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Solar Development in the Mojave Desert

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SOLAR DEVELOPMENT IN THE MOJAVE DESERT

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Table of Contents

List of Figures

List of Tables

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1 Introduction

While it is difficult to imagine today, there once existed a time when nature was large and the human race was not. During these years, civilizations coexisted with nature without altering or disturbing it, appreciative of what Mother Nature had provided for them. When Christopher Columbus reached the Americas in 1492, he did not write of smokestacks, skyscrapers, or street signs, but instead of the inherent beauty of the unconquered land, uncharted seas, and the magnificent flora and fauna that he and his crew encountered. When Meriwether Lewis and William Clark set off on their famous expedition to the Pacific coast, they did not write of highways, casinos, or oil rigs, but instead of the wild grizzly bears and bighorn sheep that roamed throughout the land. The clear skies, blue waters, herds of wild animals and flocks of elegant birds dominated the landscape; yet somewhere between then and now, something was lost. The human race is now large and getting larger, and nature appears to be shrinking at an alarming rate. As the human population continues to grow, it is easy to see that the global economy is putting more and more pressure on the environment, and in the not too distant future catastrophe will strike.

Concern surrounding the degradation of the natural environment in the United States, however, is not a new issue by any means. The modern American environmental movement began in the early 1960s, years before the creation of the Environmental Protection Agency by President Nixon. When Rachel Carson published her book, *Silent Spring,* in 1962 about the harmful effect of pesticides on bird species, she was not expecting to gather as large a fan base as she did. Her book, extremely detailed and very well-written, attracted attention around the nation and around the world, becoming Houghton Mifflin's best seller with sales reaching over a half of a million copies in its first year. Carson discussed in great depth the use of DDT and other synthetic pesticides and their poisonous effects on wildlife, the environment, and human health. Her results spurred an anti-chemical and anti-pesticide movement, eventually leading to a ban of DDT in the United States. One writer even proclaimed, "*Silent Spring* played in the history of environmentalism roughly the same role that *Uncle Tom's Cabin* played in the abolitionist movement."[1]

Fears about the state of the environment gained even further public attention when biologist Paul R. Ehrlich published *The Population Bomb* in 1968. His book, which sold over two million copies, warned the world of a massive increase in population growth that would lead to high environmental degradation and starvation and death for hundreds of millions of people. Ehrlich held that wealthy and technologically advanced countries like the United States have a significantly greater impact on the depletion of natural resources and the health of the planet than do poorer countries.[2] Both Carson and Ehrlich's ideas were criticized but ultimately succeeded in thrusting environmental issues into the forefront of public and political thought.

Over the course of the last four decades, the global environmental movement has shifted its direction and focus from conservation and contamination to the mitigation of anthropogenic climate change, one of the most pressing issues that the world is currently facing. Environmentalism today can be described as "the principle approaches to date for

[1] Jack Lewis, "The Birth of EPA," *EPA Journal*, November 1985.
[2] Jacqueline V. Switzer, *Environmental Politics: Domestic and Global Dimensions* (New York: St Martin's Press, Inc., 1994), 9.

controlling the economy's impacts on the natural world."[3] Climate change and the decline in the quality of the natural environment due to human activity (Table 1-1) are topics that arise in all countries, are discussed by the world's greatest and most powerful leaders, and are researched and examined by leading scientists. As global temperatures continue to rise, the debate about what action should be taken in the immediate future to address the problem is also heating up.

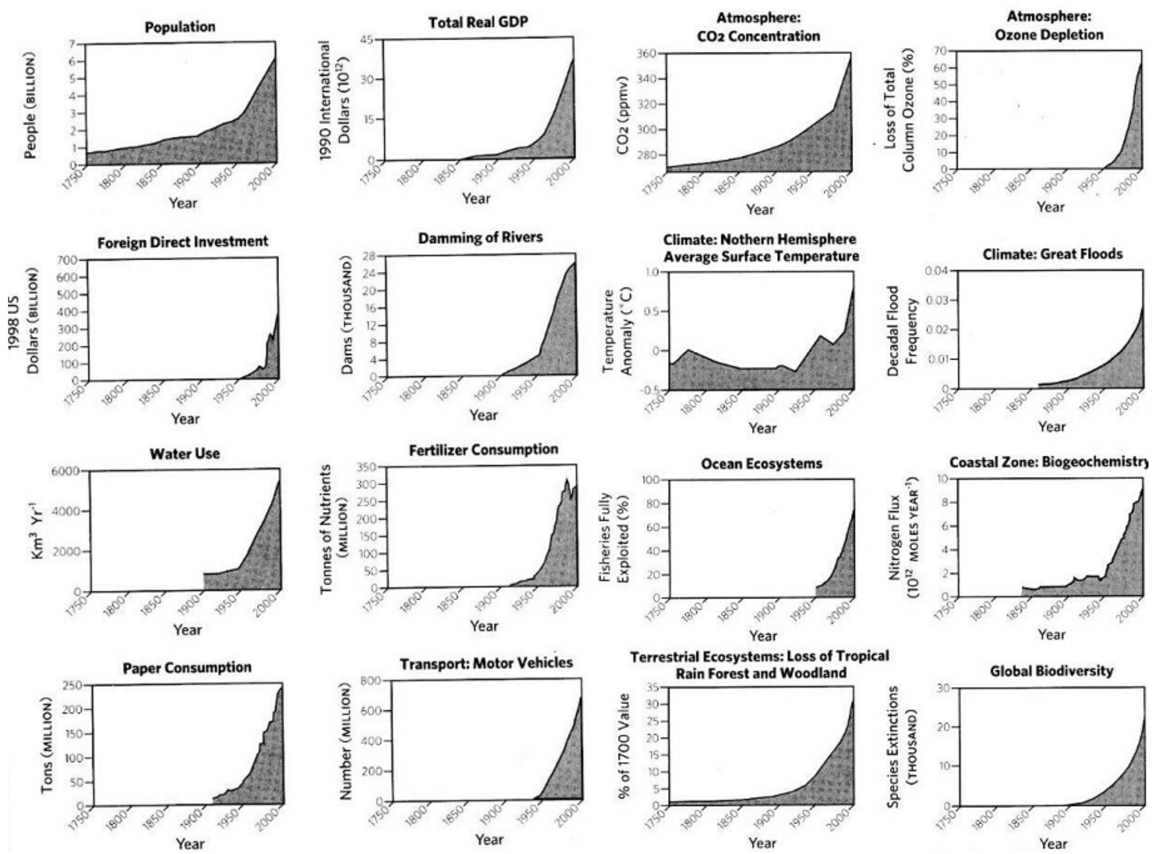

Table 1-1. Global social, economic, and environmental trends over time (1750-2000)[4]

[3] James Gustave Speth, *The Bridge at the Edge of the World* (Connecticut: Yale University Press, 2008), xi.
[4] Ibid.

1.1 Climate Change

For more than two centuries, humans have been spewing "greenhouse gases" into the atmosphere through the burning of fossil fuels, deforestation, and the development of land, causing the planet's surface temperature to increase at an accelerated rate. Greenhouse gases are naturally occurring gases that exist in the atmosphere and prevent heat from escaping Earth and entering space. These gases absorb the energy released from the planet and then radiate most of this heat back to the Earth's surface, creating what is called a "greenhouse effect"; without this process, life on Earth would not be viable. However, due to human activity and the increased amount of these gases in the atmosphere, this process has been intensified and the global average temperature has increased.

The Intergovernmental Panel on Climate Change, a United Nations' scientific body, calculated in their *2007 Assessment Report* that "the 100-year linear warming trend (1906-2005) was 0.74C, with most of the warming occurring in the past 50 years. The warming for the next 20 years is projected to be 0.2C per decade."[5] If warming continues as projected, a number of negative impacts will be observed: a rise in sea level, increased risk of plant and animal species extinction, more intense and frequent severe weather events such as hurricanes and tornadoes, higher number of droughts and floods, glacier melting, earlier spring events, and changes in flora and fauna ranges, among others. Although numerous gases contribute to climate change, atmospheric carbon dioxide (CO_2) is the primary contributor. Scientists and climate change activists advocate the idea

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[5] United Nations Framework Convention on Climate Change, "Fact sheet: Climate change science – the status of climate change science today," November 2010, available from http://unfccc.int/press/fact_sheets/items/4987.php; Internet: accessed November 4, 2010, 2.

of a target for a "safe" level of atmospheric CO_2 that will steer the Earth clear of irreversible climate catastrophe. Currently, atmospheric CO_2 levels are around 385 parts per million (ppm). In the pre-industrial world and during the preceding ten thousand years, however, levels hovered around 280 ppm. The majority of scientists concur that "paleoclimate evidence and ongoing climate change suggest that CO_2 will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that."[6] This CO_2 target level, though formidable and difficult to achieve, is necessary for the survival of the planet.

The phasing out of fossil fuels is widely accepted as the most pragmatic and effective way of decreasing the high concentration of greenhouse gases in the atmosphere. Some of the world's most developed countries are beginning to pave the way for technological innovation and the implementation of new technologies to aid this process. In the United States in 2009, 69% of the country's electricity generated was from fossil fuels (Figure 1-1). Non-hydro renewable, on the other hand, only made up 4% of the United States electricity generation portfolio. These renewable sources (solar, wind, geothermal, biomass, biofuel, tidal) are essential to the phase out of fossil fuels as energy demand keeps growing, especially because the nation's large hydro resources have been tapped and nuclear energy remains controversial. In the coming years, more renewable energy will be emerging onto the scene, mainly in the forms of solar and wind generation, and fossil fuels will play a smaller role in meeting the electricity demands of the United States.

[6] James Hansen, "Target atmospheric CO2: Where should humanity aim?" *The Open Atmospheric Science Journal* (2008) 2(15): 217.

