of a Cap and Trade (C&T) policy. Cap and Trade is a market-based form of emissions control that uses an increasingly stringent limit, or cap, on emissions levels for industry. This limit is usually on a total mass basis and refers to the amount of CO_2 or CO_2 equivalent gasses that can be released by industry, typically on an annual basis. This cap is enforced by a governing body that issues credits to industry. The credits correspond to the cap, specifically to the amount each industry is allowed to emit per year. Each year the cap is reduced, thus forcing industry to reduce their pollution by any means necessary. Some companies will find it far easier to meet these emission limits while others will struggle to meet the cap. The trade system is meant to alleviate this discrepancy. Those companies that cannot meet the limit can purchase additional credits from the companies that are far below the emissions cap. The trade system provides a revenue stream for the companies that are the least polluting and provides an incentive for the heavy polluters to reduce their emissions, thereby saving money.

Another well-known emissions policy option is the carbon tax. This method sets a guaranteed price on a unit of carbon (usually CO_2) released to the atmosphere and charges industry a tax for each unit they emit. Emitters have an incentive to reduce their emissions and thereby reduce their tax burden. The two policy options both achieve the same goal but have a very different mechanism. A C&T policy uses a 'quantity instrument' while a carbon tax has a 'price instrument'. What this means is that a C&T policy limits the quantity of emissions but the price of the credits is controlled by industry; therefore the price may fluctuate depending on supply and demand. On the other hand, a carbon tax policy sets the price of carbon emissions via a tax but places no controls on the amount of emissions being released. The success of carbon tax as a policy is primarily determined by what tax value is chosen. If the tax is low, polluters may choose to continue emitting at unrestricted rates and just pay the penalty, while if the tax is set too high it could impact the profitability of the industry and thereby affect consumer cost and job growth.

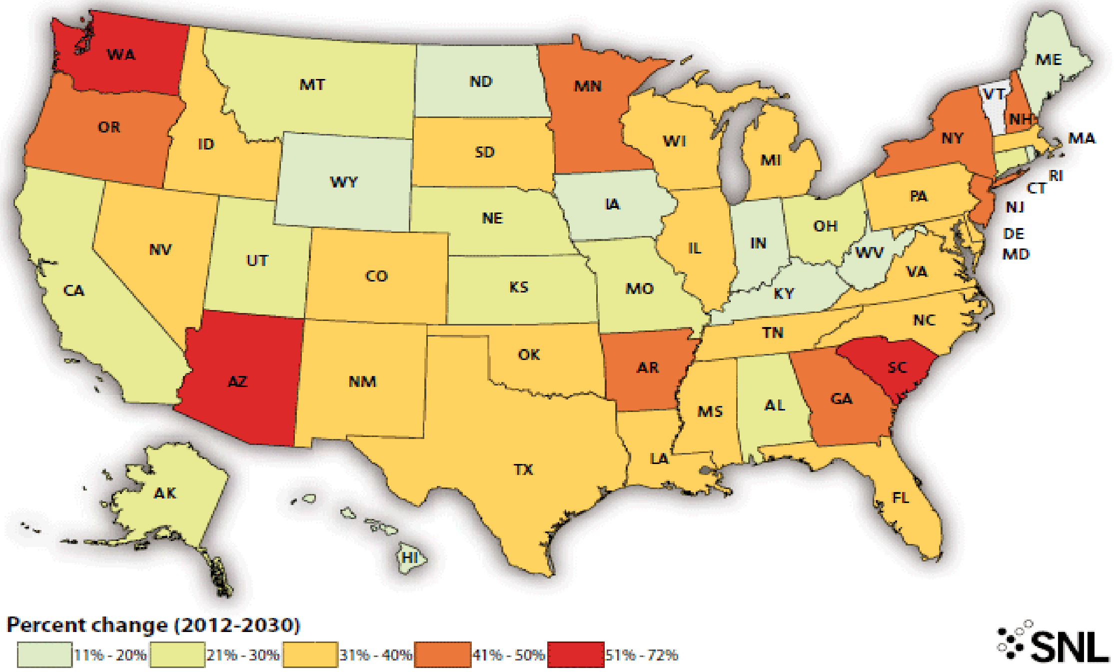
The primary policy option suggested by the RFF proposal was that of a C&T policy that included an aggregate reduction on CO_2 emissions of 17% by 2020, relative to 2005, in addition to offset availability. This would allow domestic companies to invest in lower cost emissions reductions opportunities in other sectors if it is not economically viable for the company to reduce their own emissions. In addition to the C&T policy, RFF had several other policy variants including a less stringent carbon cap, a program with no available offsets, and a program with more offsets to serve as comparisons to their primary policy suggestion[24].

Another policy option was introduced was the Clean Energy Standard Act of 2012. This was a bill initiated by Senator Jeff Bingham of New Mexico. He introduced the bill to Congress in March of 2012, however the bill quickly "died" in committee [26]. Nevertheless, the bill was an interesting attempt at bringing in major reform to the power industry. In the bill, Senator Bingham suggested an increasingly stringent percentage requirement for each state in regard to the state's individual clean energy mix[26]. This requirement started at 24% renewables fuel mix by 2015 and increased to 84% by 2035. Bingham submitted his bill to the Energy Information Administration (EIA) for analysis using the NEMS modeling system. According to their report[27], if enacted CES2012 would drastically alter the energy market. Coal use would fall by 54% by 2035 (when compared to the Reference case), and natural gas, nuclear and renewables would fill the gap. Initially, natural gas use would increase significantly; however, by 2025 this would gradually be replaced by non-hydro based renewables and nuclear power. Nuclear was projected to increase by 62% by 2035 (compared to Reference) and non-hydro renewables to increase by 34% by 2035[27]. Due to this, carbon dioxide emissions were predicted to decrease by 44% within the power sector by 2035 but the overall cost of electricity would increase by an average of 18%. This would yield an estimated increase in cost to total residential power of 139 billion dollars as compared to the Reference Case[27].

At the other end of the spectrum, there have been several proposals that represent the upper-bounds of a renewable energy transition. A very well-known paper of this genre would be a report by Mark Jacobson and Mark Delucchi. Their report, titled *Providing all global energy with wind, water, and solar power* described a global plan that would lead the world to 100% renewable energy by 2050[28]. The WWS (Wind, Water, and Solar) plan is known for being one of the most comprehensive and largest scale suggestions for a renewable energy policy. The paper details their reasoning behind the WWS plan and includes descriptions of the mathematics in which they determine the exact amount of wind turbines, various solar plants, geothermal facilities, hydroelectric, tidal, and wave power plant that the world will need to meet and even exceed our power demands by 2050[28]. They propose that a global collaboration could accomplish these tasks and that there is more than enough global renewable potential.

The most recent of the suggested renewable energy policies is that of the U.S. E.P.A's Clean Power Plan (CPP). This proposed regulatory rule, released on June 2nd of 2014 makes up a crucial part of a series of changes proposed by President Obama's Climate Action Plan. The Clean Power Plan is a regulatory proposal by the U.S. E.P.A that places restrictions on carbon dioxide emission rates for power generating facilities. It serves as the first federal government attempt at regulating CO_2 emissions. The CPP provides target values of pounds of CO_2 emissions per MWh of power generated. According to the plan, these targets must be reached by 2030. If all 50 states accomplish this, it is projected that the country will see a 30% reduction in CO_2 emissions indexed to 2005 levels and a 25% reduction in soot and smog. It is estimated that the price of electricity will be reduced by 8% by 2030 and that the CPP can lead to health benefits between $50 and $90 billion dollars[29]. The national goal is for a 30% reduction of emissions but each state has an individual CO_2 rate to reach. The percent change ranges from as low as 11% in North Dakota, to 72% in Washington (See Figure 5 for details). According to the CPP proposal, the EPA custom tailored the reduction requirements by carefully examining current strategies that are being implemented across the nation as well as taking into consideration the state's current fuel mix and electricity market. Some of the strategies examined include heat rate improvements for power plants, investment in low emission or renewable power sources, and improvement in dispatch priority within the power grid.

EPA's proposed carbon emissions rates for existing power plants (lbs/MWh)



State	Historical emissions rate (2012)	Avg. interim emissions rate goal (2020 - 2029)	Final emissions rate goal (2030+)	Required change (2012-2030)
Alabama	1,444	1,147	1,059	27%
Alaska	1,351	1,097	1,003	26%
Arizona	1,453	735	702	52%
Arkansas	1,640	968	910	45%
California	698	556	537	23%
Colorado	1,714	1,159	1,108	35%
Connecticut	765	597	540	29%
Delaware	1,234	913	841	32%
Florida	1,200	794	740	38%
Georgia	1,500	891	834	44%
Hawaii	1,540	1,378	1,306	15%
Idaho	339	244	228	33%
Illinois	1,895	1,366	1,271	33%
Indiana	1,923	1,607	1,531	20%
Iowa	1,552	1,341	1,301	16%
Kansas	1,940	1,578	1,499	23%
Kentucky	2,158	1,844	1,763	18%
Louisiana	1,466	948	883	40%
Maine	437	393	378	14%
Maryland	1,870	1,347	1,187	37%
Massachusetts	925	655	576	38%
Michigan	1,696	1,227	1,161	32%
Minnesota	1,470	911	873	41%
Mississippi	1,130	732	692	39%
Missouri	1,963	1,621	1,544	21%
Montana	2,245	1,882	1,771	21%
Nebraska	2,009	1,596	1,479	26%
Nevada	988	697	647	34%
New Hampshire	905	546	486	46%
New Jersey	932	647	531	43%
New Mexico	1,586	1,107	1,048	34%
New York	983	635	549	44%
North Carolina	1,646	1,077	992	40%
North Dakota	1,994	1,817	1,783	11%
Ohio	1,850	1,452	1,338	28%
Oklahoma	1,397	931	895	36%
Oregon	717	407	372	48%
Pennsylvania	1,540	1,179	1,052	32%
Rhode Island	907	822	782	14%
South Carolina	1,597	840	772	52%
South Dakota	1,135	800	741	35%
Tennessee	1,903	1,254	1,163	39%
Texas	1,298	853	791	39%
Utah	1,813	1,378	1,322	27%
Virginia	1,297	884	810	38%
Washington	763	264	215	72%
West Virginia	2,019	1,748	1,620	20%
Wisconsin	1,827	1,281	1,203	34%
Wyoming	2,115	1,808	1,714	19%

Sources: U.S. EPA Clean Power Plan, CleanPowerPlanmaps.epa.gov
Map credit: Whit Varner

Figure 5: CPP map and table of proposed carbon reductions for each state by 2030 [29].

