Feasibility Study of Economics and Performance of Solar Photovoltaics at the Chino Mine in Silver City, New Mexico

A Study Prepared in Partnership with the Environmental Protection Agency for the RE-Powering America's Land Initiative: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites

Kosol Kiatreungwattana, Jesse Geiger, Victoria Healey, and Gail Mosey

Produced under direction of the U.S. Environmental Protection Agency (EPA) by the National Renewable Energy Laboratory (NREL) under Interagency Agreement IAG-09-1751 and Task No. WFD3.1001.

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Technical Report
NREL/TP-7A30-57959
April 2013
Contract No. DE-AC36-08GO28308

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Executive Summary

The U.S. Environmental Protection Agency (EPA), in accordance with the RE-Powering America's Land initiative, selected the Chino Mine site in Silver City, New Mexico, for a feasibility study of renewable energy production. The National Renewable Energy Laboratory (NREL) provided technical assistance for this project. The purpose of this report is to assess the site for a possible photovoltaic (PV) system installation and estimate the cost, performance, and site impacts of different PV options. In addition, the report recommends financing options that could assist in the implementation of a PV system at the site. This study did not assess environmental conditions at the site.

The Chino Mine is located near the town of Hurley in Grant County, New Mexico, about 12 miles east of Silver City. Chino Mine, which is owned by Freeport-McMoRan Incorporated (FMI), is one of the largest open-pit copper mines in the world, covering over 9,000 acres. There are three sites for this study. Site 1 is a smelter facility that has 23 acres, and site reclamation is complete. Site 2 has 277 acres, and site reclamation has begun and is scheduled to be complete by the end of 2014. Site 3 is the largest site with 1,700 acres, and reclamation was complete at the end of 2012.

The town of Silver City has three community benefit goals that have evolved over time starting with the application for technical assistance from EPA for this feasibility study. Given existing implementation constraints, the following goals may need creative solutions to be executed in the future:

- Expand regional deployment of renewable energy and support FMI's sustainable development framework. The FMI initiative provides an opportunity to further pursue regional deployment of renewable energy and support the area's largest employer.
- Offset municipal electric costs of the mining district. An evolving goal of this solar project is to provide a substantial economic benefit to the mining district community by offsetting their municipal electric costs.
- Offset municipal electric costs of proposed regional water system. Silver City and the mining district are planning the expansion and integration of individual water systems to a regional water distribution system whose pumping costs may be offset in large part by solar generation.

The feasibility of a PV system installed is highly impacted by the available area for an array, the solar resource, distance to transmission lines, and distance to major roads. The potential closest electrical tie-in location is at the Hurley substation. Having a substation on-site makes it an ideal location for a PV system to tie into. A detailed interconnection study is recommended and will have to be performed through the local electric utility, Public Service of New Mexico (PNM), or a third party to determine the feasibility of utilizing the on-site substation as a tie-in point for a PV system. The Chino Mine site is suitable for a large-scale PV system because it is nearly flat, has adequate road and solar access, is zoned for industrial uses, and has extensive electrical distribution to the whole site. PV cost for crystalline panels has come down dramatically and become competitive with thin-film technology. For this analysis, we assumed crystalline PV panels for this analysis. Per discussion with the geologist from the state of New Mexico, using driven piles for a ground-mounted system would be acceptable for the Chino Mine site if there was no depression next to the piles in the dirt, but in fact a small mound around each one to keep water from pooling around it. Additional considerations could be associated with designing, installing, and operating the PV system in order to maintain the integrity and effectiveness of the remediation solution or cap on the reclaimed tailings. Although a tracking system can produce more electricity, it has higher capital and long-term maintenance costs. Therefore, a fixed-tilt, ground-mounted PV system that uses driven piles is recommended for this study. Estimated PV system size and generated electricity is presented in Table ES-1.

Table ES-1. Estimated Electricity Production for Each Site

Site	Estimated PV Capacity (MW)	Annual Electricity Production (MWh/yr)	Annual Energy Value ($)
Site 1	4	6,848	753,280
Site 2	48	82,176	9,039,360
Site 3	296	506,752	55,742,720
Total	**348**	**595,776**	**65,535,360**

The Chino Mine site has significant on-site energy use. Annual on-site electricity consumption of the Hurley area is approximately 15,684 MWh/yr (calculated using average monthly consumption). Chino Mine is primarily served by the wholesale electricity market. PNM does not supply the electricity to Chino Mine, so they are not obligated to net meter. Further negotiation with PNM and the public utility commission (PUC) could be required for a net-metering arrangement in the future. Currently, net metering is not an available option for the site.

The economic performance of a PV system installed on the site is evaluated using a combination of the assumptions and background information discussed previously, as well as a number of industry-specific inputs determined by other studies. In particular, this study uses the NREL System Advisor Model (SAM). Using varied inputs and the assumptions summarized in Section 5 of this report, the SAM tool predicts net present value (NPV), power purchase agreements (PPA), and levelized cost of energy (LCOE), among other economic indicators.

To evaluate employment and economic impacts of the PV project associated with this analysis, NREL's Jobs and Economic Development Impact (JEDI) models are used. JEDI estimates the economic impacts associated with the construction and operation of distributed generation power plants. It is a flexible input-output tool that estimates, but does not precisely predict, the number of jobs and economic impacts that can be reasonably supported by the proposed facility.

There are three scenarios for the analysis. All detailed assumptions and results for the analysis can be found in the appendices.

Case 1—Investor owned/PPA with 348 MW

This case assumes a third-party investor exists for the PV system. All electricity is assumed to be sold. The results of this case are to estimate the electricity rate as a PPA to receive an acceptable return on investment (15% internal rate of return).

Case 2—Developer owned/PPA with 348 MW

This case assumes FMI owns the PV system. All electricity will be sold as a PPA with PNM or an interstate utility at the rate of $0.055/kWh.

Case 3—Developer owned/virtual net metering with 348 MW

Virtual net metering (VNM) is currently not available in New Mexico. Case 3 is to demonstrate the potential economic benefits for this option. This case assumes FMI owns the PV system. All electricity would be VNM to generate credits at a retail electricity rate that can be used to offset charges at one or more other locations within the same geographic boundary. Retail electricity rate at $0.11/kWh is used for this analysis.

Results

Three scenarios were run for the Chino Mine to encompass the options available to this site. The independent variables include a third-party developer versus existing site ownership. There are multiple factors that go into choosing which scenario to pursue beyond NPV, PPA, and LCOE. Table ES-2 shows the modeled results from the different scenarios.

Case 1—Investor owned/PPA will work if the investor can sell the electricity of the PPA at $0.0727/kWh. Because the retail rate of the electricity at $0.045/kWh is a lot lower than that of the PPA, the Chino Mine is unlikely to buy this electricity. In addition, PNM's purchase rate is estimated to be approximately $0.055/kWh which is lower than PPA. Therefore, it is unlikely a solar investor would invest, given current conditions.

Case 2—Developer owned/PPA has a positive NPV and shows the low LCOE of $0.0454/kWh. The developer can develop the feasible project and then sell the electricity to the utility at $0.055/kWh. This case is economically viable with a NPV of $4,615,125 and payback of 14 years.

Case 3—Developer owned/virtual net metering shows a positive NPV and a feasible shorter payback of 7 years. Therefore, this case has the best economic scenario.

Table ES-2. PV System Summary

Investor-Owned Cases	Capacity (MW)	LCOE ($/kWh)	NPV ($)	PPA ($/kWh)	Payback (yr)
Case 1—Investor owned/PPA	348	0.0821	$21,307,301	0.0727	N/A
Case 2—Developer owned/PPA	348	0.0454	$4,615,125	-	14
Case 3—Developer owned/virtual net metering	348	0.0454	$275,789,664	-	7

Conclusion

The Chino Mine site is suitable for a large-scale PV system because it is nearly flat, has adequate road and solar access, is zoned for industrial uses, and has extensive electrical distribution to the whole site. PV projects can provide a viable, beneficial reuse, and in many cases, generate significant revenue on a site that would otherwise go unused. The PV projects will also support the community benefit goals. In addition, the PV projects can have other economic impacts to the local area, such as the number of created jobs and the installation of a distributed-generation facility that would have on it not only the manufacturers of PV modules and inverters but also the associated construction materials, metal fabrication industry, project management support, transportation, and other industries that are required to enable the procurement and installation of the complete system. To find potential buyers for the generated electricity through a PPA at a reasonable price, whether they are a local or interstate utility company, will be a key to the project development. Based on the analysis, the developer-owned PV project becomes feasible with a PPA agreement at the rate of $0.055/kWh and above. The rate of $0.055/kWh is the rate that the utility is offering to pay for. Therefore, it is highly probable the PV project for this case is feasible. VNM, while currently not available, can also be a good option to sell the electricity credits to one or other locations if the state allows. The VNM arrangement might be pursued with the PUC in the future. Furthermore, any environmental considerations shall be included in the request for proposal during project development.

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1 Study and Site Background

The U.S. Environmental Protection Agency (EPA), in accordance with the RE-Powering America's Land initiative, selected the Chino Mine site near Silver City, New Mexico, for a feasibility study of renewable energy production. The National Renewable Energy Laboratory (NREL) provided technical assistance for this project. The purpose of this report is to assess the site for a possible photovoltaic (PV) system installation and estimate the cost, performance, and site impacts of different PV options. In addition, the report recommends financing options that could assist in the implementation of a PV system at the site. This study did not assess environmental conditions at the site.

The Chino Mine is located near the town of Hurley in Grant County, New Mexico, about 12 miles east of Silver City, which has a population of 10,315 as of the 2010 census. Silver City has an average high temperature in January of 50.7°F and an average high of 87.3°F in July. The average low temperature in January is 24°F, whereas the average low temperature in July is 59.6°F. The average total precipitation is 16.08 inches (40.8 cm) per year, and heavy thunderstorms and monsoons characterize July and August. Silver City has on average of 295 days of sunshine each year.

Chino Mine currently buys electricity from a wholesale electricity market. Public Service of New Mexico (PNM) is the local utility that can buy electricity generated by renewable energy from Chino Mine; it is a regulated utility. PNM does not supply the electricity to Chino Mine, so they are not obliged to net meter with the site. Therefore, net metering with PNM is currently not an available option.

Chino Mine, which is owned by Freeport-McMoRan Incorporated (FMI), is one of the largest open-pit copper mines in the world, covering over 9,000 acres. The Hurley smelter was completed in 1939 and modernized in 1984. The smelter operated until 2003 and was decommissioned in 2007.

In the smelter area, soil contamination resulting from smelter stack air emissions deposition could include metals (i.e., antimony, arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, selenium, silver, and sulfate). Within the tailings area, a similar suite of metals could be present in low concentrations similar to what is found in the in situ mineralized area that is being mined. The predominance potential contamination pathway on the un-reclaimed areas is groundwater. A groundwater containment pumping system at the south end of Tailing Pond 7 intercepts all potentially impacted groundwater for the smelter and tailing area and pumps this water back into the process-water system. All surface water coming off un-reclaimed areas is also captured and reused in the process water system. The underlying native ground is composed of alluvium and the Gila Conglomerate that naturally buffers groundwater causing metal attenuation. The only contaminates that exceed New Mexico groundwater quality standards at the interception system are total dissolved solids (TDS) and sulfates.

A major portion of the smelter was reclaimed by 2007 and is subject to monitoring requirements to ensure reclamation success. Parts of the smelter residuals (slag) and the original tailing point adjacent to the smelter site are scheduled to be reclaimed by 2014. Site information and reclamation status are presented in Table 1.

Table 1. Site Information and Reclamation Status

Site	Acreage	Description	Slope	Status
Site 1	23	Smelter facility	Top surface: 0.5%-1.0%	Reclamation was complete.
Site 2	277	Lake 1 and residual smelter material	Preliminary design: 0.5% (north to south)	Reclamation work will begin on Lake 1 and the smelter slag area; work is scheduled to be complete by the end of 2014.
Site 3	1,700	Tailing Ponds 1, 2, B, C, 4, and 6	Top surface: 0.5%-1.0% Side slopes: 3.5:1 (H:V)	Top surface and side slopes are generally completed for Tailing Ponds B, C, and much of 4 and 6. Reclamation was completed on all tailing ponds at the end of 2012.