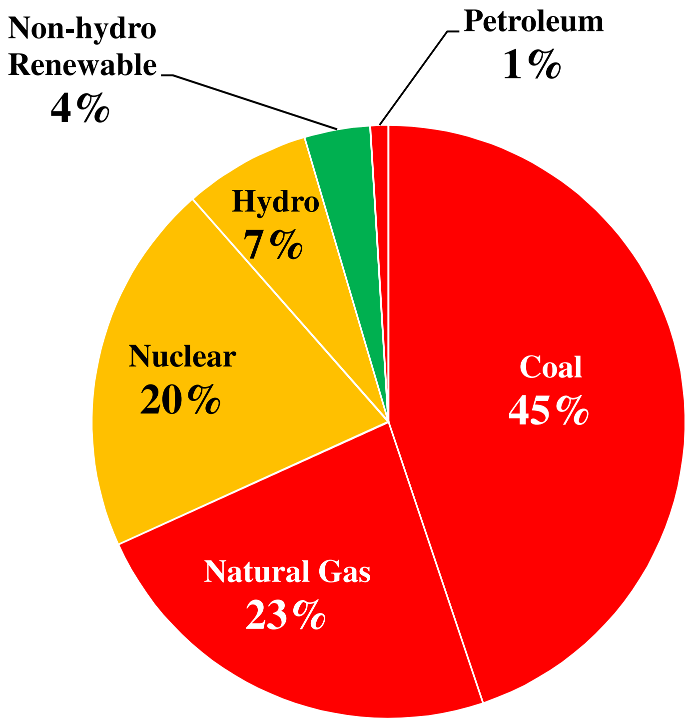

Figure 1-1. United States net electricity generation (by energy sector, 2009)[7]

1.2 Renewable energy

Much like the Industrial Revolution improved socioeconomic and cultural conditions for all of society, a "Renewable Revolution" could help society by saving the planet from an environmental crisis and the effects of global climate change. Undoubtedly, a revolution of this sort and scale will not occur in months or even years, but more like decades. Rochelle Lefkowitz, president of Pro-Media Communications, has it right when contrasting different sources of energy. She supports that coal, oil and natural gas are "fuels from hell" because they are obtained from underground, their reserves are finite, and they emit greenhouse gases when burned. On the other hand, she

[7] Energy Information Administration, "Net Generation by Energy Source," available from http://www.eia.doe.gov/electricity/epm/table1_1.html; Internet; accessed October 12, 2010.

holds that solar, wind, hydroelectric, tidal, and biomass are "fuels from heaven" because they originate from above ground, are inherently renewable, and do not emit harmful gases when used.[8] It is these heavenly fuels that will power the United States and the planet into a more promising future. In addition to the obvious advantage of limiting the effects of climate change, there are numerous other benefits that would come with a renewable energy revolution.

Much of the debate surrounding renewable energy at the moment concerns the economic viability of implementing such projects. The United States is in the midst of the worst economic downturn in recent history. Unemployment in some parts of the country has hit record highs, and the forecast for the coming years is bleak. The introduction of a new industry, especially with a focus on manufacturing and construction, has the potential to create millions of jobs and spur technological innovation. The green sector, if grown to the scale needed to transform the energy portfolio of the United States, could help to carry the nation out of the downturn and employ the jobless. Furthermore, the economic risk associated with relying on petroleum and other fuels that have fluctuating prices would diminish, as the energy sector would be powered by *free* and *limitless* raw materials.

Another worry of the American government and public is national security. Thomas Friedman, in his book *Hot, Flat, and Crowded*, argues that the United States and other high energy-consuming countries are pumping "hundreds of billions of dollars a year" into oil-producing countries and thereby, "strengthening nondemocratic actors and

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[8] Thomas Friedman, *Hot, Flat, and Crowded* (New York: Farrar, Straus, and Giroux, 2008), 32.

trends" in these countries ruled by what Friedman calls "petrodictators."[9] A country powered by renewable energy would avoid this trend and would help to put an end to petrodictatorships. In a 2007 report entitled "National Security and the Threat of Climate Change," former United States Army Chief of Staff, General Gordon R. Sullivan states: "We never have 100 percent certainty. We never have it. If you wait until you have 100 percent certainty, something bad is going to happen on the battlefield. That's something we know. You have to act with incomplete information."[10] The deployment of renewable energy would help to avoid "something bad" that could happen in the future due to the effects of climate change.

1.3 Solar electricity generation

Though the idea of converting sunlight into electricity has been around for hundreds of years, the solar power industry has made great advancements in just the last 30 years in terms of utility-scale solar generation, meaning the use of solar plants capable of producing more power than distributed generation or rooftop systems. There are two distinct ways of capturing the sun's energy and utilizing it to power homes: directly through the use of photovoltaics (PV) and indirectly using concentrated solar power (CSP). Both types of solar technologies require large tracts of land and access to freshwater. The efficiency of power plants that utilize intermittent energy sources such as sunlight or wind is measured by its capacity factor, or the ratio between the plant's actual output and its normal maximum output. For example, a power plant with 100 megawatts

[9] Ibid., 42.

[10] Center for Naval Analyses, "National Security and the Threat of Climate Change," April 1, 2007, available from http://www.cna.org/reports/climate; Internet; accessed October 30, 2010, 10.

(MW) capacity and a capacity factor of 25 percent will have a yearly energy output of roughly 100 MW x 24 hours x 365 days x 25% = 290,000 MWh/year.

1.3.1 Photovoltaics

Photovoltaic systems use solar cells made from materials such as silicon, cadmium, and copper to directly convert sunlight into electricity through a photovoltaic process. Flat plate and thin film PV are the two main types of PV technologies that are researched and manufactured. Flat plate PV systems, the most common solar array design, can be both fixed or part of a computerized system that tracks the sun's path. Crystalline silicon-based flat plate PV technology currently achieves module conversion efficiency, or effectiveness of converting sunlight directly into electricity by a collection of solar cells, of between 15 and 20 percent.[11] Thin film solar is produced using much fewer materials than flat plate PV, making production of solar cells cheaper and quicker. While thin film PV has its advantages in production and manufacturing, its module conversion efficiency ranges from 8 to 13 percent,[12] significantly lower than that of flat plate PV. A third type of PV system is concentrated PV (CPV), which consists of either parabolic dish mirror systems or flat Fresnel lenses that direct the energy from the sun onto a small cluster of photovoltaic cells. Some CPV systems have achieved module efficiencies of 29 percent, but very few utility-scale systems of this type have been installed.[13]

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[11] Jesse Fernandes et al., "Renewable Energy in the California Desert: Mechanisms for Evaluating Solar Development on Public Lands," *University of Michigan School of Natural Resources and Environment*, April 2010, 49.

[12] Ibid., 50.

[13] L. Stoddard, J. Abiecunas, and R. O'Connell, "Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California," *National Renewable Energy Laboratory*, April 2006, 14.

Photovoltaic technology has seen a steady increase in efficiency and a steady decline in production cost since the first solar cells were manufactured years ago. Today, solar PV is in use in more than one hundred countries and is the fastest-growing power technology in the world.[14] One major hurdle that PV must overcome is its inability to store energy so that a plant can provide energy when the sun goes down. Some argue that solar PV cannot really establish itself as a major power source until an efficient and inexpensive battery is invented to store the large amount of electrons produced. Also, water use is a concern for the future of PV technology, as solar arrays need to be washed regularly. Though the amount of water required is nominal, every drop of water is important, especially in desert regions where water resources are scarce.

1.3.2 Concentrated solar

The second way of harnessing the sun's energy is through concentrated solar power, also known as solar thermal power. CSP systems employ mirrors or lenses to concentrate large amounts of sunlight onto a receiver to produce heat and drive a gas or steam-driven engine. There are three main types of CSP: parabolic trough, power tower, and dish engine.

Parabolic trough systems consist of rows of linear parabolic mirrors that concentrate solar energy to a receiver tube that runs the length of the mirrors. The receiver tube is filled with a heat transfer fluid (HTF), usually oil or ethylene glycol, that when heated turns water into high-pressure steam and powers a turbine-generator to produce electricity. The HTF then flows back to the receiver tube to create a close looped

[14] J. Matthew Roney, "Solar cell production climbs to another record in 2009," *Earth Policy Institute*, September 21, 2010, available from http://www.earth-policy.org/index.php?/indicators/C47/; Internet; accessed September 23, 2010.

system (Figure 1-3). Parabolic trough systems are quite efficient, achieving “at least a 25 percent capacity factor, which means about a quarter of the sun’s energy that is captured by the system is converted to usable electricity.”[15]

For the past 25 years, parabolic trough plants have been in use around the world. The construction of the Solar Energy Generating Systems (SEGS) I through IX plants between 1985 and 1991 proved very important for CSP technology promotion and advancement. The system, located in the Mojave Desert with a total capacity of 354 MW, is the largest solar power plant in the world, and its success has demonstrated that CSP is reliable, efficient, and can produce at utility-scale.[16] Because of parabolic trough systems’ long-time use and research done on generating plants, there is very detailed information and data available regarding construction, operation, and the economic and environmental impacts of this type of CSP.

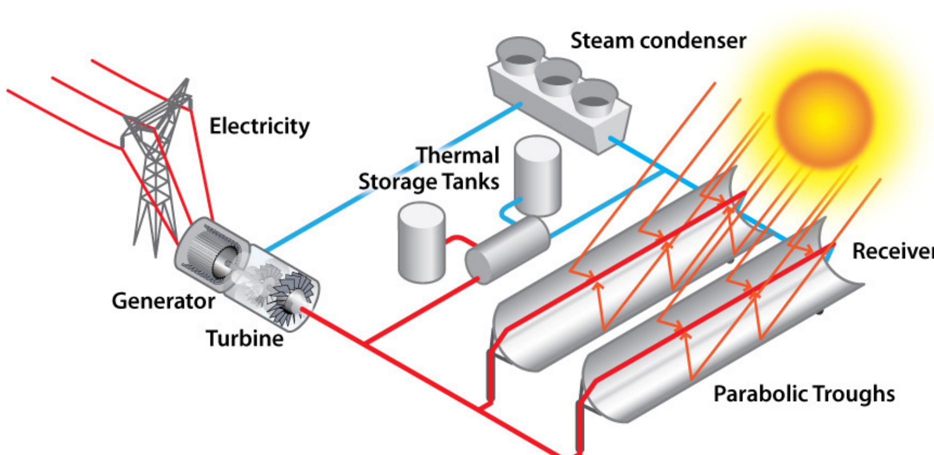

Figure 1-2. Parabolic trough CSP plant[17]

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[15] Jesse Fernandes et al., “Renewable Energy in the California Desert,” 46.

