Accessible Solar Farm Design

Creating a construction manual and handbook for a universal solar farm design for small-scale utilization.

This report represents the work of four WPI undergraduate students submitted to the faculty as evidence of completion of a degree requirement. WPI routinely publishes these reports on the web without editorial or peer review.

Produced by Louis Lavenda, Devin Patel, Rosemary Shelton,

and Grace Stevens

5 May 2023

Abstract

As a contribution to addressing the UN's directive for Israel to produce 30% of its energy from non-fossil sources by 2030, the Mityaalim Foundation tasked our team with developing an open-source construction manual for a solar farm that can be built anywhere in the world. Our design features a 1.4 kW three-panel stationary unit that can be scaled up or down in any environment. Implementing our design will prove to be a strong step towards making green energy goals more attainable.

Executive Summary

Overview

The goal for this project is to create a construction manual of a solar farm under a few guidelines. The farm must be one hectare in size and must withstand the conditions of the Israeli desert. It must also be capable of being built anywhere in the world. Lastly, the manual is to be made for the construction company who will be installing the farm, as it is not a task that inexperienced individuals can do alone.

The Problem

The UN requires Israel to have 30% of the country's power usage come from renewable energy sources by the year 2030. Currently, they sit far behind that goal at only 9%.

The Objectives

While the solar farm design must fit the requirements for its potential Israeli location, it must also be easily accessible and adaptable for usage outside Israel.

The Solution

Our construction manual allows anyone to bypass the need to hire engineers, instead needing only to pass our manual onto a construction company. The design features a triple-panel mount which can be made in any quantity, making the design completely scalable and shapeable. Additionally, the manual specifies exactly how to alter the design to work in various locations and soil conditions.

Authorship

Project Section	Creator	Editor
Accessible Solar Farm Design Paper		
Abstract	Grace Stevens	Devin Patel
Executive Summary	Grace Stevens	Devin Patel
Acknowledgements	Grace Stevens	Devin Patel
1: Introduction	Rosemary Shelton	Devin Patel
2: Background	Rosemary Shelton, Grace Stevens, Devin Patel, Louis Lavenda	Devin Patel
3: Methodology	Rosemary Shelton, Grace Stevens, Louis Lavenda	Devin Patel
4: Findings	Rosemary Shelton, Grace Stevens, Louis Lavenda	Devin Patel
5: Deliverables	Rosemary Shelton, Grace Stevens, Louis Lavenda	Devin Patel
6: Conclusions and Recommendations	Rosemary Shelton	Devin Patel
Solar Farm Construction Manual		
1: Introduction and Important Details	Louis Lavenda	Devin Patel
2: Material Breakdown	Devin Patel	Louis Lavenda
3: Assembling the Mount	Devin Patel	Louis Lavenda
4: Mounting the Panels	Louis Lavenda	Devin Patel
5: Connecting to the Grid	Devin Patel	Louis Lavenda
CAD Design		
Triple-Panel Mount	Devin Patel	N/A
Concrete Layout	Louis Lavenda	N/A
CAD Drawings	Devin Patel	N/A
Final Presentation		
Slideshow	Grace Stevens, Rosemary Shelton	Everyone

Acknowledgments

First, we would like to thank our sponsor Maor Zlotzever, the CEO of the Mityaalim Foundation. Without Maor, this project would never have happened, and his direction and guidance was critical to the success of this project.

Secondly, we would like to thank the Braude College of Engineering for hosting us during our stay in Karmiel. We would not have been able to work directly in Israel with our sponsor without Braude.

We would also like to thank Professor Alejandro Manga from Worcester Polytechnic Institute. Professor Manga helped us in narrowing our direction and led us towards the critical research that was required for this project.

We also appreciate the group of students from the University of Haifa who administered our survey to Israeli citizens. This survey let us understand the social implications of this project by interviewing those who had solar panels installed on their own homes.

Lastly, we would like to thank our project advisors from Worcester Polytechnic Institute, Professor Svetlana Nikitina and Professor Ivan Mardilovich, for their effort in planning the Israel trip and guiding our project. They provided crucial guidance in our project direction and completion.

Contents

List of Figures

List of Tables

1: Introduction

This research proposal discusses the various aspects of building photovoltaic solar panels, particularly in desert areas. Thorough research was conducted on the distinct ways to use solar panels, including mounting options, electrical cell type, and storage methods. This culminated in a decision based on a careful balance of efficiency, cost, usability, and maintainability. With this decided panel type, a 3D CAD model was produced, from which a final construction manual was created.

The research question has two parts. Firstly, what is the most efficient, cost-effective way to build a solar farm? Secondly, how can a solar farm design be made accessible to communities across the globe? To meet the final goal of a design that can be used anywhere by anyone, it's just as important to make the design accessible as it is to make the design efficient.

1.1: Introduction to Solar Technology

Solar technology has been around since the 1800s but grew exponentially during and after the 1970s. In 1839, French physicist Edmond Becquerel discovered what came to be known as the photovoltaic effect, when he discovered voltage and current flowing through electrodes that were exposed to light. Famous physicist Albert Einstein then went on to win a Nobel Prize in 1921 for being the first to explain how the photoelectric effect works.[44] Modern solar panel technology, however, wouldn't take shape until 1954, when the modern photovoltaic cell was invented. Initially, this technology was incredibly expensive, and thus was reserved for orbital satellites. This would change thanks to the 1970s energy crisis, which caused the United States government to encourage further research into solar energy technology, funding cheaper technology that eventually led to its widespread usage.[44]

2: Background

Electricity is a fundamental part of modern human life, and electricity reliability is a huge factor in standard of living. Without electricity, it is difficult to get consistent access to clean water, transportation, medical aid, lighting, and cooking appliances. Unfortunately, there are roughly 2.7 billion people who do not have access to reliable electricity, which is over 34% of all the people in the world.[23] Worse yet, the majority of those who do have access to reliable electricity get it from unclean sources.

Solar energy is a potential solution to both of those problems. Solar is one of the strongest contenders for decreasing carbon dioxide emissions in the energy sector. Solar also has no continuing costs other than staffing or maintenance, as it requires no material ingredients like other green non-renewable sources, including nuclear.

