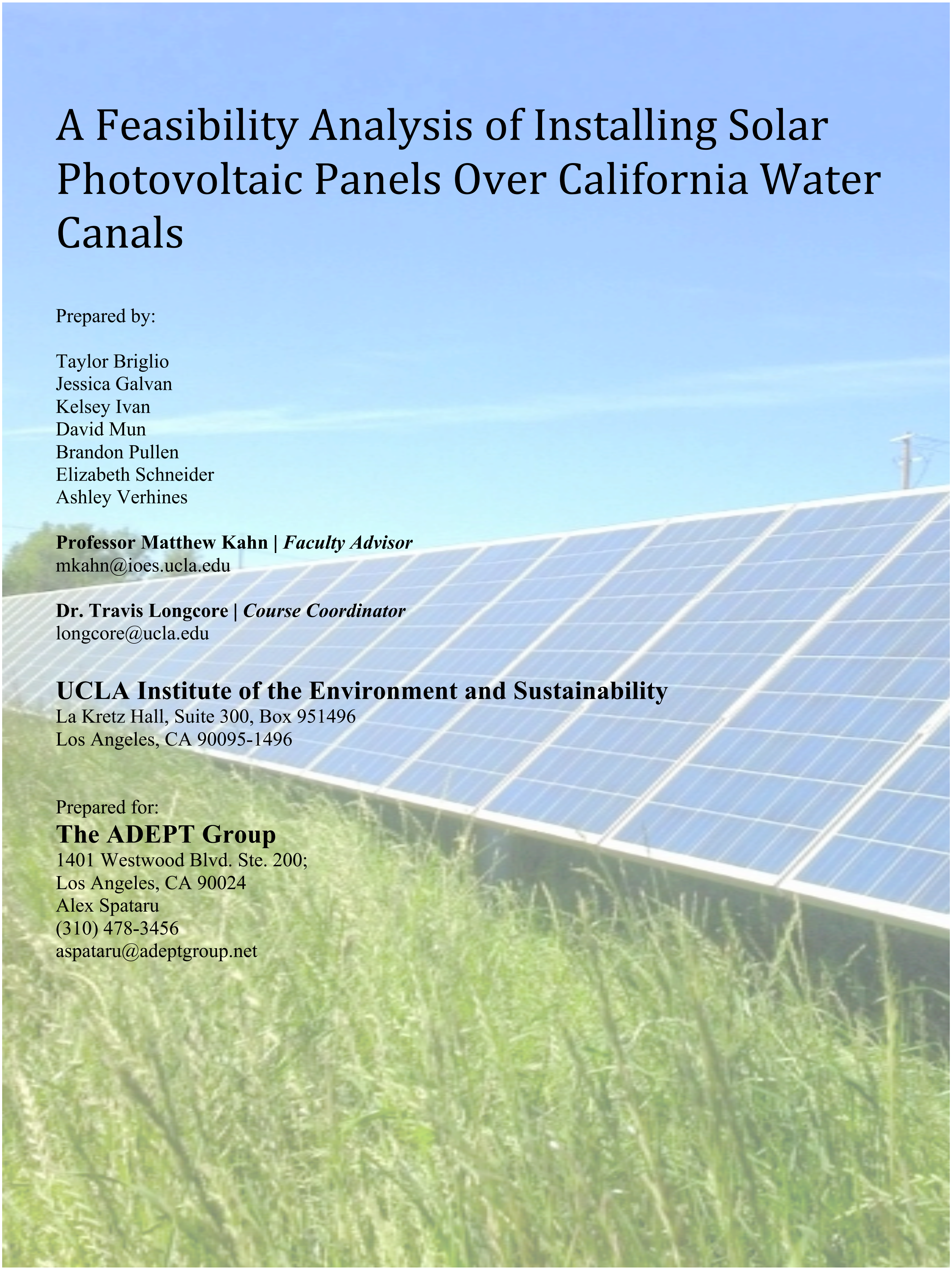

A Feasibility Analysis of Installing Solar Photovoltaic Panels Over California Water Canals

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Executive Summary

The Problem

Climate change and the extreme drought in California will lead to increases in the price of water and an overall deficit in water supply in the state. Both of these developments will compromise the state's robust economy, which make the development of novel water policies, infrastructure projects, and business models necessary. This leads to our core research question:

Could solar panels be installed over California waterways in a cost-effective way?

Who Are We?

We are seven environmental science seniors at UCLA researching the installment of solar photovoltaic panels over California's waterways. To perform this research, we are partnering with the ADEPT Group, Inc., an energy engineering consulting corporation, and Professor Matthew E. Kahn of UCLA's Institute of the Environment and Sustainability.

Our Proposed Solution

Our research on solar canals indicates that its effects include many benefits. Solar canals are similar to rooftop solar in that they are installed over existing infrastructure and do not require additional land development. Like other renewable energy sources, they reduce both greenhouse gas emissions and dependence on fossil fuels. They have the additional benefits of reducing evaporative losses and can help provide the energy needed to pump water throughout the state. This solution still has its challenges. Solar canals have a large upfront cost and we must acknowledge the uncertainty in a project with limited precedents. Still, these installments could be invaluable to the state of California by saving millions of dollars in pumping costs and potentially millions of gallons of water each year.

Why California?

California is no stranger to solar energy. With over 68 individual solar projects, averaging 310 MW per installation, and 29 more projects in development, the state's solar portfolio is growing quickly. The installment of solar power on existing water canals would be the first project of its kind in the United States. After gathering data on a number of suitability indicators (e.g. solar irradiance, proximity to water demand, accessibility to open canals, likelihood of public approval, etc.) for such an installment, we determined that California is an ideal host. Our feasibility analysis is only the beginning in the development of this project. This type of innovation is needed now more than ever and can set the example for future advances in the water-energy nexus.

Abstract

Extreme drought has heavily influenced California's water supply, necessitating rationing techniques. In light of this, the implementation of solar panels over existing water canals would be instrumental in the conservation of California's water supply and in the reduction of fossil fuel use, which could help alleviate future climate change. Reviewed in this report are the many factors that go into the planning and implementation of the proposed project. This includes a suitability index used to determine the best locations for this project, a life cycle analysis, and calculations of levelized cost of energy and net present value that support the implementation of this project. We further investigate the potential technology and financing sources for this project, as well as its risks, uncertainties, and insurance. An implementation plan is also included in the report.

Keywords: solar canal, solar technology, and renewable energy

1| Introduction

On both a local and a global scale, global warming promises to be one of the most significant challenges of the coming centuries. The Intergovernmental Panel on Climate Change (IPCC) has concluded with 90% confidence that recent warming in global climate is due to human activity, primarily due to the burning of fossil fuels (Barker, 2007). Although it is impossible to foretell the exact effects of climate change, the development of sustainable energy sources is a vital component of climate change mitigation and adaption.

With its dramatic transformation over the last few centuries — from desert and chaparral to one of the nation's largest urban areas — Southern California finds itself falling behind in the conservation of energy and natural resources. Given the state's ongoing drought, water is arguably one of the most valuable of those resources. The modern-day Southern California area provides only 30-40% of its own water through groundwater collection, with the rest coming from sources as far away as Northern California and the Colorado River. Moving this water over such significant distance requires a significant amount of energy, particularly because the water must be carried over large elevation changes **(Figure 1)**. The State Water Project (SWP), for example, lifts water 2000 feet over the Tehachapi Mountains before distributing it throughout Southern California — the highest lift of any water system in the world (Cohen et al., 2004)

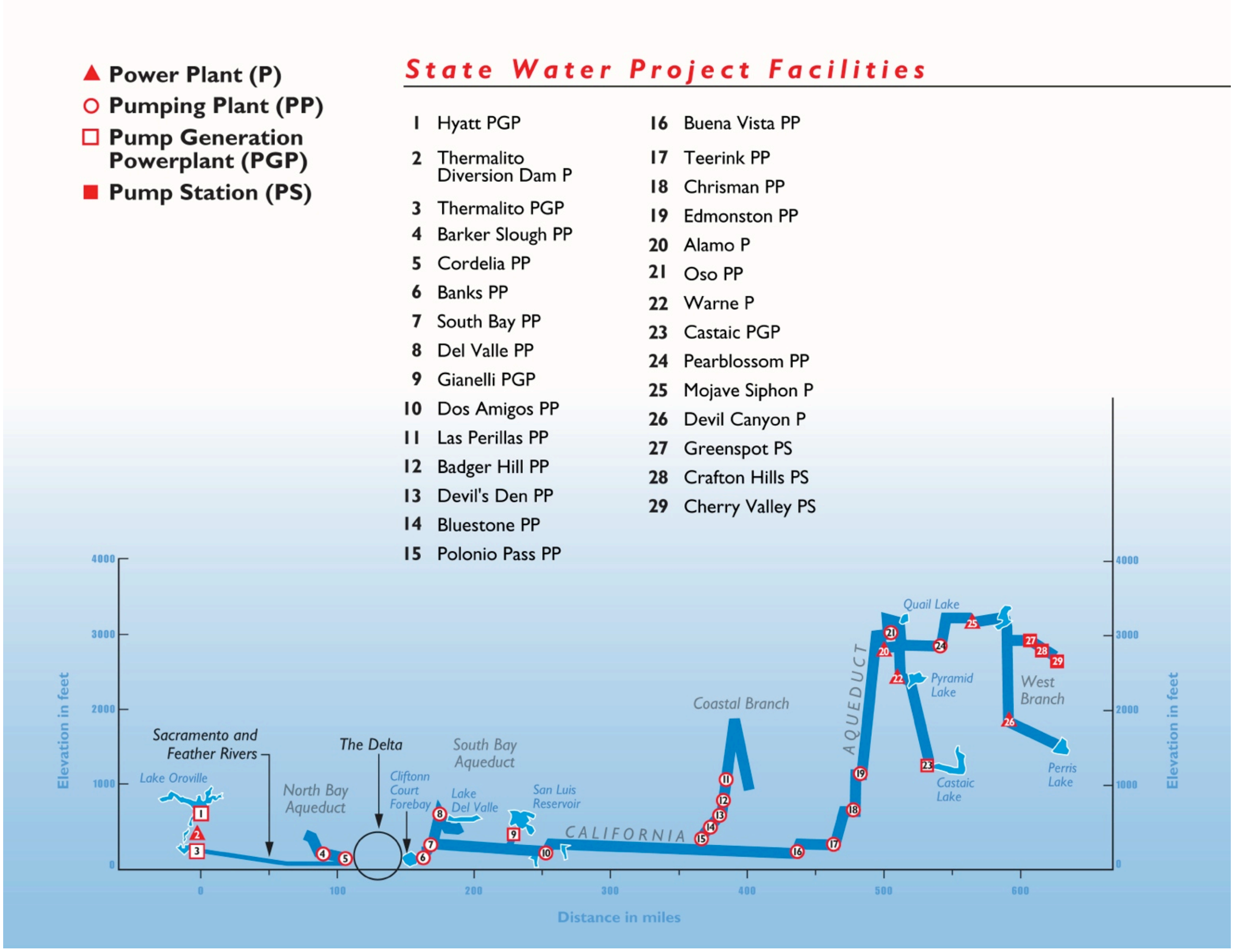

Figure 2 State Water Project Facilities. The California State Water Project pumps water over significant topographic obstacles in its route to Southern California. Source: sustainca.org/content/state_water_project_facilities_map

Partially because of these topographic hurdles, the State Water Project is the single largest energy user in the State of California. The 5 billion kWh it uses per year comprises 2-3% of California's total energy use (U. EPA, 2012). At present, the water utilities involved with pumping this water have contracts to receive power from nearby conventional power plants at rates that fall far below market value. This leads to significant greenhouse gas emissions. By its own estimation, the California Department for Water Resources places its annual greenhouse gas emissions between 3.5 million and 4.1 million metric tons per year (Schwarz, 2012).

With a drought of increasing severity and the crisis of global warming looming large, California is in need of a solution that can reduce this exorbitant energy use while also reducing water loss. Following the example of a project installed in Gujarat, India, mounting solar systems over canals represents a unique approach to energy and water savings. Before a similar project can be attempted in California, though, two vital questions must be answered. Would a solar canal system in the state make a measurable environmental impact? Can it do so in an economically feasible way? Should the answer to both of these questions be positive, solar canals could be a meaningful solution to California's water and energy crises.

Over time, the success of such a project could inspire other states and countries to follow suit, setting the stage for a more sustainable, energy-secure future.

2| Literature Review

This literature review will synthesize various research topics to provide relevant background information for answering our research questions. This review will first discuss the world's only existing solar canal, the Gujarat solar canal. It will then compare current photovoltaic (PV) technologies to determine the best suitable panel technology for a solar canal. To understand the potential costs of a solar canal, this review will examine the most up-to-date research regarding large-scale solar project costs and economies of scale. Lastly, this review will analyze the environmental benefits and costs of a solar canal.

2.1 Project Precedents – Gujarat

When Gujarat's 1-MW Canal Solar Power Project was completed in 2012, it became the first large-scale solar-covered canal system in the world ("Producing Solar Energy While Saving Water," 2012). This project is estimated to provide renewable energy to the rural area, and stop the evaporation of up to seven million liters of potable water per year ("Producing Solar Energy While Saving Water," 2012). Due to the unique nature of the solar panel installation, which covers approximately 1 km of canal, the project had significant cost beyond that of an ordinary solar project. According to Gujarat State Energy Secretary D.J. Pandian, the project cost approximately 17 crore Rupees (about $2.75 million USD), 70% more than the typical per MW cost for land-mounted PV in the region (Mahurkar, 2012). The increased costs were present in several phases of the installation, including design, manufacture, and support system construction for the panels ("Producing Solar Energy While Saving Water," 2012). Future systems, however, are likely to see significantly reduced cost. Pandian expects the cost of future solar canal projects to cost only about 20% more than land-based systems (Mahurkar, 2012).