The design criteria being deployed for all the reclamation activities is 3 feet of capping material (Gila Conglomerate) that acts as a store-and-release cover and is capable of supporting vegetation. The cover material is then ripped, seeded, and mulched. Stormwater channels are designed to convey stormwater off the reclaimed area. The reclaimed smelter site covers about 25 acres, and the older tailing dams cover about 1,920 acres. The area includes pipelines, roads, monitor wells, and buildings, but most of the site is available for consideration of renewable energy potential.

In the midst of remediation activities, plans are evolving to bring renewable energy production to the area based on the abundant solar resource. Given the substantial energy consumption at the mine and increasing electricity costs, both industrial and residential stakeholders are interested in exploring renewables as a means of offsetting and stabilizing energy prices. In this vein, development plans for regional water distribution include the investigation of the use of solar energy to power pumping stations. In addition to the potential cost savings, success in this regional project could also enhance regional sustainability and strengthen community ties.

The potential closest electrical tie-in location is at the Hurley substation. Having a substation on-site makes it an ideal location for a PV system to tie into. A detailed interconnection study is recommended and will have to be performed through local electric utility, PNM, or by a third party to determine the feasibility of utilizing the on-site substation as a tie-in point for a PV system. The Chino Mine site is suitable for PV because it is nearly flat, has adequate road and solar access, is zoned for industrial uses, and has extensive electrical distribution to the whole site.

The town of Silver City has three community benefit goals, which have evolved over time starting with the application to EPA for technical assistance for this feasibility study. Given existing implementation constraints, the following goals may need creative solutions to be executed in the future:

- Expand regional deployment of renewable energy and support Freeport-McMoRan Incorporated's (FMI) sustainable development framework. The FMI initiative provides an opportunity to further pursue regional deployment of renewable energy and support the area's largest employer.

- Offset municipal electric costs of the mining district. An evolving goal of this solar project is to provide a substantial economic benefit to the mining district community by offsetting their municipal electric costs.
- Offset municipal electric costs of proposed regional water system. Silver City and the mining district are planning the expansion and integration of individual water systems to a regional water distribution system whose pumping costs may be offset in large part by solar generation.

Feasibility assessment team members from NREL, FMI, and EPA conducted a site visit on March 5, 2012, to gather information integral to this feasibility study. The team considered information including solar resource, transmission availability, community acceptance, and ground conditions.

2 Development of a PV System on Contaminated Land

Through the RE-Powering America's Lands initiative, EPA has identified several benefits for siting solar PV facilities on contaminated land, noting that they:

- Can be developed in place of limited greenfields, preserving the land carbon sink
- May have environmental conditions that are not well-suited for commercial or residential redevelopment, and can be adequately zoned for renewable energy
- Generally are located near existing roads and energy transmission or distribution infrastructure
- Can provide an economically viable reuse for sites that may have significant cleanup costs or low real estate development demand
- Can provide job opportunities in urban and rural communities
- Can advance cleaner and more cost-effective energy technologies, and reduce the environmental impacts of energy systems (e.g., reduce greenhouse gas emissions).

By taking advantage of these potential benefits, PV can provide a viable, beneficial reuse, and in many cases, generate significant revenue on a site that would otherwise go unused.

FMI, the mine's owner, is interested in potential revenue flows on the site. For many contaminated lands, the local community has significant interest in the redevelopment of the site, and community engagement is critical to match future reuse options to the community's vision for the site.

Understanding opportunities studied and realized by other similar sites demonstrates the potential for PV system development. Due to the groundwater contamination, the site has limited building development opportunities. The site is cleared and flat and in a location in need of locally produced power. The contamination on the site relates primarily to groundwater, and remediation is at a stage to allow for installation of a PV system. PV development that provides community energy and jobs may be the highest and best use of the site.[1]

There are considerations for the installation of a solar PV system on tailing impoundments. Those considerations include potential impacts to cover system, erosion, stormwater management, compaction, construction, and vegetation. In addition, financial assurance would be required to remove the solar facility and reconstruct the cover system (including vegetation) at the end of the project's life. These considerations shall be included in the request for proposals (RFP) during project development.

Last year, Silver City awarded a large-scale solar facility to power water pumps at Silver City's wastewater treatment plant. Immediately after the award, the Joint Office of Sustainability organized and hosted two regional meetings to offer information and

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[1] For more information on similar projects, see RE-Powering America's Land website at www.epa.gov/oswercpa/.

encouragement on pursuing solar power purchase agreements (PPA). To date, the following entities have signed letters of intent with the New Mexico Cooperative Educational Services (CES) to procure PPA services to field their own solar facilities: the City of Deming, the Deming school district, and the Silver school district. Senior officials of other major institutions have expressed interest, including the City of Alamogordo and the Gila Regional Medical Center. The FMI initiative would considerably further the goal of regional deployment of renewables.

The subject site has potential to be used for other functions beyond the solar PV systems proposed in this report. Any potential use should align with the community vision for the site and should work to enhance the overall utility of the property.

Beyond the financial benefits of installing a large-scale PV system, additional nonfinancial benefits of renewable energy deployment exist. Property owners can consider many additional compelling reasons to consider moving toward renewable energy sources for power generation instead of fossil fuels, including:

- Renewable energy sources offer a sustainable energy option in the broader energy portfolio
- Renewable energy can have a net positive effect on human health and the environment
- Deployment of renewable energy bolsters national energy independence and increases domestic energy security
- Fluctuating electric costs can be mitigated by locking in electricity rates through long-term PPAs linked to renewable energy systems
- Generating energy without harmful emissions or waste products can be accomplished through renewable energy sources.

3 PV Systems

3.1 PV Overview

Solar PV technology converts energy from solar radiation directly into electricity. Solar PV cells are the electricity-generating component of a solar energy system. When sunlight (photons) strikes a PV cell, an electric current is produced by stimulating electrons (negative charges) in a layer in the cell designed to give up electrons easily. The existing electric field in the solar cell pulls these electrons to another layer. By connecting the cell to an external load, this current (movement of charges) can then be used to power the load (e.g., light bulb).

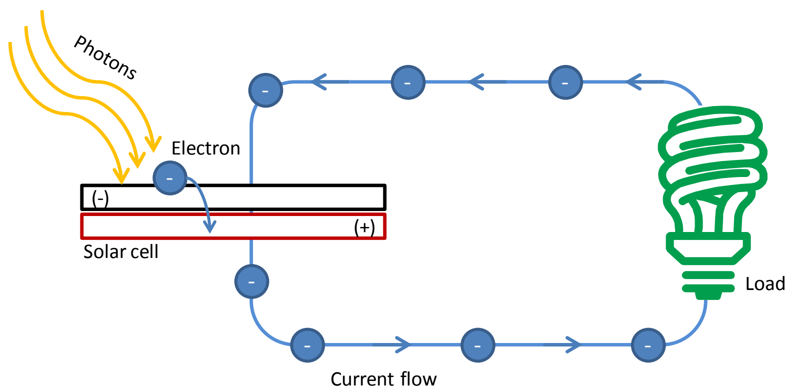

Figure 1. Generation of electricity from a PV cell

Source: EPA

PV cells are assembled into a PV panel or module. PV modules are then connected to create an array. The modules are connected in series and then in parallel as needed to reach the specific voltage and current requirements for the array. The direct current (DC) electricity generated by the array is then converted by an inverter to useable alternating current (AC) that can be consumed by adjoining buildings and facilities or exported to the electricity grid. PV system size varies from small residential (2–10 kW), to commercial (100–500 kW), to large utility scale (10+ MW). Central distribution plants are also currently being built in the 100+ MW scale. Electricity from utility-scale systems is commonly sold back to the electricity grid.

3.2 Major System Components

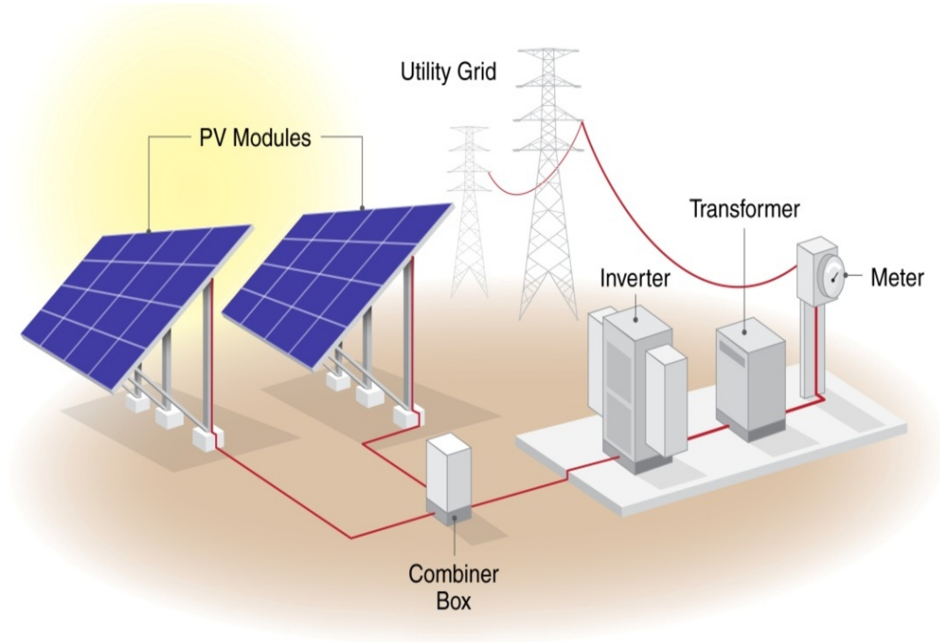

Figure 2. Ground-mounted array diagram

Source: NREL

A typical PV system is made up of several key components, including:

- PV modules
- Inverter
- Balance-of-system (BOS) components.

These, along with other PV system components, are discussed below.

3.2.1 PV Module

Module technologies are differentiated by the type of PV material used, resulting in a range of conversion efficiencies from light energy to electrical energy. The module efficiency is a measure of the percentage of solar energy converted into electricity.

Two common PV technologies that have been widely used for commercial- and utility-scale projects are crystalline silicon and thin film.

3.2.1.1 Crystalline Silicon

Traditional solar cells are made from silicon. Silicon is quite abundant and nontoxic. It builds on a strong industry on both the supply (silicon industry) and product side. This technology has been demonstrated for consistency and high efficiency for over 30 years in the field. The performance degradation, a reduction in power generation due to long-term exposure, is under 1% per year. Silicon modules have a lifespan in the range of 25–30 years but can keep producing energy beyond this range.

Typical overall efficiency of silicon solar panels is between 12% and 18%. However, some manufacturers of mono-crystalline panels claim an overall efficiency nearing 20%. This range of efficiencies represents significant variation among the crystalline silicon technologies available. The technology is generally divided into mono- and multi-crystalline technologies, which indicates the presence of grain-boundaries (i.e., multiple crystals) in the cell materials and is controlled by raw material selection and manufacturing technique. Crystalline silicon panels are widely used based on deployments worldwide.

Figure 3 shows two examples of crystalline solar panels: mono- and multi-silicon installed on tracking mounting systems.

Figure 3. Mono-crystalline and multi-crystalline solar panels. ***Photos from (left) SunPower, NREL 23816 and (right) SunPower, NREL 13823***

3.2.1.2 Thin Film

Thin-film PV cells are made from amorphous silicon (a-Si) or non-silicon materials, such as cadmium telluride (CdTe). Thin-film cells use layers of semiconductor materials only a few micrometers thick. Due to the unique nature of thin films, some thin-film cells are constructed into flexible modules, enabling such applications as solar energy covers for landfills, such as a geomembrane system. Other thin-film modules are assembled into rigid constructions that can be used in fixed tilt or, in some cases, tracking system configurations.

The efficiency of thin-film solar cells is generally lower than for crystalline cells. Current overall efficiency of a thin-film panel is between 6% and 8% for a-Si and 11% and 12% for CdTe. Figure 4 shows thin-film solar panels.

Figure 4. Thin-film solar panels installed on (left) solar energy cover and (middle/right) fixed-tilt mounting system. ***Photos from (left) Republic Services, NREL 23817, (middle) Beck Energy, NREL 14726, and (right) U.S. Coast Guard Petaluma Site, NREL 17395***

Industry standard warranties of both crystalline and thin-film PV panels typically guarantee system performance of 80% of the rated power output for 25 years. After 25 years, they will continue producing electricity but at a lower performance level.

3.2.2 Inverter

Inverters convert DC electricity from the PV array into AC and can connect seamlessly to the electricity grid. Inverter efficiencies can be as high as 98.5%.