2.1: General Renewable Energy Obstacles

One of the greatest obstacles in increasing renewable energy sources is public opinion. The phrase "too poor to be green" was thrown around to express sentiment against renewable energy for its large cost. Areas that are too poor to have reliable electricity will not look to renewable energy sources for this reason, instead favoring fossil fuel energy for its lower cost. Having sustainable, green energy has been only a backseat priority. However, as technology has evolved, green energy sources have only gotten cheaper, and solar is the cheapest of the bunch, as shown in Figure 2.1.1. This is especially true in areas like Israel or Africa, where vast areas of flat terrain with minimal cloud cover leads to optimal conditions for solar energy.[33]

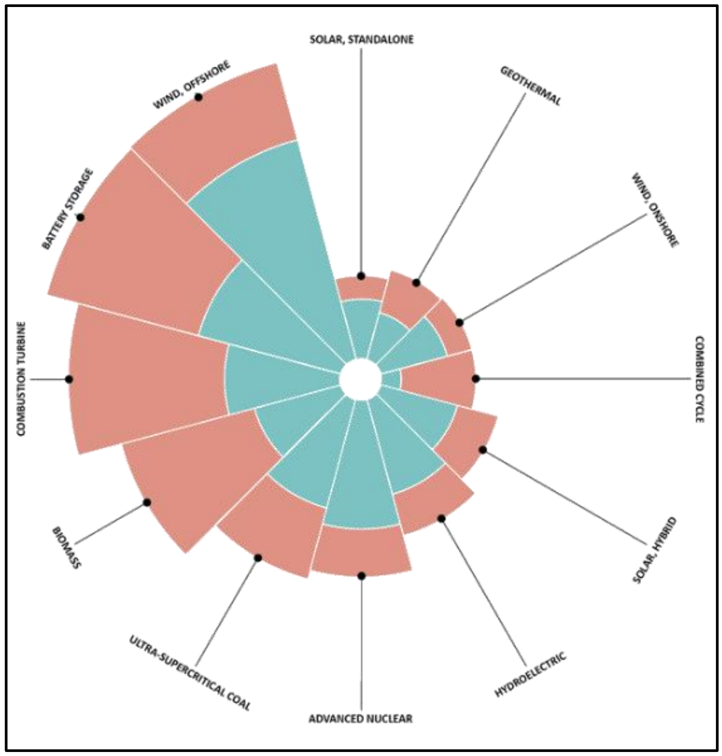
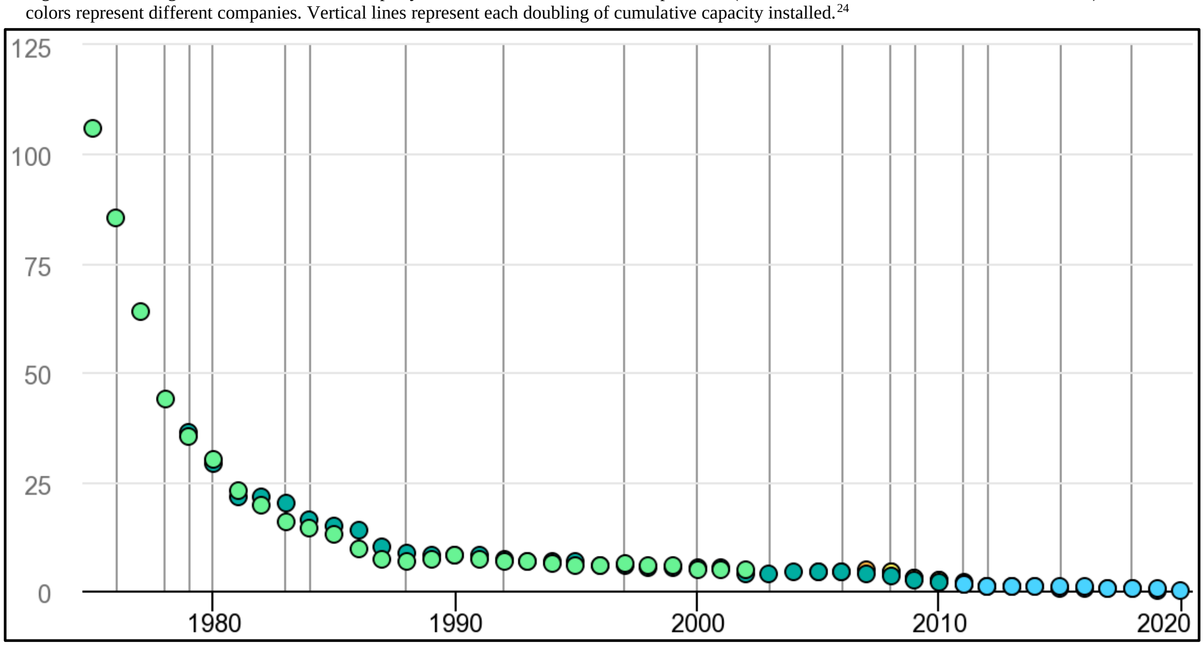


Figure 2.1.1. A visual representation of the cost of the different energy sources. The green represents the base cost (excluding storage and operation, while the orange represents levelized cost of electricity per MWh. Standalone solar is the lowest.[43]

Figure 2.1.2. Change in cost of solar modules per year. Vertical axis denotes USD per Watt (inflation accounted for at the 2015 USD value). Different colors represent different companies. Vertical lines represent each doubling of cumulative capacity installed.[24]



2.2: Israeli Renewable Energy Production

This project was started as a contribution towards the UN's directive for Israel to have 30% of its produced electricity be from green sources by 2030. Currently, Israel is lagging far behind this goal, with only 9% of produced energy being green.[25] The direct goal of this project is to make solar energy plants cheaper to build by removing the need to hire engineers, as our design can be given directly to a construction company. This also makes building a solar farm more accessible beyond only Israel's national government. Because of the farm's scalable nature, local governments or large businesses can use our design to build their own solar plant specifically for their area. By making this resource available, solar farms will be able to be built by anyone, anywhere, allowing the citizens of Israel to help their country meet their clean energy goal.