2.2 Implementation

2.2.1. Solar Photovoltaic (PV) Panel Technology

In determining the best type of solar panel technology to place over a canal, a few factors come into play. First, the efficiency, or the amount of sunlight converted into energy, of the panel must be relatively high compared to the other technologies. Currently, the most efficient panel is monocrystalline technology, reported at 24.7% efficiency, followed by polycrystalline technology, reported at 19.8% (Shah et al., 2004). Second, the cost associated with each technology must be considered. Monocrystalline technology's cost is inflated by the necessary tracking system that allows the panel to move with the sun's path (Quaschning, 2004). Polycrystalline modules do not require this tracking system, as the module is made up of shards of crystal and does not need to be repositioned to maintain alignment with the sun (Quaschning, 2004). Third, availability must be addressed. Monocrystalline and polycrystalline technologies are both readily available as they are already widely used by solar technology manufacturers and installers due to their cost effectiveness (Shah et al., 1999). Lastly, polycrystalline is already in use in a large majority of grid-tied systems (Aguillon, 2014).

The other technologies not yet discussed — including Copper Indium Gallium Selenide (CIGS) at 19.2% efficiency, dye sensitized at 7-11% efficiency, and polymer and heterojunction at 1-3.3% efficiency — are all relatively young technologies and less efficient (Aguillon, 2014; Grätzel, 2005; Liska et al., 2006; Wada et al., 2001). These were not considered due to their inefficiencies, and because polycrystalline is a proven and widely established technology. With CIGS, dye sensitized, and polymer and heterojunction technologies not heavily considered, the focus of research was placed on the implications of monocrystalline and polycrystalline technologies being the primary technology used in this project.

2.2.2 Initial Costs

Large-scale solar PV installations are primarily limited by their high upfront costs. A 1985 analysis of a 1-MW project in Hesperia, California concluded that the dominant limiting factor of solar PV for the rest of the 20th century would not be technical or operational, but economic (Patapoff & Mattijetz, 1985). Installation costs for major projects are usually in the millions of dollars. With the recent expansion of solar PV capacity and the growth of government support programs, there have been significant reductions in solar PV costs. This trend of decreasing costs is expected to continue into the future (IEA, 2012). It has been estimated that by 2020, or even sooner, solar PV could become a fully cost-competitive energy source (Bagnall & Boreland, 2008).

2.2.3 Operation and Maintenance (O&M) Cost

The O&M cost of solar PV installations is relatively small compared to the initial cost. Current data suggests that the O&M cost of utility-scale (> 2 MW) PV systems is between $20-$40 per kilowatt (kW) per year (Bolinger & Weaver, 2013). The primary O&M cost for solar PV is inverter replacement, which is usually necessary every ten years (Branker et al., 2011). Another often-overlooked variable regarding the maintenance of solar PV panels is soiling. As solar panels accumulate dirt and dust, they begin to lose efficiency, which can reduce the power output of the system by up to 40% (Mejia & Kleissl, 2013). In areas with high frequency of rainfall, the rain can act as a natural washing system. In California, however, rainfall is far too infrequent to reliably function as a washing mechanism (Mejia & Kleissl, 2013). Because of this lack of natural cleaning, calculating the total O&M cost for any system requires consideration of manual or automated cleaning processes (Mejia & Kleissl, 2013). Improvements in fabrication, installation, and operation are expected to reduce these costs by up to 30% in the future (Bagnall & Boreland, 2008).

2.2.4 Overall Lifetime Costs

Without many historical precedents for solar panel-covered canal systems, there will not be comprehensive experience upon which to base future projects. From a general solar PV perspective, the most important challenge will be choosing a site to guarantee the best solar resource. Newer, more reliable technologies with high efficiencies should be used to produce optimal power. Cost will depend on levels of government support, but operation and maintenance costs are decreasing.

One element that will play a large role in the profitability of the system is its operational lifespan, which is often hard to predict for new technologies. Even with older technology, panels have been shown to maintain functionality for decades. For example, in 1982, ARCO Solar offered a 5-year warranty on its solar panels (Green, 2005). These ARCO Solar PV panels were installed in a 10-kW grid-connected PV system in May of 1982. After 20 years of operation, this system had only decreased about 3% in power output and is still fully functional (Chianese et al., 2011). Another ARCO mirror-enhanced PV experienced extensive browning, causing those arrays to have severe degradation. A study from 1988 noted that this degradation was cause for concern, but that the design of that project was uneconomical regardless (Sumner et al., 1988). In 1990, the National Renewable Energy Laboratory (NREL) researched this issue, and within a few years the technical problem was solved (Pern, 1997). Studies on outdoor solar

PV performance do show aging systems resulting in loss of output, but the estimated output loss and the mechanisms behind aging are still being studied (Sharma & Chandel, 2013).

2.2.4 Economies of Scale

The effect of economies of scale on the cost of solar PV systems per unit energy is significant. Nowhere is this more evident than in the pricing of small residential PV systems (Feldman et al., 2012). The median installed price for a system of ≤ 2 kW in the first half of 2012 was $7.69 per watt, whereas the median installed price for all systems of ≤ 10 kW was $5.94 per watt (Feldman et al., 2012). This is approximately a 25% difference. If we look at the change in price per unit energy from systems of ≤ 10 kW to systems of 10 - 100 kW, we see a nearly 9% difference (Feldman et al., 2012). There is about a 7% difference between the per unit energy costs of systems of 10 – 100 kW and systems of > 100 kW (Feldman et al., 2012). The declining percent difference with increasing capacity suggests that there is a point of diminishing returns for this economy of scale. One study found that this point occurs at a capacity of between 5 MW and 10 MW (Bolinger & Weaver, 2013).

2.3 Evaporative Loss in Water Canals

As has been previously mentioned, conserving water is a vital issue for drought-stricken California. Thus, one of the major benefits of solar canals is their ability to shade the water and, in turn, reduce evaporative loss. Open, gravity-fed irrigation canals transport water because they do not require much energy (Pardo et al., 2013). Given the open design of these canals, as much as 40% of the water can be lost during conveyance, due to evaporation or seepage into the soil (Rocamora et al., 2012).

Evaporative loss can be easily quantified with the following mass balance equation:

$$E = 2.262x10^{-8}(1 + .25u_2)[\exp\left(\frac{17.27\,\theta_w}{237.3+\theta_w}\right) - R_h \exp\left(\frac{17.27\,\theta_a}{237.3+a}\right)$$

where E is the evaporative discharge per unit free surface area in m/s, u_2 is the wind velocity 2 meters above the water surface in m/s, θ_w is the water surface temperature in °C, θ_a is the air temperature in °C, and R_h is the relative humidity expressed as a fraction (Swamee et al., 2002). Evaporative losses tend to be smaller than seepage losses, but they are still large enough to be considered. Most methods to decrease seepage losses, such as converting from an open canal to a closed pipe, will also eliminate evaporative losses since the water is no longer exposed to the atmosphere. Some studies have shown evidence that air temperature has the largest effect on water temperature (Thompson et al., 2005). There is a growing body of evidence, however, that direct solar radiation plays a larger role on water temperature than air temperature (Johnson, 2004). Shading an irrigation canal would therefore reduce evaporative loss because it would reduce the incoming solar radiation and thus lower the water temperature.

2.4 Externalities

Though solar photovoltaics produce some carbon emissions during their life cycles from raw materials extraction, manufacturing, transportation, and disposal, they are still much less environmentally harmful than traditional energy sources like coal. Replacing grid electricity with central PV systems could reduce greenhouse gas emissions, heavy metals, radioactive species and other criteria pollutants by an estimated 89-98% for some cadmium and silicon modules (Fthenakis et al., 2008). As demand increases and technology continues to improve, solar photovoltaics will gain efficiency at a fraction of the price. In fact, 2013 experienced the greatest boom of solar energy in the United States, and this trend will likely continue (SEIA, 2013). The solar technology industry has recently garnered significant public approval in the United States. A recent poll found that 92% of U.S. citizens support the development of solar technology (Cheyney, 2009).

Solar energy can also have significant social benefits such as job creation and increased energy security. According to one U.S. Department of Energy research and development laboratory, solar creates more direct jobs per million dollars invested than any other conventional energy source ("Solar Electric Power," 2009). Furthermore, each megawatt power of solar panels installed creates an estimated 20 manufacturing job-years and 13 installation job-years (Ban-Weiss, 2010). These jobs include highly skilled engineering, assembly, sales, and installation positions. An additional 1.8 to 2.8 indirect jobs are created in other industries for every job created by the solar PV industry (Stalix). Solar energy can also reduce American dependence on foreign oil. Furthermore, a redistribution of the currently concentrated network of power plants, pipelines and other energy infrastructure will make the country less vulnerable to energy shortages resulting from natural disasters or terrorist attacks.

In this literature review, we have summarized the research topics that are applicable to a solar canal project. However, current literature addressing solar canals specifically is lacking. In this report, we aim to build on this solar literature and fill the solar canal literature gaps.

3| Methods

In this section, we will discuss all of our methods and assumptions used in determining the feasibility of a prospective solar project over California canals. These include: project location suitability, solar panel technology selection, evaporative water loss calculations, analyses of investment costs and benefits, cost calculations and life cycle analysis parameters. Subsequent results will be discussed in the Results section.

3.1 Determining Project Location Suitability

We employed Estoque's Multi-Criteria Decision Analysis framework to decide the most suitable location for an eventual large-scale solar canal project (Estoque, 2011). We first broke the factors into two groups: physical and demographic. The physical variables summarized in **Table 3.1-a** were the solar insolation and the proximity to water pumping plants, as one of the goals of a large-scale project would be to offset the significant energy used to pump water. We chose to include the demographic variables summarized in **Table 3.1-b** based on research that suggests they are significant in determining support for alternative energy installations (Cragg et al., 2013; Dastrup et al., 2012; Krause, 2011). Although the subjective nature of this analysis required us to make assumptions regarding relevant factors and their weights, the method is easily adaptable to changes in criteria. To determine geographic suitability for locations throughout California, a map was created for each group of variables (**Appendix A**), as well as for the combined score (refer to **Section 4.2**).

Table 3.1-a Summary of Physical Variables.

Type of variable	Name of variable	Weighting	Source
Physical	Canal location	N/A	USGS National Hydrography Dataset for California
Physical	Solar intensity	70%	National Renewable Energy Laboratory Solar Data - Southwest US, Slope <5%, 10km Resolution, 1998 to 2009
Physical	Proximity to pumping stations	30%	Coordinates of pumping plants gathered from California Data Exchange Center, Center for Land Use Interpretation, Mindat, Wikimapia, and Wikipedia. Coordinates Confirmed via Google Maps.

Table 3.1-b Summary of Demographic Variables.

Type of variable	Name of variable	Weighting	Source
Demographic	County water use	10%	USGS Water Use Data for California 2005
Demographic	Percent college graduates	30%	2008-2012 American Community Survey, Educational Attainment for the Population Aged 25 Years and Older (Accessed via American Census Factfinder)
Demographic	Median income	15%	2008-2012 American Community Survey, Median Household Income in the Past 12 Months (Accessed via American Census Factfinder)
Demographic	Percent liberal	20%	California Secretary of State - 2013 Registration by County
Demographic	Percent county homeowners	10%	2010 Census Demographic Profile joined to TIGER Shapefiles (Accessed via US Census website)
Demographic	Percent target age range (18-55)	15%	2010 Census Demographic Profile joined to TIGER Shapefiles (Accessed via US Census website)

First, we extracted the canals and aqueducts from the hydrology dataset, created a new layer, and overlaid a set of point data representing all the water pumping stations in California. We then clipped the solar intensity dataset to the extent of the canals and divided each value by the maximum value to get a suitability index. We then used the "Near" tool in ArcGIS to calculate distance from the canals to the nearest pumping plant and got another index. Finally, we combined the two variables according to their weights to determine overall suitability. The overall rankings were sorted 1-5, with 1 being the lowest and 5 being the highest.

The demographic map was created by downloading each set of data on a county scale. All the files were then joined to a shapefile of counties in California to produce a single layer where each county had a value for each variable. Dividing each county's score by the maximum score for that category standardized the scores for each category. Then, each category was multiplied by the weight assigned in the table above. Finally, the weighted values for each county were added together to create a suitability index. The scores were grouped into five classes, with one being the lowest and five being the highest. To determine the ideal location, the demographic map was superimposed on the physical map to look for areas of optimal overlap. Ultimately, this analysis offered us two benefits. It allowed us to examine the feasibility of the project as a whole, on a statewide level, and also allowed us to determine which counties have high enough potential to merit future research.

3.2 Choosing Solar Panel Technology

The optimal solar panel technology for our proposed project was selected based on three factors: efficiency, cost-effectiveness and availability. Solar panel efficiency is defined as the amount of sunlight that the module can convert to electricity. The technology should be highly efficient over the entire panel lifespan, while maintaining a reasonable cost that appeals to potential project investors. Finally, it should be widely available and sufficiently proven through use in similar large-scale installations.

Table 3.2 Solar panel technology type and percent efficiency. Data gathered from various literatures.