Inverters also sense the utility power frequency and synchronize the PV-produced power to that frequency. When utility power is not present, the inverter will stop producing AC power to prevent "islanding," or putting power into the grid while utility workers are trying to fix what they assume is a de-energized distribution system. This safety feature is built into all grid-connected inverters in the market. Electricity produced from the system may be fed to a step-up transformer to increase the voltage to match the grid.

There are two primary types of inverters for grid-connected systems: string and micro-inverters. Each type has strengths and weaknesses and may be recommended for different types of installations.

String inverters are most common and typically range in size from 1.5–1,000 kW. These inverters tend to be cheaper on a capacity basis, as well as are highly efficient and have lower operation and maintenance (O&M) costs. String inverters offer various sizes and capacities to handle a large range of voltage output. For larger systems, string inverters are combined in parallel to produce a single point of interconnection with the grid. Warranties typically run between 5 and 10 years, with 10 years being the current industry standard. On larger units, extended warranties up to 20 years are possible. Given that the expected life of the PV panels is 25–30 years, an operator can expect to replace a string inverter at least one time during the life of the PV system.

Micro-inverters are dedicated to the conversion of a single PV module's power output. The AC output from each module is connected in parallel to create the array. This technology is relatively new to the market and in limited use in larger systems due to potential increase in O&M associated with significantly increasing the number of inverters in a given array. Current micro-inverters range in size between 175 W and 380 W. These inverters can be the most expensive option per watt of capacity. Warranties range from 10–20 years. Small projects with irregular modules and shading issues typically benefit from micro-inverters.

With string inverters, small amounts of shading on a solar panel will significantly affect the entire array production. Instead, it impacts only that shaded panel if micro-inverters are used. Figure 5 shows a string inverter.

Figure 5. String inverter. ***Photo by Warren Gretz, NREL 07985***

3.2.3 *Balance-of-System Components*

In addition to the solar modules and inverter, a solar PV system consists of other parts called BOS components, which include:

- Mounting racks and hardware for the panels
- Wiring for electrical connections.

3.2.3.1 Mounting Systems

The array has to be secured and oriented optimally to maximize system output. The structure holding the modules is referred to as the mounting system.

3.2.3.1.1 Ground-Mounted Systems

For ground-mounted systems, the mounting system can be either directly anchored into the ground (via driven piers or concrete footers) or ballasted on the surface without ground penetration. Mounting systems must withstand local wind loads, which range from 90–120 miles per hour (mph) for most areas to 130 mph or more for areas with hurricane potential. Depending on the region, snow and ice loads must also be a design consideration for the mounting system. For reclaimed mine site applications, mounting system designs will be primarily driven by these considerations coupled with settlement concerns.

Typical ground-mounted systems can be categorized as fixed tilt or tracking. Fixed-tilt mounting structures consist of panels installed at a set angle, typically based on site latitude and wind conditions, to increase exposure to solar radiation throughout the year. Fixed-tilt systems are used at many reclaimed mine sites. Fixed-tilt systems have lower maintenance costs but generate less energy (kWh) per unit power (kW) of capacity than tracking systems.

Tracking systems rotate the PV modules so they are following the sun as it moves across the sky. This increases energy output but also increases maintenance and equipment costs slightly. Single-axis tracking, in which PV is rotated on a single axis, can increase energy output up to 25% or more. With dual-axis tracking, PV is able to directly face the sun all day, potentially increasing output up to 35% or more. However, the movable trackers require more space between roles. System capacity for tracking systems is less than that for the fixed tilt at the same land area. Depending on underlying soiling conditions, single- and dual-axis trackers may not be suitable due to potential settlement effects, which can interfere with the alignment requirements of such systems.

Table 2. Energy Density by Panel and System

System Type	Fixed-Tilt Energy Density (DC-Watts/ft^2)	Single-Axis Tracking Energy Density (DC-Watts/ft^2)
Crystalline Silicon	4.0	3.3
Thin Film	3.3	2.7
Hybrid High Efficiency	4.8	3.9

The selection of mounting type is dependent on many factors, including installation size, electricity rates, government incentives, land constraints, latitude, and local weather. Contaminated land applications might raise additional design considerations due to site conditions, including differential settlement.

Selection of the mounting system is also heavily dependent on anchoring or foundation selection. The mounting system design will also need to meet applicable local building code requirements with respect to snow, wind, and seismic zones. Selection of mounting types should also consider frost protection needs, especially in cold regions, such as New England.

3.2.3.2 Wiring for Electrical Connections

Electrical connections, including wiring, disconnect switches, fuses, and breakers, are required to meet electrical code (e.g., NEC Article 690) for both safety and equipment protection.

In most traditional applications, wiring from (1) the arrays to inverters and (2) inverters to point of interconnection is generally run as direct burial through trenches. In a reclaimed mine site, this wiring may be required to run through above-ground conduit due to restrictions with cap penetration or other concerns. Therefore, developers should consider noting any such restrictions, if applicable, in RFPs in order to improve overall bid accuracy. Similarly, it is recommended that PV system vendors reflect these costs in the quote when costing out the overall system.

3.2.3.3 PV System Monitoring

Monitoring PV systems can be essential for reliable functioning and maximum yield of a system. It can be as simple as reading values, such as produced AC power, daily kilowatt-hours, and cumulative kilowatt-hours, locally on an LCD display on the inverter. For more sophisticated monitoring and control purposes, environmental data, such as module temperature, ambient temperature, solar radiation, and wind speed, can be collected. Remote control and monitoring can be performed by various remote connections.

Systems can send alerts and status messages to the control center or user. Data can be stored in the inverter's memory or in external data loggers for further system analysis. Collection of this basic information is standard for solar systems and not unique to landfill applications.

Weather stations are typically installed in large-scale systems. Weather data, such as solar radiation and temperature, can be used to predict energy production, enabling comparison of the target and actual system output and performance, and identification of under-performing arrays. Operators can also use this data to identify required maintenance, shade on panels, and accumulating dirt on panels, for example. Monitoring system data can also be used for outreach and education. This can be achieved with publicly available, online displays, wall-mounted systems, or even smartphone applications.

3.2.4 Operation and Maintenance

PV panels typically have a 25-year performance warranty. Inverters, which come standard with a 5-year or 10-year warranty (extended warranties available), would be expected to last 10–15 years. System performance should be verified on a vendor-provided website. Wire and rack connections should be checked annually. This economic analysis uses an annual O&M cost computed at $20/kW/yr, which is based on the historical O&M costs of installed fixed-axis grid-tied PV systems. In addition, the system should expect a replacement of system inverters in year 15 at a cost of $0.25/W.

3.3 Siting Considerations

PV modules are very sensitive to shading. When shaded (either partially or fully), the panel is unable to optimally collect the high-energy beam radiation from the sun. As explained above, PV modules are made up of many individual cells that all produce a small amount of current and voltage. These individual cells are connected in series to produce a larger current. If an individual cell is shaded, it acts as resistance to the whole series circuit, impeding current flow and dissipating power rather than producing it.

The NREL solar assessment team uses a Solmetric SunEye solar path calculator to assess shading at particular locations by analyzing the sky view where solar panels will be located. By finding the solar access, the NREL team can determine if the area is appropriate for solar panels.

Following the successful collection of solar resource data using the Solmetric SunEye tool and determination that the site is adequate for a solar installation, an analysis to determine the ideal system size must be conducted. System size depends highly on the average energy use of the facilities on the site, PPAs, incentives available, and utility policy.

4 Proposed Installation Location Information

This section summarizes the findings of the NREL solar assessment site visit on March 5, 2012.

4.1 Chino Mine Site PV System

As discussed in Section 1, the Chino Mine site, managed by FMI, is suitable for PV because it is nearly flat, has adequate road and solar access, is zoned for industrial uses, has extensive electrical distribution nearby serving the City of Hurley, and can potentially sell electricity to PNM.

In order to get the most out of the ground area available, it is important to consider whether the site layout can be improved to better incorporate a solar system. If there are unused structures, fences, or electrical poles that can be removed, the un-shaded area can be increased to incorporate more PV panels.

Figure 6 shows an aerial view of the Chino Mine sites. The feasible areas for PV are outlined in orange and the electrical tie-in point for the PV system is given.

Figure 6. Aerial view of Chino Mine sites

Illustration made using Google Earth.

There are three proposed sites for Chino Mine. The area for each site, estimated PV capacity, and distance to utility tie-in are presented in Table 3.

Table 3. Area for Each Site, Estimated PV Capacity, and Distance to Utility Tie-in

Site	Acreage	Estimated PV Capacity (MW)	Distance to Utility Tie-In (ft)
Site 1	23	4	4,624
Site 2	277	48	2,570
Site 3	1,700	296	8,130

The total Chino Mine area for this study is approximately 2,000 acres, divided into three major sites. Sites 1, 2, and 3 are approximately 23, 277 acres and 1,700 acres, respectively. The areas are relatively flat, un-shaded land, which makes them suitable candidates for a PV system. Additional considerations may be associated with designing, installing, and operating the PV system in order to maintain the integrity and effectiveness of the remediation solution or cap on the reclaimed tailings. The PV capacity of a fixed-tilt ballasted system estimated for sites 1, 2, and 3 are 4 MW, 48 MW, and 296 MW, respectively.

PV systems are very well-suited to the Silver City, New Mexico, area, where the average global horizontal annual solar resource—the total solar radiation for a given location, including direct, diffuse, and ground-reflected radiation—is 6.41 kWh/m^2/day. Figure 7, Figure 8, and Figure 9 show various views of the Chino Mine site.

Figure 7. Views of the feasible area for PV at site 1 of the Chino Mine. ***Photos by Kosol Kiatreungwattana, NREL***

Figure 8. Views of the feasible area for PV at site 2 of the Chino Mine. ***Photos by Kosol Kiatreungwattana, NREL***

Figure 9. Views of the feasible area for PV at site 3 of the Chino Mine. ***Photos by Kosol Kiatreungwattana, NREL***

4.2 Utility-Resource Considerations

The expected electrical tie-in point and inverter for the PV system at the Chino Mine is located on the west side of each site. Site 1 has the potential to tie into the 24-kV or 69-kV power line on the west side of the site. Site 2 has the potential to tie into the 69-kV or 115-kV power line. Site 3 is the largest site and has the potential to tie into the 115-kV power line. Site and line location is showed in Figure 6.

Per conversation with PNM personnel, this 115-kV line at Chino Mine should have adequate capacity to accommodate a large utility PV system. A technical analysis is required with PNM, to be performed in a Preliminary Interconnection System Impact Study (PISIS) cluster study. The additional fee for a PISIS cluster study is presented in Table 4.

PNM requires each applicant to submit an application for interconnection. For a large system (10 kW to 10 MW), the fee is $100 plus $1/kW for each kilowatt over 100 kW.[2]

Table 4. Fee for Preliminary Interconnection System Impact Study (PISIS)

System Capacity	Fee ($)
Less than 50 MW	75,000
Greater than 50 MW but less than 200 MW	199,000
200 MW and greater	250,000

Figure 10. Electrical tie-in point of 24-kV and 115-kV lines for the PV system at the Chino Mine. ***Photos by Kosol Kiatreungwattana and Lars Lisell, NREL***

4.3 Useable Acreage for PV System Installation

Typically, a minimum of 2 useable acres is recommended to site PV systems. Useable acreage is typically characterized as "flat to gently sloping" southern exposures that are free from obstructions and get full sun for at least a 6-hour period each day. For example, eligible space for PV includes underutilized or unoccupied land, vacant lots, and/or unused paved area (e.g., a parking lot or industrial site space, as well as existing building

[2] For more information, see www.pnm.com/customers/pdf/ic_app_large.pdf.

rooftops). The total of 2,000 acres (site 1 with 23 acres, site 2 with 277 acres, and site 3 with 1,700 acres) is flat and free of all major shading obstructions.

4.4 PV Site Solar Resource

The Chino Mine site has been evaluated to determine the adequacy of the solar resource available using both on-site data and industry tools.

The assessment team for this feasibility study collected multiple Solmetric SunEye data points and found a solar access of 95% or higher. All data gathered using this tool is available in Appendix B.

The predicted array performance was found using PVWatts Version 2[3] for Silver City, New Mexico.

Table 5 shows the station identification information, PV system specifications, and energy specifications for the site. For this summary, a hypothetical 20-degree fixed-tilt, 1-kW system was used to show the estimated production for each kilowatt so that additional analyses can be performed using the data indicated below. It is scaled linearly to match the proposed system size.