2.3: Solar Panel Styles and Components

Electronics Basics

Solar Cells

The phrase 'solar panel' refers to a surface that is used to absorb energy from the sun to turn into electricity using photovoltaic technology. Photovoltaic technology turns light into electricity, and there are three types of photovoltaic technology that are used in solar panels. The standard photovoltaic cell, or PV cell, converts light into electrical current by using concentrated light energy to release electrons from stable atoms, starting an electric current. PV cells are the most common type of cells for solar panels because they are both cheap and easy to install.[14] The biggest drawback of photovoltaic cells is that they lose efficiency at higher temperatures. As a result, solar panels that use only PV cells often need a cooling system to keep the panels operational in extreme heat.[14]

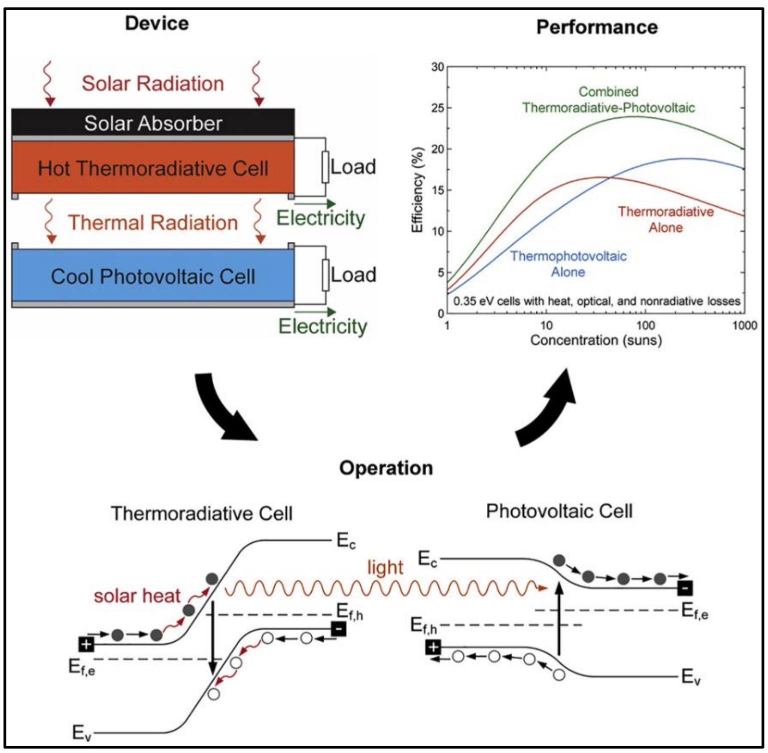


Figure 2.3.1. Top-left: Design chart for a photovoltaic cell. Bottom: Operation diagram for converting light to energy. Top-right: Performance graph demonstrating the efficiency curves of different types of cells.[50]

The two less common technologies used in solar panels are TPV and TR cells. TPV cells, short for thermophotovoltaic cells, work like PV cells, except they work on infrared light instead of visible light. Because they utilize distinct parts of the light spectrum, combining TPV and PV cells into one panel can significantly increase output and efficiency. TR cells, or thermoradiative cells, convert heat into electricity by converting the heat into light before shining it at a PV cell. This eliminates the PV cell's major downside of working less efficiently at higher temperatures.[50]

As shown by the graph in Figure 2.3.1, the peak efficiency for TPV and TR cells on their own are only around 17% and 20%, respectively. When TR cells are combined with PV cells in a panel, however, the peak efficiency maxes out at close to 25%. As a result, a TR-PV combination panel may prove to be the king of efficiency, especially in the sweltering heat of the Israeli desert.

Power Storage and Transfer

The most common method of storing electricity is using batteries. Other possible methods include pumped-storage hydropower, thermal energy storage, flywheel storage, compressed air storage, solar fuels, and virtual storage.[51] Most of these, however, require specific land features to be implemented, and all of them have not been heavily tested. For this reason, batteries are considered the most effective method for energy storage. However, batteries are not necessarily necessary to create a working power plant. With private solar farms especially, it is often more practical to sell excess energy to the grid, rather than storing it in batteries, due to how expensive they are.

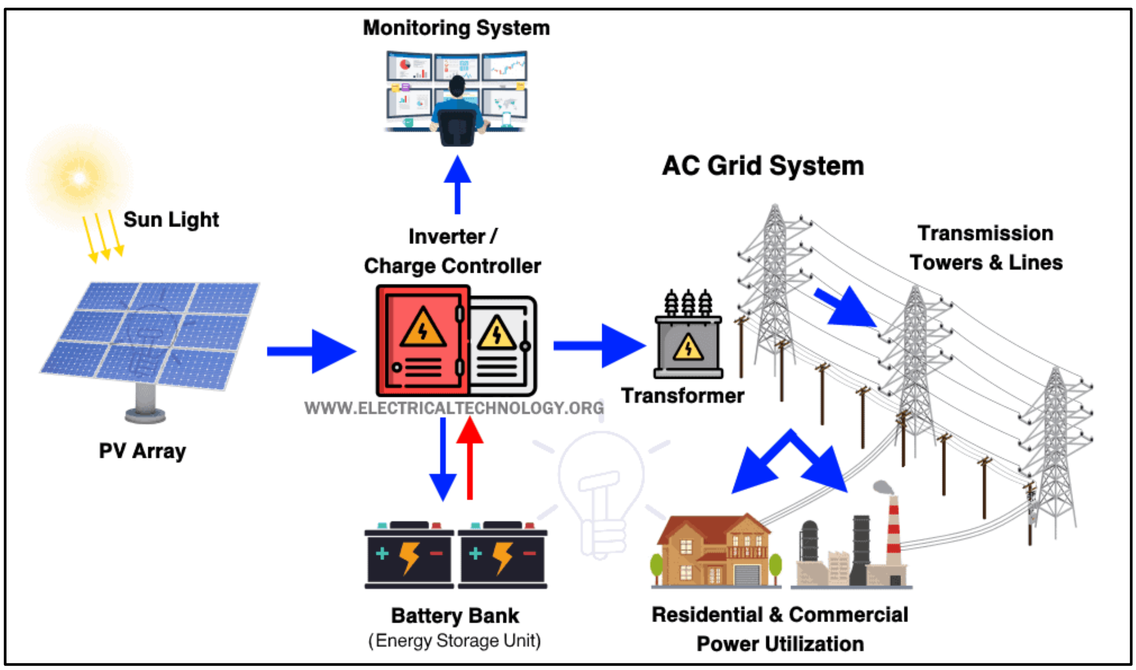


Figure 2.3.2. A general diagram of how a power plant transfers electricity to its destination. Batteries can be utilized as a side path for leftover electricity, but they are not required.[15]