Technology	Efficiency
Monocrystalline Silicon	24.7%
Polycrystalline Silicon	19.8%
CIGS	19.2%
Dye Sensitized	7-11%
Polymer/Heterojunction	1-3.3%

3.3 Evaporative Loss

To calculate water saved from reduced evaporative loss we used the following equation:

$$E = 2.262x10^{-8}(1 + .25u_2)[\exp\left(\frac{17.27\,\theta_w}{237.3+\theta_w}\right) - R_h \exp\left(\frac{17.27\theta_a}{237.3+a}\right)$$

where E is the evaporative discharge per unit free surface area in m/s, u_2 is the wind velocity 2 m above the water surface in m/s, θ_w is the water surface temperature in °C, θ_a is the air temperature in °C, and R_h is the relative humidity expressed as a fraction (Swamee et al., 2002).

We calculated the difference in the amount of evaporation before and after shading to determine how much water is saved in gallons per year per unit area. To calculate the surface area of the panels needed for a 1-MW project, we used the following equation:

$$A = \frac{day x m^2}{X\ kWh} x \frac{1kWh}{1000W} x \frac{24\ hr}{1day} x \frac{1000000W}{1MW} x \frac{1}{.19}$$

The last term represents the efficiency of the solar panels.

Table 3.3 Assumptions used in evaporative loss calculations. Data taken from usa.com and wholesalesolar.com

Location	Air Temperature (°C)	Wind Speed (m/s)	Humidity (%)	Solar insolation (kWh/day)
Lancaster	15.4	6.95	79.76	6.56
California	16.2	6.05	80.36	5

Estimates for canal width were taken from Google Earth. In Lancaster, the canal width is approximately 24 meters. For canals in the Central Valley, the average canal width is approximately 40 meters. We assumed that the water temperature is equal to the air temperature for un-shaded canals (Stefan and Preud'homme, 1993). Shading reduces direct solar radiation to the water, thereby decreasing its temperature (Johnson, 2004). For shaded canals, we calculated evaporative loss savings assuming three scenarios: water temperature decreases by .5°C, 1°C and 1.5°C. Shading does not significantly affect average air temperatures, so we can assume that air temperature remains constant.

3.4 Life Cycle Analysis (LCA)

We conducted an LCA to quantify the potential environmental impacts of this project. This enabled us to develop a more complete understanding of the potential effects. We used the online tool "PVWatts Calculator," provided by the National Renewable Energy Laboratory (NREL, 2014b), which calculates how much energy would actually be produced by a solar project at a given location. This tool produces an attributional LCA (ALCA), which provides information about the impacts of the processes involved with production, consumption and disposal of a product, but does not account for indirect effects associated with changes in output. An ALCA provides information on the average unit of product and consequently, does not consider time-of-day fluctuations in pricing. We did not have enough resources to factor these fluctuations into our calculation; however, our parameters provided sufficiently reasonable estimations of impact. Additionally, we did not run end-of-life analyses due to similar limitations.

We also estimated how much water would be saved from being withdrawn from thermoelectric plants. Approximately 0.05 gallons of water are consumed per kWh of electricity produced for thermoelectric power plants and of all the water withdrawn for cooling about 2.5% is consumed (Torcellini et al., 2004). To calculate how much water can be diverted away from thermoelectric power plants we divided 0.05 gallons by 0.025. This gave us the estimate of a thermoelectric power plant needing 2 gallons of water to produce 1 kWh of electricity. We used this water-use rate of 2 gal/kWh to calculate how much water will be diverted away from thermoelectric power plants from our solar panels.

The carbon dioxide (CO_2) emission rate in California is 610.82 pounds of CO_2 per MW produced (U. S. EPA, 2010). We calculated our CO_2 abatement by multiplying the emission rate by our energy produced. For a scaled up scenario, we used a value of 5 kWh/day for solar insolation (Solar, 2014).

Cadmium emissions are a negative externality from manufacturing solar panels that must be calculated as well. Cadmium is emitted during the manufacturing at a rate of 0.19g/GWh (Fthenakis et al., 2008).

While water savings, carbon abatement, and cadmium emissions are typical of any solar installation, other externalities are either too abstract to quantify at this time or are site-specific. In particular, many toxics aside from cadmium vary significantly with location and consequently, calculation of their impacts using LCA would risk inaccuracy.

3.5 Job Creation Analysis

To determine the job creation potential of our project we used the Jobs and Economic Development Impacts Photovoltaic model (JEDI PV) from the National Renewable Energy Laboratory (NREL, 2014a). We ran the model for a 500-kW, 1-MW, and 10-MW utility system. 'Utility scale' and 'crystalline silicon' were selected as inputs for each scenario (**Table 3.5**).

Table 3.5 Assumptions used in NREL JEDI PV tool.

Model Variable	**Inputs Inserted in Model for Each Scenario**		
Project Location	California	California	California
Year of construction	2016	2016	2016
System application	Utility	Utility	Utility
Solar cell	Crystalline Silicon	Crystalline Silicon	Crystalline Silicon
System Tracking	Fixed Mount	Fixed Mount	Fixed Mount
System Size (kW)	500	1000	10000
Number of systems	1	1	1
Money value (Dollar Year)	2014	2014	2014

3.6 Analysis of the Investment's Costs and Benefits

3.6.1 Levelized Cost of Energy

We also calculated the levelized cost of energy (LCOE), which is the average cost at which energy generated must be sold over the lifetime of the system in order for the project to break even, (Yaqub et al., 2012). The LCOE was calculated using the following equation:

$$LCOE = \frac{\sum_{t=0}^{T} (I + OM + S)/(1+r)^t}{\sum_{t=0}^{T} E(1-d)^t/(1+r)^t}$$

The variables in this equation are defined in **Table 3.6**. Multiple LCOE calculations were done using varying assumptions of installed cost and discount rate to display the range of possible outcomes based on uncertain real-world conditions.

3.6.2 Net Present Value

The net present value (NPV) of an investment is the sum of yearly differences between its associated benefits and costs, each discounted to their present value. This metric is essential in evaluating the economic feasibility of an investment, especially if a project is to be privately funded. Theoretically, any investment with a positive NPV is economically beneficial to the investor. In actuality there are a variety of other factors that must be considered as well. The NPV was calculated using the following equation:

$$NPV = \sum_{t=0}^{T} \frac{P(1+i)^t * E(1-d)^t - (I + OM + S)}{(1+r)^t}$$

The variables in this equation are defined in **Table 3.6**. Similarly to LCOE calculations, multiple NPV calculations were done for each system size using varying assumptions of installed cost and discount rate.

Table 3.6 Variables used in Levelized Cost of Energy and Net Present Value equations.

Variable	Definition
I	Total installed cost of the system
OM	Annual operation and maintenance cost
r	Discount rate
E	Energy produced in year $t = 0$
d	Annual solar panel energy degradation rate
T	Total lifetime of the system in years
S	Annual insurance cost
P	Price of electricity in year $t = 0$
i	Annual rate of energy price inflation

3.6.3 Assumptions

The first step in generating the range of initial costs used in the calculation of LCOE and NPV was establishing the cost of traditional land-based systems of the same sizes. For a 500-kW system, we received a quote of $3.25 - $3.50 per watt from solar panel installers LA Solar Group and SolarCity (Sales-Representative, 2014; SolarCity:Sales-Representative, 2014). For a 1-MW system, we received a quote of $2.70 – $3.00 per watt from SunEdison (SunEdison:Sales-Representative, 2014) For a 10-MW system we received a quote of $2.00 per watt from Sun Edison (SunEdison:Sales-Representative, 2014). The highest per watt price was used in all cases to calculate a cost of $1,750,000 for a 500-kW land-based system, $3,000,000 for a similar 1-MW system, and $20,000,000 for a similar 10-MW system. We multiplied these numbers by a factor of 1.2 for our low-end cost estimate, 1.5 for our mid-level cost estimate, and 1.7 for our high-end cost estimate. The factors of 1.2 and 1.7 are based on an interview with Gujarat state energy secretary, D.J. Pandian. In this interview, he said that the solar-canal project he oversaw ended up costing 70% more than a land-based system, but that the original budget for the project was 20% more than a land-based system (Mahurkar, 2012). As an intermediate factor, our team chose 1.5 as a value between the other two factors. Due to the varying prices of different solar panel technologies, the spreadsheets created will only be representative of systems using polycrystalline panels like those we received quotes for. Panel types of a higher cost per installed watt would negatively affect our economic calculations, while those of a lower cost per installed watt would positively affect them.

To offset some of the high initial cost of installing renewable energy systems the federal government has put into place a program that allows businesses or individuals to receive tax credit equal to 30% of the total system cost (DSIRE, 2014). This would effectively reduce the initial cost by 30%, since that percentage of the money will offset an equal value of federal tax owed. We evaluated the LCOE and NPV, taking into account the effective 30% discount of initial cost.

The two ongoing sources of costs for this project that were factored into our analysis are O&M and insurance. The annual O&M costs were assumed to be $30 per kW of capacity based on the range of $20 - $40 per kW reported by existing utility-scale solar projects (Bolinger & Weaver, 2013). The annual insurance cost was assumed to be $3000 for a 1-MW system based on a quote we received from Solar Insure of $3000 to $4000 (refer to **Section 4.4**). For all system sizes other than 1 MW, annual insurance cost was estimated using linear interpolation based on the ratio of assumed land-based system quotes that we received.

The values for discount rates were obtained from the White House Office of Management and Budget website (OMB, 2013). The 25-year discount rates were linearly interpolated using the average of the 20-year and 30-year discount rates as per the websites instructions (OMB, 2013). The 25-year real discount rate of 1.75% — which has been adjusted for inflation — is our low-end figure. The 25-year nominal discount rate of 3.75% — which has not been adjusted for inflation — is our high-end figure. We chose the discount rate of 2.75% as an intermediate value.

The energy prices used were the February 2014 California average prices for each sector, obtained from the U.S. Energy Information Administration website (EIA, 2014). The yearly inflation rate of energy prices was calculated using the average percentage change in the California average energy price for each respective sector from the years 1982 through 2010. This data was obtained from the California Energy Almanac website, which is run by the California Energy Commission (CEC, 2014).

Amount of energy produced in the first year was calculated using the “PVWatts Calculator” (NREL, 2014b) (refer to **Section 3.4)**. The first-year energy production for a 1-MW system was calculated to be 1,677,634 kWh. This number was multiplied by 0.5 to obtain the first-year energy production of a 500-kW system, and by 10 to find the first-year energy production of a 10-MW system.

Because solar panels experience a decrease in efficiency over time, it is necessary to consider the degradation rate of solar panels (Jordan & Kurtz, 2013). A solar panel degradation rate of 0.5% was chosen as it was established as the median value in a recent study by the NREL (Jordan & Kurtz, 2013).

In these calculations, all costs and benefits were assumed to be incurred at the beginning of each year. Since the typical warranty on a solar PV system is 25 years, we used this as our assumption for system lifetime (Singh & Singh, 2010). This means that our calculations run from year 0 to year 24, a total of 25 years.

4| Results

4.1 Economic Calculation Results

From the total 162 scenarios we evaluated, 82% had a lifetime positive NPV. Due to the effect of economies of scale, the percentage of profitable scenarios increased with system size. While only 67% of 500-kW systems evaluated using our range of variables were profitable, that percentage rose to 80% when the system size was increased to 1 MW. Every scenario evaluated for a 10-MW system came out with a positive NPV.

Table 4.1-a shows all calculated NPVs for all considered system sizes, installed costs, tax incentives, energy prices, and discount rates. The most profitable solar canal systems would be those that are larger in scale with the power sold at residential rates, although other configurations may be profitable as well.

Table 4.1-a Calculated NPVs for all considered system sizes, installed costs, tax incentives, energy prices, and discount rates. Green indicates net profit; red indicates net loss.