Table 5. Site Identification Information and Specifications

Station Identification	
Cell ID	0192378
State	New Mexico
Latitude	32.9° N
Longitude	108.4° W
PV System Specifications	
DC Rating	1.00 kW
DC-to-AC Derate Factor	0.8
AC Rating	0.8 kW
Array Type	Fixed Tilt
Array Tilt	20°
Array Azimuth	180°
Energy Specifications	
Cost of Electricity (retail)	$0.11/kWh

Table 6 shows the performance results for a 20-degree fixed-tilt PV system in Silver City, New Mexico, as calculated by PVWatts. Estimated electricity production and value of the energy for each system at each site is presented in Table 7.

[3] http://www.nrel.gov/rredc/pvwatts/.

Table 6. Performance Results for 20-Degree Fixed-Tilt PV

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	4.97	120	13.20
2	5.68	122	13.42
3	6.81	161	17.71
4	7.61	167	18.37
5	7.59	170	18.70
6	7.62	159	17.49
7	7.12	153	16.83
8	6.68	145	15.95
9	6.51	137	15.07
10	6.21	141	15.51
11	5.41	123	13.53
12	4.67	114	12.54
Year	6.41	1,712	188.32

Table 7. Estimated Electricity Production for Each Site

Site	Estimated PV Capacity (MW)	Annual Electricity Production (MWh/yr)	Annual Energy Value ($)
Site 1	4	6,848	753,280
Site 2	48	82,176	9,039,360
Site 3	296	506,752	55,742,720
Total	348	595,776	65,535,360

4.5 Chino Mine Energy Usage

The Chino Mine site has significant on-site energy use. On-site monthly electricity consumption for the Hurley area of Chino Mine is presented in Table 8. Annual on-site electricity consumption in the Hurley area is approximately 15,684 MWh/yr (calculated using average monthly consumption). Chino Mine is primarily served by the wholesale electricity market. PNM does not supply the electricity to Chino Mine, so they are not obligated to net meter. Further negotiation with PNM and the PUC may be required for a net-metering arrangement in the future. Currently, net metering is not an available option for the site.

Table 8. Chino Mine On-Site Monthly Electricity Consumption

Year 2011	Consumption (kWh)	Cost ($)
February	1,077,840	60,390.17
March	1,282,286	65,528.31
April	1,560,853	81,787.79
Average	1,306,993	69,235.43

4.5.1 Net Metering

Net metering is an electricity policy for consumers who own renewable energy facilities. "Net," in this context, is used to mean "what remains after deductions"—in this case, the deduction of any energy outflows from metered energy inflows. Under net metering, a system owner receives retail credit for at least a portion of the electricity it generates. As part of the Energy Policy Act of 2005, under Sec. 1251, all public electric utilities are required upon request to make net metering available to their customers:

> (11) NET METERING.—Each electric utility shall make available upon request net metering service to any electric consumer that the electric utility serves. For purposes of this paragraph, the term 'net metering service' means service to an electric consumer under which electric energy generated by that electric consumer from an eligible on-site generating facility and delivered to the local distribution facilities may be used to offset electric energy provided by the electric utility to the electric consumer during the applicable billing period.

Chino Mine buys electricity from a wholesale market. The wholesale energy supplies are not subject to New Mexico's renewable energy standards. Net metering is not an option for Chino Mine. The net-metering arrangement would have to be negotiated.

4.5.2 Virtual Net Metering

Some states and utilities allow for virtual net metering (VNM). This arrangement can allow certain entities, such as a local government, to install renewable generation of up to 1 MW at one location within its geographic boundary and to generate credits that can be used to offset charges at one or more other locations within the same geographic boundary. Silver City is interested in buying electricity from the Chino Mine PV system. Unfortunately, New Mexico currently does not offer VNM to PV generators. However, we include this analysis to demonstrate the potential economic benefits.

5 Economics and Performance

The economic performance of a PV system installed on the site is evaluated using a combination of the assumptions and background information discussed previously, as well as a number of industry-specific inputs determined by other studies. In particular, this study uses the NREL System Advisor Model (SAM).[4]

SAM is a performance and economic model designed to facilitate decision making for people involved in the renewable energy industry, ranging from project managers and engineers to incentive program designers, technology developers, and researchers.

SAM makes performance predictions for grid-connected solar, solar water heating, wind, and geothermal power systems and makes economic calculations for both projects that buy and sell power at retail rates and power projects that sell power through a PPA.

SAM consists of a performance model and financial model. The performance model calculates a system's energy output on an hourly basis (sub-hourly simulations are available for some technologies). The financial model calculates annual project cash flows over a period of years for a range of financing structures for residential, commercial, and utility projects.

The model calculates the cost of generating electricity based on information provided about a project's location, installation and operating costs, type of financing, applicable tax credits and incentives, and system specifications.

5.1 Assumptions and Input Data for Analysis

Cost of a PV system depends on the system size and other factors, such as geographic location, mounting structure, and type of PV module. Based on significant cost reductions seen in 2011, the average cost for utility-scale ground-mounted systems have declined from $4.80/W in the first quarter of 2010 to $2.79/W in the first quarter of 2012. With an increasing demand and supply, the potential of further cost reduction is expected as market conditions evolve.

For this analysis, the installed cost of fixed-tilt ground-mounted systems was assumed to be $2.79/W. We assumed crystalline PV panels for this analysis. Per discussion with the geologist from the state of New Mexico, using driven piles for ground mounting would be acceptable if there was no depression next to the piles in the dirt but rather a small mound around each one to keep water from pooling around it. Although a tracking system can produce more electricity, it has higher capital and long-term maintenance costs. Therefore, the fixed-tilt ground-mounted PV system that uses driven piles is recommended for this study. The installed system cost assumption is summarized in Table 9.

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[4] For more information about the NREL System Advisor Model, see https://sam.nrel.gov/cost.

Table 9. Installed System Cost Assumption

System Type	Fixed Tilt ($\$/W_e$)
Total installed cost for ground-mounted system	2.79

These prices include the PV array and the BOS components for each system, including the inverter and electrical equipment, as well as the installation cost. This includes estimated taxes and a national-average labor rate but does not include land cost. The economics of grid-tied PV depend on incentives, the cost of electricity, the solar resource, and panel tilt and orientation. Currently, solar incentives are only available for a system up to 1 MW. A larger system capacity over 1 MW is under the RFP process with PNM, and the buy-back rate is negotiated for a case-by-case basis. For this analysis, Chino Mine buys electricity from wholesale market at $0.045/kWh and can sell electricity from PV systems at $0.055/kWh (based on available information for a system up to 1 MW with an incentive of $0.02/kWh renewable energy credit price plus $0.035/kWh Cogeneration and Small Power Production Facilities, Rate 12). For VNM analysis, the retail rate was assumed at $0.11/kWh, as the generated electricity will be credited to other locations at the retail rate.

It was assumed for this analysis that relevant federal incentives are received for taxable entities. It is important to consider all applicable incentives or grants to make PV as cost-effective as possible. If the PV system is owned by a private tax-paying entity, this entity may qualify for federal tax credits and accelerated depreciation on the PV system, which can be worth about 30% of the initial capital investment. The total potential tax benefits to the tax-paying entity can be as high as 45% of the initial system cost. Because state and federal governments do not pay taxes, private ownership of the PV system would be required to capture tax incentives.

For the purposes of this analysis, the project is expected to have a 25-year life, although the systems can be reasonably expected to continue operation past this point. Inflation is assumed to be 1.5%, the real discount rate to be 6%, and financing secured via a 25-year loan at a 7% interest rate and 80% debt fraction. The panels are assumed to have a 1% per year degradation in performance. The O&M expenses are estimated to be $20/kW/yr for the life of the system. In addition, it is expected that there will be a $250/kW charge to O&M in year 15 to replace the inverters associated with the system. A system DC-to-AC conversion of 80% was assumed. This includes losses in the inverter, wire losses, PV module losses, and losses due to temperature effects. PVWatts Version 2 was used to calculate expected energy performance for the system.

The full list of incentives used in this study can be found in Table 10.

Table 10. Summary of Incentives Evaluated

Incentive Title	Modeled Value	Expected End
Federal Investment Tax Credit	30% of total investment	2016
Advanced Energy Tax Credit (Corporate)	6% of total investment	$60 million
Renewable Energy Production Tax Credit (Corporate)	$0.027/kWh (average)	Statewide cap: 2,500 GWh
Advanced Energy Gross Receipts Tax Deduction	100% of sales tax	$60 million
Energy Efficiency & Renewable Energy Bond Program	Government bonds for government buildings	$20 million
Net Metering Available	Up to site loads	

The Energy Efficiency & Renewable Energy Bond Program can only be taken advantage of by a municipality. This was modeled as a 0.5% interest loan over the life of the project to simulate the actual stipulations of the program. The program allows for repayment to occur through recouping 90% of energy savings in order to not affect the local general fund.

5.2 SAM-Forecasted Economic Performance

Using varied inputs and the assumptions summarized in Section 5.1 of this report, the SAM tool predicts net present value (NPV), PPAs, and levelized cost of energy (LCOE), among other economic indicators.

The LCOE in cents per kilowatt-hour accounts for a project's installation, financing, tax, operating costs, and the quantity of electricity it produces over its life. The LCOE makes it possible to compare alternatives with different project lifetimes and performance characteristics. Analysts can use the LCOE to compare the option of installing a residential or commercial project to purchasing electricity from an electric service provider or to compare utility and commercial PPA projects with investments in energy efficiency, other renewable energy projects, or conventional fossil fuel projects. The LCOE captures the trade-off between typically higher-capital-cost, lower-operating-cost renewable energy projects and lower-capital-cost, higher-operating-cost fossil-fuel-based projects.

The PPA price is the first-year price that electricity could be sold to the property owner, allowing the developer to own a certain internal rate of return. For this analysis, the required internal rate of return used was 15%, and the first-year PPA price escalates at 1.5% per year.

There are three scenarios for the analysis. All detailed assumptions and results for the analysis can be found in the appendices.

Case 1—Investor owned/PPA with 348 MW

This case assumes third-party investor for the PV system. All generated electricity from case 1 is assumed to be sold to the utility. The results of this case are to estimate the electricity rate as a PPA to receive an acceptable return on investment (15% internal rate of return).

Case 2—Developer owned/PPA with 348 MW

This case assumes FMI owns the PV system. All generated electricity will be sold as a PPA with PNM or an interstate utility at the rate of $0.055/kWh.

Case 3—Developer owned/virtual net metering with 348 MW

VNM is currently not available in New Mexico. Case 3 is to demonstrate the potential economic benefits for this option. This case assumes FMI owns the PV system. All electricity would be VNM to generate credits at a retail electricity rate that can be used to offset charges at one or more other locations within the same geographic boundary. A retail electricity rate at $0.11/kWh is used for this analysis.

5.2.1 Results

Three scenarios were run for the Chino Mine to encompass the options available to this site. The independent variables include a third-party developer versus existing site ownership. There are multiple factors that go into choosing which scenario to pursue beyond NPV, PPA, and LCOE. Table 11 shows the modeled results from the different scenarios. The entire results and summary of inputs to the SAM is available in Appendix D.

- **Case 1**—Investor owned/PPA with 348 MW will work if the investor can sell the electricity of the PPA at $0.0727/kWh. Because the Chino Mine buys electricity from the wholesale market at $0.045/kWh, which is much lower than that of the PPA, so the Chino Mine is unlikely to buy the electricity from the PV systems. In addition, PNM's purchase rate is estimated to be approximately $0.055/kWh. Therefore, a solar investor is unlikely to invest given current conditions.
- **Case 2**—Developer owned/PPA has positive NPV and shows the low LCOE of $0.0454/kWh. The developer can develop the feasible project and then sell electricity to the utility at $0.055/kWh. This case is economically viable with an NPV of $4,615,125 and a payback of 14 years.
- **Case 3**—Developer owned/virtual net metering shows a positive NPV and a feasible shorter payback of 7 years. Therefore, this case has the best economic scenario.