The CPP is targeted specifically at fossil-fuel based electric generating units (EGUs) and those affected by the plan are characterized as having a capacity of at least 250 million BTU per hour, a fuel mix containing at least ten percent fossil fuels and sales of at least 219,000 MWh per year of electricity. All EGUs that fall below these constraints will not be considered when determining the state CO_2 emission rate.

In order to legally justify the CPP, the EPA proposed it as a regulation under Section 111(d) of the Clean Air Act. The section they based the CPP on is a rarely used paragraph within the Clean Air Act that allows EPA to create a policy that enables states to establish plans for implementing and enforcing a mandated emissions standard for an air pollutant. The one proviso for this is that the EPA had to establish a standard of performance for all new sources of the pollutant as well. This explains the previously established rule that the EPA released in September of 2013. The New Source Performance Standards contain regulations that will be applied to all new EGU's. The proposed legislation places mandated limits on CO_2 emission rates for all EGU's built over the next decade. Of note, the legislation sets limit on the emissions rate for coal-fired power facilities at 1100 lbs. CO_2/MWh[29]. Additional limits exist for natural gas based facilities and all limits are scaled according to the size of the facility.

Within the CPP, the state goals, as well as the implementation policy suggested by the EPA, are categorized into four building blocks which EPA refers to as the Best System of Emission Reduction (BSER). The BSERs represent one of the first attempts at a national energy policy that contains some basic implementation suggestions. The building blocks are merely guidelines and are not mandated. States can choose which blocks to use or may choose to disregard them entirely. However, the blocks are set up to provide very feasible goals that can drastically reduce state CO_2 emissions. The first of the blocks is focused on technological constraints associated with coal-fired facilities. The EPA suggests that each state can achieve as much as a 6% improvement in the heat rate for coal combustion. The heat rate refers to the amount of electricity that can be generated from a unit mass of fuel.

Second, the EPA suggests that there be a national transition away from coal-fired facilities and towards increased use of natural gas combined cycle combustion (NGCC). This is partly due to the recent increase in natural gas reserves that have become accessible in North Dakota, Texas, Pennsylvania and Canada. In addition, natural gas is known to be a cleaner burning fuel. The current average places CO_2 emissions from combined cycle natural gas at 1135 lbs/MWh which is half of the average CO_2 emissions associated with coal-fired facilities. In addition to significant CO_2 reductions, NGCC systems produce one third of the nitrogen oxides and one percent of the sulfur oxides at the power plant when compared to coal-fired systems [*EPA.gov*]. According to the EPA's BSER, by scaling all existing NGCC facilities up to a capacity factor of 70% and reducing production from coal-fired facilities by the corresponding amount, each state can achieve significant CO_2 reductions.

In the third building block, EPA suggests increasing renewable energy generation capacity over time to meet state-level target values that would be determined by renewable portfolio standards (RPS) set by states within the region. In addition to increased renewable capacity, an additional viable option in this building block is that all construction be complete on any nuclear facilities that are currently being built in addition to foregoing the planned retirement of 6% of the national nuclear capacity.

Finally, the CPP proposes increasing state demand-side energy efficiency requirements at a rate of 1.5% annually. This building block refers to promoting the efficient use of energy by consumers. By increasing efficiency at the consumer end of the pipeline, there will be a corresponding decrease in required generation from the electric generation units (EGUs) and thereby decrease in emissions, regardless of fuel source[29].

While the Clean Power Plan is promising, all of the previously mentioned policy solutions share a vital shortcoming. They are only policy suggestions (RFF Proposal, CES2012, WWS Plan and CPP) and do not actually provide guidelines for industry leaders to follow. It is one thing for the government to mandate change, but the power industry is responsible for implementation. If an energy policy is to succeed, it must be accompanied by either a comprehensive national or state-based implementation plan. The RFF proposal discusses many potential energy policy variants. Using the NEMS model, it managed to estimate the effects the policy would have. It discusses a Cap and Trade policy option but without instructions on how to actually set up a Cap and Trade system so that it is economically viable, the proposal is merely an intriguing idea. As for the CES2012 suggestion by Senator Bingham, a fuel mix of 84% renewables in the next 20 years is not practical. The technological and economic constraints are too vast for such a drastic change to the system. The solution posited by Jacobson and Delucchi in their Wind, Water, and Solar proposal is also an upper-bound scenario that is impractical for the same reasons as CES2012.

While a transition to renewables is certainly important, the free-market system that our economy is based around does not cope well with drastic changes to vital aspects of infrastructure over a short time frame. As described by the concept of Creative Destruction and the Innovator's Dilemma, changes such as those that are brought on by renewable energy technologies are slow to gain footing because of the resistance to change and the economic challenges. Therefore, proposing national or even global collaboration to achieve a 100% transition to renewable fuels within the next 50 years is unlikely.

The U.S EPA's Clean Power Plan represents a different energy policy option. By incorporating the BSER's and tailoring them to each state's unique situation, the CPP provides the suggested BSER options with the four Building Blocks but also expressly stipulates that each state is required to submit their unique implementation policy by 2016. This is especially important when considering that there are different constraints for each state. Specifically, the CPP places a unique, mandated CO_2 reduction based on what the EPA believes to be feasible. Additionally, by allowing states to choose their own implementation plans, this gives them the freedom to tailor to their strengths. For example, certain states may have a large amount of NGCC power generation facilities. Therefore, upscaling these to a 70% capacity factor could radically affect emissions. Other states may have a significant amount of nuclear capacity under construction that will aid them in meeting their reduction requirements.

This study proposes that in order to comply with the Clean Power Plan's guidelines, each state will focus on an implementation policy that will allow them to reach their individual mandated goals. For Georgia and the other southeastern states, a renewable implementation plan will be challenging, but necessary, as these states have limited renewable potential. However, through the use of a thorough decision-making tool, states can determine the best way to implement renewable technologies and mitigate associated costs. Georgia has notable solar PV potential. On the other hand, the state is an invaluable producer of many agricultural products. Therefore it is important when considering a technology that requires a large geographic footprint, like solar PV, that the arrays be placed such that there is minimal impact, particularly with respect to agricultural systems. In order to promote the use of renewable technologies, it is important that all unnecessary costs be mitigated. If solar PV can be implemented without a detrimental impact on local economies, there will be positive feedback which in turn can help to promote the increased use of solar and other renewable energy generation methods. Not only will this aid Georgia in meeting any carbon emission limit set by CPP but also promotes sustainability, helps to reduce the effects of climate change, and moves Georgia, as a state, to the forefront of the renewable technology revolution.

Methods:

The methodology developed for this tool uses a GIS based approach to evaluate and rank certain indicators that represent consistently available and standardized indicators of economic activity and land-use trends. The primary data set is that of the NREL solar PV technical potential. The data are provided in the form of a ten square km. grid of average solar radiation values generated over a period of 15 years from 1991 to 2005 as collaboration between NREL and the State University of New York Albany (SUNY) using data collected from NREL's Meteorological-Statistical model and the Geostationary Operational Environment satellite system. By means of a combination of satellite imagery, historically recorded solar radiation values, and solar modeling techniques, NREL generated technical potential maps, providing estimated solar radiation data, in the form of $kWh/m^2/day$[3].

By evaluating solar PV potential data alone, one can simply identify regions that receive the greatest portion of solar insolation as being suitable for development of solar PV technology. However, this type of analysis can be overly simplistic and will rarely be used for implementation due to the variety of other considerations such as cost benefit analysis, funding, local political pressures, environmental concerns, etc. By incorporating more constraints in the initial analysis, such as economic data or current land use metrics, a more accurate decision making process can be developed.

Although solar PV potential is a crucial component to the analysis, it was decided that in Georgia, where solar insolation is relatively low and only varies by 0.75 $kWh/m^2/day$ across the whole state, other indicators are needed to accurately assess the impacts of solar PV development. A process which includes these additional considerations was used for this study and is described below.

In order to identify the additional considerations, a rigorous analysis of potential economic indicators was conducted. In particular, Georgia's economy has a strong agricultural sector. In 2012, the state had a total economic expenditure of $810 billion, the majority of which was made up of private business transactions. A total of $77 billion of that economic activity comprised of agricultural expenditures, specifically food and fiber production. The state had a farm gate value of $13.9 billion. Farm gate value is defined as the net value of the product after it leaves the farm, not including marketing costs and represents a common way to estimate agriculture value. In Georgia, broilers make up the majority of the agriculture products, accounting for $4.7 billion of the state's farm gate value. The next largest category is that of row and forage crops. With a total farm gate value of $3.3 billion dollars, these crops consist of primarily cotton (40%) and peanuts (27%)[30]. The geographic footprint of solar PV is a very important consideration, especially in an area where agriculture is predominant. Georgia has over 4.5 million acres of cropland and produces nearly half of the nation's peanuts and has the second highest cotton production acreage in the country [30].

These are important considerations when evaluating the placement of utility scale solar PVs, which can have a footprint on the order of hundreds or even thousands of acres. In addition, there is concern that much of the high value cropland is located in the southwest region of the state, which also represents the area of highest solar radiation. Figure 6 illustrates the distribution of row and forage crops based on their farm gate value on a county level. The overlapping high solar potential and high agriculture output further emphasizes the need for a formal approach of identifying the ideal geographic regions for solar PV development by optimizing competing constraints. Therefore while the NREL renewable technical potential data are essential to this analysis, it is also important to include economic, especially agricultural, indicators. The indicators used in this analysis described below.