			Industrial ($0.1073 / kWh)			Commercial ($0.1357 / kWh)			Residential ($0.1618 / kWh)		
			r = 1.75%	r = 2.75%	r = 3.75%	r = 1.75%	r = 2.75%	r = 3.75%	r = 1.75%	r = 2.75%	r = 3.75%
500 kW	Without 30% Federal Tax Credit	I_0 = $2,100,000	$73,625	-$175,346	-$385,436	$739,647	$415,646	$142,165	$1,217,206	$844,216	$529,017
		I_0 = $2,625,000	-$451,375	-$700,346	-$910,436	$214,647	-$109,354	-$382,835	$692,206	$319,216	$4,017
		I_0 = $2,975,000	-$801,375	-$1,050,346	-$1,260,436	-$135,353	-$459,354	-$732,835	$342,206	-$30,784	-$345,983
	With 30% Federal Tax Credit	I_0 = $1,470,000	$703,625	$454,654	$244,564	$1,369,647	$1,045,646	$772,165	$1,847,206	$1,474,216	$1,159,017
		I_0 = $1,837,500	$336,125	$87,154	-$122,936	$1,002,147	$678,146	$404,665	$1,479,706	$1,106,716	$791,517
		I_0 = $2,082,500	$91,125	-$157,846	-$367,936	$757,147	$433,146	$159,665	$1,234,706	$861,716	$546,517
1 MW	Without 30% Federal Tax Credit	I_0 = $3,600,000	$757,481	$258,509	-$162,550	$2,089,524	$1,440,493	$892,652	$3,044,642	$2,297,632	$1,666,357
		I_0 = $4,500,000	-$142,519	-$641,491	-$1,062,550	$1,189,524	$540,493	-$7,348	$2,144,642	$1,397,632	$766,357
		I_0 = $5,100,000	-$742,519	-$1,241,491	-$1,662,550	$589,524	-$59,507	-$607,348	$1,544,642	$797,632	$166,357
	With 30% Federal Tax Credit	I_0 = $2,520,000	$1,837,481	$1,338,509	$917,450	$3,169,524	$2,520,493	$1,972,652	$4,124,642	$3,377,632	$2,746,357
		I_0 = $3,150,000	$1,207,481	$708,509	$287,450	$2,539,524	$1,890,493	$1,342,652	$3,494,642	$2,747,632	$2,116,357
		I_0 = $3,570,000	$787,481	$288,509	-$132,550	$2,119,524	$1,470,493	$922,652	$3,074,642	$2,327,632	$1,696,357
10 MW	Without 30% Federal Tax Credit	I_0 = $24,000,000	$19,779,418	$14,769,098	$10,540,951	$33,099,849	$26,588,939	$21,092,966	$42,651,024	$35,160,328	$28,830,022
		I_0 = $30,000,000	$13,779,418	$8,769,098	$4,540,951	$27,099,849	$20,588,939	$15,092,966	$36,651,024	$29,160,328	$22,830,022
		I_0 = $34,000,000	$9,779,418	$4,769,098	$540,951	$23,099,849	$16,588,939	$11,092,966	$32,651,024	$25,160,328	$18,830,022
	With 30% Federal Tax Credit	I_0 = $16,800,000	$26,979,418	$21,969,098	$17,740,951	$40,299,849	$33,788,939	$28,292,966	$49,851,024	$42,360,328	$36,030,022
		I_0 = $21,000,000	$22,779,418	$17,769,098	$13,540,951	$36,099,849	$29,588,939	$24,092,966	$45,651,024	$38,160,328	$31,830,022
		I_0 = $23,800,000	$19,979,418	$14,969,098	$10,740,951	$33,299,849	$26,788,939	$21,292,966	$42,851,024	$35,360,328	$29,030,022

Table 4.1-b shows highest and lowest calculated NPVs for each system size and subset as a percentage of installed cost. While there is some level of financial risk associated in the implementation of a project such as this, there is also significant potential for reward. It should be noted that some risk would be mitigated, however, as a specific installation price quote would need to be obtained before beginning construction on the project. A more definite cost would provide a starting point to establish the conditions under which a project would be profitable.

Table 4.1-b Highest and lowest calculated NPVs for each system size and subset as percentage of installed cost. Green indicates net profit; red indicates net loss.

		Industrial ($0.1073 / kWh)		Commercial ($0.1357 / kWh)		Residential ($0.1618 / kWh)	
		Highest Calculated Profit (% of initial cost)	Lowest Calculated Profit (% of initial cost)	Highest Calculated Profit (% of initial cost)	Lowest Calculated Profit (% of initial cost)	Highest Calculated Profit (% of initial cost)	Lowest Calculated Profit (% of initial cost)
500 kW	Without 30% Federal Tax Credit	3.51%	-42.37%	35.22%	-24.63%	57.96%	-11.63%
	With 30% Federal Tax Credit	47.87%	-17.67%	93.17%	7.67%	125.66%	26.24%
1 MW	Without 30% Federal Tax Credit	21.04%	-32.60%	58.04%	-11.91%	84.57%	3.26%
	With 30% Federal Tax Credit	72.92%	-3.71%	125.77%	25.84%	163.68%	47.52%
10 MW	Without 30% Federal Tax Credit	82.41%	1.59%	137.92%	32.63%	177.71%	55.38%
	With 30% Federal Tax Credit	160.59%	45.13%	239.88%	89.47%	296.73%	121.97%

Table 4.1-c shows all calculated LCOEs for all considered system sizes, installed costs, tax incentives, and discount rates. Many scenarios yield competitive energy costs given the current California energy prices and historical price inflation trends. Similar to the NPV, we can see that the LCOE benefits greatly from the economy of scale effect. Although we are unsure of the current pricing structures between the State Water Project and their energy providers, it is possible that they could cut costs by purchasing electricity generated by solar canal systems to help power their pumps.

Table 4.1-c Calculated LCOEs for all considered system sizes, installed costs, tax incentives, and discount rates.

			r = 1.75%	r = 2.75%	r = 3.75%
500 kW	Without 30% Federal Tax Credit	I_0 = $2,100,000	$0.1504	$0.1644	$0.1791
		I_0 = $2,625,000	$0.1827	$0.2003	$0.2187
		I_0 = $2,975,000	$0.2042	$0.2242	$0.2450
	With 30% Federal Tax Credit	I_0 = $1,470,000	$0.1116	$0.1214	$0.1317
		I_0 = $1,837,500	$0.1342	$0.1465	$0.1594
		I_0 = $2,082,500	$0.1493	$0.1632	$0.1778
1 MW	Without 30% Federal Tax Credit	I_0 = $3,600,000	$0.1316	$0.1436	$0.1562
		I_0 = $4,500,000	$0.1593	$0.1744	$0.1901
		I_0 = $5,100,000	$0.1778	$0.1948	$0.2127
	With 30% Federal Tax Credit	I_0 = $2,520,000	$0.0983	$0.1068	$0.1156
		I_0 = $3,150,000	$0.1177	$0.1283	$0.1393
		I_0 = $3,570,000	$0.1307	$0.1426	$0.1551
10 MW	Without 30% Federal Tax Credit	I_0 = $24,000,000	$0.0940	$0.1020	$0.1104
		I_0 = $30,000,000	$0.1125	$0.1225	$0.1330
		I_0 = $34,000,000	$0.1248	$0.1362	$0.1481
	With 30% Federal Tax Credit	I_0 = $16,800,000	$0.0719	$0.0775	$0.0833
		I_0 = $21,000,000	$0.0848	$0.0918	$0.0991
		I_0 = $23,800,000	$0.0934	$0.1014	$0.1097

4.2 Ideal Site Locations

After calculating the physical variables for the canals and the demographic variables for the counties through which they pass, the two types of scores were combined into a final map (**Figure 4.2**). The five counties with the highest scores, in order of highest to lowest, were: Los Angeles, Contra Costa, Yolo, Riverside and Fresno (**Figure A-8**).

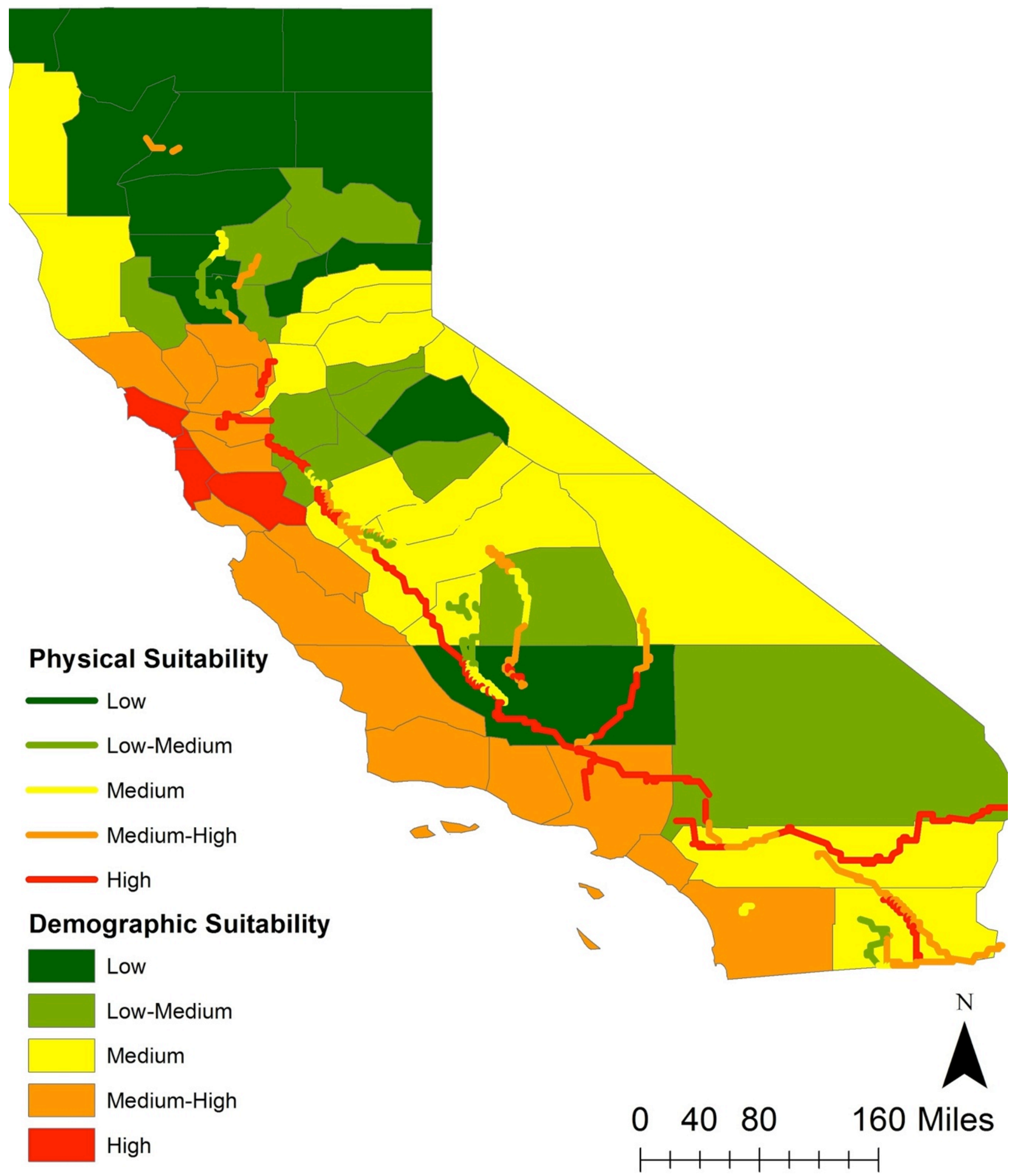

Figure 4.2 Combined Suitability Layers. Overlaying the results of the physical analysis on the county demographic scores allowed us to assign each county an overall suitability score.

4.3 Ideal Technology and Mounting

4.3.1 Solar Panel Technology

Although monocrystalline silicon technology is the most efficient, polycrystalline technology is also highly efficient and has the added benefit of being cost-effective (Shah et al., 2004). Monocrystalline is very expensive, and its cost is further increased by the technology needed to tilt the panels to track sunlight throughout the day (Quaschning, 2004). Polycrystalline does not incur this extra cost, as the complex cell structure eliminates the need for sun tracking (Quaschning, 2004). The panels can instead be configured in any way.

Polycrystalline panels are widely used in various existing projects across California, and have already been implemented over multiple reservoir projects (Aguillon, 2014). Compared to monocrystalline technology, polycrystalline panels are a superior choice for this project, given their cost-to-efficiency ratio, and their already widespread use (Aguillon, 2014; Shah et al., 1999). Other technologies such as CIGS and dye-sensitized cells have the potential for improvement, but are years away from becoming serious competitors in the solar technology market (Grätzel, 2005; Liska et al., 2006; Wada et al., 2001).

4.3.2 Installer Technology

Domestic solar panel manufacturers and installers are the most ideal for this project, and local, California-based companies are preferred. Close proximity would diminish both transportation costs (associated with panel installation and maintenance) and harmful greenhouse gas emissions. Furthermore, reputable solar panel installers with many years of experience in the industry will minimize project risk.

Table 4.3 Solar panel installers/manufacturers and their years of establishment. Data gathered from information provided by each installer/manufacturer.

Installer/Manufacturer	Year Established
Kyocera	1959
First Solar	1999
Evergreen Solar	1994
Sun Edison	2003

4.3.3 Mounting

The solar panel mounting system can be designed specifically for this system. For example, the design can feature the panels sitting over rails, as recommended by our client The ADEPT Group Inc. The mounting would be able to slide out from over the canal onto land to allow for proper maintenance. The exact technology and cost for the system is difficult to determine, as such a system has not yet been designed and manufactured. We expect the cost to mirror a traditional PV mounting system but with altered engineering, as identical materials can be used.

4.4 Risks, Uncertainties and Insurance

Like any other solar photovoltaic installation, solar canals are subject to risks. These include physical damage from earthquakes, fires, other extreme weather events, and criminal activity. Other risks affect the economic feasibility of solar canals and include technology failure, overestimation of output, variable insurance costs, and any other causes of business interruptions. With the exception of variable insurance costs and overestimation of output, these risks can be accounted for with proper commercial insurance.

A representative of SolarInsure, a commercial insurance brokerage firm, estimated that the cost of insuring a 1-MW solar photovoltaic installation would range from $3,000 - $4,000 per year (SolarInsure:Sales-Representative, 2014). This covers the following, as quoted by SolarInsure: a) All Risk Property Coverage: All risk coverage for protecting the equipment against loss from theft, fire, wind and earthquake; b) General Liability: General liability starting at $1 million per occurrence / $2 million aggregate with limits available up to $50 million; c) Equipment Breakdown: Pays for the loss that results when solar equipment is damaged by mechanical breakdown, power surges, electrical short circuits, overloads and electrical arcing; 4) Business Interruption: Insures against loss or damage to the income or profit of a business due to an interruption in the down time of the solar array.

Coverage of a 1-MW installation over water canals, however, would likely be more expensive as additional risks are involved. To account for the variable cost of insurance, potential overestimation of output, and the possible added expense of a non-standard solar canal installation, we increased our project costs by up to 50% for conservative estimates.