[16] Stoddard, Abiecunas, and O'Connell, “Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California,” 15.

[17] Department of Energy, “Linear Concentrators Research and Development,” available from http://www1.eere.energy.gov/solar/linear_concentrator_rnd.html; Internet; accessed November 3, 2010.

The second CSP technology is power tower systems. These systems are comprised of a large field with thousands of heliostats, or sun-tracking, computer-controlled mirrors, that follow the sun and reflect sunlight onto a central receiver located on top of a 300 to 650 foot-tall tower. Much like parabolic trough CSP, the central receiver contains a HTF that is fed to a heat exchanger where high-pressure steam is created to drive a turbine. Power towers are also close-looped systems, and therefore, the water and HTF need not be replaced regularly. Today, the only commercial power tower system in use is an 11-megawatt plant located in Seville, Spain.[18] Interest in this technology has risen in recent years and numerous pending projects utilize this type of technology.

Finally, dish engine systems, sometimes called dish Sterling systems, use stand-alone, dish-shaped reflectors to direct sunlight onto a central receiver mounted on a boom at the focal point. The reflectors follow the sun's path across the horizon using a two-axis tracker. Hydrogen or helium is heated by the reflected light in the receiver, and the gas drives a Stirling engine-generator located at the end of the boom in a power conversion unit. The generator produces electricity to be fed directly to the grid. The gas is then air-cooled and returned to the system. Dish Stirling systems, "the most efficient of any solar technology…are being promoted (with good reason) as good investments, especially versatile for large-scale and distributed set-ups."[19] Reaching a capacity factor of up to 31

[18] Ibid.

[19] Christian Hunold and Steven Leitner, "'Hasta la vista, Baby!' The Solar Grand Plan, Environmentalism, and Social Constructions of the Mojave Desert," paper presented at the annual meeting of the WPSA, Hyatt Regency Vancouver, Canada, March 19, 2009, available from http://www.allacademic.com/meta/p317497_ index.html; Internet; accessed September 20, 2010, 6.

percent,[20] this type of CSP could become competitive in distributed markets thanks to its modular structure and ability to be mass-produced. Because each dish engine unit can function separately, these systems are ideal for small, remote applications but can also be used in large arrays to produce electricity at commercial scale.

Solar thermal power plants present numerous advantages over photovoltaic technology. CSP plants exhibit economies of scale, meaning that cost per kilowatt declines as the plant's size increases. For example, the larger the field of heliostats that concentrates sunlight onto the central receiver in a power tower system, the greater the plant's generation capacity. Adding more heliostats to a field is a much more inexpensive procedure compared to the construction of a new plant to produce the same net generation capacity gain. Also, in regions with high irradiation such as the Mojave Desert, solar thermal projects are more economically feasible due to low manufacturing costs. One of the biggest advantages that solar thermal holds offers over PV is the ability to store energy through heat.

Though dish Stirling technology does not lend itself to thermal storage yet, both parabolic trough and power tower CSP are capable of utilizing varying types of energy storage. Energy storage allows for greater flexibility in electricity production, making the systems more dispatchable, or able to generate electricity when the grid demands it like after sunset or periods when cloud cover restricts insolation. Most thermal storage technologies employed at parabolic trough plants are two-tank, indirect systems, which consist of a hot and a cold storage tank that are filled with molten salt. The hot HTF flows through heat exchangers while cold molten salt from the cold tank is run counter

[20] Fernandes et al., "Renewable Energy in the California Desert," 48.

currently through the exchangers and heated. The heated molten salt is then stored in the hot storage tank, and when this energy is demanded later, "the system simply operates in reverse to reheat the solar heat transfer fluid, which generates steam to run the power plant." [21] The system is "indirect" because the fluid used for storage is different than the fluid directly heated by the sun in the receiver tubes, and the heat must be transferred through an oil-to-salt and salt-back-to-oil exchange.

Thermal energy storage in power tower CSP is a simpler process than in parabolic trough CSP. Power tower systems are able to use a *direct*, two-tank system because molten salt is used both as the HTF and the storage medium. When the HTF is heated by the concentration of the sun's rays, the molten salt can be transported directly to the hot storage tank, where it will remain until the stored energy is needed to produce electricity. This process increases a power tower plant's "capacity factor from 34 to over 40 percent."[22] Because of its less complex nature, energy storage systems for power tower CSP are less expensive to construct and maintain than those of parabolic trough systems, making power tower technology more competitive in the US market in the near future.[23] In addition to thermal energy storage to generate electricity when the grid demands it, parabolic trough and power tower plants can utilize hybrid fossil fuel systems to increase dispatchability.

While advancements in energy storage technology and solar research and development will increase module conversion efficiency and capacity factor, the driving

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[21] National Renewable Energy Laboratory, "Parabolic Trough Thermal Energy Storage Technology," available from http://www.nrel.gov/csp/troughnet/thermal_energy_ storage.html#tank; Internet; accessed November 1, 2010.

[22] Fernandes et al., "Renewable Energy in the California Desert," 47.

[23] Craig Turchi et al., "Current and Future Costs for Parabolic Trough and Power Tower Systems in the US Market," *National Renewable Energy Laboratory*, October 2010.

force of the success of solar generation is the power of the sun. Just as wind farms are most effective in regions with high wind speed, solar developments are most effective where the sun shines brightest. In the United States, the Sun Belt states of the Southwest receive the highest average daily solar radiation (Figure 1-4). Within this region of high solar radiation, the Mojave Desert experiences exceptionally high insolation, making it a prime location for the implementation of solar technologies.

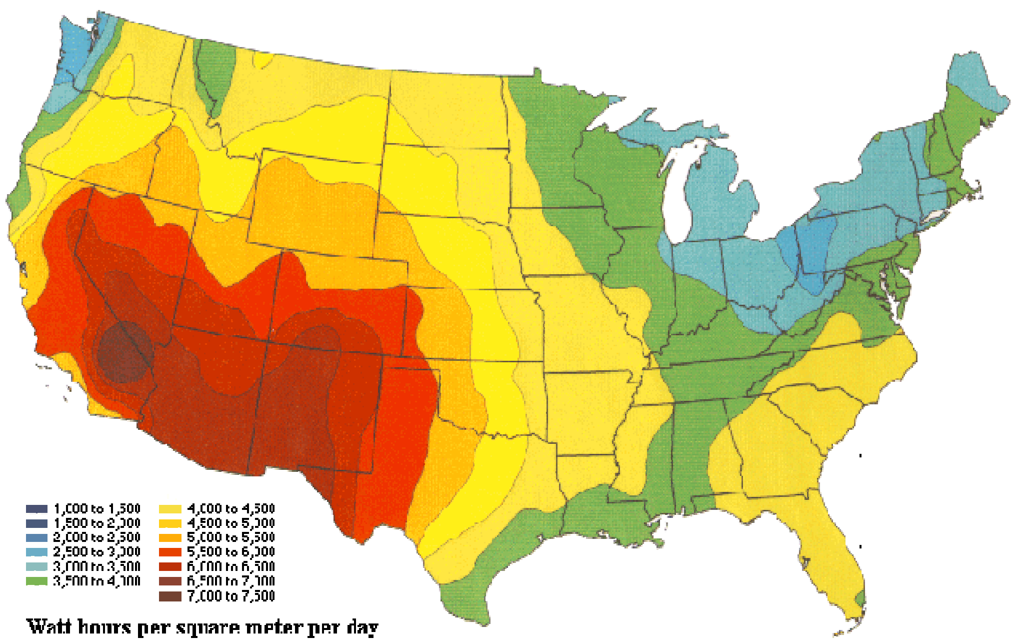

Figure 1-3. Average daily solar radiation in the United States[24]

However, the largest hurdle that solar technology needs to overcome is its impact on the local ecology. Vast tracts of land are needed for the deployment of CSP and PV utility-scale plants, and often times, these tracts are located in regions that are highly sensitive to change and development. The remaining sections of this paper will look

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[24] Arizona Solar Center, Resource Maps, "US Solar Radiation Map," available from http://www.azsolarcenter.org/solar-in-arizona/resource-maps.html; Internet; accessed November 18, 2010.

specifically at solar development in the Mojave Desert and the policies and issues affecting its future.

2 Mojave Desert

One of the characteristics that separate a desert from other climate regions is its unchanging and static nature. Before humans began to inhabit and develop vast areas of the world's deserts (i.e. Las Vegas, Phoenix, Cairo, etc.), desert climates remained largely unchanged for millions of years. Not only did the landscape experience little alteration, but just about everything moved slowly also. Desert tortoises crept quietly and undisturbed along the desert floor in search of grasses and wildflowers; cacti and sage brush grew at a snail's pace with little access to water; the rate of soil development and weathering was undetectable.

All of a sudden at the start of the 21st century, humans started to alter the speed of things in the desert. Historically, the Mojave Desert has seen incredible habitat loss caused mainly by military use, mining, grazing, agriculture, infrastructure construction, off-highway vehicle use, and energy generation. Because of its slow recovery time from disturbance, deserts are incredibly fragile and "apparently minor actions can cause long-term effects on soils and ground water and long-lasting consequences for plant and animal populations and communities."[25] The "industrialization" of the Mojave Desert due to its renewable energy potential especially has been occurring at an astonishing rate in recent years, causing alarm among conservationists and desert advocacy groups. As the United States and California move forward with renewable energy initiatives and projects

[25] J. M. Randall et al., "Mojave Desert Ecoregional Assessment," Unpublished Report. *The Nature Conservancy*, San Francisco, California, September 2010, available from http://conserveonline.org/workspaces/mojave/ documents/mojave-desert-ecoregional- 2010/@@view.html; Internet; accessed September 14, 2010, 1.

in the Mojave Desert, it is important to understand and then minimize the detrimental effects that large fields of CSP and PV have on the local ecosystem.