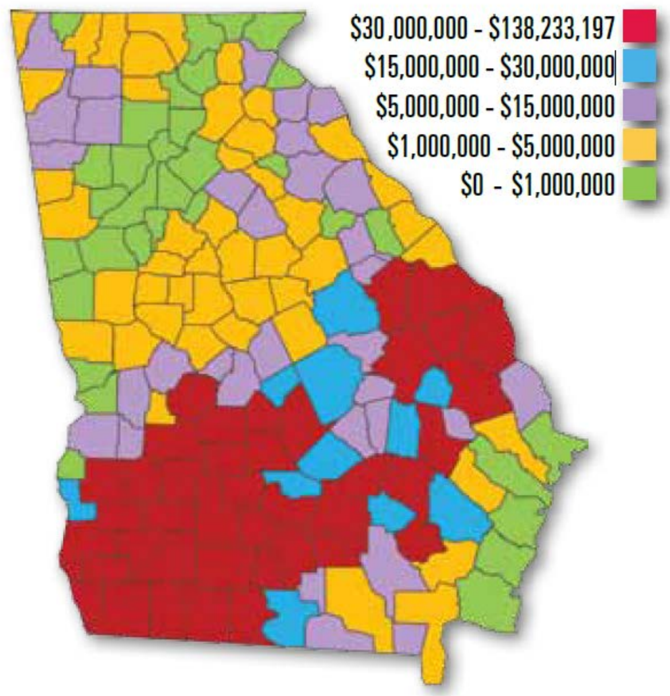


Figure 6: Value of row and forage crops in Georgia on a county level [30].

First, agricultural data, for both livestock and cropland, for the state of Georgia were collected from the United States Department of Agriculture's National Agricultural Statistics Service (NASS) 2012 Census of Agriculture. The report was released in May of 2014 and serves as a vital component in the analysis presented here[31]. On a per county level, data were collected that include the market value of agricultural products sold, the number of farms, the size, in acres, the land value of farms, and the distribution of livestock vs. cropland based farms. Using these data, the market value of crop-based farms and livestock-based farms was determined per acre of farmland. These data were translated to a geographical representation as totals for each county within the state (Appendix A, Figures 7 and 8).

Another valuable component, and the third dataset used in the decision making mechanism, is that of the state's current land use. The National Land Cover Database (NCLD) provides a comprehensive national geographic dataset that uses LandSat data to record the land cover across the country. Land covers have been grouped into fifteen categories in order to simplify the data set. The land classes are chosen based on types of land use. They include light, medium, and dense urban land cover, water, wetlands, farmlands, evergreen forest, mixed forest, pasture, etc. [32]. This comprehensive database allows for an accurate assessment of land use within the counties. The data are provided on a 30 meter resolution, making it the most detailed data set used in the analysis and providing very accurate assessments of specific land use within a county (Appendix A, Figure 9). By incorporating this dataset, it is possible to exclude areas that are incompatible for solar PV development and highlight those that are best suited for it. Specifically, urban areas, wetlands, and open bodies of water will be excluded. The other categories will be ranked according to utility and ease of development for a utility-scale solar farm.

In addition to agricultural and land use data, a fourth component was included to evaluate the distance from urban areas as an important consideration for the analysis. Although the additional costs associated with the transmission of electricity are not well known, it is likely that any solar installations would provide power to the nearest urban area, therefore, it would be ideal to place the solar PV installations near urban areas and potentially feed directly into the distribution network, thereby minimizing or negating the need for long distance transmission. With this in mind, an additional component of the analysis was a map layer depicting distance surrounding all urban areas (as defined by 2010 U.S Census) within the state (Appendix A, Figure 10).

Finally, the fifth component of the analysis is the dataset provided by NREL listing the technical potential for solar PV in the state of Georgia. The data are provided on a ten km. resolution and are presented in units of kWh/m2/day (Appendix A, Figure 11). Each of these five inputs provide valuable information to consider when determining the best location for construction of utility scale solar PV. The inputs, or layers, were individually assessed to determine their impact on solar PV development with the goal of minimizing negative economic and environmental effects. Therefore the agricultural data were assessed with the mindset that those counties with less agricultural productivity would be more desirable for locating solar facilities as they would have less of a negative economic impact. Applying this logic is not all inclusive as there will likely be exceptions. However, it allows for a generalized method of assessing the economic value of the counties without requiring an investigation of detailed tax records on a county by county basis. Similarly, it is understood that there will be exceptions to information gathered from any of the data sets.

In order to include information from all five of the datasets, a GIS weighted overlay spatial analysis was conducted in order to evaluate multiple criteria between several raster datasets. A raster dataset, which is one of the two ways to present information in a geographic information system, uses a grid pattern of equal sized cells with each representing a single data value. These cells contain geographic information as well, which is indexed to represent critical features of interest; e.g., temperature gradient, population density, land value, rainfall, etc. The weighted overlay analysis allows various raster layers to be compiled into a single output by assigning to each dataset a ranked, weighted level of importance and combining them based on those criteria. Therefore those features ranked as most desirable will receive a greater weight and consequently make up a majority of the data presented in the weighted overlay output. Two levels of weighting are applied to each input within the weighted overlay tool. The first is applied to each layer individually and the second is a percent weight that determines the contribution of each dataset to the overlay output. The values chosen for these weights are unique to the characteristics of Georgia and to the criteria of interest when identifying locations for utility scale solar PV installations in Georgia. Therefore it is important that these weighted contribution values are selected so that they represent characteristics and features considered most critical to the particular evaluation at hand.

The following methodology has been developed for the state of Georgia with a focus on the deployment of solar PV. However, this decision-making tool should be applicable to any state. By modifying the inputs as is appropriate, this process should allow any state to assess its renewable potentials to determine which is most suitable for development, as well as the best location to maximize power generation and minimize economic costs.

Analysis:

Due to the nature of the methodology, specifically the weighted overlay tool, there is a level of analysis that must be applied to achieve meaningful results. First, in order to compare different layers, a common scale must be established across all of the input layers. A one through ten scale was used for this analysis. The first set of weights that were applied are on a layer by layer basis, essentially identifying which features are deemed most valuable to this analysis and giving them a greater weight in the overlay. For example, as this analysis is focused around solar PV, the NREL dataset was given the greatest weight of the five. The ranges of insolation values across the state were reclassified into ten categories and are identified in Table 1.

Table 1: Reclassification and assigned weight of NREL solar PV technical potential dataset.

NREL Solar Reclassification:		
Insolation Range (kwh/m^2/day)	**Reclassified Value:**	**Assigned Weight:**
4.755-4.828	1	5
4.828-4.902	2	6
4.902-4.976	3	6
4.976-5.049	4	7
5.049-5.123	5	7
5.123-5.196	6	8
5.196-5.269	7	8
5.269-5.343	8	9
5.343-5.417	9	9
5.417-5.490	10	10

Within the weighted overlay tool, the individual weights for the NREL dataset were chosen to emphasize the importance of the solar data in the analysis; therefore the minimum weight assigned was a five on a 1-10 scale. By weighing the data in this manner, solar data will receive twice as much consideration for the weighted overlay computation and thereby always have a significant impact on the overlay output, regardless of the percent weight assigned to that layer.

The individual weights chosen for the other layers are based on careful analysis of the data itself as well as some considerations regarding the implicit value of the data on the analysis as a whole. Both of the agricultural datasets, crop and livestock, were weighted in a similar fashion. As the value per acre increases, the desirability for solar PV development decreases for both crop market value and livestock based market value. The justification for this weighting lies within the overall purpose of the analysis. The ideal outcome of this tool would indicate regions within the state that are suitable for solar PV development and are likely to have the least negative economic impact. These negative externalities could occur if economically valuable land was displaced with utility scale solar PV facilities. Therefore, by weighing the agricultural dataset in this manner, those regions within the state that are most productive agriculturally will receive a lower weight on the desirability index (i.e. less than 5 on 1-10 scale) therefore making them less likely to be selected in the weighted overlay output. For the crop value/acre dataset there were 142 unique values as several counties had the same value per acre. These values were separated into ten categories of 14 values per group. The group containing the greatest value per acre was assigned a weight of one on the scale with each successive group receiving a higher weight. The two remaining values were at the bottom of the range within the dataset, having the lowest value per acre and were therefore placed in the “Ten” weight category.

A similar process was applied to the livestock value dataset with the lowest values assigned a value of ten, and the greatest a value of one on the scale. There were 138 entries in this dataset; therefore the same system of ten groups of 14 entries was used with one group being two entries short. The first group, the “Ones”, containing the counties with the highest value for livestock and therefore the least desirable entries, was chosen to contain fewer values, thereby ensuring a more equal distribution among the remaining entries.

The dataset describing distance to urban areas was also weighted in a linear fashion as, in general, the shorter the distance between the urban area (load center) and the generation point (solar PV farm) the less costly the transmission of generated electricity would be. Therefore the distance data were reclassified, similar to the solar data, and weighted on the standard 1-10 scale with a “10” being those regions that are closest to urban areas (Table 2).

Table 2: Reclassification and assigned weight of Euclidean distance surrounding urban areas in the state.

Distance to Urban Area Reclassification:		
Distance from official city limit (ft.)	**Reclassified Value:**	**Assigned Weight:**
0-500	1	10
500-20,018.42	2	9
20018.42-39,536.84	3	8
39,536.84-59,055.26	4	7
59,055.26-78,573.68	5	6
78,573.68-98,092.10	6	5
98,092.1-117,610.52	7	4
117,610.52-137,128.94	8	3
137,128.94-156,647.36	9	2
156,647.36-176,165.70	10	1

Of the five datasets, the land-cover data for the state has a weighting system most subjective and dependent on the criteria of concern for the analysis. As economic productivity was a primary concern in this analysis, the land-cover data were weighted accordingly. However, if a desire to maintain ecological diversity and stability is of concern, a different weighting system should be considered.