4.5 LCA Analysis

4.5.1 Positive Externalities

For our LCA analysis and evaporative loss calculations, we used Lancaster for our project site because it is located in LA County, our highest ranked county, and it contains part of the State Water Project. We believe that the State Water Project is an ideal site because if a pilot project is successful, there is a large opportunity for it to expand. We input the following parameters into the PV watts tool: 1,000 kW, an open fixed rack, a tilt of 34.7 degrees, an azimuth of 180 degrees, a commercial system type and a cost of $4.50/watt. We used California averages in calculations for potential scaled up scenarios (**Table 4.5-a**). It is difficult to determine exactly how much the water may cool from the shading effect of the panels, so we did a sensitivity analysis to see how much water could be saved from evaporation if the water cooled by .5°C, 1°C, or 1.5 °C (**Table 4.5-b**).

Table 4.5-a Assumptions used in evaporative loss calculations. Data taken from usa.com and wholesalesolar.com

Location	Air Temperature (°C)	Wind Speed (m/s)	Humidity (%)	Solar insolation (kWh/day)
Lancaster	15.4	6.95	79.76	6.56
California	16.2	6.05	80.36	5

Table 4.5-b Potential water savings from a 1-MW project in Lancaster, CA.

Temperature Decrease (° C)	Water Saved from Evaporative Loss (gal/yr)
.5	900369
1	1775658
1.5	2623463

Using the online PV Watts tool, we were able to calculate how much fossil fuel energy and how much CO_2 would be abated by installing a 1-MW solar PV system in Lancaster over the State Water Project (NREL 2014). A 1-MW system can produce up to 1,677,634 kWh/year, which translates to 465 metric tons of CO_2 abated per year (**Table 4.5-c**). Over the 25-year lifetime of this project, it would abate 11,625 metric tons of CO_2.

Table 4.5-c Environmental Benefits from a variety of project sizes in Lancaster, CA.

Size of system	Energy Saved per Year (kWh/yr)	CO2 Abated (metric tons/yr)	Water Saved from Evaporative Loss Assuming 1° C decrease (gal/yr)	Water Not Withdrawn (gal/yr)	Total Water Savings (gal/yr)
500 kW	838817	232	887829	1677634	2565463
1 MW	1677634	465	1775658	3355268	5130926
10 MW	16776337	4648	17756580	33552674	51309254

There are water savings from two different aspects of this project: preventing evaporative loss and offsetting water withdrawals for thermoelectric power plants. We can expect a 1-MW project to save up to 1,775,658 gallons of water per year of water from preventing evaporative loss, as well as prevent 3,355,268 gallons of water from being withdrawn into thermoelectric power plants. In total 5,130,926 gallons of water can be saved per year (**Table 4.5-c**).

There are economic benefits to this project in addition to environmental benefits. Using the NREL JEDI PV tool we can expect a 1-MW project to create 46.8 direct jobs over the lifetime of the panels (**Table 4.5-d**). Most of the jobs are created during the installation of the project, which would limit their longevity. There are also some long-term jobs that would be created for continuous operation and maintenance work.

Table 4.5-d Job creation for a 500-kW, 1-MW and 10-MW project.

Variable	NREL JEDI PV Model Outputs According to System Size		
System Size	500 kW	1 MW	10 MW
Jobs Created during Installation	19.9	37.4	373.8
Jobs Created during O&M (annual)	.1	.3	3.0
Total Jobs from O&M	2.5	7.5	75.0
Total Jobs from Project	22.4	46.8	448.8

There are approximately 400 miles of open canals throughout California. This leaves huge potential for expansion. For example, we can cover up to 300 miles of the State Water Project in solar panels. Using an average solar insolation of 5 kWh/m^2/day and an average canal width of 40 meters up to 764 MW of solar panels could be installed. This is slightly over 2.5 MW per mile of canal. The panels would produce up to 1,281,712 MWh/year. Solar panels over the State Water Project in the Central Valley would prevent 2,236,704 gallons of water from evaporating per MW installed. In total, up to 1,708,841,856 gallons of water would be saved per year just from preventing evaporative loss and 355,107 metric tons of CO_2 would be abated per year.

4.5.2 Negative Externalities

There are a few negative externalities for this solar project, including greenhouse gas emissions associated with manufacturing the solar panels. Producing 47.5 g CO_2/kWh for a 25-year lifetime, a 1-MW project in Lancaster would indirectly emit about 80 metric tons of CO_2-equivalent greenhouse gases. Cadmium is similarly emitted during the manufacturing at a rate of 0.19g/GWh (Fthenakis et al., 2008). A 1-MW project would emit 0.32 g of cadmium.

Table 4.5-e Negative Externalities for various sized solar projects.

Size of system	Manufacturing GHG emissions (metric tons CO_2/lifetime)	Cadmium emissions (g/GWh)
500 kW	39.8	0.159
1 MW	79.7	0.319
10 MW	796.9	3.188

5| Implementation Plan

The previous sections demonstrate that a solar canal project in California can be profitable in theory, but the project must be implemented to be truly successful. This section will cover the financial options, permitting process, and implementation strategies for a pilot and large projects.

5.1 Financing

5.1.1 Third-Party Financing

There are several independent financing programs in California for commercial entities and municipalities (Kollins et al., 2010; SEIA, 2014b). Depending on the jurisdiction of the land where the panels are located, these programs may be applied. Many offer flexible terms and can serve as valuable options if an initial investor is not found or does not finance the total costs. Exact estimates on rates must be consulted on an individual basis once a location has been determined.

5.1.2 California Solar Initiative (CSI)

The CSI is a solar rebate program for individual projects. The program received a total budget of $2.167 billon to be used between 2007 and 2016 for the installment of approximately 1,940 MW of new solar projects (CEC&CPUC, 2013a). Within the program there are different campaigns available including the following: solar hot water rebate program (CSI-Thermal), Single-family Affordable Solar Homes (SASH) program, Multifamily Affordable Solar Housing (MASH) program, and a grant program for "research, development, demonstration and deployment of solar technologies (RD&D)" (CEC&CPUC, 2013b). The latter is the best option for a solar canal project.

The RD&D campaign was created with a budget of $50 million but only runs through 2016 (CEC&CPUC, 2013c). The primary goal for this section of the program was to stimulate "a sustainable and self-supporting industry for customer-sited solar in California…that [can] reduce technology costs, increase system performance, focus on issues that directly benefit [the state], and fill knowledge gaps to enable wide-scale deployment of distributed solar" (CEC&CPUC, 2013c). Projects that have received grants thus far have all brought in matching funds from outside sources (CEC&CPUC, 2014); this is important to keep in mind when applying for any grant resource. The program places emphasis on granting funds to projects that serve as demonstrations of new and innovative technology (CEC&CPUC, 2014). This is particularly good news for a project such as ours, but the grant timeline should be kept in strong consideration. If these funds are extended past 2016, there is a higher likelihood of being able to access them for solar canals.

5.1.3 "Crowd-funding Campaigns"

"Crowd-funding campaigns" are becoming increasingly popular as secure investments for investors and as easy financing options for solar project owners and designers. Companies connect investors to solar projects in need of financing (Gilpin, 2014). As a project produces energy, it generates revenue by selling power to solar customers and pays investors back with interest (Gilpin, 2014). Companies that organize crowd-funding can charge an annual platform fee but these fees vary according to each company's model (Gilpin, 2014). There are other platforms now emerging that connect investors to individual projects (Gilpin, 2014). These platforms continue to flourish as new and transparent opportunities for investors. Most of these companies work through online-based systems that allow investors to provide as little as $25 to a project (Gilpin, 2014). For a project such as ours that targets a public domain, crowd-funding can provide an immediate source of capital because the project ultimately benefits the greater California population.

5.1.4 Individual Company Investments

Seeking funds through individual companies or entities can serve as a great source for initial capital. Companies like Google have already invested over $1 billion in wind and solar projects (Google, 2014). Accessing individual funds such as these is common due to the growth in the popularity of clean energy. Many companies see these investments as another way to appeal to their consumers (Larson, 2013). As consumers become more aware of issues such as climate change, these same consumer-driven companies address the increase in public awareness by partaking in "feel-good" investments. In California, investor-owned utilities will need to make power-purchase agreements for individual renewable energy projects regardless, as Assembly Bill 32 requires them to incorporate at least 33% renewable energy by the year 2020 (CARB). This affects these utilities but increasing renewable energy portfolios are very common for non-utility companies as well.

5.1.5 Community Solar

Community solar is a "solar-electric system that, through a voluntary program, provides power and/or financial benefit to, or is owned by, multiple community members" (Jason Coughlin et al., 2010). Community solar projects also have the potential to see improved economies of scale, increased public understanding of solar energy, and increased opportunities to test new models of marketing, project financing, and service delivery (Jason Coughlin et al., 2010). Community solar also retains its ability to sell and gain revenue from renewable energy credits, sold at the discretion of the system owners (Jason Coughlin et al., 2010).

There are a few primary models that community solar could follow, as summarized in “A Guide to Community Solar: Utility, Private, and Non-profit Project Development” (Jason Coughlin et al., 2010):

- Utility-Sponsored Model: a utility owns or operates a project that is open to voluntary ratepayer participation
- Special Purpose Entity (SPE) Model: individual investors join in a business enterprise to develop a community solar project
- Non-Profit "Buy a Brick" Model: donors contribute to a community installation owned by a charitable non-profit corporation

The guide put together by the NREL provides a chart that outlines basic roles and expectations of participating parties (**Appendix B**).

5.2 Permitting

Any developments require the appropriate permits to proceed. For solar installations, the permitting process is complex and time-consuming. As there have been no solar canals installed in the U.S., there is no specific permitting process for solar canals. We will use the permitting process of utility-scale solar projects on land to understand the likely permitting process for solar canals.

5.2.1 Agencies

Utility-scale solar installations require approvals and permits from a collection of federal, state, and local agencies. In California, the California Energy Commission (CEC), California Department of Fish and Wildlife, U.S. Department of Fish and Wildlife, and the Bureau of Land Management (BLM) are responsible for utility-scale solar permits. These four agencies are often referred to as the Renewable Action Team (REAT) (Devine, 2010). The California Public Utilities Commission (CPUC) within the CEC is responsible for regulating the activities of the investor-owned utilities in California. To connect the project to the electric grid, the local electric utility company (e.g. PG&E, SCE, SDG&E) must be involved. The local land-use authority, such as the city or county building department, will also be involved in the permitting process. The project may also require approval from other local community groups, such as a homeowner's association or architectural committee.

5.2.2 Permits and Documents

There are a number of permits and agreements required for solar projects on California land. Depending on the characteristics of the project, certain permits may or may not be needed. The most likely permits necessary for a solar canal are discussed here.

On federal land, the BLM must approve a Right-of-Way (ROW) permit. The BLM has this permitting authority under Title V of the Federal and Land Policy Management Act of 1976 (SEIA, 2012). Endangered Species Act (ESA) permitting will also need to be performed by the U.S. Department of Fish and Wildlife if there are endangered species in the site area. This process involves completing a Habitat Conservation Plan (HCP) to obtain an Incidental Take Permit for listed endangered species in the project site area. CEC must approve solar thermal projects larger than 50 MW, however, other solar energy projects do not have to be approved by the CEC. If the project is owned by a utility, or if a utility must construct transmission lines for the project, then the CPUC will be involved in the process. The utility would have to apply for a Permit to Construct, and a Certificate of Public Convenience and Necessity (Tim Snellings & Barrett, 2012). If the project is connecting to the electric grid, then an interconnection agreement will need to be completed by the local electric utility. To ensure that there are no significant environmental impacts, a CEQA (California Environmental Quality Act) assessment may need to be performed by the city or county. The local land-use authority will need to approve a building permit, an electrical permit, or both. After the solar installation is completed, a building or electrical inspector from the local permitting agency, along with the utility, may need to inspect and sign-off on the system (CEC, 2001).

5.2.3 Estimated Time and Fast-Tracking Potential

Utility-scale solar permitting is a very slow process. There are efforts by REAT to streamline this process, but three to five years is the current estimated time to complete the permitting process for utility-scale solar projects on land in California (SEIA, 2014a).

Since there are no solar canals in California, there is potential for solar canal permitting to take even longer than the estimated three to five years. This longer permitting time would be due to securing the necessary approvals for a novel PV-system design and construction. Also, more approvals may be required from agencies that use or have jurisdiction over the canal. There are some mechanisms to fast-track the permitting process, though.

ROW permits are required for development on federal land, and can take three to five years to complete (SEIA, 2012). But if the solar canal is not developed on federal land, an ROW permit will not be needed. For example, a solar canal on a privately owned canal would not require a ROW permit. The BLM does allow ROW permits to be fast-tracked for projects that will likely pass the environmental impact assessment. Secretary of the Interior Ken Salazar announced this “Fast-Track” initiative for solar projects in 2009. Fast-tracked projects receive priority processing, but must still complete the necessary environmental reviews for the ROW permit (SEIA, 2012).

ESA permitting is only required when endangered species are present in the project site area. If there are no endangered species in the area, then ESA permitting can be bypassed. If there are endangered species in the area, then there is another fast-tracking mechanism provided by Section 7 of the ESA. This federal agency-to-agency consultation procedure can speed up the permitting process to less than one year (USFWS, 1973).

CPUC permitting is required when a public electric utility will own part, or all, of the project. This includes the construction of utility transmission lines, or if the project is owned or partially owned by the utility, as in a public-private partnership with the utility. If the project can be developed without a utility, then permits from the CPUC will not be needed. This would save a great deal of time because CPUC permitting can take three to four years to complete (TEPT, 2009).