Table 11. PV System Summary

Investor-Owned Cases	Capacity (MW)	LCOE ($/kWh)	NPV ($)	PPA ($/kWh)	Payback (yr)
Case 1—Investor owned/PPA	348	0.0821	$21,307,301	0.0727	N/A
Case 2—Developer owned/PPA	348	0.0454	$4,615,125	-	14
Case 3—Developer owned/virtual net metering	348	0.0454	$275,789,664	-	7

Table 12. Potential Energy Production and Economic Impacts on Created Jobs

System Type	PV System Size[a] (MW)	Array Tilt (deg)	Annual Output (MWh/year)	Number of Houses Powered[b]	Jobs Created[c] (job-year)	Jobs Sustained[d] (job-year)
Fixed-tilt Ballasted PV System with Crystalline Panels	348	20	595,776	53,965	10,588	129

System Type	System Cost
Fixed-tilt, ground-mounted PV System with Crystalline Panels	$ 972,425,280

[a] *Data assume a maximum usable area of 2,000 acres.*
[b] Number of average American households that could hypothetically be powered by the PV system assuming 11,040 kWh/year/household.
[c] Job-years created as a result of project capital investment including direct, indirect, and induced jobs.

[d] Jobs (direct, indirect, and induced) sustained as a result of operations and maintenance (O&M) of the system.

5.3 Job Analysis and Impact

To evaluate employment and economic impacts of the PV project associated with this analysis, the NREL Jobs and Economic Development Impact (JEDI) models are used.[5] JEDI estimates the economic impacts associated with the construction and operation of distributed-generation power plants. JEDI is a flexible input-output tool that estimates, but does not precisely predict, the number of jobs and economic impacts that can be reasonably supported by the proposed facility.

JEDI represents the entire economy, including cross-industry or cross-company impacts. For example, JEDI estimates the impact that the installation of a distributed-generation facility would have on not only the manufacturers of PV modules and inverters but also the associated construction materials, metal fabrication industry, project management support, transportation, and other industries that are required to enable the procurement and installation of the complete system.

[5] The JEDI models have been used by the U.S. Department of Energy, the U.S. Department of Agriculture, NREL, and the Lawrence Berkeley National Laboratory, as well as a number of universities. For information on the NREL Jobs and Economic Development Impact tool, see http://www.nrel.gov/analysis/jedi/about_jedi.html.

For this analysis, inputs, including the estimated installed project cost ($/kW), targeted year of construction, system capacity (kW), O&M costs ($/kW), and location were entered into the model to predict the jobs and economic impact. It is important to note that JEDI does not predict or incorporate any displacement of related economic activity or alternative jobs due to the implementation of the proposed project. As such, the JEDI results are considered gross estimates as opposed to net estimates.

For the Chino Mine site, the values in Table 13 were assumed for the maximum capacity system based on available areas.

Table 13. JEDI Analysis Assumptions

Input	Assumed Value
Capacity	348 MW
Placed In Service Year	2013
Installed System Cost	$ 972,425,280
Location	Silver City, New Mexico

Using these inputs, JEDI estimates the gross direct and indirect jobs, associated earnings, and total economic impact supported by the construction and continued operation of the proposed PV system.

The estimates of jobs associated with this project are presented as either construction period jobs or sustained operations jobs. Each job is expressed as a whole, or fraction, full-time equivalent (FTE) position. An FTE is one person working 40 hours per week for the duration of a year. Construction period jobs are considered short-term positions that exist only during the procurement and construction periods.

As indicated in the results of the JEDI analysis provided in Appendix C, the total proposed system of 348 MW is estimated to support 8,464 direct and indirect jobs per year for the duration of the procurement and construction period. Total wages paid to workers during the construction period are estimated to be $323,575,000, and total economic output is estimated to be $759,779,400. The jobs and associated spending are projected to account for approximately $6,553,300 in earnings and $10,748,500 in economic activity each year for the next 25 years.

5.4 Financing Opportunities

The procurement, development, construction, and management of a successful utility-scale distributed-generation facility can be owned and financed a number of different ways. The most common ownership and financing structures are described below.

5.4.1 Owner and Operator Financing

The owner/operator financing structure is characterized by a single entity with the financial strength to fund all of the solar project costs and, if a private entity, sufficient tax appetite to utilize all of the project's tax benefits. Private owners/operators typically establish a special purpose entity (SPE) that solely owns the assets of the project. An initial equity investment into the SPE is funded by the private entity using existing funds, and all of the project's cash flows and tax benefits are utilized by the entity. This equity investment is typically matched with debt financing for the majority of the project costs. Project debt is typically issued as a loan based on each owner's/operator's assets and equity in the project. In addition, private entities can utilize any of federal tax credits offered.

For public entities that choose to finance, own, and operate a solar project, funding can be raised as part of a larger, general obligation bond; as a standalone tax credit bond; through a tax-exempt lease structure, bank financing, grant and incentive programs, or internal cash; or some combination of the above. Certain structures are more common than others, and grant programs for solar programs are on the decline. Regardless, as tax-exempt entities, public entities are unable to benefit directly from the various tax-credit-based incentives available to private companies. This has given way to the now common use of third-party financing structures, such as the PPA.

5.4.2 Third-Party Developers with Power Purchase Agreements

Because many project site hosts have the financial or technical capabilities to develop a capital intensive project, many times they turn to third-party developers (and/or their investors). In exchange for access to a site through a lease or easement arrangement, third-party developers will finance, develop, own, and operate solar projects utilizing their own expertise and sources of tax equity financing and debt capital. Once the system is installed, the third-party developer will sell the electricity to the site host or local utility via a PPA—a contract to sell electricity at a negotiated rate over a fixed period of time. The PPA typically will be between the third-party developer and the site host if it is a retail "behind-the-meter" transaction or directly with an electric utility if it is a wholesale transaction.

Site hosts benefit by either receiving competitively priced electricity from the project via the PPA or land lease revenues for making the site available to the solar developer via a lease payment. This lease payment can take on the form of either a revenue-sharing agreement or an annual lease payment. In addition, third-party developers are able to utilize federal tax credits. For public entities, this arrangement allows them to utilize the benefits of the tax credits (low PPA price, higher lease payment) while not directly receiving them. The term of a PPA typically varies from 20–25 years.

5.4.3 Third-Party "Flip" Agreements

The most common use of this model is a site host working with a third-party developer who then partners with a tax-motivated investor in a SPE that would own and operate the project. Initially, most of the equity provided to the SPE would come from the tax investor, and most of the benefit would flow to the tax investor (as much as 99%). When the tax investor has fully monetized the tax benefits and achieved an agreed-upon rate of return, the allocation of benefits and majority ownership (95%) would "flip" to the site host (but not within the first 5 years). After the flip, the site host would have the option to buy out all or most of the tax investor's interest in the project at the fair market value of the tax investor's remaining interest.

A flip agreement can also be signed between a developer and investors within an SPE, where the investor would begin with the majority ownership. Eventually, the ownership would flip to the developer once the investors' returns are met.

5.4.4 Hybrid Financial Structures

As the solar market evolves, hybrid financial solutions have been developed in certain instances to finance solar projects. A particular structure, nicknamed "The Morris Model" after Morris County, New Jersey, combines highly rated public debt, a capital lease, and a PPA. Low-interest public debt replaces more costly financing available to the solar developer and contributes to a very attractive PPA price for the site hosts. New markets tax credits have been combined with PPAs and public debt in other locations, such as Denver and Salt Lake City.

5.4.5 Solar Services Agreement and Operating Lease

The solar services agreement (SSA) and operating lease business models have been predominately used in the municipal and cooperative utility markets due its treatment of tax benefits and the rules limiting federal tax benefit transfers from nonprofit to for-profit companies. Under IRS guidelines, municipalities cannot enter capital leases with for-profit entities when the for-profit entities capture tax incentives. As a result, a number of business models have emerged as a workaround to this issue. One model is the SSA, wherein a private party sells solar services (i.e., energy and RECs) to a municipality over a specified contract period (typically long enough for the private party to accrue the tax credits). The nonprofit utility typically purchases the solar services with either a one-time up-front payment equal to the turn-key system cost minus the 30% federal tax credit or may purchase the services in annual installments. The municipality may buy out the system once the third party has accrued the tax credits, but due to IRS regulations, the buyout of the plant cannot be included as part of the SSA (i.e., the SSA cannot be used as a vehicle for a sale and must be a separate transaction).

Similar to the SSA, there are a variety of lease options that are available to municipalities that allow the capture of tax benefits by third-party owners, which result in a lower cost to the municipality. These include an operating lease for solar services (as opposed to an equipment capital lease) and a complex business model called a "sale/leaseback." Under the sale/leaseback model, the municipality develops the project and sells it to a third-party tax equity investor who then leases the project back to the municipality under an operating lease. At the end of the lease period and after the tax benefits have been absorbed by the tax equity investor, the municipality can purchase the solar project at fair market value.

5.4.6 Sale/Leaseback

In the widely accepted sale/leaseback model, the public or private entity installs the PV system, sells it to a tax investor, and then leases it back. As the lessee, they would be responsible for operating and maintaining the solar system, as well as have the right to sell or use the power. In exchange for use of the solar system, the public or private entity would make lease payments to the tax investor (the lessor). The tax investor would have rights to federal tax benefits generated by the project and the lease payments. Sometimes, the entity is allowed to buy back the project at 100% fair market value after the tax benefits are exhausted.

5.4.7 Community Solar/Solar Gardens

The concept of community solar is one in which the costs and benefits of one large solar project are shared by a number of participants. A site owner may be able to make the land available for a large solar project that can be the basis for a community solar project. Ownership structures for these projects vary, but the large projects are typically owned or sponsored by a local utility. Community solar gardens are distributed solar projects wherein utility customers have a stake via a prorated share of the project's energy output. This business model is targeted to meet demand for solar projects by customers who rent/lease their homes or businesses, do not have good solar access at their site, or do not want to install solar system on their facilities. Customer prorated shares of solar projects are acquired through a long-term transferrable lease of one or more panels, or they subscribe to a share of the project in terms of a specific level of energy output or the energy output of a set amount of capacity. Under the customer lease option, the customer receives a billing credit for the number of kilowatt-hours their prorated share of the solar project produces each month; this is also known as VNM. Under the customer subscription option, the customers typically pay a set price for a block of solar energy (i.e., 100 kWh per-month blocks) from the community solar project. Other models include monthly energy outputs from a specific investment dollar amount or a specific number of panels.

Community solar garden and customer subscription-based projects can be solely owned by the utility, solely owned by third-party developers with facilitation of billing provided by the utility, or a joint venture between the utility and a third-party developer leading to eventual ownership by the utility after the tax benefits have been absorbed by the third-party developer.

There are some states that offer solar incentives for community solar projects, including Washington State (production incentive) and Utah (state income tax credit). Community solar is known as solar gardens, depending on the location (e.g., Colorado). However, New Mexico currently does not allow community solar or VNM. In the future, it would be a great opportunity for policy development in community solar gardens or VNM so that a community or town nearby can take advantage of the solar PV project.

6 Conclusions and Recommendations

The feasibility of a PV system installed is highly impacted by the available area for an array, solar resource, distance to transmission lines, and distance to major roads. The potential closest electrical tie-in location is the Hurley substation. Having a substation on-site makes it an ideal location for a PV system to tie into. A detailed interconnection study is recommended and will have to be performed through local electric utility, PNM, or a third party to determine the feasibility of utilizing the on-site substation as a tie-in point for a PV system. The Chino Mine site is suitable for a large-scale PV system because it is nearly flat, has adequate road and solar access, is zoned for industrial uses, and has extensive electrical distribution to the whole site.

From the SAM analysis:

- **Case 1—**Investor owned/PPA with 348 MW will work if the investor can sell the electricity of the PPA at $0.0727/kWh. Because the Chino Mine buys electricity from wholesale market at $0.045/kWh, which is much lower than that of the PPA, the Chino Mine is unlikely to buy electricity from the PV systems. In addition, PNM's purchase rate is estimated to be approximately $0.055/kWh. Therefore, a solar investor is unlikely to invest, given current conditions.
- **Case 2—**Developer owned/PPA has a positive NPV and shows the low LCOE of $0.0454/kWh. The developer can develop the feasible project and then sell electricity to the utility at $0.055/kWh. This case is economically viable with an NPV of $4,615,125 and a payback of 14 years.
- **Case 3—**Developer owned/VNM has a positive NPV and a feasible payback of 7 years. This case has the best economic scenario. However, VNM is not available for New Mexico. The VNM arrangement should be pursued with the PUC in the future.