Figure 2.3.2 shows an inverter between the panel and batteries and the main grid. This is because the grid transfers power using a different type of current (AC) than the batteries store and the panels produce (DC). DC, or direct current, involves a constant flow of electrons across the conductor. AC stands for alternating current, as it holds electrons in place, but oscillates them back and forth, transferring energy from one electron to the next. Inverters are required to turn the electricity from solar panels into electricity that can be used in an outlet or building.

Mounting Type

Fixed versus Rotational

Maximizing sun exposure is a key element towards increasing power output, and there are separate ways to physically mount panels to increase their sun exposure. Fixed solar panels are angled equivalent to the local latitude to average the best angle over a full year. Rotational solar panels, on the other hand, can follow the sun as it moves throughout the sky to get more sunlight access than fixed panels can. Despite this, fixed solar panels account for just over 47% of the solar energy produced in the US, and for good reason.[52] Their lack of moving parts leads to cheaper costs and longer lifespans. In exchange, fixed solar farms will need more panels, and thus more land area, to reach the same output as rotational farms, which is especially important in a country like Israel where land is incredibly culturally important.

Following the sun takes two important aspects into consideration. The first is how the sun moves across the sky from east-to-west over the course of one day. Single-axis rotational panels are a type of rotational panel that follows the sun from east-to-west. These panels "roll" over their center, rotating along what is known as the tilt axis. Figure 2.3.3 shows a design for an array of solar panels that can be rotated over their tilt axis by just two motors.

The sun also changes in elevation in the sky over the course of a year. Near the equator, this doesn't happen, but the further away from the equator a solar plant is built, the more extreme this change will be. Dual-axis rotational panels can both follow the east-to-west motion of the sun by rotating over the tilt axis and follow the elevation change over the year by tilting backwards and forwards. While this is more efficient, a major drawback of the dual-axis system is that every individual panel would need at least one motor, whereas in the design shown in Figure 2.3.3, a whole array of panels can be moved by just two motors.

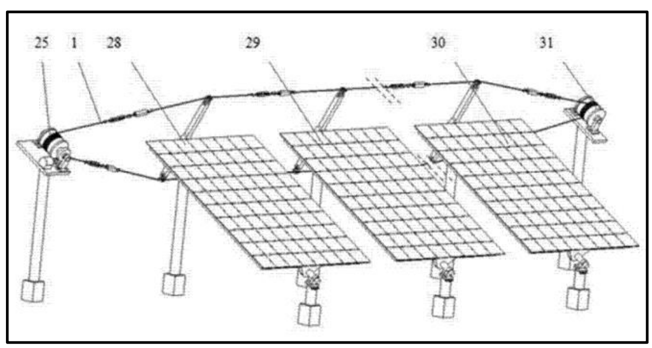


Figure 2.3.3. Chinese patent for a single-axis rotational solar farm design that allows for a long line of panels to be rotated with just two motors. This works using a cable system, similar to that of a ski lift.[32]

Rotational Tracking

An added complexity of rotational panels is having tracking software. Two types of loops have been created for coding rotational panels, referred to as the open-loop system and the closed-loop system. Open-loop tracking involves calculating the sun's position in the sky based on astronomical data and aligning the solar panels in the proper direction at regular intervals. An improved algorithm for this was created that adjusts the interval based on if the change in azimuth (horizontal rotation) and zenith (vertical rotation) angles have surpassed a certain limit or not. The open-loop tracking system results in an average of 28.5% more electricity produced than fixed solar panels, with the improved algorithm adding another 1.5% at a latitude of 40°N, close to that of Israel.[36]

The closed-loop system is more complex. Rather than angling to predetermined positions based on the known position of the sun in the sky, the closed-loop system orients the solar panels in the direction with the most amount of sunlight at any given time. This works by mounting angled sensors known as photoresistors, or LDRs (light detecting resistors), on the four cardinal sides of the panel. A photoresistor is a type of electrical resistor whose resistance increases when exposed to stronger light. By sending a known voltage into the resistor and measuring the output voltage, the resistance through the LDR can be calculated. The closed-loop system uses these resistance values to angle the panels proportionally towards the LDRs reading the most light. This method bypasses some of the problems with using open-loop tracking. The most common reason is that obstructions such as mountains, trees, or buildings might cut off the view to the sun, so the angle with the most sunlight would be around the obstruction, away from the sun. A secondary reason is that in unideal weather, clouds or sandstorms could obstruct the sun, but a nearby pocket in the clouds or sand may have a higher exposure to sunlight. In both, the closed-loop system detects this change, but an open-loop system does not. For these reasons, closed-loop systems perform better, producing an average of 33% more power than fixed panels, in comparison to open-loop systems' 28.5-30%.[36] Figure 2.3.4 shows the results of testing the different methods across the day and year.