Since a solar canal project is of a large scale, it will most likely need California Environmental Quality Act (CEQA) approval. This process can take a long time if an Environmental Impact Report needs to be completed. This process may be easier for a solar canal project since the construction will occur on an already developed canal. Additionally, the CEQA process has certain exemptions, and a solar canal could potentially fall within one of these exemption categories (OHP, 2013). If this is the case, then the CEQA process could be expedited further.

Interconnection agreements with utilities are needed when a project will connect to the electric grid. These contracts can take more than two years for utility-scale solar projects (Eddy). If the solar canal is only connected to the pumping station and will not feed electricity into the electric grid, then an interconnection agreement will not be necessary.

There are no known, formal mechanisms for fast-tracking land-use authority permits, including building and electrical permits. In addition, there are no known, formal mechanisms for fast-tracking approval from local community groups. Working with community groups during the planning and construction process will likely make approval from those groups easier. Also, support from an influential government official or community leader is also likely to fast-track approval and potentially the permitting process, as well.

With all of these different mechanisms for fast-tracking the permitting and approval process, the process could be shortened to six months to one year. This time frame is much shorter than the projected three to five years. Not connecting to the electric grid and building on private land that does not have endangered species could save a lot of time in the permitting process.

5.2.4 Cost, Risks, and Uncertainties

There will be costs associated with the solar canal permitting process. Certain permits do have their own fees, which may vary according to location. However, most of the cost will result from the time spent paying for employees to obtain these documents. An estimated three to five years spent in the permitting process is a long time to delay project construction. There is opportunity cost and risk in waiting years to obtain the correct permits.

Firstly, there is risk associated with the uncertainty in the time spent to obtain proper permits. A project may be expected to take a certain amount of time, but the permitting process may take much longer, which will cost the developers more. Secondly, there is risk in the possibility of not obtaining a necessary permit. For example, an endangered species may stop a project from being approved, or the CPUC may not deem utility construction a public necessity. Lastly, there is risk of external trends associated with the delay. Interest rates may become less favorable, or subsidies or tax credits may change. These risks are serious and should be taken into account when deciding to go ahead with a solar canal project.

It is also important to note the uncertainties in the permitting process for a solar canal. The subject of solar permitting lacks any comprehensive academic literature. Permitting information was found from agency websites and articles, which may be less accurate than researched, peer-reviewed literature. The time and costs associated with some of the permits are unknown. There is also uncertainty in applying these land permits to a project over a canal. The land permits may not apply to construction over canals, or other permits not mentioned here may be required. We acknowledge these uncertainties and have presented the most complete permitting process for a solar canal, given our limitations.

Table 5.2 Summary of the permits and approvals needed for construction of a utility-scale solar canal.

Agency	**Permit or Approval**	**Time**	**Potential for Fast-tracking**
U.S. Bureau of Land Management	Right-of-Way Permit	3-5 years	If project is not on federal land, then an ROW permit is not needed. Can be fast-tracked for projects that will likely pass the environmental impact assessment.
U.S. Department of Fish and Wildlife	Incidental Take Permit	Varies	If no endangered species are present, then ESA permitting is not needed. Can be fast-tracked to less than one year using Section 7 (agency to agency).
California Public Utilities Commission (under the California Energy Commission)	Certificate of Public Convenience and Necessity, Permit to Construct	3-4 years	For construction of transmission lines or projects owned by utilities. If a utility is not involved in the process, then CPUC and CEC permitting is not needed.
California Department of Fish and Wildlife	CEQA	Varies	CEQA has exemptions, and this project may fall under one of these exemption categories.

Electric Utility (PG&E, SCE, SDG&E)	Interconnection Agreement	≥ 2 years	If project is not connected to the grid, then an interconnection agreement is not needed.
City or County Building Department	Building permit, Electrical permit	Varies - weeks or months	No opportunities for fast-tracking known.
Local Community Groups and Local Agencies	Approval (if necessary)	Varies	Working with community officials and groups will make this approval process easier.
	Estimated Time	3-5 years	6 months to 1 year using these fast-tracking mechanisms

5.3 Pilot Project Implementation Strategies

The purpose of pilot projects is to prove a concept by demonstrating that it is successful on a small-scale. A pilot solar canal is a relatively small project compared to a utility-scale project. We have suggested a pilot project size of 500 kW. In certain conditions, a pilot project of this size is profitable. However, a pilot does not necessarily have to be financially successful since it is meant to be a proof of concept. A successful pilot project would encourage the construction of larger solar canal projects. Therefore, it is very important to be able to implement a pilot solar canal project in California.

Since a pilot project may not provide a high enough return on investment (ROI) to catch the eye of many investors, it will be critical to present this concept to parties with other interests than profit. Companies, individuals, groups, or communities that want to have the reputation of being a green first-mover would be more interested in a pilot solar canal. These parties would be willing to earn less ROI in exchange for the prestige of funding the first solar canal project in North America. For example, a city mayor may try to encourage the growth of the city's green economy and would therefore be seeking projects in his or her city that promote renewable energy. In addition, a new or growing solar manufacturing company may be interested in proving their panel design in a project that would garner media attention. A solar canal would be a great marketing tool, so this company may be willing to sell their panels for less or even give them away for free in exchange for the media attention. Lastly, some parties may be encouraged to support a solar canal pilot project based on the environmental benefits. Water-scarce areas such as the Southwestern U.S. may find the environmental benefits worth the lower ROI and higher risk.

The key to implementing a solar canal pilot project is finding an investor who is motivated by other concerns than profit alone. When these other concerns are in line with a solar canal's mission and benefits, then an investor for a pilot project can be found.

5.4 Large Project Implementation Strategies

Implementing a utility-scale solar canal in California will likely be a difficult task. Investors are likely to earn higher ROIs on other investments, so it is necessary to find parties that are interested in having green reputations, proving their solar panel design, or reaping environmental benefits. These investors are more likely to take on the extra risk and to stay on-board when the road to construction gets difficult or more costly. In addition to getting the right investor, another important strategy to implement a large solar canal is to have a successful pilot project. Completing a solar canal pilot project would prove to investors that the concept works and can work on a large scale.

6| Discussion

6.1 Revisiting Conventional wisdom

Solar panels over the Colorado River Aqueduct have been proposed previously, but the concept was rejected. The main argument against the project is the panels would get in the way of performing maintenance required to maintain maximum flows and respond to emergencies (MWD). It would also be more difficult to clean the panels when they are over the canal (MWD). Extra power lines would need to be built to transport the power to either a pump or another facility (MWD). Evaporative losses are small, so there is relatively little water to gain by shading the canal (MWD). Furthermore, the remoteness of likely locations increases the chances for theft and vandalism (MWD).

Circumstances, however, are changing. The price of solar panels is continuing to decrease, making them more economically viable than before. California is also suffering one of the worst droughts in its history, which necessitates water conservation now more than ever. A 1-MW project can save over 5 acre-feet per year from evaporating. This amount may seem trivial, but in a severe drought, every drop counts. As water distributions decrease, major aqueducts will transport less water – making absolute maximum flow even more important. An innovative support structure will quell concerns that the panels would be a hindrance to canal and panel maintenance. In addition to water pressures, the deadline for Assembly Bill 32 is coming soon and electric utilities need to meet their Renewable Portfolio Standard goals. Being "green" is similarly valued in the private industry and private firms have incentives to increase their own renewable energy portfolios.

This project will carry extra expenses to build solar canal infrastructure, but that can be seen as an investment in energy security and could even provide imported energy in the case of local blackouts. The upcoming deadline for solar tax credits in 2016 urges projects to be installed quickly while the economic incentives still exist.

6.2 Policy Recommendations

Based on our permitting research, we suggest that federal, state, and local agencies integrate and streamline their permitting process. Step-by-step guides or all-in-one packaged permits for utility-scale solar projects would make the permitting process much easier for developers. A simpler and faster permitting process may encourage more solar projects because less time and money would be spent in the pre-construction phase of the projects. A faster permitting process will also reduce some of the risks associated in delaying construction of a project, including changing interest rates or financial incentives. As shown by Assembly Bill 32 and subsequent solar incentives programs, California is committed to increasing its share of renewable energy in the state's energy budget. Reexamining the solar permitting process is an important part of this commitment.

7| Conclusion

As students and environmental researchers who are realizing the drastic effects of climate change more and more each day, it is our responsibility to analyze the feasibility of sustainable innovations and push for the implementation of smart options. In short, solar canals present great potential for a more sustainable future of California. Our research indicates that implementation of systems of varying scales would have significant environmental and economic benefits. Though new innovations are accompanied by inevitable risks, taking precautions such as accounting for these risks in cost projections and purchasing proper insurance can greatly minimize these. Solar canals would increase California's renewable energy portfolio and could provide the impetus for adoption of similar technologies across other city and statewide municipalities — especially in the midst of the Obama Administration's recent proposal to slash carbon emissions from power plants by 30% by the year 2030. California, as a first green mover of this technology, could be a necessary catalyst in the global battle against climate change.

Appendix A

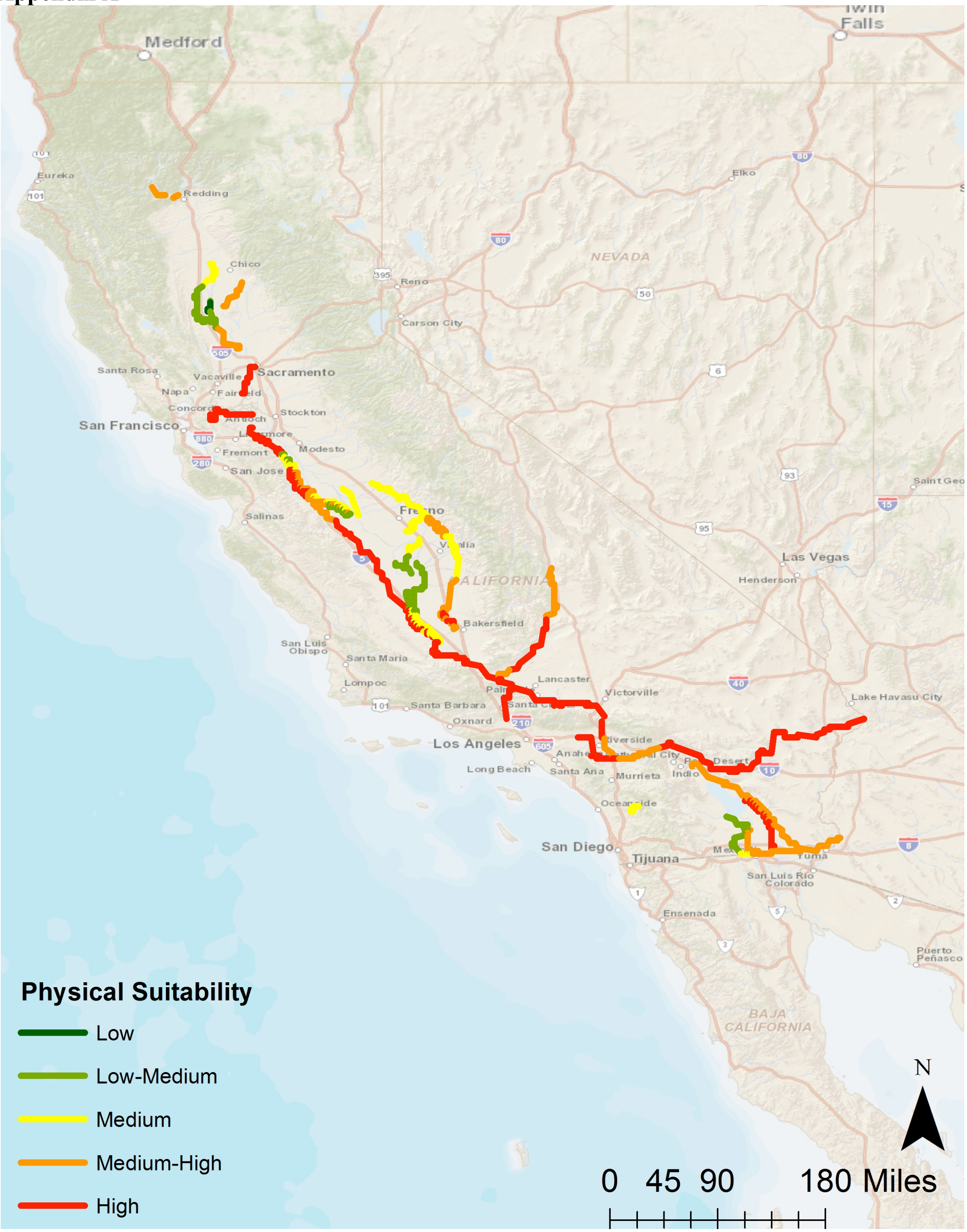

Figure A-1 Physical Suitability Layer. Physical suitability showing combined physical variables (solar insolation and proximity to water pumping stations).