Several constraints are present in this analysis regarding placement of utility scale solar PV installations. These constraints had a significant influence on the land cover weights in that several of the classifications used within the NLCD dataset included values for open water land cover, woody wetlands, and emergent herbaceous wetlands. These areas all represent regions that are not suitable for development of solar PV and were therefore marked as "Restricted" in the weighted overlay tool. This means that these data were not considered at all. As for the remaining 12 land cover classifications, they were weighted such that the least valuable (economically and environmentally) land would be considered most desirable for development of utility scale solar PV. Therefore, areas classified as "Barren" land were weighted as a "Ten" on the scale ranging up to high intensity developed land cover that was weighted as a "One". As for those classifications that represented very similar types of land cover, either an economic or environmental justification was used to rank them. For example, it was decided that, economically, the cost will be essentially indistinguishable when assessing forested land for development of solar PV. Therefore all three of the forest land cover classes were weighted equally. In addition, the major goal behind incorporating the agricultural data described above is to attempt to avoid displacing valuable farmland with large scale solar PV facilities. Therefore the farmland classifications (Hay/Pasture and Cropland) were given the next lowest weight above the urban areas to ensure that farmland is understood to be considered not desirable by the weighted overlay tool. Specifically, on a per acre basis, pasture land is more valuable than cropland, therefore pasture is weighted as a “Five” and cropland is a “Six”. Finally both the shrub and herbaceous plant life land cover classes represent regions that are made up by un-managed vegetation that does not exceed five meters in height. However, upon investigation of the individual classifications it was discovered that, in general, plants classified as shrubs have more leaf area than those referred to as herbaceous. Therefore, from an environmental standpoint, shrubbery would represent more valuable land cover as a larger leaf area is associated with a greater amount of photosynthetic activity and thereby carbon dioxide conversion. An environmental justification was chosen for these two classifications because they are considered equivalent from an economic perspective. The full weighting system employed in this analysis is given in Table 3.

Table 3: Classification and weighting system used for NLCD dataset.

NLCD Classification:	Assigned Weight:
Open Water:	RESTRICTED
Woody Wetlands:	RESTRICTED
Emergent Herbaceous Wetlands:	RESTRICTED
High Intensity Development:	1
Medium Intensity Development:	2
Low Intensity Development:	3
Open Area Development:	4
Hay/Pasture:	5
Cropland:	6
Mixed Forest:	7
Deciduous:	7
Evergreen:	7
Shrub:	8
Herbaceous:	9
Barren:	10

This concludes the process used for assigning the first level of weighting within the weighted overlay tool. In addition to these distinctions, the tool allows for an additional percent weight to be assigned to each layer such that the percentage always totals 100. For example, by using five datasets, an equal weight of 20% could be assigned to each, allowing a total of 100. Any variation of percent weight can be used so long as the sum is always equal to 100. In order to restrict the combinations of percent weight to a manageable number, an additional level of analysis was required. First, as locating regions for development of solar PV is the primary desired goal of this tool, it was decided that the NREL solar PV data should always have a majority weight. Therefore, while theoretically any value between 0 and 100 can be assigned, it was decided to restrict the NREL data percent contribution to between 50-80% in increments of 5. This was chosen to simplify the analysis process and limit the number of results. Similarly, NLCD data were chosen to contribute between 20-50% and market value of crop products per acre was limited to 0-30%. Livestock market value data and distance to urban area data were both restricted to 0-20% contribution because, of the five, these were considered the least valuable datasets. Distance to urban areas, while important, is not a significantly deciding factor in this analysis since the maximum distance to urban centers within the state of GA does not exceed 35 miles. Additionally, while livestock market value makes up a significant portion of Georgia's agriculture productivity, the areas within the state that are predominately livestock based agriculture are located mainly in the north and north east regions of the state, which correspond to some of the lowest regions of solar insolation. Therefore it is very unlikely that a county that is highly productive in livestock based agriculture will be considered desirable according to the parameters of this analysis.

By restricting the percent weight options in this manner, the number of potential results is significantly reduced. A simple matrix was developed via a MATLAB script (see Appendix B) to determine the exact combination of percentages that are possible given the above constraints, totaling to 200 possibilities. A sample of these, including the first ten combinations, can be seen in Table 4. The full matrix can be seen below in the Appendix B.

Table 4: First ten overlays and corresponding percent weights as listed in matrix.

Overlays:	NREL Solar PV data (%)	NLCD data (%)	Crop Market Value (%)	Distance to Urban Area (%)	Livestock Market Value (%)
1	50	20	0	10	20
2	50	20	0	15	15
3	50	20	0	20	10
4	50	20	5	5	20
5	50	20	5	10	15
6	50	20	5	15	10
7	50	20	5	20	5
8	50	20	10	0	20
9	50	20	10	5	15
10	50	20	10	10	10

By using a matrix such as this to determine percent contribution, every possible combination can be analyzed, allowing for a more stochastic based analysis and one that is less subject to individual influence or personal perspective. However, 200 resulting overlay outputs still represent a significant amount of data that needed to be further focused. Therefore it was decided to eliminate all of the overlay outputs that included a zero percentage in their percent weight. This allows for all five layers to contribute some information to the analysis. If a zero percentage is used, it essentially removes that dataset from the overlay tool which negates the entire purpose of having five datasets as inputs. While the tool could easily be modified to include fewer or more data inputs, for this analysis five datasets were chosen for the reasons described previously, therefore it was decided to analyze only those overlay outputs that contained a real percentage value for all five data layers. By doing this, the 200 outputs were reduced to 35, a more manageable number for individual assessment. These 35 are highlighted below in the Appendix B.

These 35 overlay outputs are in the form of maps of the state in which regions that are considered most desirable according to the defined constraints are shaded green and those that are less desirable are shaded red. An example of this can be seen in Figure 12 which represents the output from the first overlay using the percent weights mentioned above in Table 4. Finally, an additional analysis was applied to determine which areas within the state are most desirable, regardless of percent weight. To do this, all 35 of the remaining overlay outputs were combined using ArcMap's Intersect tool. This tool calculates the geographic intersection of various map layers and outputs only those regions that are present in all of the inputs. By choosing to isolate only those regions that are rated as an 8 or above on the desirability scale and calculating the intersect for all 35 of the overlays, the output presents only the regions in the state that are considered desirable (greater than 8 on 1-10 scale) regardless of the percent weight of the individual layers. In other words, the output of the Intersect process will represent the geographic parcels in the state that are best suited for development of utility scale solar PV according to defined criteria.

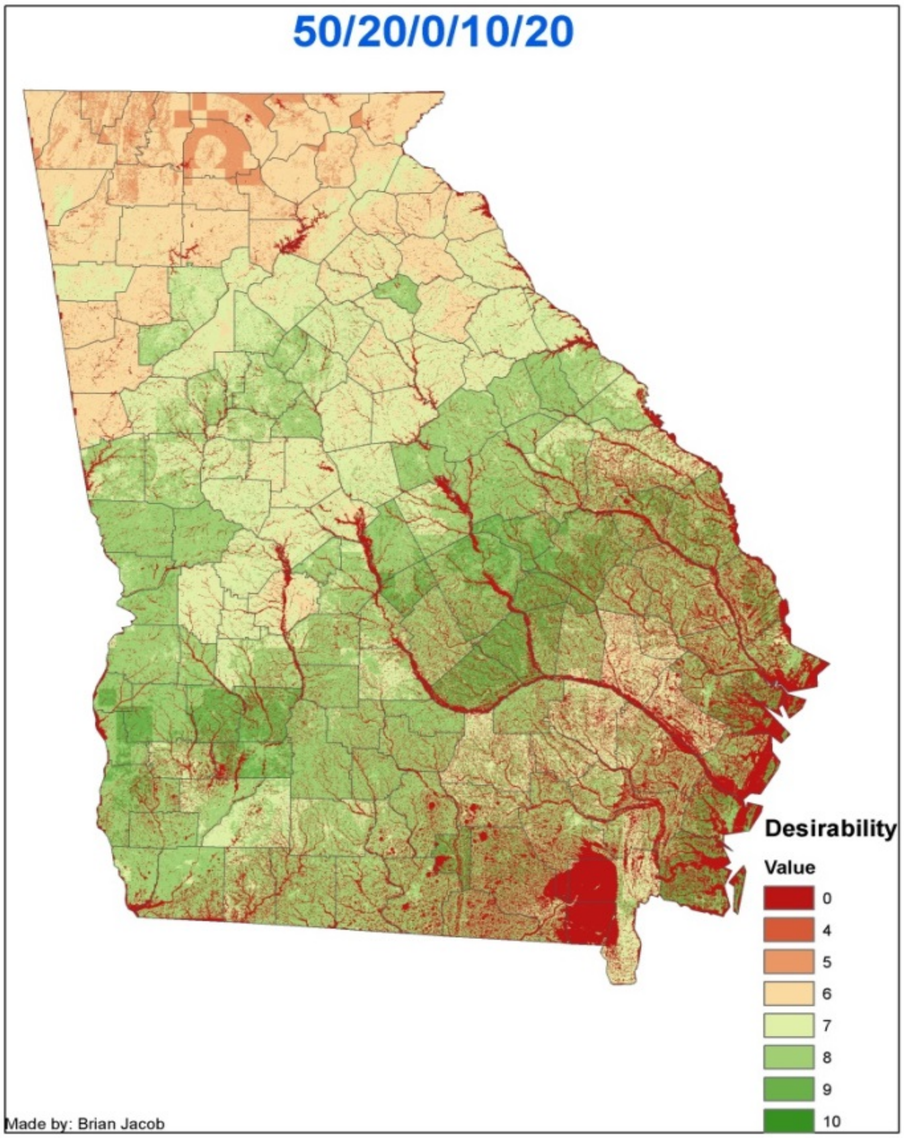


Figure 12: One of the 200 overlay maps created, showcasing desirability distribution for a single weighting scenario.

Results and Discussion:

By following the above described methodology and analysis, a comprehensive output was generated identifying regions within Georgia that are optimal for development of utility-scale solar PV. This represents one potential outcome from the methodology created here and serves as a case study of what can be accomplished. In order to move forward with actual implementation of renewable technology, further analysis will be required on a more detailed scale. With that in mind, these analytical results present some interesting and unexpected conclusions. Figure 13 displays the most desirable (8 or above on scale) regions in the state based on the described inputs and applied weights. The map has been formatted to display solar PV potential in those regions that are already identified as being desirable. These optimal locations represent areas in the state that have low economic and agricultural activity, are near urban centers, and have reasonable solar potential, making them good candidates for development of solar PV.