Results of the JEDI model analysis show that the total proposed system of 348 MW is estimated to support 10,588 direct and indirect jobs per year for the duration of the procurement and construction period. Total wages paid to workers during the construction period are estimated to be $323,575,000, and total economic output is estimated to be $759,779,400. The annual O&M of the new PV system is estimated to support 129 FTEs per year for the life of the system. The jobs and associated spending are projected to account for approximately $6,553,300 in earnings and $10,748,500 in economic activity each year for the next 25 years.

Improvements to the incentives could change these projects to be very favorable. Such incentives would include an increase to the purchase price from PNM, loan guarantees with longer repayment periods, and higher REC payments that would apply to larger systems.

A very large PV capacity can potentially be developed at the Chino Mine sites. To find potential buyers for the generated electricity through a PPA at a reasonable price, whether they are a local or interstate utility company, will be a key to the project development. Based on the analysis, the developer-owned PV project becomes feasible with a PPA at the rate of $0.055/kWh and above. The rate of $0.055/kWh is the rate that the utility is offering to pay for. Therefore, there is a high probability of the PV project for this case being successful. VNM can also be a good option to sell the electricity credits to one or other locations if the state allows. The VNM arrangement may be pursued with the PUC in the future. In addition, any environmental considerations shall be included in the RFP during project development.

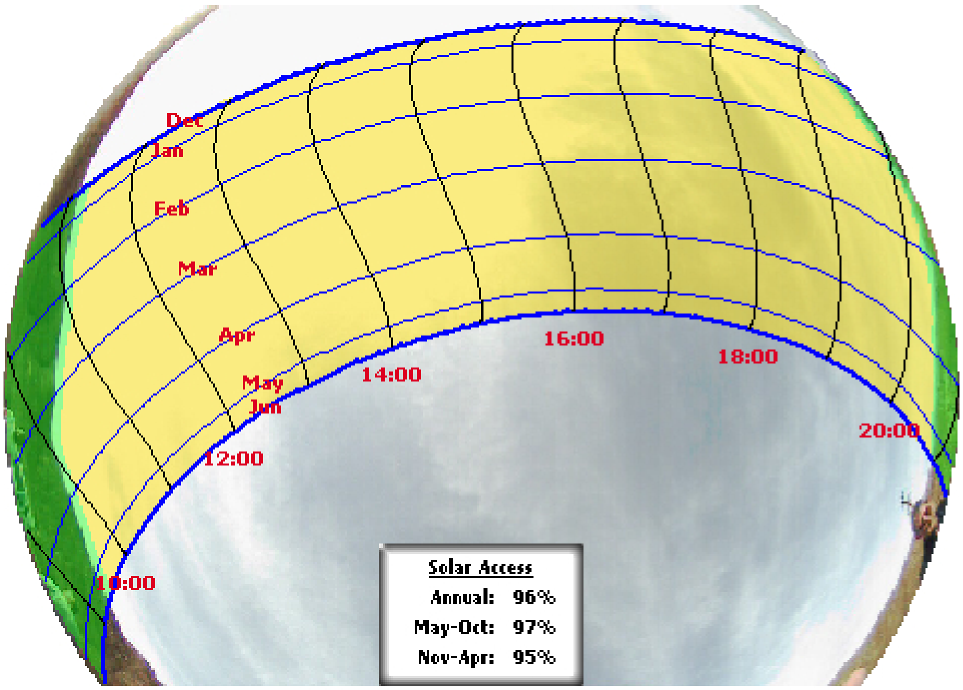
For multiple reasons, such as the high cost of energy, the dropping cost of PV, and the existence of an adequate solar resource and available incentives, this report finds that a large PV system is feasible for the site currently and in the future. The developer-owned PV system with a PPA provides a reasonable payback. Alternatively, a third-party ownership PPA can also be the feasible way for a system to be financed and installed on this site. It is recommended that the Chino Mine and Silver City further pursue opportunities of developing the PV project at the Chino Mine site. A smaller project (~1 MW) may be developed as a good starting point. For future work, the RFP shall be developed and issued and sent out to third-party investors/developers.

Appendix A. Assessment and Calculations Assumptions

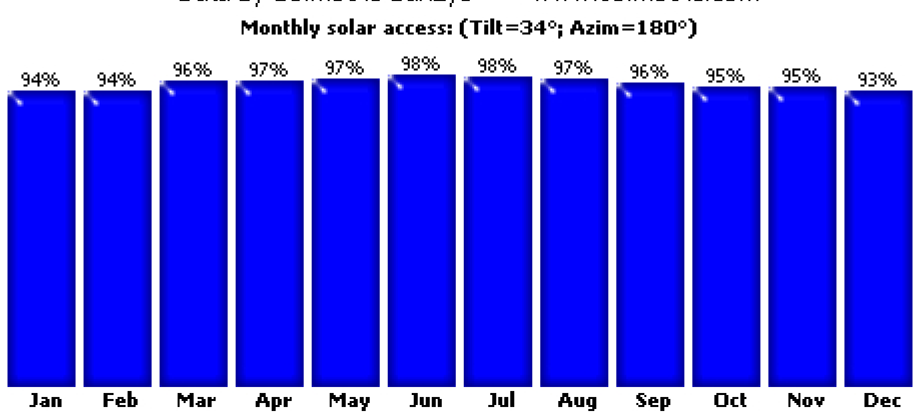
Table A-1. Cost, System, and Other Assessment Assumptions

Cost Assumptions			
Variable	**Quantity of Variable**	**Unit of Variable**	
Cost of Site Electricity (buyback/retail)	0.055/0.045	\$/kWh	
Annual O&M (fixed)	20	\$/kW/year	
System Assumptions			
System Type	**Annual energy kWh/kW**	**Installed Cost (\$/W)**	**Energy Density (W/ft^2)**
Fixed-Tilt Ground-Mounted System	1,712	\$2.79	4.0
Other Assumptions			
	1 acre	43,560 ft^2	
	1 MW	1,000,000 W	
	Ground utilization	90% of available area	

Appendix B. Solar Access Measurements



Data by Solmetric SunEye™ -- www.solmetric.com



Data by Solmetric SunEye™ -- www.solmetric.com

Figure B-1. Solar access measurements for Chino Mine PV site

Appendix C. Results of the JEDI Model

Table C-1. JEDI Results

Project Descriptive Data	
Project Location	NEW MEXICO
Population (only required for county/region analysis)	
Year of Construction or Installation	2013
System Application	Utility
Solar Cell/Module Material	Crystalline Silicon
System Tracking	Fixed Mount
Average System Size—DC Nameplate Capacity (kW)	348,000.0
Number of Systems Installed	1.0
Total Project Size—DC Nameplate Capacity (kW)	348,000.0
Base Installed System Cost (\$/kWDC)	\$2,790
Annual Direct Operation and Maintenance Cost (\$/kW)	\$25.00
Money Value (Dollar Year)	2012

Local Economic Impacts—Summary Results

	Jobs	**Earnings**	**Output**
During Construction and Installation Period		\$ (2012)	\$ (2012)
Project Development and On-Site Labor Impacts			
Construction and Installation Labor	1,366.0	\$88,468.50	
Construction and Installation-Related Services	2,437.6	\$75,672.50	
Subtotal	3,803.5	\$164,140.90	\$269,687.20
Module and Supply Chain Impacts			
Manufacturing	0.0	\$0.00	\$0.00

Impacts			
Trade (Wholesale and Retail)	406.8	$17,045.00	$50,901.20
Finance, Insurance, and Real Estate	0.0	$0.00	$0.00
Professional Services	491.5	$16,922.10	$55,713.40
Other Services	675.1	$49,949.70	$173,448.00
Other Sectors	1,556.1	$28,556.40	$51,542.80
Subtotal	3,129.5	$112,473.20	$331,605.40
Induced Impacts	1,531.5	$46,960.80	$158,486.80
Total Impacts	8,464.6	$323,575.00	$759,779.40

	Annual	**Annual Earnings**	**Annual Output**
During Operating Years	Jobs	$ (2012)	$ (2012)
On-Site Labor Impacts			
PV Project Labor Only	80.6	$4,848.40	$4,848.40
Local Revenue and Supply Chain Impacts	30.4	$1,245.30	$4,011.30
Induced Impacts	18.3	$559.80	$1,888.70
Total Impacts	129.3	$6,653.50	$10,748.50

Notes: Earnings and output values are thousands of dollars in year 2012 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Detailed PV Project Data Costs		(New Mexico)	
Installation Costs	**Cost**	**Purchased Locally (%)**	**Manufactured Locally (Y or N)**
Materials and Equipment			

Mounting (rails, clamps, fittings, etc.)	$44,290,853	100%	N
Modules	$486,422,163	100%	N
Electrical (wire, connectors, breakers, etc.)	$50,499,107	100%	N
Inverter	$72,339,706	100%	N
Subtotal	$653,551,829		
Labor			
Installation	$110,664,860	100%	
Subtotal	$110,664,860		
Subtotal	$764,216,689		
Other Costs			
Permitting	$5,113,674	100%	
Other Costs	$113,012,195	100%	
Business Overhead	$332,177,443	100%	
Subtotal	$450,303,311		
Subtotal	$1,214,520,000		
Sales Tax (Materials and Equipment Purchases)	$33,494,531	100%	
Total	$1,248,014,531		

PV System Annual Operation and Maintenance Costs

	Cost	**Local Share**	**Manufactured Locally (Y or N)**
Labor			
Technicians	$5,220,000	100%	
Subtotal	$5,220,000		
Materials and Services			
Materials and	$3,480,000	100%	N

Equipment		
Services	$0	100%
Subtotal	$3,480,000	
Sales Tax (Materials and Equipment Purchases)	$178,350	100%
Average Annual Payment (Interest and Principal)	$140,884,320	0%
Property Taxes	$0	100%
Total	$149,762,670	

Other Parameters		
Financial Parameters		
Debt Financing		
Percentage Financed	80%	0%
Years Financed (term)	10	
Interest rate	10%	
Tax Parameters		
Local Property Tax (percent of taxable value)	0%	
Assessed Value (percent of construction cost)	0%	
Taxable Value (percent of assessed value)	0%	
Taxable	$0	

Value			
Property Tax Exemption (percent of local taxes)	0%		
Local Property Taxes	$0		100%
Local Sales Tax Rate	5.13%		100%
Sales Tax Exemption (percent of local taxes)	0%		
Payroll Parameters	Wage per hour		Employer payroll overhead
Construction and Installation Labor			
Construction Workers/ Installers	$21.39	45.6%	
O&M Labor			
Technicians	$21.39	45.6%	

Appendix D. Assumptions and Results of the System Advisor Model

Case 1: Investor owned/PPA with 348 MW

This case assumes third-party investor for the PV system. All generated electricity from case 1 is assumed to be sold. The results of this case are to estimate the electricity rate as a PPA to get acceptable return on investment (15% internal rate of return).

Case 2: Developer owned/PPA with 348 MW

This case assumes FMI owns the PV system. All generated electricity will be sold as a PPA with PNM or an interstate utility at the rate of $0.055/kWh.

Case 3: Developer owned/virtual net metering with 348 MW

VNM is currently not available in New Mexico. Case 3 is to demonstrate the potential economic benefits for this option. This case assumes FMI owns the PV system. All electricity would be VNM to generate credits at retail electricity rate that can be used to offset charges at one or more other locations within the same geographic boundary. Retail electricity rate of $0.11/kWh is used for this analysis.