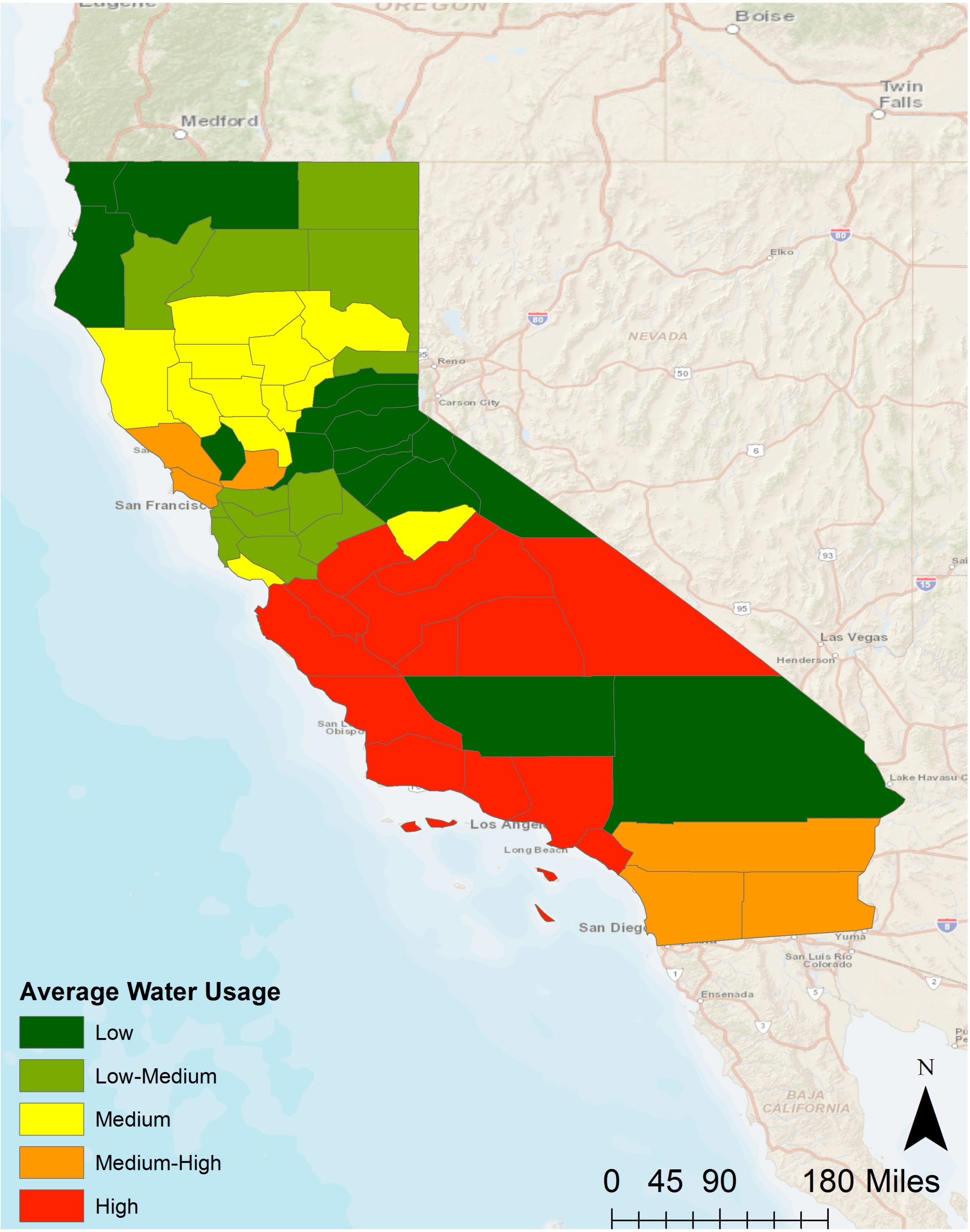

Figure A-2 Average water use by county.

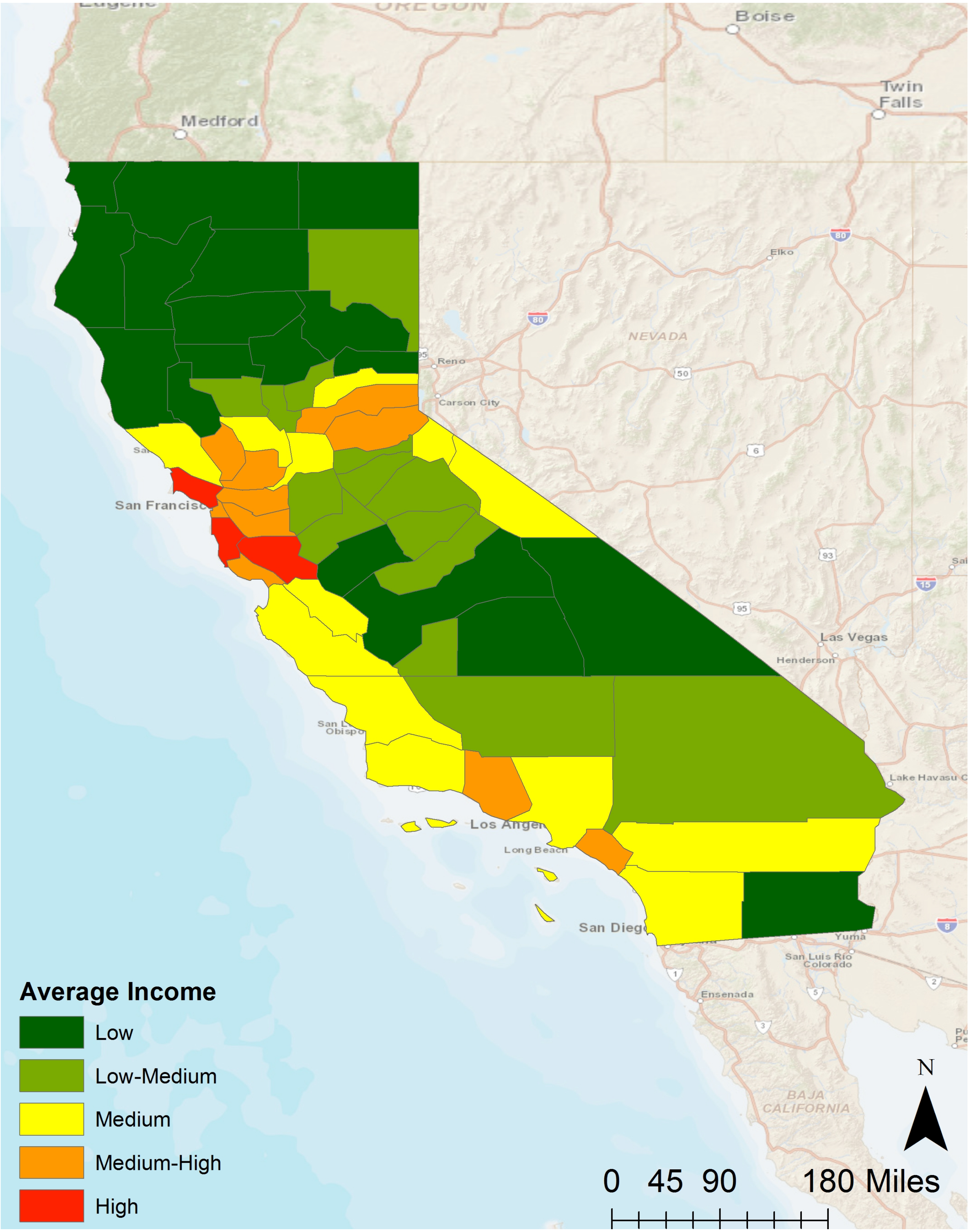

Figure A-3 Median income by county.

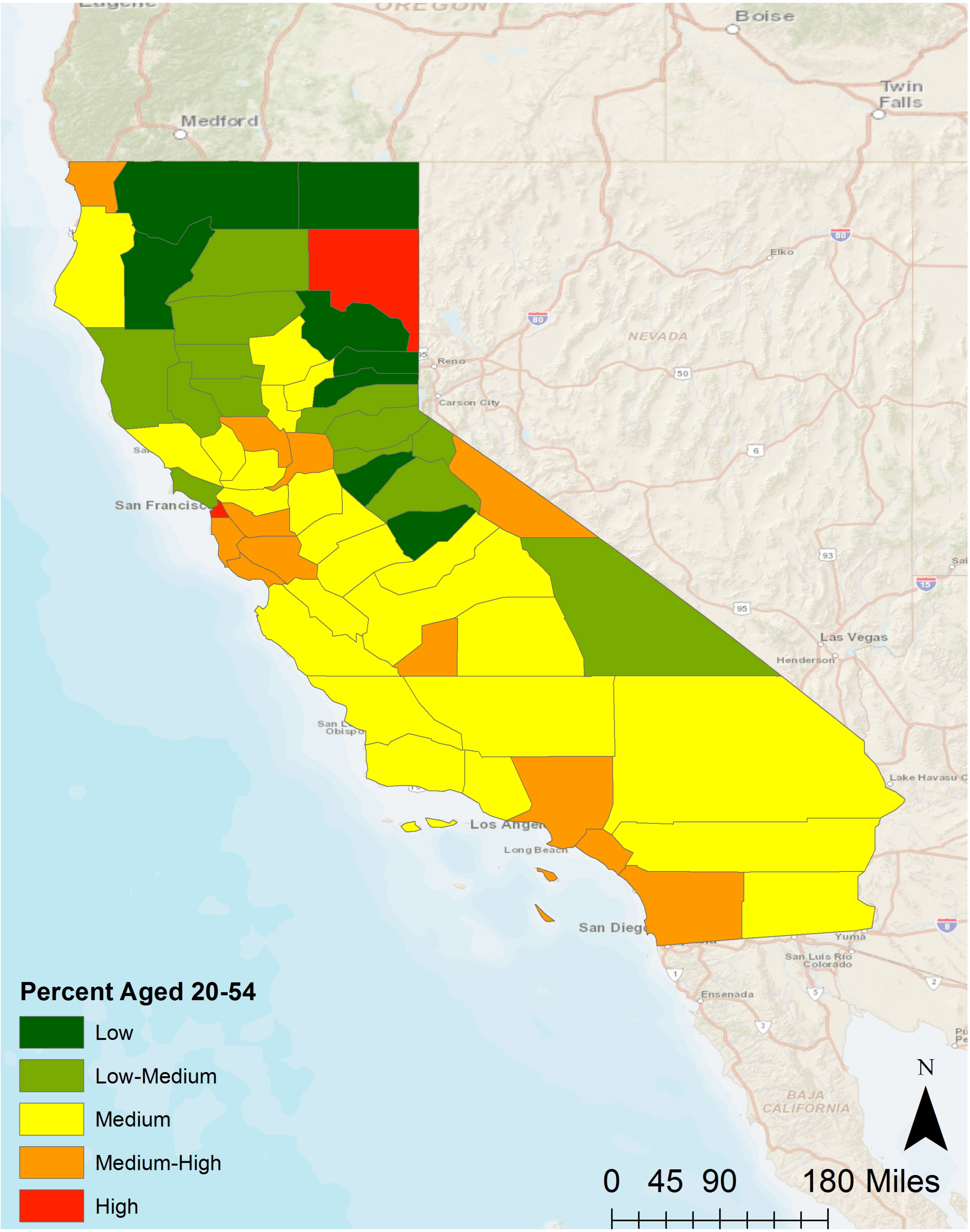

Figure A-4 Percentage of population aged 20-54 by county.

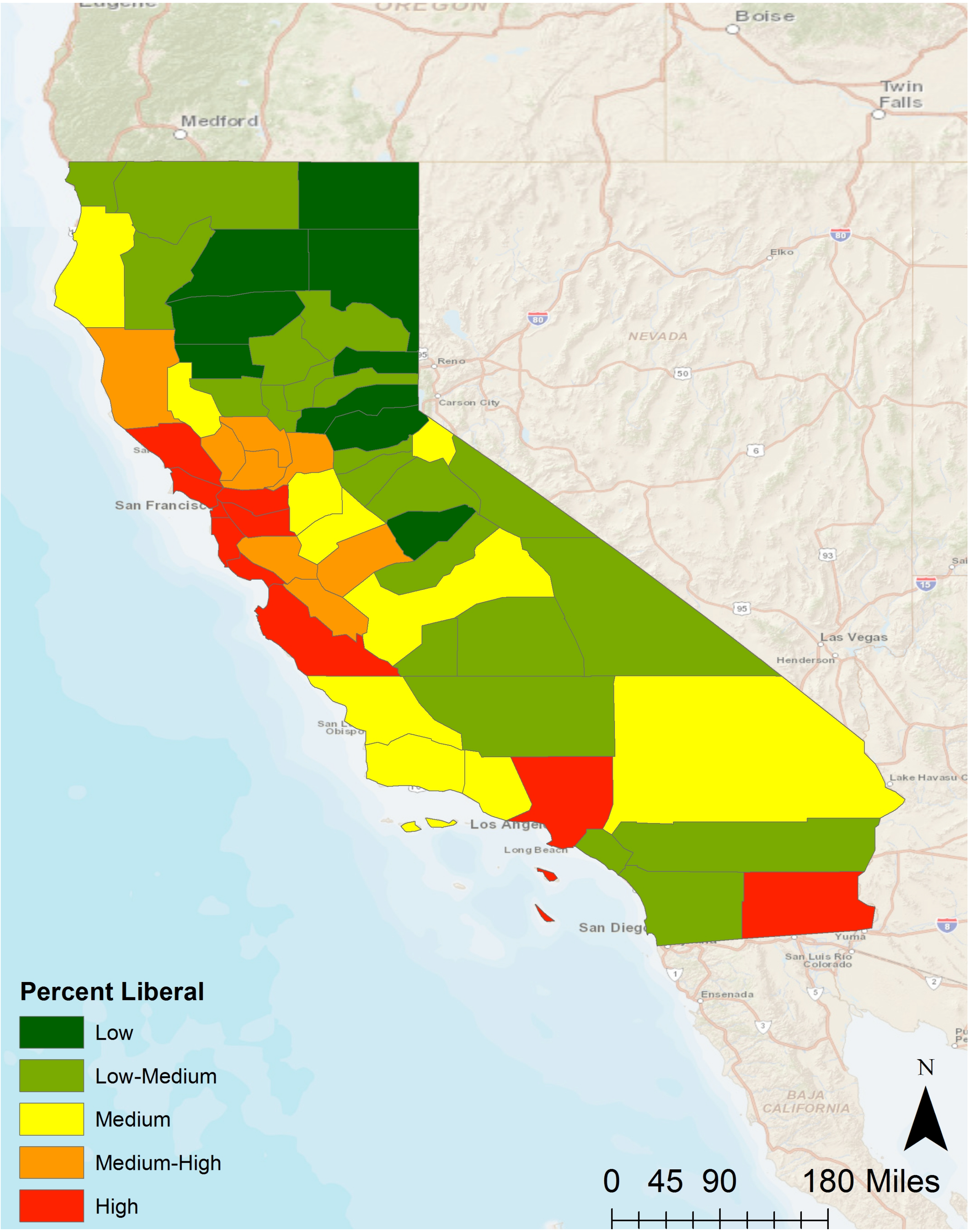

Figure A-5 Percentage of population registered as liberal.