At present, the California Bureau of Land Management (BLM) is processing 31 large solar energy applications that, if all were to be approved and constructed, would have a total capacity of 16,979 MW and cover 210,558 acres. Since September 2010, the BLM has approved six solar applications in California with a total combined capacity of 3,038 MW and coverage of 23,625 acres. These six projects, if built as planned, will generate enough electricity to power at least 911,050 homes and will create 4,751 jobs.[26]

2.1 Geography, climate, and ecology

The Mojave Desert is located mostly in southeastern California and southern Nevada, but also reaches western Arizona and the southwestern tip of Utah. The region spans over 32 million acres of land with roughly 20 million acres occupying the state of California, about one-fifth of the state's total area (Figure 2-1). Considered one of North America's last great wilderness areas, the Mojave Desert remains untouched by human activity in most areas. The desert is a land of extremes; brutal winds, extreme temperatures, blistering sunlight, and severe aridity make the region seemingly difficult to sustain life. Death Valley, located in the Mojave Desert, is both the lowest and hottest place in North America and can experience temperatures greater than 130 degrees Fahrenheit. Other regions of the desert record temperatures below 20 °F in the valleys and below 0 °F at higher elevations during the winter.

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[26] Bureau of Land Management, "Solar Applications and Authorizations," available from http://www.blm.gov/pgdata/content/ca/en/fo/cdd/alternative_energy/ SolarEnergy.html; Internet; accessed November 23, 2010.

Deserts also receive an extremely low amount of rainfall annually. Between October 15th and April 15th, the desert's cool season, rainfall averages 95 mm, while during the dry season rainfall averages just 35 mm. Much of this rainfall comes from powerful storms originating in the Pacific Ocean.[27]

Found within the boundaries of the Mojave Desert are "a wide variety of habitat types and microclimates, including shifting sand dunes, streambeds and flood-prone washes, intermittently flooded playas, natural desert pavement, marshes, canyon bottoms and adjacent terraces, seeps and springs, rocky mountain slopes, and sky islands."[28] Despite encountering some of the harshest conditions on Earth, a surprising variety of flora and fauna exist in the Mojave Desert.

Figure 2-1. Map of the Mojave Desert[29]

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[27] Richard Hereford, Robert H. Webb, and Claire I. Longpre, "Precipitation History of the Mojave Desert Region, 1893-2001," U.S. Geological Survey, 2004, available from http://pubs.usgs.gov/fs/fs117-03/; Internet; accessed September 24, 2010.

[28] Randall et al., "Mojave Desert Ecoregional Assessment," 25.

[29] Ibid., 11.

Home to over 2,400 native plant and animal species, at least 72 of which are endemic, meaning they are found nowhere else, the Mojave Desert is one of the most biologically diverse regions in the 48 contiguous United States.[30] The region's geographic isolation has allowed for great speciation and high biodiversity. The California portion of the Mojave Desert alone supports 439 vertebrate species, including 252 species of birds, 101 mammals, 57 reptiles, 10 amphibians, and 19 fishes. Out of these species, 14 are endemic to the Mojave Desert and 28 are on the federal threatened or endangered species list, including the desert tortoise, Devil's Hole pupfish, and the desert bighorn sheep.[31] Most of these animals have adapted to the arid and hot conditions of the desert over the course of millions of years and rely on the vegetation and diverse habitats for their survival.

One of the best ways to determine where the desert begins is to look for the presence of certain desert plant species; creosote bush and Joshua trees are abundant in the Mojave Desert and serve as great indicators of the desert's boundaries.[32] Though dominated mainly by perennial plant species such as willows and scrub, the Mojave Desert boasts more than 250 ephemeral plant species. Out of these plants, 80-90 are endemic[33] and 16 are federally listed as threatened or endangered. Desert conditions do not regularly allow new plant establishment, therefore many plant communities are long-lived and fragile.

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[30] B.M. Pavlik, *The California Deserts: an ecological rediscovery* (Berkeley and Los Angeles: University of California Press, 2008).

[31] Randall et al., "Mojave Desert Ecoregional Assessment," 23.

[32] Sia Morhardt and Emil Morhardt, *California Desert Wildflowers* (Berkeley and Los Angeles: University of California Press, 2004) 4.

[33] R. M. Turner, "Mojave desertscrub," *Desert Plants* 4 (1982): 157-168.

2.2 Policies affecting solar development

Beginning in 1981 with the completion of the 10 MW Solar One plant and the subsequent completion of the SEGS I-IX between 1984 and 1990, the California desert has been regarded as the state's and the country's most promising region for the development of utility-scale solar because of its solar resources and proximity to large, expanding cities. According to the Department of Energy's (DOE) preliminary 2009 statistics, the United States' net summer capacity of solar was 603 MW. California provided the bulk of this capacity with 446 MW, while nearby states Nevada, Arizona, and Colorado provided 89 MW, 11 MW, and 14 MW, respectively.[34] With the help of federal and state policy incentivizing the growth of solar, the Mojave Desert can become a hotbed for renewable energy generation and significantly increase these capacity figures. Over the course of the last 30 years, policies have been enacted that have both helped and hindered the growth of solar energy.

2.2.1 Federal policy

In spite of the project development during the 1980s and a promising outlook for the future, the Reagan Administration slashed the budget allocated for renewable energy research and development by nearly 90 percent between 1981 and 1989, leaving solar developers in the dust as cheaper, fossil fuel-based sources of energy commanded the market.[35] Little happened for years in the solar industry, and during 2001 and 2002, California experienced an energy crisis consisting of rolling summer blackouts following

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[34] Energy Information Administration, "Total Renewable Net Summer Capacity by Energy Source and State, 2009," August 2010, available from http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/table8.html; Internet; accessed September 13, 2010.

[35] Fernandes et al., "Renewable Energy in the California Desert," 58.

the deregulation of the energy industry and price hikes and manipulation by energy companies like Enron. This crisis forced the state and the country to rethink energy policy. Of the many outcomes of the crisis, certainly the most important was the recognition of the energy industry's overdependence on foreign sources, thus the demand for solar and other renewables increased. Today, the United States makes up less than 5% of the world population but consumes roughly 23% of the energy produced. As of 2005, the United States was the world's second greatest emitter of greenhouse gases, slightly behind China.[36] While these figures may not change drastically for decades, it is necessary that the United States government adopt policies that make the energy consumed more sustainable.

One of the largest energy bills in years, the Energy Policy Act of 2005 altered federal energy policy in an attempt to fight an expanding array of energy problems. With regards to renewable energy development, the bill authorized loan guarantees and subsidies for alternative energy producers, giving "a short term boost to the developers and investors waiting for better economic incentives to build utility-scale solar facilities."[37] Tax incentives for solar developers increased from 10 to 30 percent and the production tax credit was extended through December 31, 2007. The legislation established Clean Energy Renewable Bonds (CREBs) that allow tax-exempt entities such as governmental organizations or electric cooperatives to issue interest-free bonds. With this program, the borrower only pays back the principal of the bond while the bondholder receives federal tax credits in place of traditional interest payments. These tax credits

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[36] Bill Gross, "Sustainable Energy," 2010 Nelson Speaker Series, Harvey Mudd College, Claremont, California, October 22, 2010.

[37] Fernandes et al., "Renewable Energy in the California Desert," 60.

help to make investments in solar power less risky and foster solar power purchase agreements between developers and utilities. In addition, the Energy Policy Act of 2005 states that within ten years of the date of enactment, the Secretary of the Interior should “seek to have approved non-hydropower renewable energy projects located on the public lands with a generation capacity of at least 10,000 megawatts of electricity."[38]

However, at the same time that the Energy Policy Act of 2005 aided the development of renewable energy, the bill also benefited big oil companies with “billions of dollars in tax and royalty relief to encourage drilling for oil and gas in the Gulf of Mexico and other offshore areas. There was even a $50-million annual earmark to support technical research for the industry.”[39] Policies such as this hinder the renewable industry’s goal of achieving grid-parity, meaning the cost of generating electricity is equal to, or cheaper than the cost of conventional energy sources.

Three years later, the Energy Improvement and Extension Act of 2008, part of the Emergency Economic Stabilization Act of 2008, further extended tax credits and the CREBs program. The 30 percent investment tax credit for solar energy property was extended through 2016 and an additional $800 million in CREBs was authorized for a period of two years.[40]

Early on in Barack Obama’s campaign for president in 2007 and 2008, it was very clear that, if elected, he would maintain a strong focus on the deployment of renewable energy. Once in office, President Obama enacted a Renewable Portfolio Standard (RPS)

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[38] Library of Congress, “Bill Summary and Status: Energy Policy Act of 2005,” available from http://thomas.loc.gov/cgi-bin/bdquery/z?d109:h6:; Internet; accessed October 12, 2010.

[39] Kim Geiger and Tom Hamburger, “Oil companies have a rich history of U.S. subsidies,” *Los Angeles Times*, May 25, 2010.