One notable conclusion that is immediately apparent from these results is that areas that are most desirable are not located in regions of the state with the highest solar potential, as might be expected. Instead the suitability analysis identified parcels of the state that represent the lowest economic value. Because solar insolation only varies by 0.75 kWh/m^2/day across the state, the effect of the other 4 data inputs becomes more significant, thereby truly identifying regions that are best suited for utility scale solar from a more economic perspective, but still placing the necessary consideration on solar insolation.

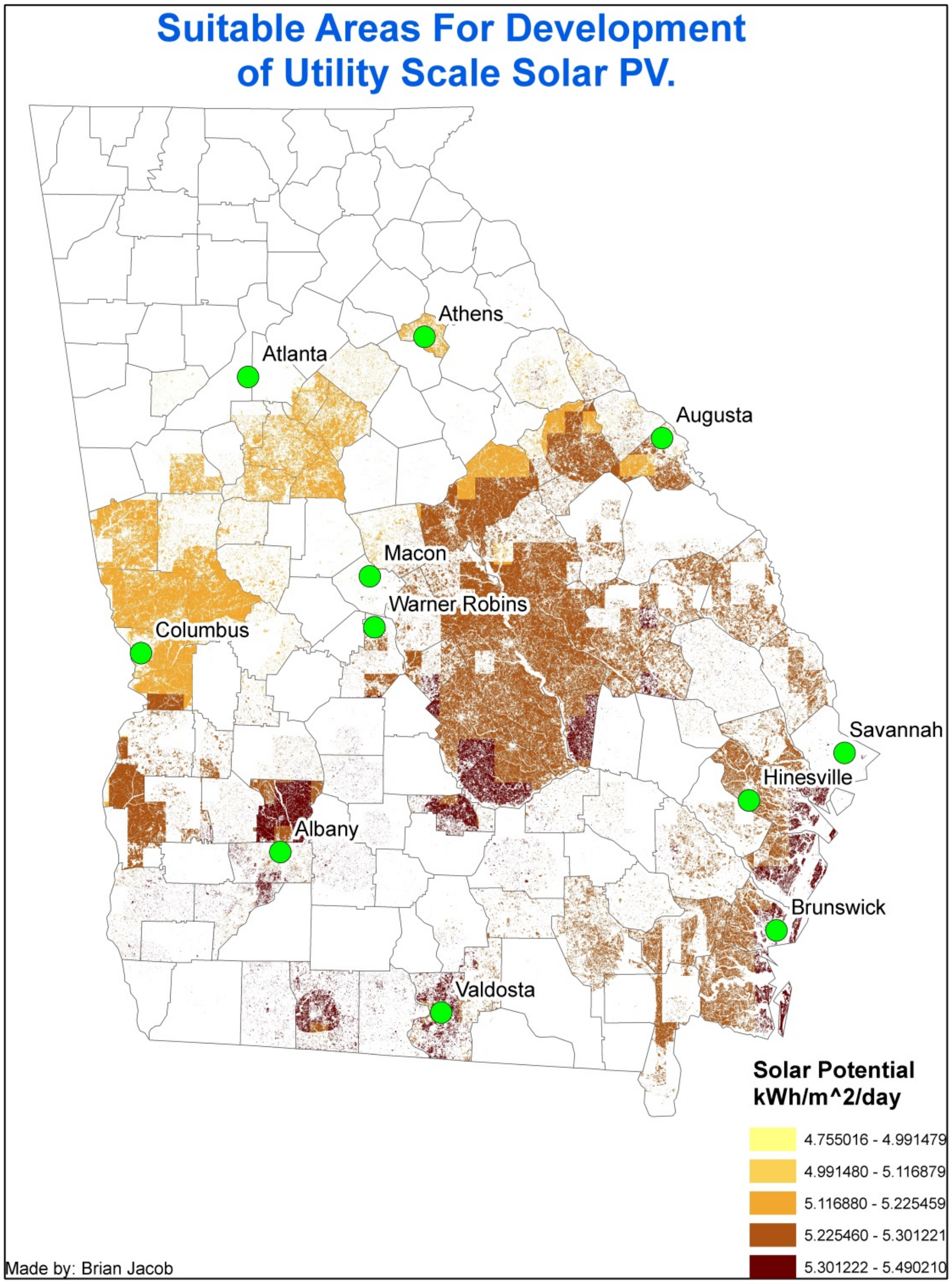


Figure 13: Final results representing the intersect of the 35 most relevant overlays and highlighting regions that are most desirable for development of solar PV.

The largest contiguous area on the map is located in central Georgia near Macon and Warner Robins and represents approximately 3,500 square miles. To the west, along the Georgia/Alabama line, there is another large region of desirable land, comprised of approximately 1,800 square miles. Other parcels are scattered around the state. When examining the larger parcel near Warner Robins, the GIS can be queried to determine that solar insolation for that region is greater than 5.25 kWh/m^2/day, 12.5% of the land consists of either crop fields or pasture, 22.4% is forested, and 28.5 % has a land cover made up of shrubbery and herbaceous plant life. This information supports the conclusion that it is an ideal region for development of utility scale solar PV.

If a further analysis is to be conducted, depending on the additional project guidelines, a parcel within these regions may be chosen for a more detailed examination. Due to the level of detail provided by the NLCD dataset, each county can be examined at up to a 30 by 30 square meter resolution allowing for a precise assessment of a parcel’s land availability. In addition, more data can be included to allow for consideration of additional constraints such as tax based land value, federally protected lands, regions containing endangered species and habitats, etc. Each of these additional datasets would provide information to allow for a more constrained placement of utility scale solar PV. Depending on the desired outcome, parcels could be sectioned off based on a defined contiguous area. For example, a large scale facility may require a minimum of 500 acres of land for development. This information could easily be incorporated into the GIS to isolate contiguous parcels of this size within the desirable regions. These examples serve to illustrate the flexibility that this suitability analysis accommodates. While the focus of this particular analysis was to assess options for the development of solar PV in Georgia, it has the flexibility to be modified to conduct a multi-input suitability analysis to suit additional preferences. By incorporating economic data and developing a detailed weighting system, the tool allows for a level of accuracy that would be lacking in suitability methods that use only one or two inputs. In addition, the economic input provides a metric that is influential in any real world decision-making process.

The output generated from this analysis is limited by the data originally provided. For example, most of the Georgia coastal area is considered “desirable” according to Figure 13. However, this is unlikely to be accurate due to the high land value that is typically associated with coastal property. Land value was not a consideration in this analysis because there was no easily accessible summary of consistent land value across the state. In addition, the immediate result of this study is focused on a state-wide macro level although a more detailed analysis is would include tax land value data on a much smaller scale. Therefore by focusing on a macro level analysis, to the exclusion of tax value data, there are some obvious shortcomings in the results, which could easily be rectified if a more detailed analysis was conducted.

Conclusion:

Georgia, lacking an abundance of any particular renewable primary energy resource, has a notable potential for the development of solar PV. As climate change becomes better understood, the societal value for renewable energy technologies will continue to rise, likely promoting increased growth of the solar PV market. In addition, new technological breakthroughs have started solar PV on the path to price parity with conventional fossil fuel based energy generation. Finally, there has been, and will likely continue to be, increased pressure from state and federal policymakers to introduce additional renewable energy to the power grid so as to reduce the carbon dioxide emissions. Combined, these criteria create an ideal environment for the development of utility scale solar PV. By using careful analytical and suitability assessment methods, such as the one developed for this study, it is possible to identify parcels, within a geographic region, that are most likely to be well-suited for the development of utility scale solar PV facilities. While informative, solar maps alone are insufficient for determining areas for installation of PV facilities as so many other critical and relevant constraints are ignored. Therefore, by including economic and geographic data in the assessment, a comprehensive analysis can be conducted, generating results more applicable and respective of other constraints. As Georgia begins investigating its renewable energy options, a tool such as this can be used to maximize the state's potential and introduce clean energy to the state grid in a manner that is sustainable, both environmentally and economically.

Bibliography:

1. IEA, I., *Key World Energy Statistics, 2013*, 2013, International Energy Agency Paris, France.
2. E.P.A, U.S. *Monthly Energy Review October 2014*. 40th Anniversery Issue 2014 [cited 2014 November]; Available from: http://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3.
3. Lopez, A., et al., *US renewable energy technical potentials: a GIS-based analysis.* Contract, 2012. **303**: p. 275-3000.
4. IPCC, C.C., *The Physical Science Basis-Summary for Policymakers, Observed Changes in the Climate System.* IPCC AR5 WG1, 2013: p. 2.
5. IPCC. *History*. 2014 [cited 2014 11/12]; Available from: http://www.ipcc.ch/organization/organization_history.shtml.
6. Swanson, R. *The Silicon Photovoltaic Roadmap*. in *Stanford Energy Seminar Nov*. 2011.
7. Wright, T.P., *Factors affecting the cost of airplanes.* Journal of the Aeronautical Sciences (Institute of the Aeronautical Sciences), 1936. **3**(4).
8. Boston Consulting Group, *Perspectives on Experience*. 1972, Boston, Mass: BCG.
9. Neij, L., *Use of experience curves to analyse the prospects for diffusion and adoption of renewable energy technology.* Energy policy, 1997. **25**(13): p. 1099-1107.
10. Wene, C.-O., *Experience curves for energy technology policy*. 2000: OECD.
11. de Moor, H., et al. *Experience curve approach for more effective policy instruments*. in *Photovoltaic Energy Conversion, 2003. Proceedings of 3rd World Conference on*. 2003. IEEE.
12. Reichelstein, S. and M. Yorston, *The prospects for cost competitive solar PV power.* Energy Policy, 2013. **55**: p. 117-127.
13. Pierce, E.R. *Progress Report: Advancing Solar Energy Across America*. Department of Energy, 2014.
14. EIA, U., *Annual energy outlook 2014.* US Energy Information Administration, Washington, DC, 2014.
15. Lazard, *Levelized Cost of Energy Analysis Version 8.0*, 2014, Lazard.
16. EIA, U., *Annual energy outlook 2013.* US Energy Information Administration, Washington, DC, 2013.
17. Kristen Ardani, R.M., *2010 Solar Technologies Market Report*, in *Energy Efficiency and Renewable Energy*, N.R.E. Laboratory, Editor 2011, U.S Department of Energy.
18. European Photovoltaic Industry Association, *Solar generation 6: Solar photovoltaic electricity empowering the world.* Retrieved February, 2011. **23**: p. 2012.
19. Finkenrath, M., *Cost and performance of carbon dioxide capture from power generation*, 2011, IEA.
20. Wimer, J.G., *Fossil Energy RD&D: Reducing the Cost of CCUS for Coal Power Plants*, NETL, Editor 2012, U.S D.O.E.
21. Schumpeter, J.A., *Socialism, capitalism and democracy*. 1942: Harper and Brothers.
22. Cox, W.M. and R. Alm, *Creative destruction.* The Concise Encyclopedia of Economics. Available online at http://www. econlib. org/library/Enc/CreativeDestruction. html, 2008.
23. Christiansen, C., *The innovator's dilemma.* Harvard Business School Press, Boston, 1997.
24. Krupnick, A.J., et al., *Toward a new national energy policy: assessing the options*. 2010: Washington: Resources for the Future. Available at http://www. energypolicyoptions. org.
25. E.I.A, *The National Energy Modeling System: An Overview*, E.I. Administration, Editor 2009, G.P.O: Washington, DC.
26. *Clean Energy Standard Act of 2012*, in *16 U.S.C. 2601*2012.