UCLA Institute of the Environment and Sustainability

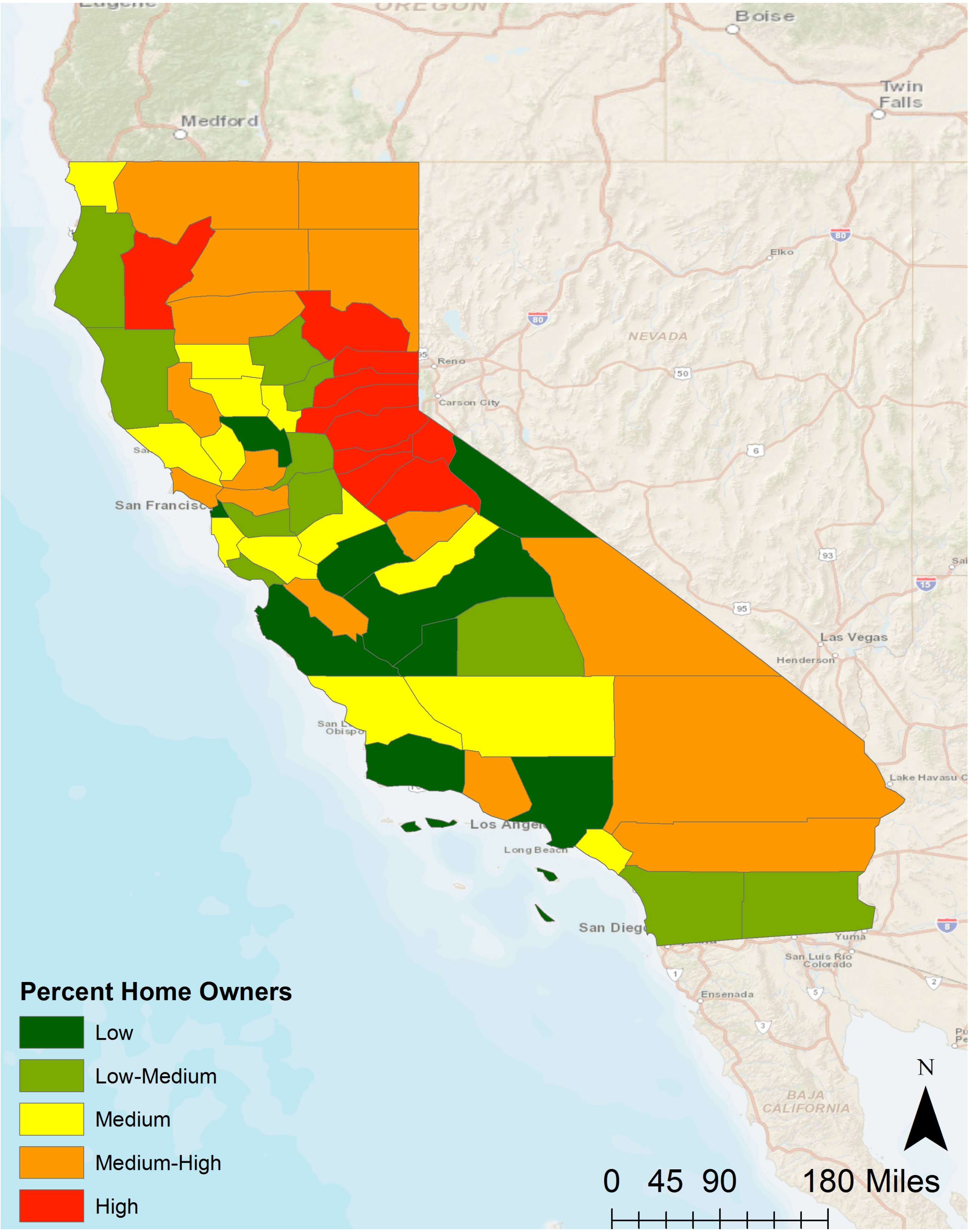

Figure A-6 Percentage of population that are homeowners.

UCLA Institute of the Environment and Sustainability

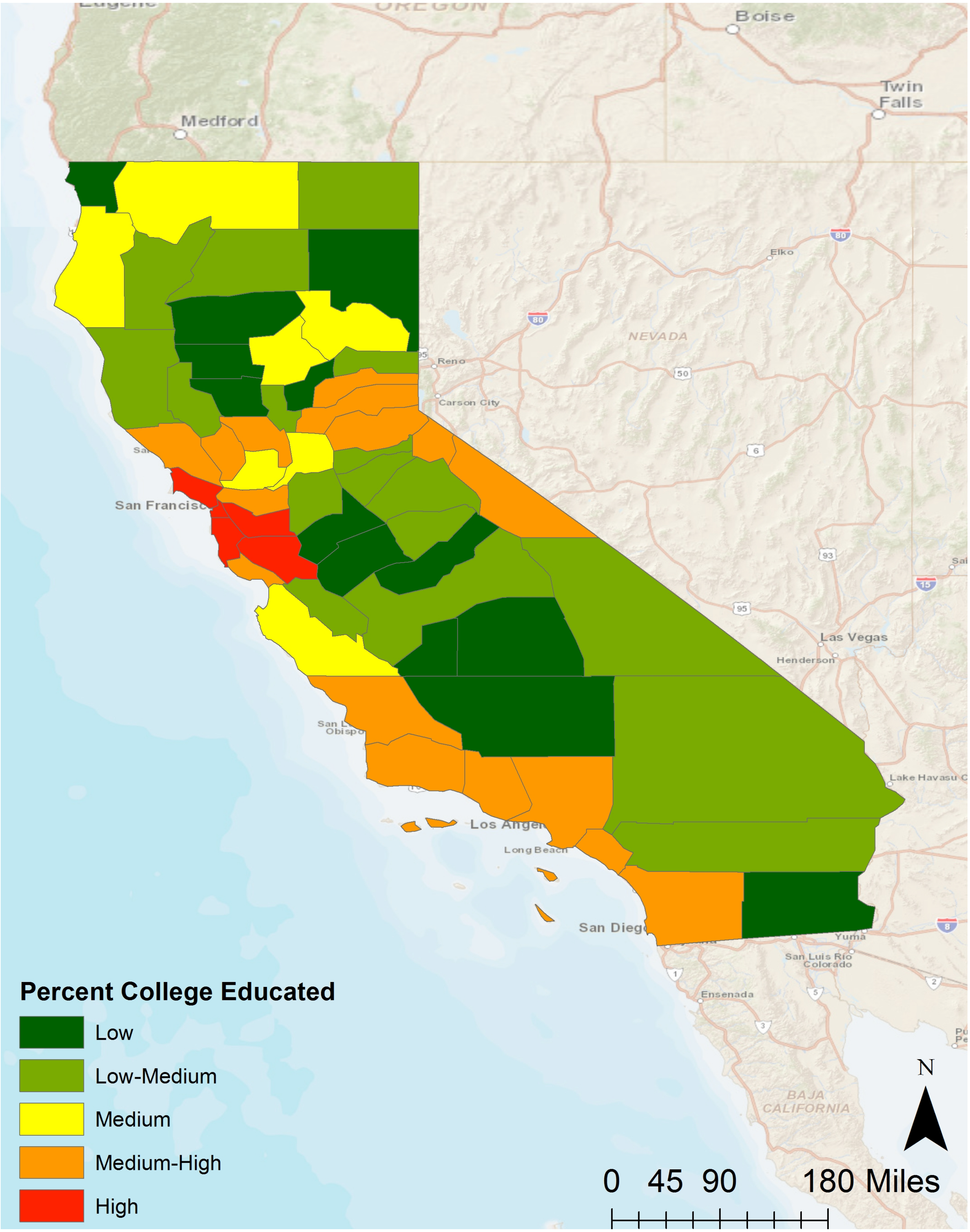

Figure A-7 Percentage of population that graduated from college.

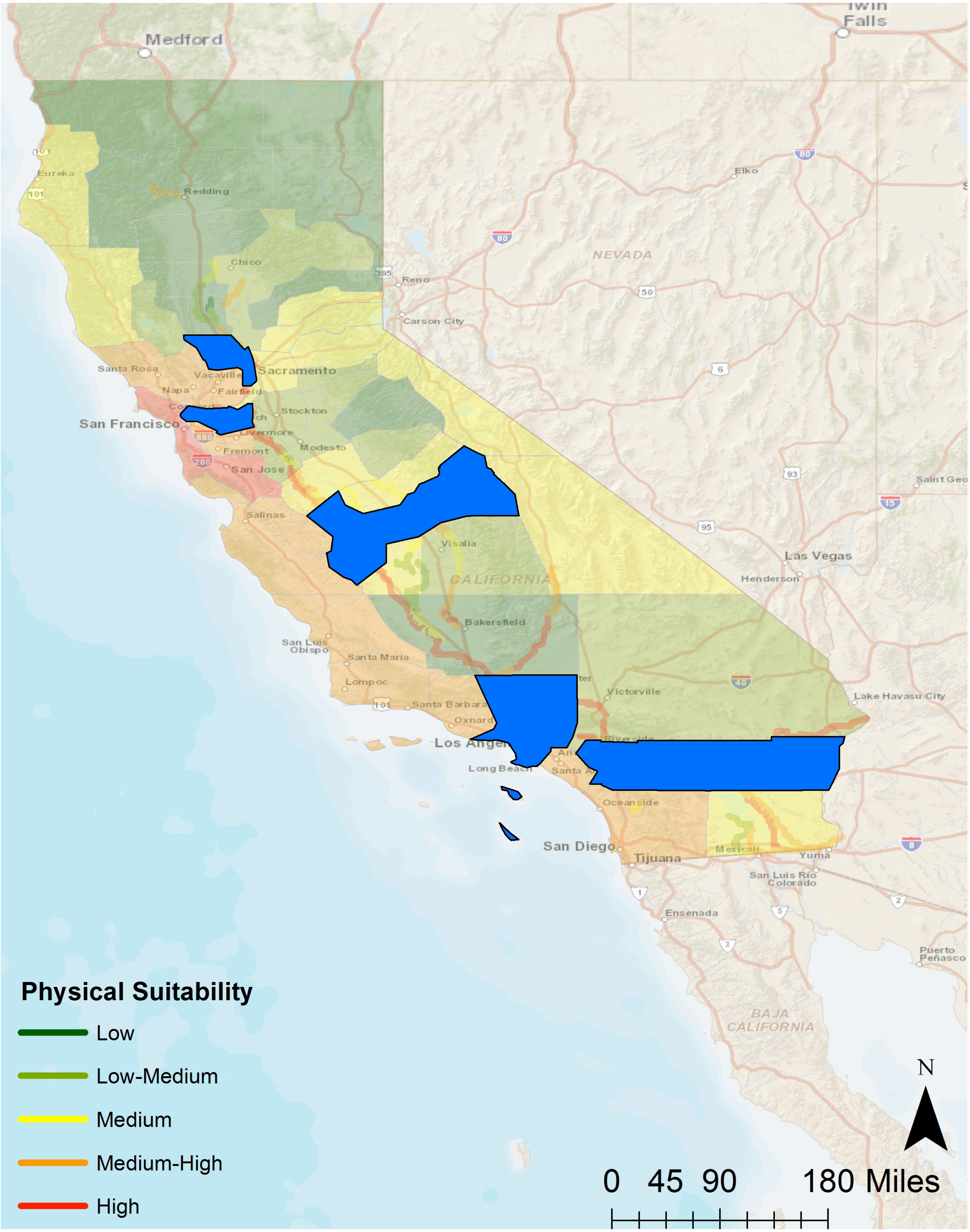

Figure A-8 Top five counties in California according to suitability index.

Appendix B

Table B Comparison Chart for Community Solar Models. Source: NREL "A Guide to Community Solar: Utility, Private, and Non-profit Project Development" http://www.nrel.gov/docs/fy11osti/49930.pdf

Administered by	Utility	Special Purpose Entity	Non-profit
Owned by	Utility or 3rd party	SPE members	Non-profit
Financed by	Utility, grants, ratepayer subscriptions	Member investments, grants, incentives	Donor contributions, grants
Hosted by	Utility or 3rd party	3rd party	Non-profit
Subscriber Profile	Electric rate payers of the utility	Community investors	Donors
Subscriber Motive	Offset personal electricity use	Return on investment; Offset personal electricity use	Philanthropy
Long-term Strategy of Sponsor	Offer solar options Add solar generation (possibly for Renewable Portfolio Standard)	Sell system to host Retain for electricity production for life of system	Retain for electricity production for life of system
Examples	Sacramento Municipal Utility District – Solar-Shares Program United Power Sol Partners	University Park Community Solar, LLC Clean Energy Collective, LLC	Solar for Sakai

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