[40] Department of Energy, “The Emergency Economic Stabilization Act of 2008: Energy Tax Incentives,” available from http://www.energy.gov/media/HR_1424.pdf; Internet; accessed October 12, 2010.

that set a 2025 goal requiring that 25 percent of the United States' power originate from renewable sources. According to the DOE, there are currently 24 states plus the District of Columbia that have enacted similar RPS goals.[41] In an important symbolic step showing his continued commitment to his goal, President Obama agreed to install solar hot water panels and PV technology on the White House roof. Also under his command, the Department of the Interior (DOI) has promised to increase renewable energy capacity on public lands by at least 9,000 MW by 2011, making the Energy Policy Act's target of 10,000 MW by 2015 very feasible.[42]

When the economy took a turn for the worse and entered a recession in December of 2007, the American public looked to the government for answers. Congress passed the American Recovery and Reinvestment Act of 2009 (ARRA), often known as the stimulus package, on February 17, 2009, with roughly $787 billion worth of initiatives aimed at creating jobs and spurring investment and consumer spending. The stimulus package earmarked a significant sum of money to renewable energy. More than $16.8 billion went toward funding the DOE's Office of Energy Efficiency and Renewable Energy (EERE). Additional money was allocated for a new renewable energy grant program that provides 30 percent grants in the form of a cash payment in lieu of investment tax credits for projects that break ground before 2011. Billions more went towards investing in energy

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[41] Department of Energy, "States with Renewable Portfolio Standards," available from http://apps1.eere.energy.gov/states/maps/renewable_portfolio_states.cfm; Internet; accessed October 29, 2010.

[42] Department of the Interior, "New Energy Frontier," available from http://www.doi.gov/whatwedo/energy/index.cfm; Internet; accessed October 29, 2010.

and grid efficiency, transmission technologies, electric vehicles, and renewable energy research.[43]

Developers and investors over the past few years have been critical of the application process for large-scale solar, claiming that it is too long and expensive. Nevertheless, the application and approval process for large plants is very important in addressing the specific effects of each particular project. In California, projects with a generating capacity of 50 MW or greater must endure an extensive review process, requiring approval from both the BLM and the California Energy Commission (CEC). Per state and federal law, the proposal must include an environmental assessment (EA) and an environmental impact statement (EIS) under the National Environmental Protection and an environmental impact report (EIR) under the California Environmental Quality Act. If an EA determines that a project will have significant effect on the environment, then an EIS and EIR need to be prepared. Both documents state the purpose and need for the proposed project, analyze its environmental and socioeconomic impacts, discuss alternatives, and incorporate a public scoping period. Once completed, the final process is to obtain a right-of-way (ROW) grant from the BLM, if the project is to be located on public lands, and an Application for Certification (AFC) from the CEC.

In April of 2009, the BLM announced that they would be implementing a "fast-track" program that would speed up the review process of renewable energy projects if developers could prove their commitment and readiness. The program strives to approve as many proposed solar projects as possible so that they can be eligible for the ARRA's

[43] Internal Revenue Service, "Energy Incentives for Businesses in the American Recovery and Reinvestment Act," available from http://www.irs.gov/newsroom/article/ 0,,id=209564,00. html; Internet; accessed October 29, 2010.

grants that expire at the end of 2010 and the United States can meet its RPS goals. Ethan Zindler, Head of Policy Analysis at Bloomberg New Energy Finance, believes that "large-scale CSP stands to benefit. Right now, the process of filing for an individual EIS for each project is long and time-consuming and expensive. Anything to make the process more streamlined, fast-trackable and predictable would be a good thing."[44] The Administration hopes to achieve exactly this in order to make solar development more attractive for developers and investors.

2.2.2 California and regional policy

In California, where the majority of solar projects in the United States have been proposed or already approved, the state government has enacted numerous policies in just the last decade that promote the development of solar. Leading the way in renewable energy and battling climate change, California is making itself one of the best states to deploy renewable energy projects. Most significantly, the state adopted what is considered to be the world's most ambitious law to combat climate change.

Signed into law by Governor Arnold Schwarzenegger on September 27, 2006, the Global Warming Solutions Act, usually referred to as simply AB 32, uses market-based incentives to reduce the state's carbon emissions to 1990 levels by 2020 and to 80 percent below 1990 levels by 2050. The timetable created by the bill attempts to bring California into compliance with the Kyoto Protocol, which the Bush Administration rejected on the federal level in 2001. As noted in the bill, large emitters are required to report annual greenhouse gas emissions and an emissions limit will be implemented on January 1, 2012

[44] Bob Moser, "The BLM fast track: Speeding CSP project development in the US?" *CSP Today*, July 16, 2010, available from http://social.csptoday.com/industry-insight/blm-fast-track-speeding-csp-project-development-us; Internet; accessed November 6, 2010.

with the possible utilization of a market-based cap-and-trade system.[45] Overall, AB 32 encourages the development of renewable technologies and the adoption of small and large-scale alternative energies such as solar in order to cut harmful emissions that contribute to global warming.

California has also set RPS targets of its own. Established in 2002, its target was accelerated in 2003 under Energy Action Plan I to require "electric corporations to increase procurement from eligible renewable energy resources by at least 1% of their retail sales annually, until they reach 20% by 2010."[46] Senate Bill 107 later codified the deadline, the most aggressive in the United States, into law. Two years later, Governor Schwarzenegger issued Executive Order S-14-08 mandating that utilities reach 33 percent renewable sources by 2020.[47] In 2008, non-hydro renewable made up just 11% of California's total system power (Figure 2-2). In order to meet the 33% RPS target, renewable electricity generation needs to triple from 27 terawatt hours (TWh) in 2009 to approximately 75 TWh in 2020.[48] These ambitious goals set out by the state have further helped spur solar development. In order to facilitate this rise in solar, numerous new transmission lines must be built to transmit the electricity generated from renewable sources in the desert and other remote areas to the consumer.

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[45] California Air Resources Board, "Assembly Bill 32: Global Warming Solutions Act," available from http://www.arb.ca.gov/cc/ab32/ab32.htm; Internet; accessed October 15, 2010.

[46] California Public Utilities Commission, "RPS Program Overview," available from http://www.cpuc.ca.gov/PUC/energy/Renewables/overview.htm; Internet; accessed October 15, 2010.

[47] Office of the Governor, "Executive Order S-14-08," November 17, 2008, available from http://www.gov.ca.gov/executive-order/11072/; Internet; accessed October 15, 2010.

[48] California Public Utilities Commission, "33% Renewables Portfolio Standard Implementation Analysis Preliminary Results," June 2009, available from http://www.cpuc.ca.gov/PUC/energy/Renewables/hot/33implementation.htm; Internet; accessed October 20, 2010.

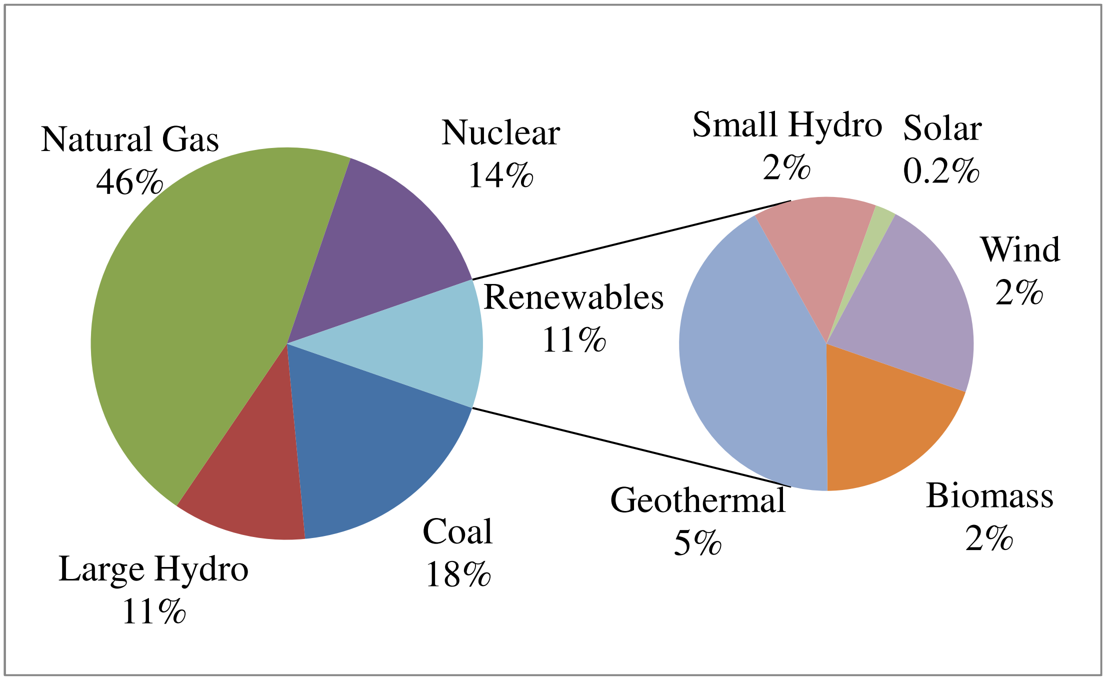

Figure 2-2. California total system power (by source, 2008)[49]

To address the issue of transmission lines, California has adopted the statewide Renewable Energy Transmission Initiative (RETI). The RETI effort seeks to identify the transmission projects and transmission corridors that are needed in order to meet the RPS goals. The initiative also hopes to prepare transmission line plans for projects that are the most inexpensive and have few effects on the natural environment.[50] The issues regarding transmission line siting and construction will be discussed in the next chapter.

Because of the influx of solar applications since RPS and other state and federal mandates have been implemented, the DOE and DOI have begun to prepare a Solar Energy Development Programmatic EIS (PEIS) that would help to expedite the long and expensive application process for solar projects. The PEIS covers the six western states of

[49] California Energy Commission, "Total Electricity System Power," available from http://energyalmanac.ca.gov/electricity/system_power/2008_total_system_ power.html; Internet; accessed September 23, 2010.

[50] California Energy Commission, "Renewable Energy Transmission Initiative," available from http://www1.eere.energy.gov/solar/linear_concentrator_rnd.html; Internet; accessed September 29, 2010.