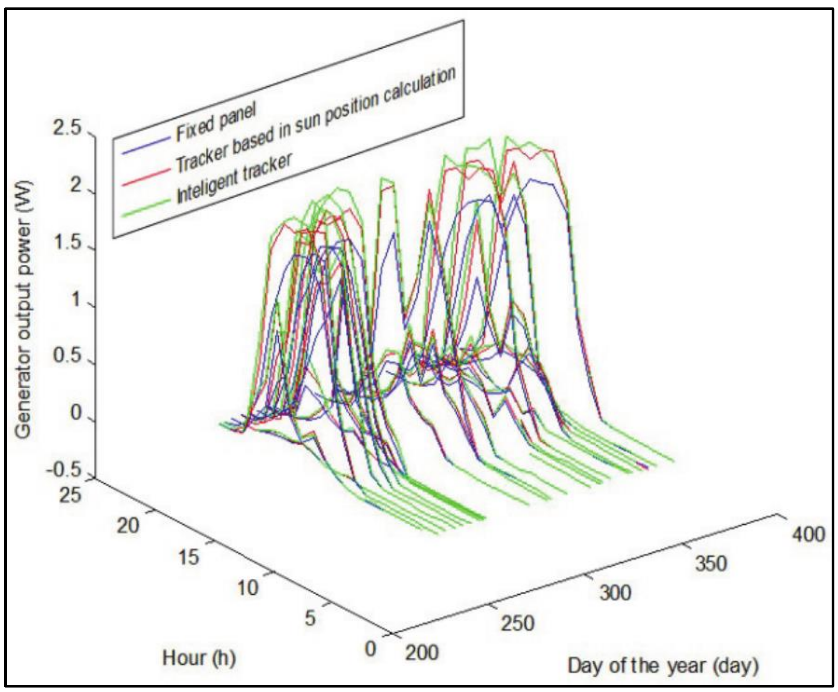


Figure 2.3.4: Performance comparison of closed-loop tracking (green), open-loop tracking (red), and fixed panels (blue). The two horizontal axes represent the course of a day and the course of a year.[36]

Actuation

Surprisingly, there are quite a few diverse ways these panels can be actuated. Active tracking is the simplest, most reliable, yet most expensive system. Active tracking uses electric motors to rotate the panels. On the opposite end is manual tracking, where a person manually adjusts the angle of the solar panels to the correct position. While cheaper and more maintainable, manual tracking is impractical for solar panels on a large scale. Passive tracking is another method of panel angling that requires no motors, humans, or electricity to function. Passive tracking refers to an inventive solution where pneumatic cylinders are used to hold up the four corners of a solar panel. The cylinders closest to the sun experience more heat, which changes the pressure in the cylinders and thus raises or lowers the corresponding corner, angling the panel correctly. This is less precise than active tracking, but also significantly reduces cost and increases lifespan.[22]

There is one more comparatively newer method of tracking known as semi-passive tracking. Semi-passive tracking keeps the solar panels themselves completely stationary, but instead moves an array of small mirrors such that they focus the sunlight onto the panels. An example of this can be seen in Figure 2.3.5. These mirrors, known as micro-heliostats, reflect light through a type of lens called a Fresnel lens. Fresnel lenses are very thin lenses that can be fit into a moving unit like the one shown in Figure 2.3.5.[22] This method keeps the accuracy of active tracking but with reduced motor and maintenance costs. However, this technology is overly complex, and implementing such a model would make our design significantly less accessible as a result.

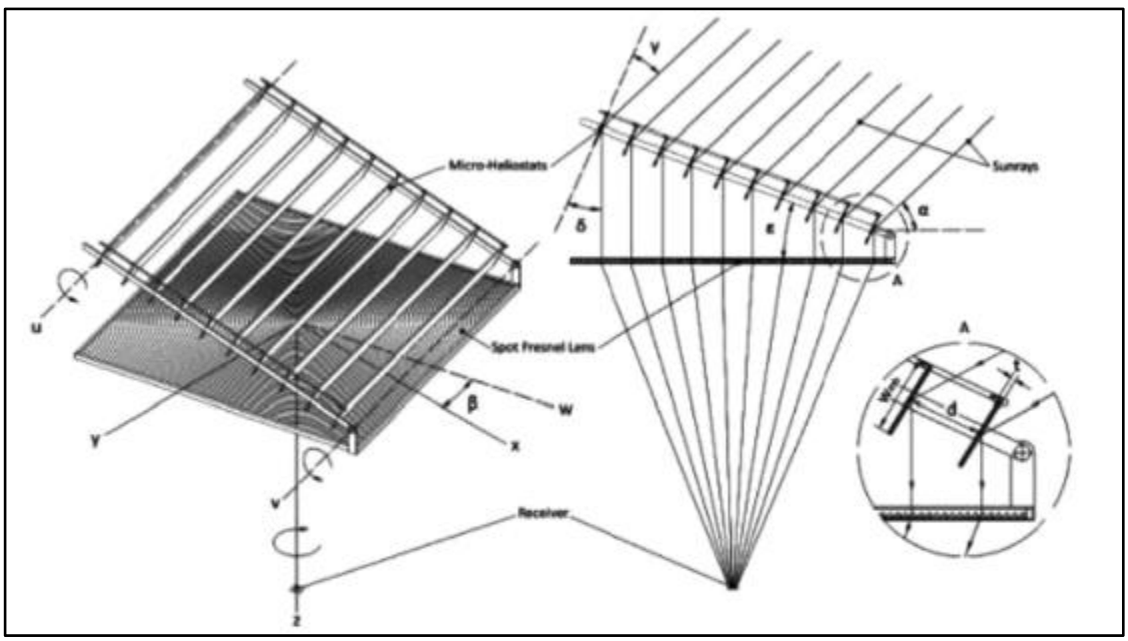


Figure 2.3.5. A semi-passive tracking system using a micro-heliostat array and a Fresnel lens. This system keeps the solar panels stationary, instead moving the mirror array on top.[22]

Desert Engineering

The Israeli desert will prove to be a challenging terrain to build in. To understand why, we need to examine the unique environmental and geographical factors that make this region so difficult for construction.