27. John Conti, J.A.B., Robert T. Eynon, *Analysis of Clean Energy Standard Act of 2012*, I.S.a. Analysis, Editor 2012, U.S D.O.E.
28. Jacobson, M.Z. and M.A. Delucchi, *Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials.* Energy Policy, 2011. **39**(3): p. 1154-1169.
29. Environmental Protection Agency, *Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units*, E.P.A, Editor 2014, G.P.O.
30. CAES, *2014 Ag Snapshots*, 2014, University of Georgia: Athens, GA.
31. CAIT, W., *2.0.,(2014). Climate Analysis Indicators Tool: WRI's Climate Data Explorer. Washington, DC: World Resources Institute*.
32. Jin S., Y.L., Danielson P., Homer C., Fry J., Xian G., *A comprehensive change detection method for updating the National Land Cover Database to circa 2011.* Remote Sensing of Environment, 2013. **132**: p. 159-175.

Appendix A:

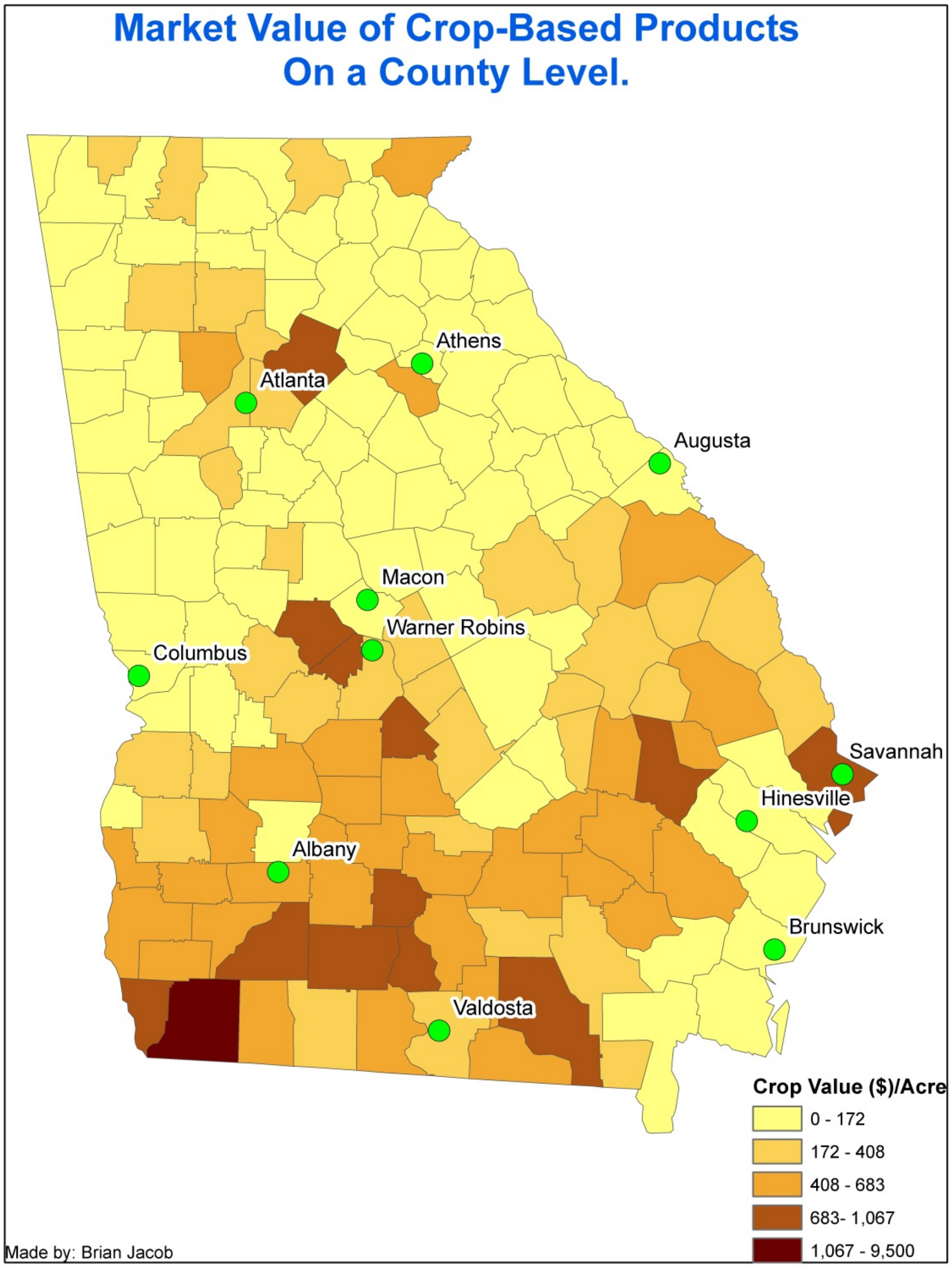


Figure 7: Map illustrating the market value of crop based agricultural outputs on a county basis. Data provided by 2012 Agricultural Census [31].

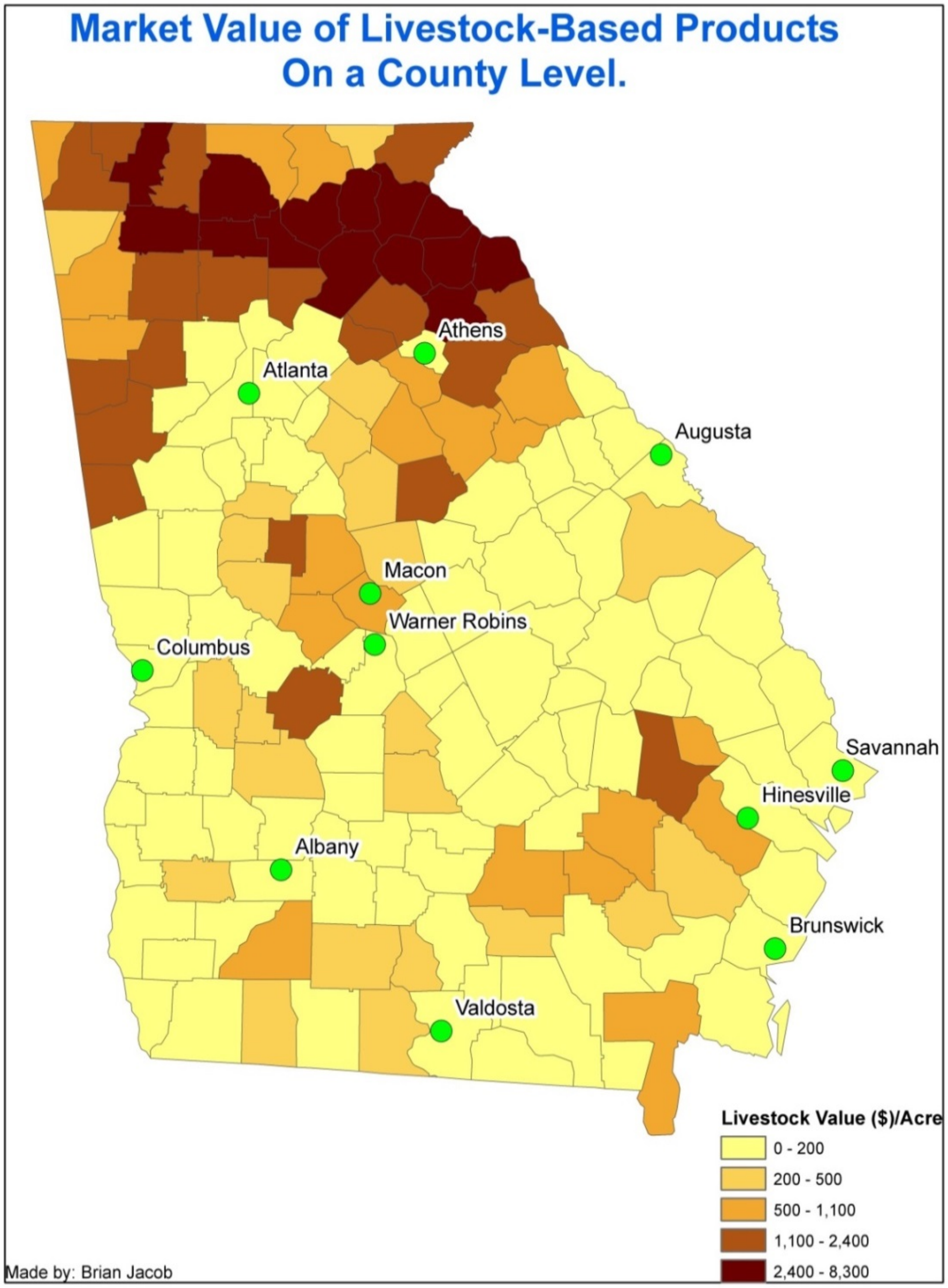


Figure 8: Map illustrating the market value of livestock based agricultural outputs on a county basis. Data provided by 2012 Agricultural Census [31].