California, Arizona, Colorado, New Mexico, Nevada, and Utah and will assess the environmental, cultural, and socioeconomic impacts of "broad agency actions, such as the development of programs or the setting of national policy."[51] More specifically, the PEIS will steer future application decisions, evaluate the cumulative effects of numerous projects, consider mitigation strategies, and identify BLM lands that are potentially environmentally suitable for development. If the BLM offices in the six-state study area were to adopt a new solar energy development program, the agency would be better equipped to process and review new project applications, resulting in more sustainable projects in predetermined areas and quicker application turnover.

The BLM's fast-track program in California, also aimed at dealing with the influx of solar applications, has been very successful up to date. Of the eight solar projects in the BLM's California Desert District (Figure 2-3) considered for the fast-track process, seven have been approved. In an October 2010 interview with online magazine *Yale Environment 360*, John Woolard, CEO of BrightSource Energy, proclaimed that the United States has "done 74,000 permits for oil and gas in the last 20 years and we finally have five or six for solar. That's a good step forward. The agencies are learning how to permit, they're learning how to move forward."[52] He adds that if policies continue to be implemented that accelerate the application and approval process, the future looks bright for solar energy development.

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[51] Department of Energy and Department of the Interior, "Solar Energy PEIS Fact Sheet," available from http://solareis.anl.gov/documents/index.cfm; Internet; accessed November 9, 2010.

[52] Todd Woody, "In California's Mojave Desert, Solar-Thermal Projects Take Off," *Yael Environment 360*, October 27, 2010, available from http://e360.yale.edu/content/feature.msp?id=2334; Internet; accessed November 3, 2010.

Figure 2-3. Bureau of Land Management California Desert District[53]

In addition to policies affecting large-scale solar, the state of California has also adopted policies that promote distributed generation solar, most commonly in the form of rooftop PV arrays. Through the "Go Solar California!" campaign, the CEC and the California Public Utilities Commission (CPUC) encourage home and business owners to install 3,000 MW of solar systems statewide by 2016, which could contribute significantly to the state's energy portfolio. As part of the campaign, the California Solar Initiative funds small solar systems and provides customers with incentives based on the performance of the solar systems. The New Solar Homes Partnership, also part of the campaign, incentivizes home builders to construct new, energy efficient homes that incorporate PV. Small system owners are allowed to earn credits from feeding surplus

[53] Bureau of Land Management, "California Desert District," available from http://www.blm.gov/ca/st/en/fo/cdd.html; Internet; accessed September 20, 2010.

electricity back to the grid through net-metering. Moreover, feed-in tariffs currently permit the owners of small systems to sign 10-20 year contracts with utility companies, allowing them to sell electricity at a calculated price.

One outcome of all of the debate and legislation affecting solar energy is that it has created a divide amongst interested and affected parties, sometimes pitting "green versus green." The main argument is whether combating the long-term effects of global climate change through the generation of carbon-free electricity is worth compromising the local environment affected by solar projects. While many of the aforementioned policies promote solar development, they do not deal directly with conservation efforts. As a result, conservationists have raised questions concerning the ecological impacts of solar projects and whether siting decisions are made in a responsible manner.

Introduced to the United States Senate in December 2009, one bill hopes to bridge this divide. The California Desert Protection Act of 2010, proposed by Diane Feinstein (D-CA), would establish nearly 1.1 million acres as national monuments or wilderness designations, rendering them permanently undevelopable. However, of the 351,000 acres of land designated by the BLM as Solar Energy Study Areas, none would be affected by the legislation. The bill also contains provisions to increase solar development on military lands and expedite renewable energy projects proposed on private lands.[54]

2.3 Benefits of solar in the Mojave Desert

Solar development in the Mojave Desert would come with numerous benefits to the state and region. Most significantly, solar development would create thousands of

[54] Campaign for the California Desert, "Renewable Energy Development Fact Sheet," available from http://www.californiadesert.org/; Internet; accessed October 23, 2010.

jobs in a region that is suffering greatly from the effects of the recession. In July of 2010, San Bernardino and Riverside counties experienced unemployment rates of 14.8% and 15.4%, respectively, among some of the highest in the country.[55] Unemployment rates this high in these counties have not been recorded since 1990 when the Bureau of Labor Statistics began recording countywide employment data. The demand for "green" jobs due to solar plant construction and operations would most certainly help to curb unemployment rates in the desert region.

There exist few places in the world that are so predisposed to such favorable solar generation conditions as the Mojave Desert. With high solar radiation, large cities nearby, millions of acres of undeveloped land, and advantageous government policies, California and the Mojave Desert can become the world's hub for solar technologies. The state, already home to many "cleantech" startups, could attract even more companies, investors, research organizations, and innovators to the region, which would generate revenue for both the state and desert region.

A 2006 National Renewable Energy Laboratory (NREL) study of the economic and environmental benefits of CSP development in California calculated results assuming a scenario in which 4,000 MW of CSP would be deployed by 2020. They found that power generation by CSP power plants in place of natural gas plants would offset "at least 300 tons per year of NO_x emissions, 180 tons of CO emissions per year, and 7,600,000 tons per year of CO_2." The report also concluded that CSP plant operations would create more permanent jobs than a natural gas plant and each dollar spent on CSP

[55] Bureau of Labor Statistics, "Local Area Unemployment Statistics," available from http://bls.gov/data/; Internet; accessed November 24, 2010.

compared to each dollar spent on natural gas plants contributes more to California's Gross State Product.[56]

[56] Stoddard, Abiecunas, and O'Connell, "Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California," 11.

3 Impacts

There are many challenges that come with utility-scale solar power generation in the Mojave Desert. Though solar energy systems contribute to the sustainable development of human activities because of their use of clean and renewable sources, just like any method of electricity generation, solar plants have detrimental impacts on the environment. The goal of permitting agencies and participating parties is to minimize the negative effects of solar development on the environment, plant and animal species, and humans. Because of the considerable pressures placed on permitting agencies by the state and federal government to quickly review proposals in order to meet RPS targets and other requirements, some of the impacts can be given insufficient attention or looked over completely. Though the extent and severity of the impacts of solar development cannot be 100 percent known for certain because such few solar plants have been operated at a large scale, mitigation measures and sensible planning must be utilized before solar deployment.

3.1 Land use

All commercial-scale solar plants require vast tracts of land to generate electricity. For technologies exhibiting economies of scale, the larger the solar field, the more efficient the power system is, and therefore it is often in the developers' best interest to construct systems that span thousands of acres. Solar thermal technology has a clear advantage over photovoltaic technology in terms of land use because of its higher efficiency (Table 3-1). Based on data from current and proposed solar plants with varying CSP technology types, power tower and dish engine systems are more than twice as efficient as parabolic trough systems, meaning they produce more MWh per acre distributed. Thin film photovoltaics require more land per MWh produced than any other type of technology.

Proposal Name	Nameplate Capacity	MWh Produced Per Acre Distributed	CSP or PV	Technology Type
Solar Millennium - Blythe	1,000	352.11	CSP	Parabolic Trough
Solar Millennium - Ridgecrest	250	283.90	CSP	Parabolic Trough
Solar Millennium - Palen	484	336.50	CSP	Parabolic Trough
Beacon Solar Energy Project	250	455.95	CSP	Parabolic Trough
Abengoa Mojave	250	409.60	CSP	Parabolic Trough
Genesis Solar	250	407.00	CSP	Parabolic Trough
City of Palmdale - Hybrid Gas-Solar	62	356.46	CSP	Parabolic Trough
Parabolic Trough Average	364	371.65		
Calico (formerly Solar One)	850	1000.20	CSP	Dish Engine
Imperial Valley (formerly Solar Two)	750	845.20	CSP	Dish Engine
Dish Engine Average	800	922.70		
Ivanpah	400	991.70	CSP	Power Tower
Power Tower Average	400	991.70		
Chevron Lucerne Valley	60	211.55	PV	Thin Film
FirstSolar's Desert Sunlight	550	226.90	PV	Thin Film
PV Average	305	219.23		

Table 3-1. Land use efficiency by project size and technology type[57]

These vast tracts of land may already be used for other kinds of activities such as mining, livestock grazing, agriculture, or recreational use. Mining production in the California Desert is currently valued at more than $1 billion a year, making it a vital economic activity for California and the United States.[58] In converting the land to area suitable for solar development, previous land uses are lost. In the California Desert

[57] Fernandes et al., "Renewable Energy in the California Desert,"104.

[58] Bureau of Land Management, "CDCA Development," available from http://www.blm.gov/ca/st/en/fo/cdd/cdca_development.html; Internet; accessed November 4, 2010.

Conservation Area, the BLM is in charge of protecting and preserving close to 11 million acres. This responsibility involves overseeing and defending the natural, historic, recreational and economic assets of the California Desert.

Not under the oversight of the BLM are the 4,743,574 acres of the Mojave Desert that are privately owned or the 139,154 acres that belong to Native American tribal lands.[59] Much of the Mojave Desert can be described as a "checkerboard" of public and private land, making development across many acres difficult because projects may cross tracts of land that belong to multiple private landowners. Some developers prefer the advantages of siting on public land only: working with one federal landowner (as opposed to many private landowners), the capability of returning the land if the project does not go through, the fast-tracking process. Others prefer the advantages of siting on private land: a faster permitting process, a fixed price for the land used, often level land from previous agricultural use. Despite the differences of constructing solar power on public versus private land, the impacts of such projects can be observed outside of just the acres designated for development. Solar facilities require roads to facilitate the construction and operation of the plants and transmission lines to facilitate the transmission of electricity to areas where there is demand. These construction activities further alter the natural landscape.

One recent study looked at the importance of the Mojave Desert as a carbon sink. The authors found that the "desert ecosystem CO_2 exchange may be playing a much larger role in global carbon cycling…than previously assumed.[60] The construction of

[59] Randall et al., "Mojave Desert Ecoregional Assessment," 18.