By far the biggest challenge is the sand. Soil, in comparison, is wet, and sprawling with plant life, holding the dirt together. Sand is devoid of life, and completely dry, making it behave at times more like a fluid than a solid. Like a whirlpool in water, sand often sinks and drains in certain areas, which would shift structures on the surface. Additionally, the lack of infrastructure can make it difficult to transport materials out to the build site. While construction in this environment may seem impossible, it has been done before. In fact, the tallest building in the world, the Burj Khalifa, was constructed completely in the desert on loose sand. This massive superstructure was made possible using an elaborate foundation system. The foundation consists of a shallow concrete raft sitting atop 192 concrete piles that go 50 meters into the earth. These piles completely prevent shifting because they assume so much space. A concrete piling system similar to this could be implemented on a smaller scale to keep our panels stable.[20]

Figure 2.3.6. The Burj Khalifa's foundation. Concrete pilings go deep into the sand to keep the structure stable.[20]

Sandstorms can also present significant challenges. The high winds can cause damage to the delicate panels and cells. Flying debris and sand can be a hazard to such high-voltage equipment. This could also reduce panel efficiency, with dust landing on the panel's surface. These conditions require maintenance schedules to clean and inspect the panels. When solar panels become damaged, it will oftentimes be easier to replace the panels outright than to try to fix them. This is expensive and could require a surplus of panels in storage nearby as backups. Additionally, the intense heat of the desert could cause potentially serious issues both to the farm's efficiency and to its integrity. The extreme heat potentially could warp the aluminum or melt any plastic or rubber used in the farm. Additionally, solar panels tend to become less effective in hot temperatures. This could require a cooling system to be put in place to keep the panels operating at a usable efficiency.

2.4: Background Conclusion

There are several important considerations that need to be made surrounding the technical components of solar panel engineering. The final design will need to incorporate the right considerations to perfectly balance efficiency, cost, usability, and maintainability. Modern technology proves a compelling case for rotational tracking as the future of solar panels. However, for the sake of accessibility, it may prove to be too complex for our purpose.

3: Methodology

Data collection and analysis are key to achieving the main objectives of making a solar farm design that is adaptable and user-friendly. It is of the utmost importance that the data being presented is accurate and supported by qualified professionals. Data from solar panel companies, manufacturers, and solar energy researchers, as well as qualitative data obtained from surveys with citizens and interviews with manufacturers, are essential for ensuring our project meets its purpose of accessibility.

The two parts of our research question connect to the two types of research that need to be conducted. The first is technical information about building an effective solar plant. This includes everything discussed in the background in Chapter 2. The second part surrounds the language, social implication, and public perception. Although our handbook will be an open resource for anyone around the world, our public perception data will be focusing on interviews and surveys with Israeli citizens who could potentially use this technology or already have experience using solar technology.

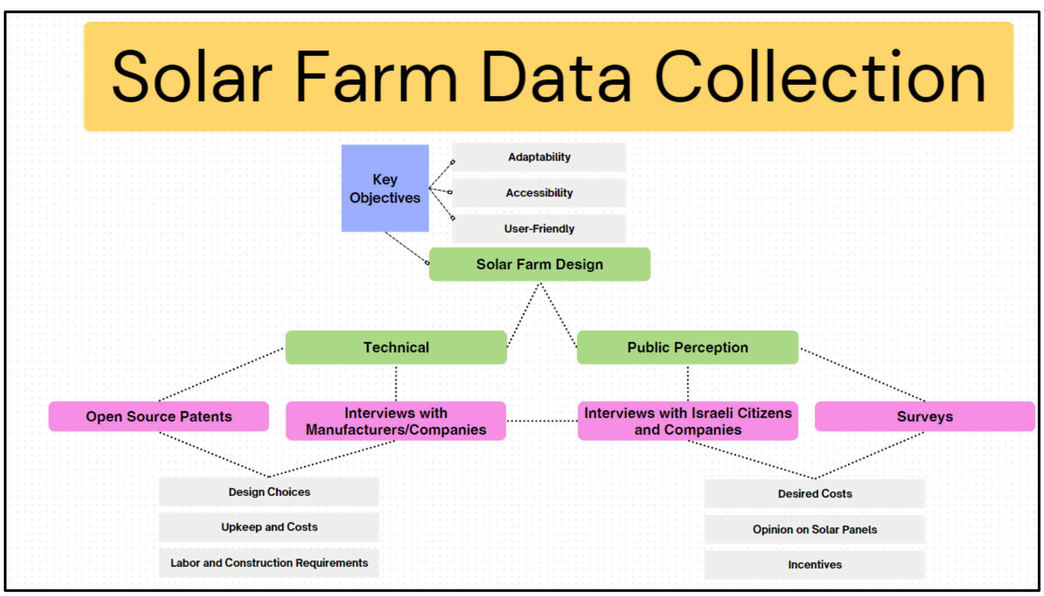


Figure 3.0.1. Data collection chart with the research methods being used to achieve the key objectives.

3.1: Building Case Studies of Solar Panel Providers

Researching solar panel companies that have built solar farms in desert areas such as Israel, south-eastern Europe, Dubai, and the southwest United States will supply insightful knowledge on aspects of building desert solar farms that we may have otherwise not considered. As will be discussed later, Dubai in particular would be notable for harnessing solar power in a completely different method from that of solar panels.

3.2: Collecting Data with Interviews and Surveys

Interviewing manufacturers will provide us with insight into the costs, availability, and manufacturing processes behind solar panels. Manufacturers often can provide more practical knowledge about the process than can be found simply in patents and literature reviews. Additionally, interviewing companies and local governments that have installed solar farms before will provide us with a secondary layer of knowledge on the installation process behind solar power plants. This knowledge will be especially important to ensure that our handbook addresses any installation issues that users may run into. A tour and interview have been scheduled with the Ma'ale Gilboa power plant at Mount Gilboa. We may also schedule interviews with other solar companies like Apollo, a company that our sponsors work with.

One of the other most critical aspects to properly understand going into this project will be the monetary value that Israeli citizens place on solar energy. If a local government wants to employ our farm design, but our design is more expensive than the taxpayers are willing to pay for, then they will vote against it being built. Not everyone values green energy the same, so it is important to know what the opinions that taxpayers have are. To gauge the Israeli public perception of solar panels, a survey questionnaire was created and will be administered to Israeli citizens by students at the University of Haifa. This will be important in estimating an appropriate cost for our power plant design.