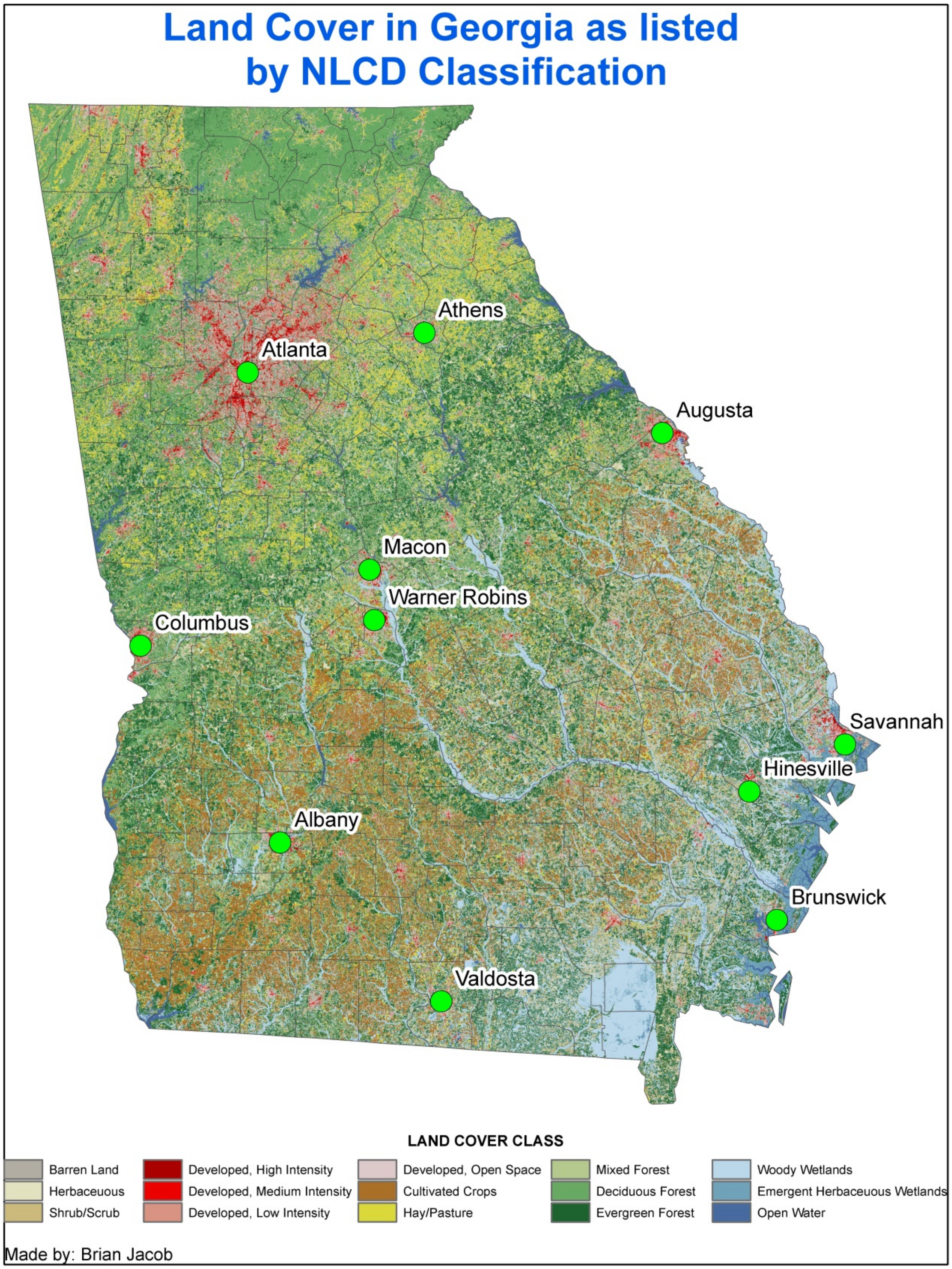


Figure 9: Map of land cover in Georgia according to National Land Cover Database (NLCD) Classification System [32].

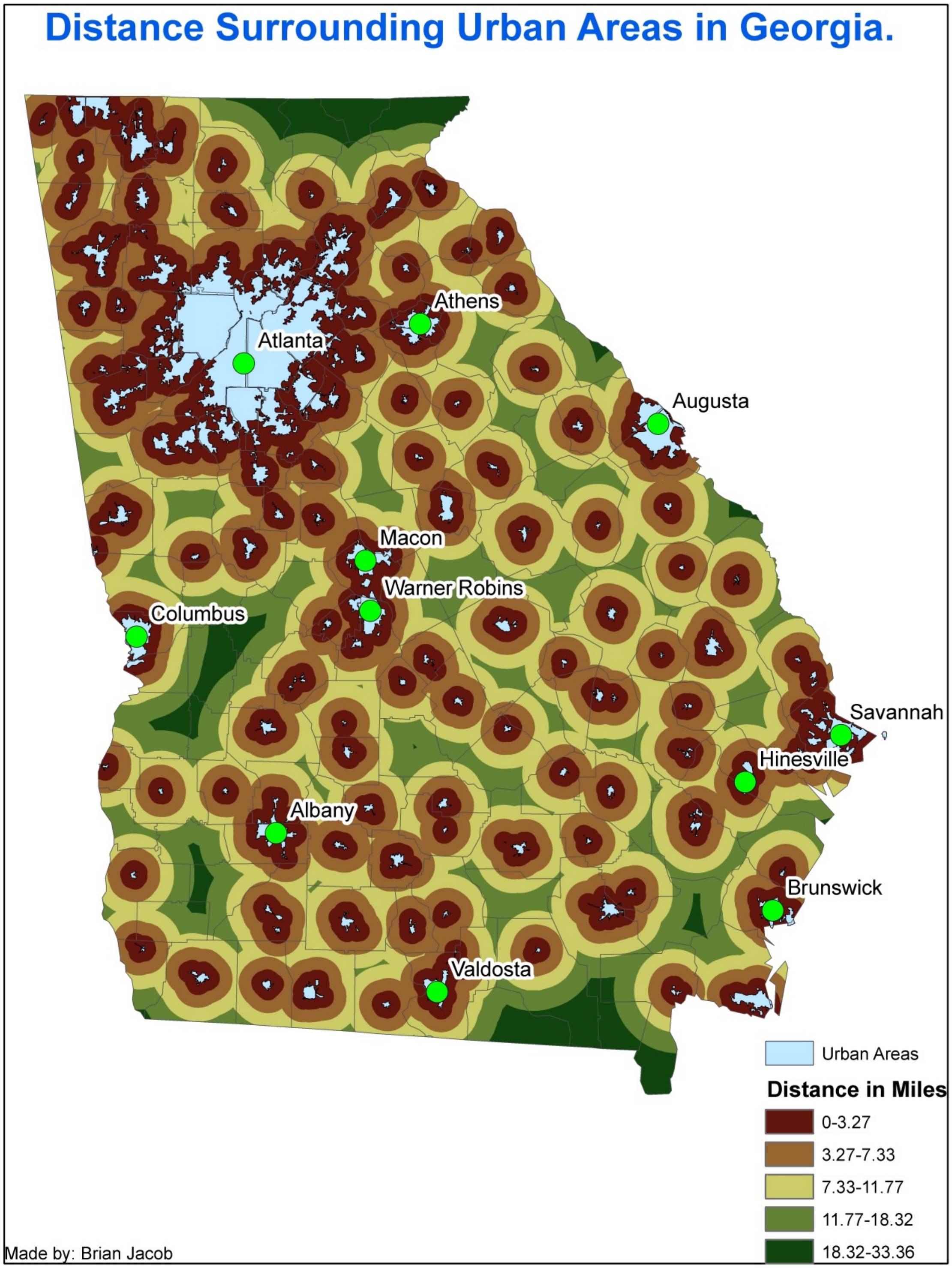


Figure 10: Map indicating Euclidean distance surrounding all urban areas in the state.