[60] George Wohlfahrt, Lynn F. Fenstermaker, and John A. Arnone III, "Large annual net ecosystem CO_2 uptake of a Mojave Desert ecosystem," *Global Change Biology* (2008) 14: 1475-1487.

solar systems involves the destruction of soil, plants, and animals through bulldozing, the grading of land, and the installation of facility structures. This process releases large amounts of carbon into the atmosphere and reduces the future carbon sequestration abilities of the ecosystem.[61] Whether this release of carbon is greater than the amount of carbon saved from entering the atmosphere by utilizing renewable technologies instead of conventional energy sources is unknown and debated.

3.2 Desert ecosystem

The most obvious impact of solar electricity generation in the Mojave Desert is its degradation of the ecosystem. The implementation of CSP and PV systems causes incalculable effects on the stability, diversity, and productivity of the desert's land and plant and animal species. These impacts are both seen in the short-term and long-term. After grading, vegetation removal, and soil disturbance has occurred, "recovery to predisturbance plant cover and biomass may take 50–300 years, while complete ecosystem recovery may require over 3000 years."[62] The desert's slow rate of recovery means that natural landscapes would be affected for many years after the construction and/or decommission of solar projects.

Arrays of photovoltaics and mirrors across large fields obstruct natural sunlight, rainfall, and drainage. This interference could result in diminished plant growth, poor soil stability, soil compaction, vulnerability to wind erosion, increased dust emission, altered nutrient cycles, uneven water infiltration, and diverted water flow, among other impacts.

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[61] Holly Campbell et al., "Here Comes the Sun: Solar Thermal in the Mojave Desert – Carbon Reduction or Loss of Sequestration?" March 13, 2009, 22.

[62] Jeffrey E. Lovich and David Bainbridge, "Anthropogenic Degradation of the Southern California Desert Ecosystem and Prospects for Natural Recovery and Restoration," *Environmental Management* 24 (1999): 309.

Ecological impacts such as these can completely alter the Mojave Desert's natural cycles that have made the region suitable for the native flora and fauna for millions of years.

One considerable concern indicated by desert biologists is the proliferation of fires in the future, a direct result of human activity. In the desert, native species, especially perennial plants, are not adapted to frequent fires. Solar development facilitates the spread of invasive plant species, which increase the frequency of fires. The decomposition of organic matter in the desert occurs at a slow rate, therefore the buildup of plant material acts as added fuel for destructive fires. Invasive grasses and shrubs such as *Bromus, Schismus,* and *Salsola* have decreased plant community spacing and increased groundcover, making the California desert much more vulnerable to fire.[63] The potential for Mojave Desert ecosystems to recover from such blazes is low.

Accidental chemical discharges or leakages also represent a threat to the health of the ecosystem. PV technology is sometimes made up of hazardous materials, and if damaged during the life of the plant, these materials can pollute the surrounding environment. The HTF of CSP systems are of more concern because the fluid is often heated to a very high temperature, thus posing a fire risk if discharged or leaked. Other fluids found at the solar facilities can be hazardous and could damage the plant and animal species. If any of these fluids were to reach soil or groundwater, there would be a danger to the public as well.[64]

Vehicle traffic in the Mojave Desert has been the cause of the deaths of numerous animal species. The deaths of desert tortoises and other animals attempting to cross roads

[63] Ibid., 318.

[64] Theocharis Tsoutsos, Niki Frantzeskaki, and Vassilis Gekas, "Environmental impacts from the solar energy technologies," *Energy Policy 33 (2005) 289-296.*

are inevitable even though measures have been taken to try to mitigate the problem. Increased vehicle traffic for construction activities and general plant operations would surely increase the number of unintended fatal vehicle strikes. Vehicles and construction equipment also facilitate the introduction of nonnative and invasive plant species, acting as transporters of seeds from one place to another.

The Mojave Desert is a critical corridor for wide-ranging species such as the jackrabbit and desert bighorn sheep. Fences (serving as security for the solar plants and as a barrier to prevent wildlife from entering project sites) and roads can block off these corridors, restricting or blocking a species' ability to migrate or access suitable habitat areas. For example, the desert bighorn sheep might abstain from crossing a busy road because of the risk of getting hit, essentially resulting in a loss of habitat due to fragmentation.

3.3 Endangered species

The Mojave Desert's geographic isolation has allowed for great speciation and high biodiversity. However, speciation as a result of isolation has also made species more susceptible to extinction by limiting their natural habitats to specific regions and reducing their population size due to reproductive isolation. The Endangered Species Act (ESA), signed into law in 1973, was designed to prevent the extinction of species by protecting threatened plants and animals, preserving critical habitat areas, enacting recovery plans, and prohibiting activities that may further endanger a listed species. Numerous federally listed species call the Mojave Desert home. Although critically endangered, endangered, and vulnerable species are protected under federal law, the imminent rise in solar developments will adversely affect these populations.

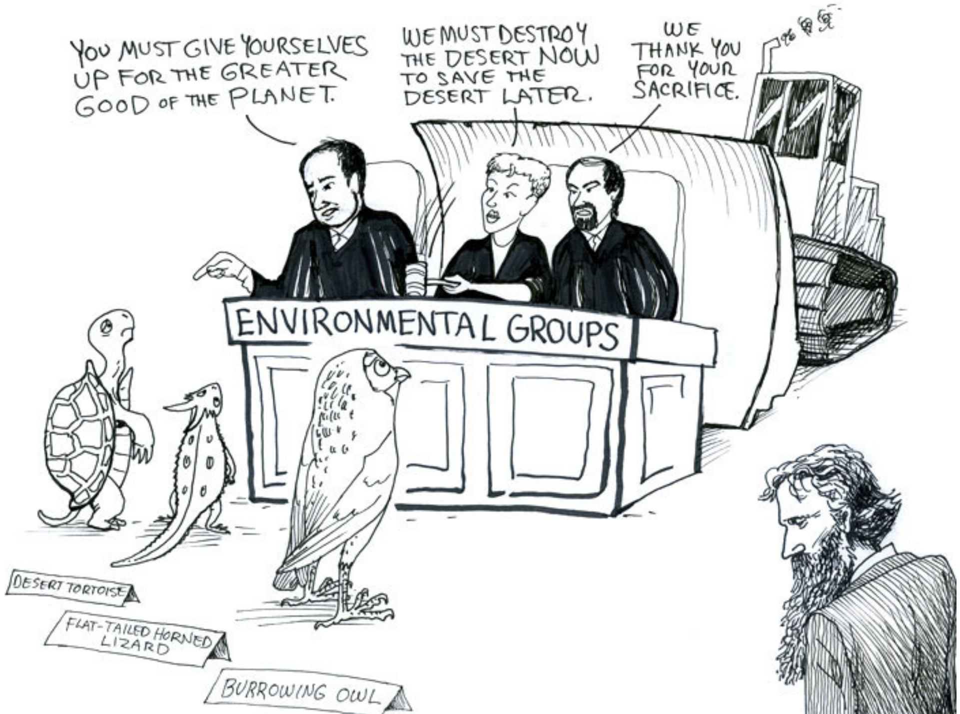

Figure 3-2. Some environmental groups views on solar development[65]

The desert tortoise, one of the most widely-known listed species for its recovery efforts, has been listed under the ESA since 1990. A surprising number of solar developments are being built or are proposed to be built in or near the tortoise's designated critical habitat areas. While most of the sited land may not be designated as "critical" habitat for the desert tortoise, solar developments will increase habitat fragmentation and restrict its migration between critical habitats, which is extremely important for the full recovery of the species. Fires affect the mortality rate of tortoises by directly killing them or burning their habitat and sources of food. Solar facility infrastructure (fences, transmission lines, buildings, etc.) also creates avian perching

[65] Basin and Range Watch; available from http://www.basinandrangewatch.org/ Cartoons.html; Internet; accessed September 12, 2010.

opportunities that could increase the number of birds that prey on the newly-hatched desert tortoise such as the common raven. As a result of these various impacts, populations have seen continued declines for a number of years.[66]

Other endangered species such as the Coachella Valley fringe-toed lizard and the foxtail cactus face similar scenarios. Whether they are threatened by invasive species, decreased water availability, or greater human presence, endangered species in the Mojave Desert are fighting for survival because of an increase in solar development.

3.4 Transmission lines

In order to bring the approved solar projects on line in California, massive improvements to existing transmission line and construction of entirely new transmission lines are necessary. The state's RETI aims to facilitate transmission corridor designation and transmission siting permitting. Solar developers maintain that "while solar projects are in the fast-lane, transmission projects are still in the slow-lane." John Woolard compares the encouragement of solar energy development in the desert without transmission infrastructure to support it to "promoting interstate commerce without the infrastructure to achieve it."[67] Though transmission lines are characterized by long, narrow corridors, their impacts are not confined to their immediate areas; their impacts usually extend far past the physical structures and linear corridors.

While transmission lines are necessary, just as roads and fences cause habitat loss, degradation, and fragmentation, transmission lines cut across hundreds of miles, disrupt the natural environment, and pose a fire risk. Soil disturbance during construction allows

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[66] Fernandes et al., "Renewable Energy in the California Desert," 118.
[67] Todd Woody, "In California's Mojave Desert, Solar-Thermal Projects Take Off."

the intrusion of invasive plant species and contributes to soil erosion. Transmission towers placed on sloped land can significantly increase wind erosion and erosion from water runoff.

When transmission lines are first constructed, the recovery of the disturbed land is gradual. Immediately following construction, invasive ephemeral plant species inhabit the area, but perennial plant species could not return for more than five years after.[68] Increased human access via roads accompanying transmission lines can hinder this plant growth and deter animals from inhabiting the corridor.

3.5 Water use

Solar electricity systems require significant amounts of water annually to operate and have very serious impacts on groundwater and surface water availability. In the Mojave Desert, where water resources are scarce, water use is a very heated issue. Parabolic trough plants and power towers sometimes use water as an HTF and for cooling systems. They also use a very small amount of water for washing heliostats and mirrors. Photovoltaic plants do not require cooling systems and only use water to clean dust and other particles off of PV arrays to improve efficiency.