3.3: Ethical Considerations and the Institutional Review Board

The installation of solar panels leads to some important ethical considerations. Solar farms can assume a large land area, so it's important to ensure that no local landmarks are being disturbed, and that historic and religious land remains untouched. Despite the amount of history that can be found in Israel, the government has been making a push toward the world of renewable energy, and as a result are expanding the rules and regulations around building renewable energy. As mentioned, "As of July 2013, SI 5281 is undergoing another revision. Changes that will be made may include expanding it to industrial buildings, neighborhoods and campuses, and more".[26] Although the main project will be taking place in Israel, it should be assumed that not all other countries would have the same building regulations. Awareness of the various types of building regulations will be critical in ensuring adaptability and accessibility in our handbook.

In addition, the research protocol has been reviewed by the Institutional Review Board at Worcester Polytechnic Institute. The purpose of the board is as follows, “The Institutional Review Board (IRB) at WPI promotes and supports efforts to conduct innovative research at WPI while also helping researchers understand and comply with the ethical guidelines and regulatory requirements for research involving human subjects”.[55] Since our project heavily relies on trust between various groups of people, the IRB has been a part of the process of ensuring that our survey methods present well.

4: Findings

Across the different power plants, many unique designs featured many different parts. Solar plants from Europe, America, Dubai, and Israel were researched, and across them technology was seen from American, Chinese, and German manufacturers. In this section, our findings on these topics will be discussed as we narrow down our design for the type of solar panel we will be using.

4.1: Case Studies of Solar Panel Providers in Desert Areas

Eastern and Southern Europe

The Francisco Pizarro Solar Power Project in Extremadura, Spain boasts an impressive 1.59 million single-axis rotational panels, powering up to 375,000 houses. This farm powers 0.24 households per panel and fills 1223 panels per hectare.[19] The whole farm costs 300,000,000 USD, featuring PV modules from Chinese manufacturers Trina Solar and JA Solar. This farm uses polycrystalline solar panels, which are significantly cheaper than their monocrystalline counterparts.[19]

Solar panels in this region are highly efficient because of the abundant sun exposure and cooler temperatures. This region has also made big advancements in technology due to the focus on renewables in the region’s politics.[16] As a result, the cost for solar panels in this region has been steadily declining, reaching 5000–6000 euros (5520–6620 USD) for a 5kW panel in 2021. Solar prices in this region have even become equally competitive with coal and gas prices. It is predicted that the cost of solar panels in eastern and southern Europe will continue to decrease as production and technology advancements increase.[19]

The panels at Francisco Pizarro have proven to hold their own against the harsh weather conditions of southeastern Europe. They can withstand wind, rain, heat, and heavy snowfall with few problems. The aluminum used in the panel framing is resistant to rust and ultraviolet rays, giving the polycrystalline solar panels a lifespan of around 25 years.[19] This plant’s design is also modular, allowing simpler repair processes and easy diagnostic capabilities.[16]

Southwest United States of America

The largest solar farm in the United States is the Solar Star Projects found in Rosamond, California. This plant is split into two sections with capacities of 265 MW and 314MW each, totaling 1.73 million single-axis rotational panels.[47] This farm squeezes in 1335 panels per hectare over its 1300-hectare span, and can power 250,000 homes (0.145 houses per panel). The cost to build the Solar Star PV Park was about 2.5 billion dollars.[47] That puts this farm at over eight times more expensive than Francisco Pizarro, which has a similar amount of panels, thanks to the much higher quality equipment used in Solar Star Park. Solar Star uses monocrystalline panels, which usually cost 1.00–1.50 USD per Watt. In comparison, Francisco Pizarro uses polycrystalline panels, which cost roughly 0.70–1.00 USD per Watt. The modules in this farm are produced by American manufacturer Sunpower, and cost 599 USD per panel.[48]

While most polycrystalline solar panels have lifespans of only ten to twenty years, Sunpower's monocrystalline solar panels in the Solar Star Projects come with warranties for up to thirty years.[48] However, the solar tracking technology, like with Francisco Pizarro, does come with risk of increased maintenance, due to the moving parts.

Dubai

The Shams 1 is a massive solar power plant in Dubai, but unlike the rest of the plants researched here, it does not use photovoltaic technology. Instead of using solar panels, this farm uses parabolic trough technology, which uses a curved mirror to focus light onto a water tube, turning it into steam that can spin a turbine. Within this farm, there are over 258,000 mirrors and 192 solar collectors.[13]

The main drawback of parabolic trough technology is the incredibly low efficiency that it comes with. For comparison, the Solar Star Projects can power 192 houses per hectare of panels, while Shams 1 can only power 80 houses per hectare of mirrors.[13] However, its upside lies in its price. The total construction cost of Shams 1 was 600 million USD, sitting at only 24% the cost of the Solar Star Projects. At a size of 250 hectares, that puts Shams 1 at roughly 2.4 million USD per hectare.[39]

Shams 1 used mostly German technology in its design. Unfortunately, because such a large majority of the parts made for this farm were custom designed specifically for Shams 1, there is not a lot of available information on specific pricing breakdowns. The main component of parabolic troughs is the collector module, which for Shams 1, is the model PTR70 from Schott, a German glass manufacturer.[39] The PTR70 3rd Generation used in Shams 1 was designed over ten years ago, and as such, Schott no longer lists them for sale nor mentions their price. However, in Schott's promotional material leading up to the launch of Shams 1, it was revealed that, for a 50MW farm, the PTR70 3rd Generation would cost 1.35 to 9.97 million USD less than its competitors at the time, revealing that Schott managed to produce one of the cheapest but most effective collector modules at the time.[39] The other main component is the mirrors themselves. The mirrors are the model RP3 parabolic mirrors from the German mirror and glass company Flabeg. While Flabeg does not publicly list the pricing for these mirrors, it can be assumed that they are a large part of the Shams 1 materials cost, due to the careful machining process that goes into making such large and precise mirrors.[13]

The heat caused by parabolic troughs can also cause damage to the infrastructure. However, unlike with solar panels, parabolic troughs can withstand some damage and still work near maximum efficiency. A crack or missing corner won't require a replacement mirror, like it may with a solar panel.