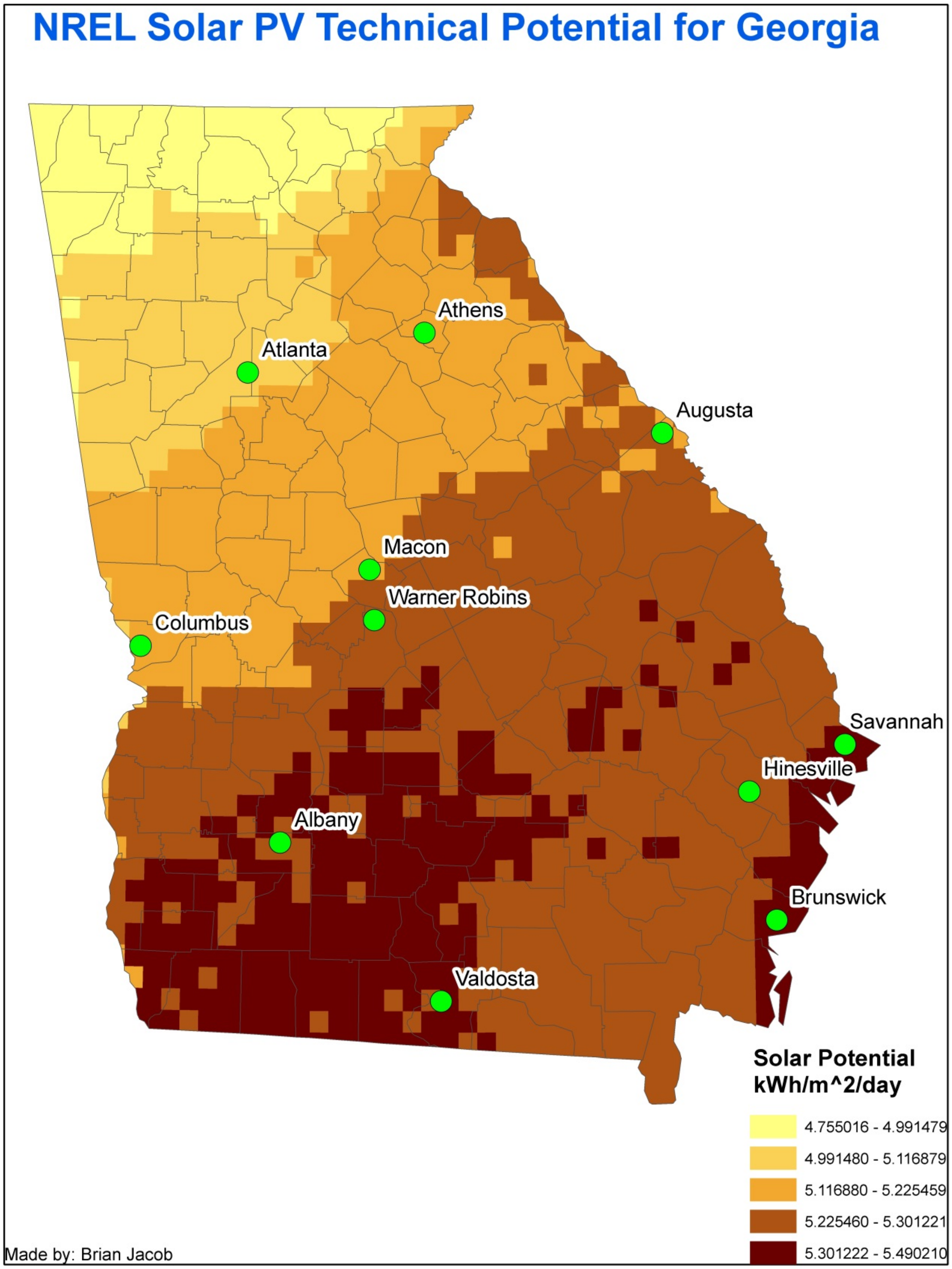


Figure 11: Map of National Renewable Energy Laboratory (NREL) Solar PV Technical Potential on a 10x10 kilometer grid for the state of Georgia.

Appendix B:

Full matrix of 200 overlays generated in this analysis displaying all possible combinations of percent weight for five datasets. Those overlays marked in green represent the 35 that were chosen to be intersected to create the final output map.

Overlays:	NREL Data	NCLD	Crop Value	Dist. To Urban	LiveStock Value
1	50	20	0	10	20
2	50	20	0	15	15
3	50	20	0	20	10
4	50	20	5	5	20
5	50	20	5	10	15
6	50	20	5	15	10
7	50	20	5	20	5
8	50	20	10	0	20
9	50	20	10	5	15
10	50	20	10	10	10
11	50	20	10	15	5
12	50	20	10	20	0
13	50	20	15	0	15
14	50	20	15	5	10
15	50	20	15	10	5
16	50	20	15	15	0
17	50	20	20	0	10
18	50	20	20	5	5
19	50	20	20	10	0
20	50	20	25	0	5
21	50	20	25	5	0
22	50	20	30	0	0
23	50	25	0	5	20
24	50	25	0	10	15
25	50	25	0	15	10
26	50	25	0	20	5
27	50	25	5	0	20
28	50	25	5	5	15
29	50	25	5	10	10
30	50	25	5	15	5
31	50	25	5	20	0
32	50	25	10	0	15
33	50	25	10	5	10
34	50	25	10	10	5
35	50	25	10	15	0
36	50	25	15	0	10
37	50	25	15	5	5
38	50	25	15	10	0
39	50	25	20	0	5

Overlays:	NREL Data	NCLD	Crop Value	Dist. To Urban	LiveStock Value
40	50	25	20	5	0
41	50	25	25	0	0
42	50	30	0	0	20
43	50	30	0	5	15
44	50	30	0	10	10
45	50	30	0	15	5
46	50	30	0	20	0
47	50	30	5	0	15
48	50	30	5	5	10
49	50	30	5	10	5
50	50	30	5	15	0
51	50	30	10	0	10
52	50	30	10	5	5
53	50	30	10	10	0
54	50	30	15	0	5
55	50	30	15	5	0
56	50	30	20	0	0
57	50	35	0	0	15
58	50	35	0	5	10
59	50	35	0	10	5
60	50	35	0	15	0
61	50	35	5	0	10
62	50	35	5	5	5
63	50	35	5	10	0
64	50	35	10	0	5
65	50	35	10	5	0
66	50	35	15	0	0
67	50	40	0	0	10
68	50	40	0	5	5
69	50	40	0	10	0
70	50	40	5	0	5
71	50	40	5	5	0
72	50	40	10	0	0
73	50	45	0	0	5
74	50	45	0	5	0
75	50	45	5	0	0
76	50	50	0	0	0
77	55	20	0	5	20
78	55	20	0	10	15

Overlays:	NREL Data	NCLD	Crop Value	Dist. To Urban	LiveStock Value
79	55	20	0	15	10
80	55	20	0	20	5
81	55	20	5	0	20
82	55	20	5	5	15
83	55	20	5	10	10
84	55	20	5	15	5
85	55	20	5	20	0
86	55	20	10	0	15
87	55	20	10	5	10
88	55	20	10	10	5
89	55	20	10	15	0
90	55	20	15	0	10
91	55	20	15	5	5
92	55	20	15	10	0
93	55	20	20	0	5
94	55	20	20	5	0
95	55	20	25	0	0
96	55	25	0	0	20
97	55	25	0	5	15
98	55	25	0	10	10
99	55	25	0	15	5
100	55	25	0	20	0
101	55	25	5	0	15
102	55	25	5	5	10
103	55	25	5	10	5
104	55	25	5	15	0
105	55	25	10	0	10
106	55	25	10	5	5
107	55	25	10	10	0
108	55	25	15	0	5
109	55	25	15	5	0
110	55	25	20	0	0
111	55	30	0	0	15
112	55	30	0	5	10
113	55	30	0	10	5
114	55	30	0	15	0
115	55	30	5	0	10
116	55	30	5	5	5
117	55	30	5	10	0

Overlays:	NREL Data	NCLD	Crop Value	Dist. To Urban	LiveStock Value
118	55	30	10	0	5
119	55	30	10	5	0
120	55	30	15	0	0
121	55	35	0	0	10
122	55	35	0	5	5
123	55	35	0	10	0
124	55	35	5	0	5
125	55	35	5	5	0
126	55	35	10	0	0
127	55	40	0	0	5
128	55	40	0	5	0
129	55	40	5	0	0
130	55	45	0	0	0
131	60	20	0	0	20
132	60	20	0	5	15
133	60	20	0	10	10
134	60	20	0	15	5
135	60	20	0	20	0
136	60	20	5	0	15
137	60	20	5	5	10
138	60	20	5	10	5
139	60	20	5	15	0
140	60	20	10	0	10
141	60	20	10	5	5
142	60	20	10	10	0
143	60	20	15	0	5
144	60	20	15	5	0
145	60	20	20	0	0
146	60	25	0	0	15
147	60	25	0	5	10
148	60	25	0	10	5
149	60	25	0	15	0
150	60	25	5	0	10
151	60	25	5	5	5
152	60	25	5	10	0
153	60	25	10	0	5
154	60	25	10	5	0
155	60	25	15	0	0
156	60	30	0	0	10

Overlays:	NREL Data	NCLD	Crop Value	Dist. To Urban	LiveStock Value
157	60	30	0	5	5
158	60	30	0	10	0
159	60	30	5	0	5
160	60	30	5	5	0
161	60	30	10	0	0
162	60	35	0	0	5
163	60	35	0	5	0
164	60	35	5	0	0
165	60	40	0	0	0
166	65	20	0	0	15
167	65	20	0	5	10
168	65	20	0	10	5
169	65	20	0	15	0
170	65	20	5	0	10
171	65	20	5	5	5
172	65	20	5	10	0
173	65	20	10	0	5
174	65	20	10	5	0
175	65	20	15	0	0
176	65	25	0	0	10
177	65	25	0	5	5
178	65	25	0	10	0
179	65	25	5	0	5
180	65	25	5	5	0
181	65	25	10	0	0
182	65	30	0	0	5
183	65	30	0	5	0
184	65	30	5	0	0
185	65	35	0	0	0
186	70	20	0	0	10
187	70	20	0	5	5
188	70	20	0	10	0
189	70	20	5	0	5
190	70	20	5	5	0
191	70	20	10	0	0
192	70	25	0	0	5
193	70	25	0	5	0
194	70	25	5	0	0
195	70	30	0	0	0
196	75	20	0	0	5
197	75	20	0	5	0
198	75	20	5	0	0
199	75	25	0	0	0
200	80	20	0	0	0

MATLAB script used to generate the matrix of all 200 combinations of percent weight.

```
% Input Matrix
A =[50,20,0,0,0;...
    55,25,5,5,5;...
    60,30,10,10,10;...
    65,35,15,15,15;...
    70,40,20,20,20;...
    75,45,25,-1,-1;...
    80,50,30,-1,-1];     % note (-1) denotes the cell is blank

counter = 0;  % Initialize counter

% Move through each coloumn of the matrix
for a=1:1:length(A(:,1))
    for b=1:1:length(A(:,2))
        for c=1:1:length(A(:,3))
            for d=1:1:length(A(:,4))
                for e=1:1:length(A(:,5))

                    % check to see if data is in the cell
                    if A(a,1)==-1 || A(b,2)==-1 || A(c,3)==-1 || A(d,4)==-1 || A(e,5)==-1
                        sum = 0;
                    else
                        sum = A(a,1)+A(b,2)+A(c,3)+A(d,4)+A(e,5);
                    end

                    % If sum is equal to 100% then display
                    if sum == 100
                        fprintf('(%f,1)+(%f,2)+(%f,3)+(%f,4)+(%f,5) = 100\n',a,b,c,d,e);
                        counter = counter+1;  % update counter
                    end


                end
            end
        end
    end
end
```