CSP technology types are capable of using either a wet or dry-cooling system. Though water is inexpensive and effective for cooling, water scarcity issues have forced some projects to employ dry-cooling. Dry-cooling systems utilize fans to blow air directly across solar arrays and wet-cooling systems utilize water to create an evaporative cooling effect. While dry-cooling drastically reduces water consumption, overall power

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[68] Lovich and Bainbridge, "Anthropogenic Degradation of the Southern California Desert Ecosystem and Prospects for Natural Recovery and Restoration," 314.

generation performance is decreased and operation costs are increased. Most power towers are beginning to use dry-cooling systems and dish engine systems never use water for cooling. Water use efficiency in parabolic trough plants that employ dry-cooling systems is over ten times higher than that of parabolic trough plants that employ wet-cooling systems (Table 3-2). Power towers use even less water per MWh produced, and dish engine technology uses a fraction of the water used in any other solar thermal plant type.

Proposal Name	Water Consumption per Unit of Electricity Produced (Gal/MWh)	Cooling Type	Technology Type
Solar Millennium - Blythe	93	Dry	Parabolic Trough
Solar Millennium - Ridgecrest	98	Dry	Parabolic Trough
Solar Millennium - Palen	98	Dry	Parabolic Trough
Parabolic Trough Average	96		
Beacon Solar Energy Project	869	Wet	Parabolic Trough
Abengoa Mojave	557	Wet	Parabolic Trough
Genesis Solar	1,786	Wet	Parabolic Trough
Parabolic Trough Average	1,071		
Ivanpah	34	Dry	Power Tower
Rice Solar Energy Project	109	Dry	Power Tower
Power Tower Average	71.52		
Calico (formerly Solar One)	3.94	N/A	Dish Engine
Imperial Valley (formerly Solar Two)	4.10	N/A	Dish Engine
Dish Engine Average	4.02		

Table 3-2. Water use efficiency based on annual water consumption per project and technology[69]

A big concern for people dependent on water in the American Southwest is where water will come from in the future. A 2008 study predicts that Lake Mead, a key water source for millions of people in this region, has a 50 percent chance of drying up by

[69] Jesse Fernandes et al., "Renewable Energy in the California Desert," 110.

2021.[70] If Lake Mead does dry up as predicted, southwestern states will have a severe crisis on their hands. The hydrology of the desert has already exhibited its sensitivity to regional water use as increased consumption from cities like Las Vegas has directly affected groundwater systems.

3.6 Air quality

Though global air quality will generally benefit from the deployment of CSP and PV, local air quality could suffer. The Mojave Desert is a region that has very little air pollution because of its lack of industry and its vast tracts of undeveloped land. With the introduction of more solar facilities to the desert, more emissions of pollutants into the atmosphere would occur. Sometimes, solar thermal plants are used in conjunction with hybrid fossil fuel systems to generate electricity during the night or when it's cloudy. In the SEGS plants in the Mojave Desert, generated power from natural gas systems accounts for about ten percent of total generation power per year.[71] Electricity generation from fossil fuels used in conjunction with solar plants produces harmful emissions that affect the local environment.

Additional emissions would come from increased traffic to and from the solar generating facilities. During construction, a temporary increase in emissions from construction vehicles and equipment would be seen. Nitrogen deposition would increase due to human activities and is known to be a threat to biodiversity and ecosystems

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[70]Robert Monroe, "Lake Mead could be dry by 2021," UC San Diego, February 12, 2008, available from http://ucsdnews.ucsd.edu/newsrel/science/02-08LakeMead.asp; Internet; accessed November 12, 2010.

[71] Hunold and Leitner, "'Hasta la vista, Baby!' The Solar Grand Plan, Environmentalism, and Social Constructions of the Mojave Desert," Paper presented at the annual meeting of the WPSA, Hyatt Regency Vancouver, Vancouver, BC Canada, March 19 2009, available from http://www.allacademic.com/meta/p317497_index.html; Internet; accessed September 20, 2010, 5.

because of its toxicity to native plants and apparent benefit to non-native species.[72] Impaired visibility from the emission of air pollutants would also impact the region's aesthetic value.

3.7 Socioeconomic effects

The previous sections focus on the environmental effects of solar development but do not address the socioeconomic dimensions that the entire region will confront. Some residents of the desert have formed solar development opposition groups that hope to convince developers and permitting agencies to mitigate the negative socioeconomic effects of large-scale solar. Unlike some states, communities in the Mojave Desert will not receive rent payments from the development of solar despite the fact that they will bear the brunt of the negative impacts that come with solar generation. Instead, lease payments from projects on BLM lands are paid to the U.S. Treasury and are not directly seen by Californians. Additionally, because of heightened demand for land in the Mojave Desert from solar developers, the cost of private land has risen from around $500 an acre to $10,000 an acre in the past five years.[73] On the other hand, land costs could also decrease if transmission lines are built close by, disrupting the landscape vista. Desert residents and visitors will also see increased traffic and pollution.

Solar generation *will* offer local communities job opportunities, mainly in manufacturing and construction. The exact number of jobs to be created in the near future from solar development is unknown, but employment will provide the local economy with more revenue, spurring investment and local economic growth. It is also unclear

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[72] J. M. Randall et al., "Mojave Desert Ecoregional Assessment," 62.

[73] Campbell et al., "Here Comes the Sun: Solar Thermal in the Mojave Desert – Carbon Reduction or Loss of Sequestration?" 10.

whether tourism, recreational activities, or quality of life will increase or decrease as a result of development.

3.8 Aesthetic effects

The aesthetic effects of solar development, though highly subjective, are also important to recognize. Along with increased traffic and visible pollution, residents could be affected by noise pollution and the appearance of solar arrays, transmission lines, new roads, and other accompanying infrastructure. Visual externalities such as construction workers, traffic, and transmission lines could have a measurable impact on tourism in the Mojave Desert. While many visitors already flock to the desert to visit the national parks and monuments, solar farms could increase or decrease tourism based on public perception.[74] Similar to the public perception of wind farms, some believe that solar farms negatively affect the public vista whereas others might see the solar farms as a tourist attraction.

Noise pollution from solar thermal plants that employ dry cooling could diminish the quality of life for nearby residents as well. The giant fans used for cooling create a noise that could disturb residents, making camping, hiking, and other recreational activities less enjoyable. The types of transmission poles installed in certain locations have been known to create controversy and details regarding pole visibility, color, and size are often included in environmental impact statements.

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[74] Tsoutsos, Frantzeskaki, and Gekas, “Environmental impacts from the solar energy technologies,” 292.

4 Conclusion

As the United States and California continue to increase solar energy generation in the near future, it is important to address all of the issues and challenges presented by each project. Policymakers, permitting authorities, investors, developers, and residents alike must work together to identify the impacts of solar development, determine the best ways to mitigate the negative impacts, and ultimately implement the technology responsibly. All actors involved must make informed land use decision making in order to avoid lasting and pervasive impacts. By utilizing an ecological approach that builds from the ground-up and understands the local environment, challenges confronted can be dealt with more easily.

4.1 Recommendations

Given the analysis of policies affecting solar development and the benefits and impacts of solar generation in the Mojave Desert, this section offers fundamental yet useful recommendations that aim to support continued growth of large-scale solar and avoid or mitigate negative impacts:

1. Projects should be "smart from the start," meaning they should be sited on level, degraded or disturbed land with low value for wildlife, near existing roads, transmission lines, and water sources. Brownfield sites should be explored as options. Lands of highest conservation value, critical for the long-term conservation of biodiversity, should remain untouched. Where projects are not located is as important as where they are located. Solar developments

should also minimize aesthetic effects by listening to public input. Also, planning should begin early and involve cooperation between developers, permitting agencies, and the public.

2. Habitat fragmentation should be minimized by building transmission lines (if necessary) near roads.
3. Solar arrays should be constructed with as few points of contact with the land as possible so the ecosystem is less disturbed.
4. Efficient technologies (power towers, dish engine, parabolic trough, CPV) should be promoted in the near-term until other technologies become more efficient. This way, the amount of land and water used per MWh generated is reduced.
5. Dry-cooling systems should be favored in parabolic trough and power tower systems because of the adverse effects of water use on the desert ecosystem and the uncertainty of the availability of water in the near future.
6. It is necessary to recognize the cumulative, regional-level impacts of utility-scale solar development and various policies affecting solar. For example, it is important to know if water use in Nevada affects the Mojave Desert ecosystem in California.
7. A program should be developed whereby local communities receive money from the rent payments to the U.S. Treasury in order to compensate for the negative socioeconomic effects.

8. Subsidies to big oil companies should be cut. During years of record profit for oil companies, the federal government was pouring money into programs that offered tax breaks and royalty waivers to encourage offshore drilling.
9. Government policies should continue to subsidize renewable energy development in order to make solar energy technologies more competitive in the marketplace. If government agencies stop "incentives that vastly reduce the risks to investors, solar companies planning another dozen or so plants say they may not be able to raise enough capital to proceed."[75]
10. Research and development in solar technologies and energy transmission infrastructure should be supported by both the federal government and California government in order to improve efficiency, spur innovation, and potentially bring in money from the sale of solar energy products and services.

4.2 Conclusion

Solar development in the Mojave Desert of California comes with numerous advantages. The region, state, and country would stand to benefit from job growth, diversification and security of energy sources, independence from foreign fuels, innovation, and a reduction of greenhouse gas emissions. Despite these benefits, solar energy still faces a long road ahead. The Mojave Desert is a fragile ecosystem sensitive to minor changes, and pressures from solar developers are testing its limits. Policies and strategies need to be formulated that will accommodate solar development while preventing or mitigating the adverse impacts of solar energy generation in the Mojave

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[75] Todd Woody, "Solar Power Projects Face Potential Hurdles," *New York Times*, October 28, 2010, available from http://www.nytimes.com/2010/10/29/business/energy-environment/29solar.html?_r=2; Internet; accessed October 29, 2010.

Desert. This paper is intended to provide an overview of the issues surrounding solar development in the Mojave Desert.

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