Case 3 Results

Table D-1. Case 3 Results

Metric	Base
Net Annual Energy	596,137,301 kW
LCOE Nominal	4.54 ¢/kWh
LCOE Real	3.61 ¢/kWh
First Year Revenue without System	$ -101.52
First Year Revenue with System	$ 65,575,001.6
First Year Net Revenue	$ 65,575,103.1
After-tax NPV	$ 275,789,664.
Payback Period	6.90685
Capacity Factor	19.5 %
First year kWhac/kWdc	1,711

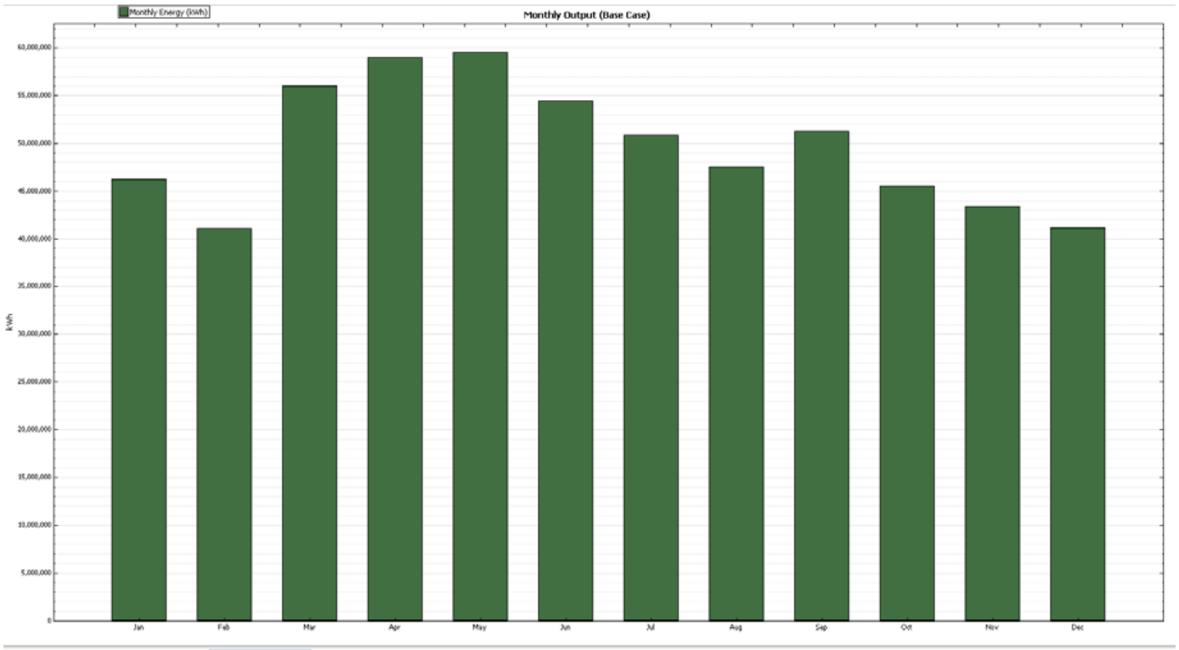


Figure D-1. PV system output

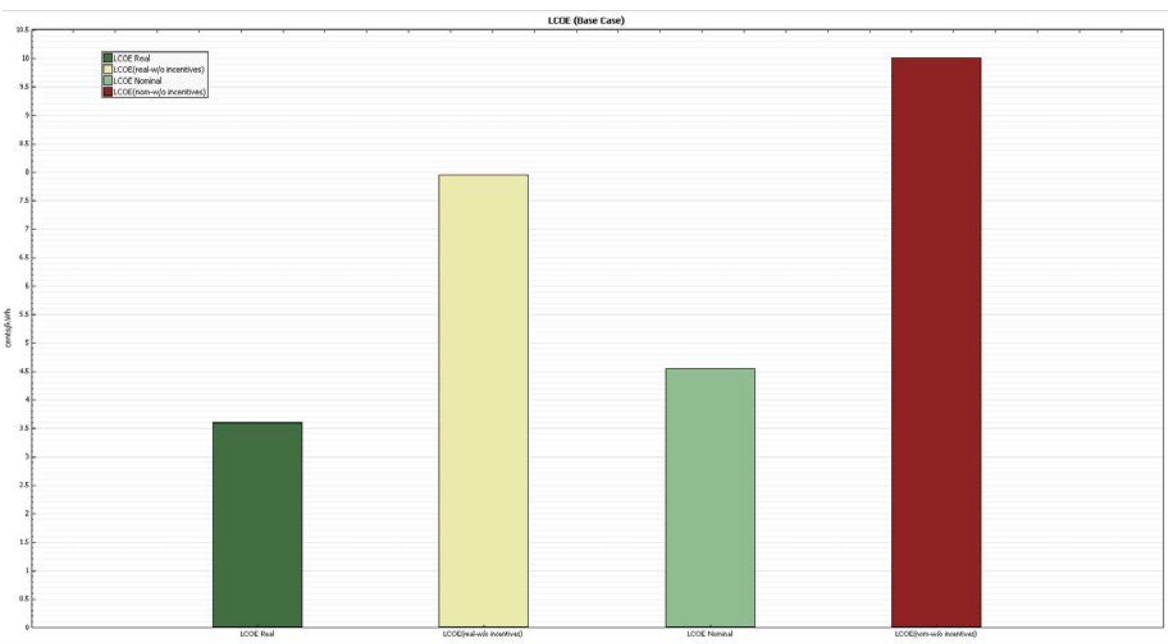


Figure D-2. Levelized cost of energy

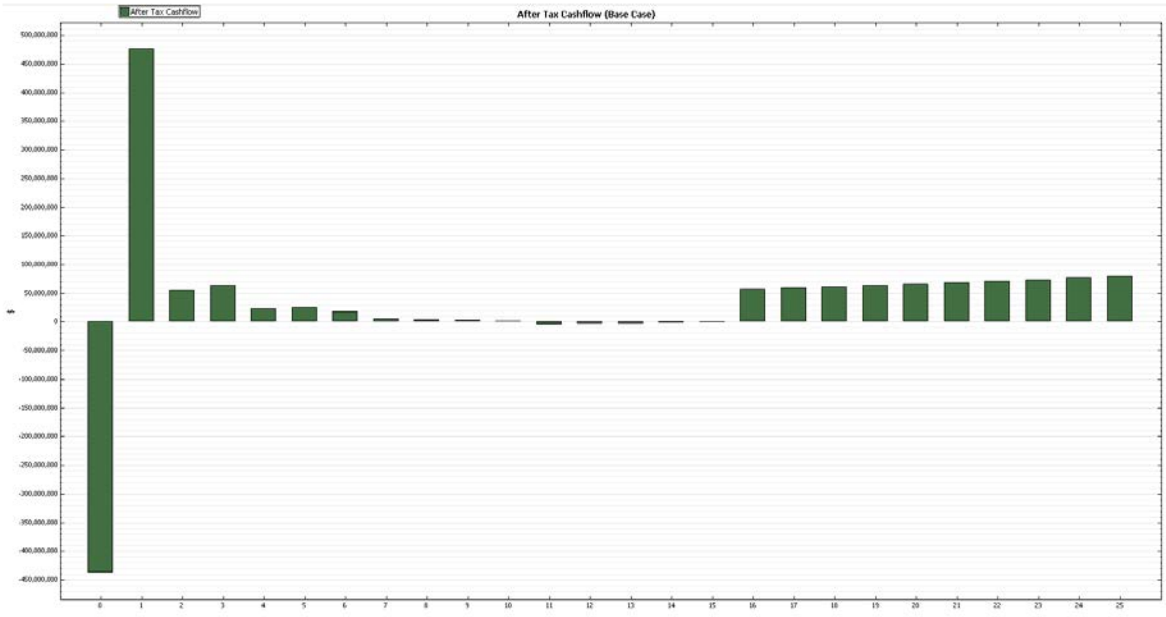


Figure D-3. After tax cash flow

Assumptions for Inputs (For case 3 as the best economic results)

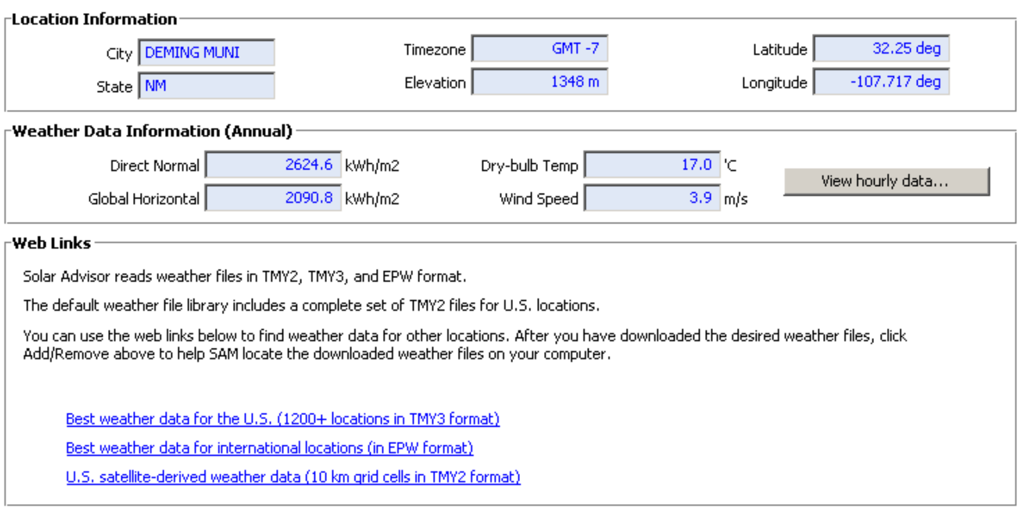


Figure D-4. Climate input

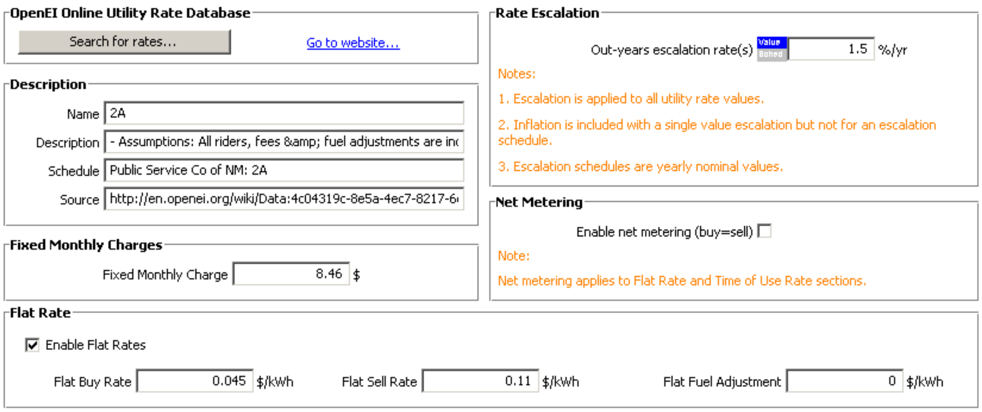


Figure D-5. Utility rate assumptions

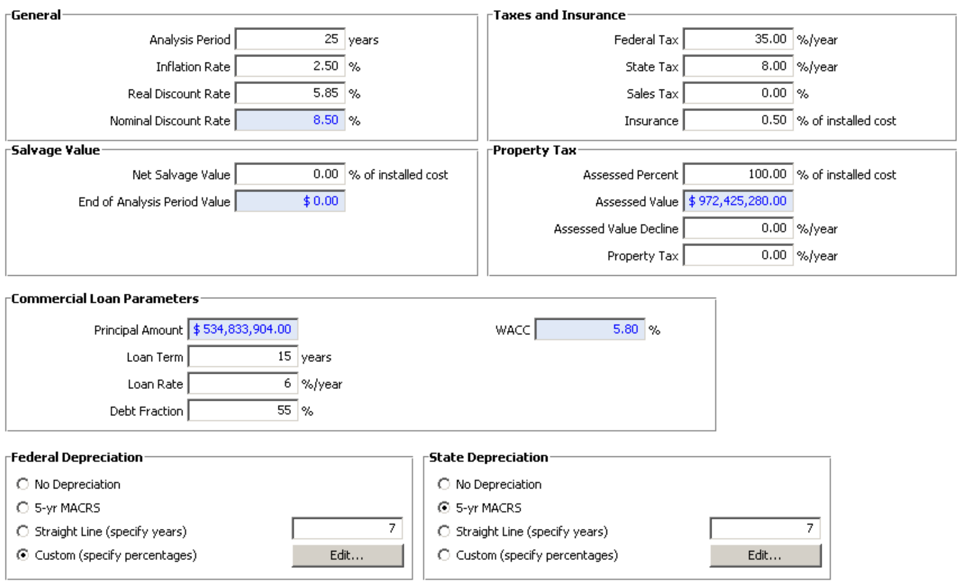


Figure D-6. Financing assumptions

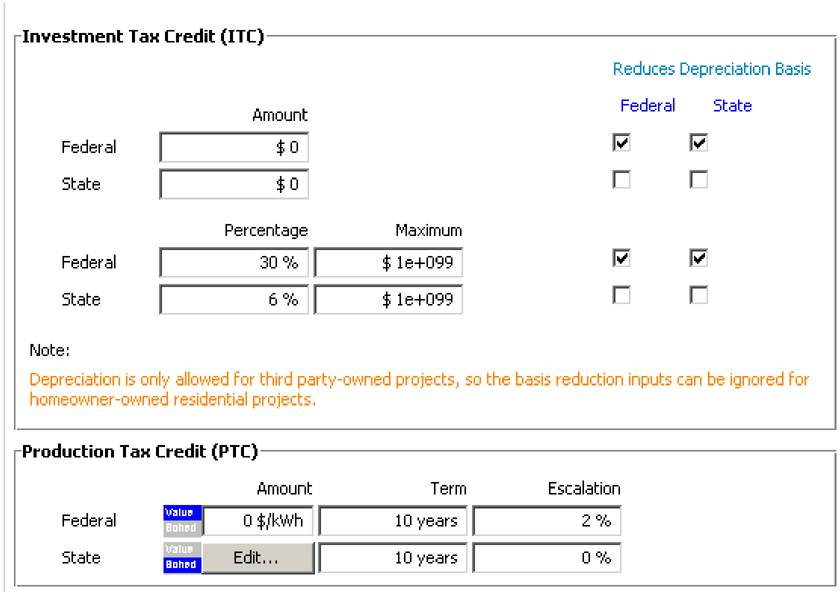


Figure D-7. Tax credit incentives assumptions

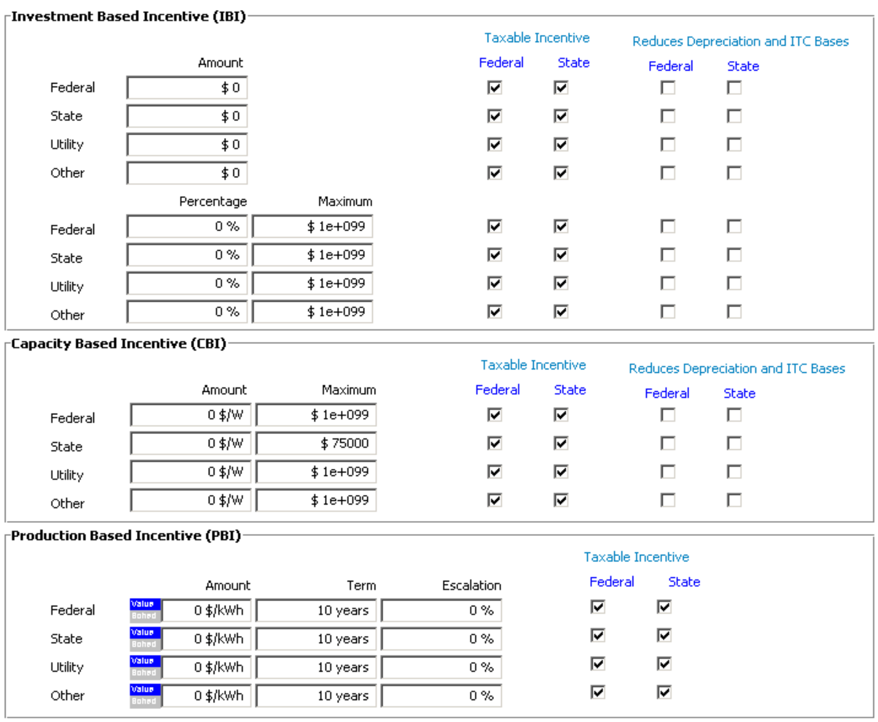
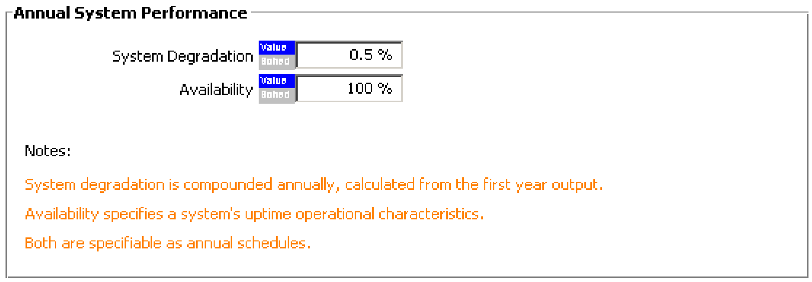


Figure D-8. Payment incentives assumptions


Annual System Performance

System Degradation 0.5 %

Availability 100 %

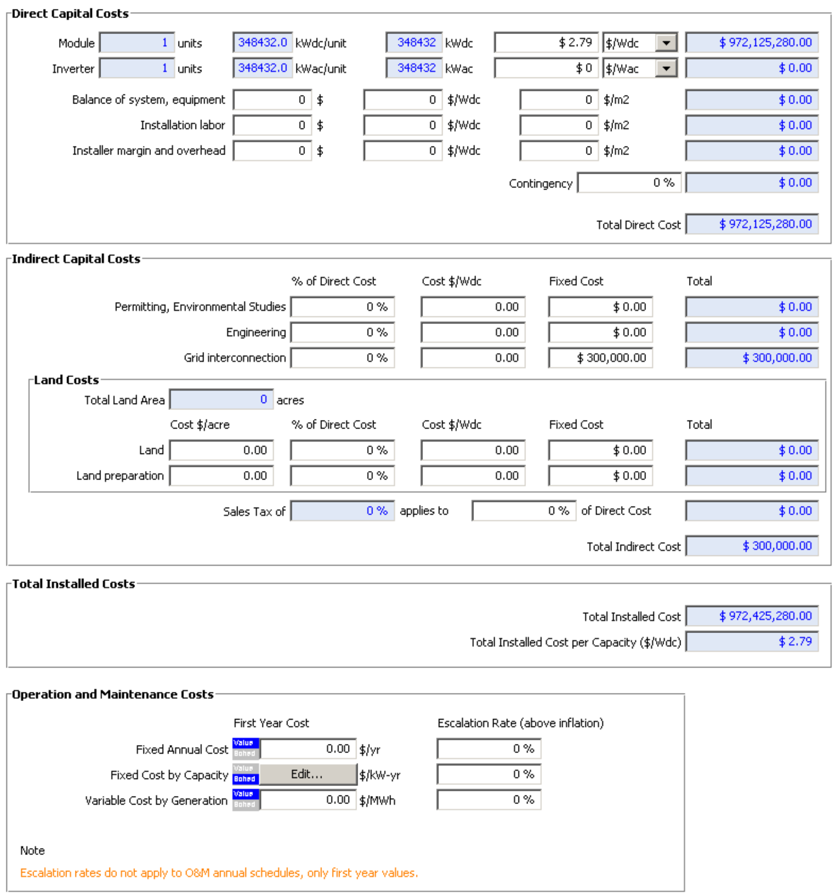
Notes:

System degradation is compounded annually, calculated from the first year output.

Availability specifies a system's uptime operational characteristics.

Both are specifiable as annual schedules.

Figure D-9. Annual performance assumptions


Direct Capital Costs

Module	1 units	348432.0 kWdc/unit	348432 kWdc	$ 2.79 $/Wdc	$ 972,125,280.00
Inverter	1 units	348432.0 kWac/unit	348432 kWac	$ 0 $/Wac	$ 0.00
Balance of system, equipment	0 $	0 $/Wdc	0 $/m2		$ 0.00
Installation labor	0 $	0 $/Wdc	0 $/m2		$ 0.00
Installer margin and overhead	0 $	0 $/Wdc	0 $/m2		$ 0.00
			Contingency	0 %	$ 0.00
				Total Direct Cost	$ 972,125,280.00

Indirect Capital Costs

	% of Direct Cost	Cost $/Wdc	Fixed Cost	Total
Permitting, Environmental Studies	0 %	0.00	$ 0.00	$ 0.00
Engineering	0 %	0.00	$ 0.00	$ 0.00
Grid interconnection	0 %	0.00	$ 300,000.00	$ 300,000.00

Land Costs

Total Land Area 0 acres

	Cost $/acre	% of Direct Cost	Cost $/Wdc	Fixed Cost	Total
Land	0.00	0 %	0.00	$ 0.00	$ 0.00
Land preparation	0.00	0 %	0.00	$ 0.00	$ 0.00

Sales Tax of 0 % applies to 0 % of Direct Cost $ 0.00

Total Indirect Cost $ 300,000.00

Total Installed Costs

Total Installed Cost $ 972,425,280.00

Total Installed Cost per Capacity ($/Wdc) $ 2.79

Operation and Maintenance Costs

	First Year Cost		Escalation Rate (above inflation)
Fixed Annual Cost	0.00	$/yr	0 %
Fixed Cost by Capacity	Edit...	$/kW-yr	0 %
Variable Cost by Generation	0.00	$/MWh	0 %

Note

Escalation rates do not apply to O&M annual schedules, only first year values.

Figure D-10. PV system costs

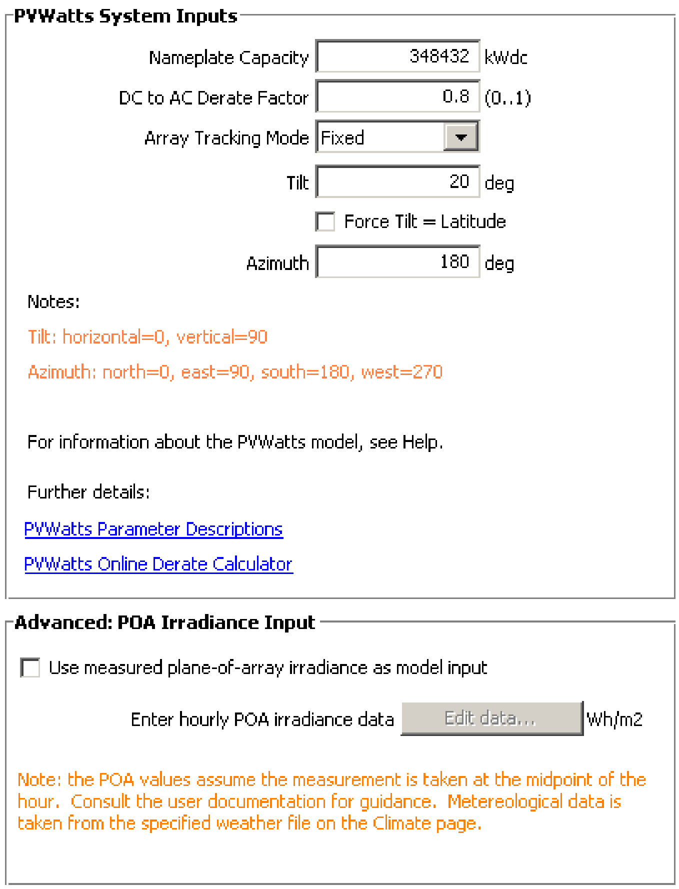


Figure D-11. PVWatts solar array assumptions

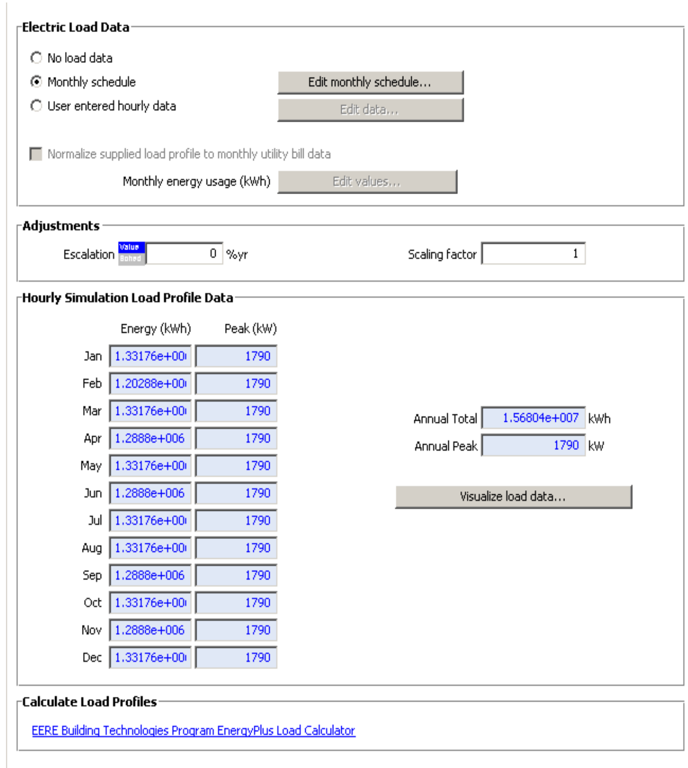


Figure D-12. Electrical loads assumptions