Israel

One of the most prominent solar energy companies in Israel is Doral Energy. Doral Energy was the first company to connect a solar energy facility to the Israeli power grid, and over the years they have built and run many facilities not only in Israel but across the world. Doral Energy is now the market leader in solar energy in Israel. Doral Energy's recent venture into the United States is a massive 5260-hectare, 1.5 billion USD investment called the Mammoth Solar Project.[6] In Israel, Doral Energy currently has over 850 megawatts of ground-mounted projects with 1,666 megawatts of storage.[13] Doral Energy has been starting to partner with solar inverter company Sungrow, which offered to supplement Doral's solar energy storage methods with a liquid-cooling system.[11]

The two most recent Doral Energy projects are the Mammoth Solar Project in the United States and the Hamaayanot Valley solar project in Israel. The Mammoth Solar Project is expected to provide 40kW of solar energy per hectare, at roughly 46,000 USD per hectare. The monocrystalline panels Doral Energy uses cost 262.50 USD, with each panel providing around 175W, putting it at roughly 1.15 USD per watt. In comparison, the Hamaayanot Valley solar project is expected to cost roughly 0.69 USD per watt.[34]

Both farms will be using fixed solar panels, instead of rotational ones, which will save massively on maintenance. However, these designs are only expected to last 10-15 years.[13]

Conclusion

The current state of solar panel infrastructure and technology across the world has shown that solar technology varies greatly between regions, and there is still a lot of innovation in progress in this field. Despite the new tech arriving to the industry, the best choice for our farm appears to be a basic, fixed mounting type. Our project's purpose requires that our design is accessible, and adding a rotational component may make the task too difficult for many to consider using. While a single-axis rotational mounting system like the examples in Europe or Southwest America would increase efficiency for not a huge increase in cost, the assembly and maintenance may prove to be too impactful for it to be an effective choice for our design.

4.2: Analysis of Different Solar Panel Manufacturers

American

For this analysis, we chose to look at Heliene's 144HC M6 Monofacial Module, a monocrystalline panel capable of producing up to 470 watts. This panel has an efficiency of 21.3% and a temperature coefficient of -0.26% per degree Celsius, meaning it is capable of operating at near peak performance even in the sweltering heat of the desert, thanks to its anti-reflective coating. This panel uses a double webbed frame that is made to withstand rain, wind, and snow, making it a reliable panel choice for a design that could go anywhere in the world, like ours.[1] This panel uses PERC cells, a modern improvement to the standard photovoltaic cell that produces 6 to 12 percent more energy. This panel comes with a 15-year manufacturer's workmanship warranty and a 25-year linear power guarantee.[1]

Figure 4.2.1. Rendering of the Heliene 144HC M6 Monofacial module.[1]

This panel is made by the company Heliene. This company's solar panels have been given "Top Performer Rankings" for the PV Evolution Labs' independent quality evaluations. Heliene is a tier 1 manufacturer and is used by the U.S. Department of Defense.[1] Heliene specializes in building solar panels for large-scale power plant applications, rather than roof panels, making them a well-qualified candidate for our final panel selection.

Each panel costs roughly 375 USD. With our farm design of 3627 panels, that would bring the total panel cost for our design up to 1.36 million USD.

Chinese

We have looked at two different Chinese panels, the first of which is the 200-Watt 12-Volt Monocrystalline Solar Panel from Renogy. This solar panel has an efficiency of 18.1%. This panel is made with encapsulation material with a multi-layered sheet lamination to help with cell performance and elongate the lifespan. This panel has no hot-spot heating guaranteed, meaning individual cells could suffer from being overheated or overworked. However, this solar panel has bypass diodes that minimize the power drop that can be caused by the lack of sun in certain areas. It also has a top-ranked PTC rating, meaning it was proven effective under a wide variety of conditions.[46]

The lifespan of this panel is significantly less than that of the Heliene panel. This is generally expected from Chinese panels. This solar panel comes with only a 5-year material and workmanship warranty and a tiered performance warranty of 95% within 5 years, 90% within 10, and 80% within 25.[46] To make up for this, it is cheaper than the Heliene panels, at only 235 USD, but they are also only half the size. Thus, our full design could fit between 833,000 and 1.67 million USD worth of these panels.

Figure 4.2.2. Image of Renogy's 200-Watt Monocrystalline Solar Panel.[46]

Figure 4.2.3. Image of Risen's RSM 144-7-455M module.[38]

The second Chinese panel we looked at is the Risen RSM 144-7-455M, a high-performance monocrystalline module capable of producing up to 455 watts. Like the Heliene module, this 144-cell panel features PERC cells that work at a maximum efficiency of 20.6%. These panels feature both an anti-reflective and an anti-soiling surface, minimizing the effects of dirt, dust, sand, and heat on the solar panels. This could be valuable to our design, as it would reduce maintenance costs by needing less frequent cleaning. Risen is a global tier 1 brand, known for its panels with industry-leading thermal technology. These panels are highly efficient, like the Heliene panels.[38]

The biggest drawback compared to the Heliene panels is, like Renogy panels, the lifespan. Risen gives these panels a 12-year warranty, with a linear performance warranty of 84.8% after 25 years. In exchange, these panels only cost around 255 USD each, putting the total panel cost of our farm at 925,000 USD.[38]

German

The German solar panel we examined is the AxSun M-108 Premium panel, a monocrystalline beast capable of producing up to 405 watts at a 19.98% efficiency. Like the Risen and Heliene panels, the 108-cell design uses PERC cells modified to reduce potential induced degradation.[4]

As expected from German panels, these are both highly efficient and exceptionally durable. AxSun is incredibly reputable for the incredible quality of their panel equipment. AxSun gives these panels a 15-year product warranty and a 25-year performance warranty. However, they struggle to outcompete the Heliene module. Additionally, they cost significantly more, at over 465 USD per panel. The total panel cost for our farm design would thus cost 1.67 million USD.[4]

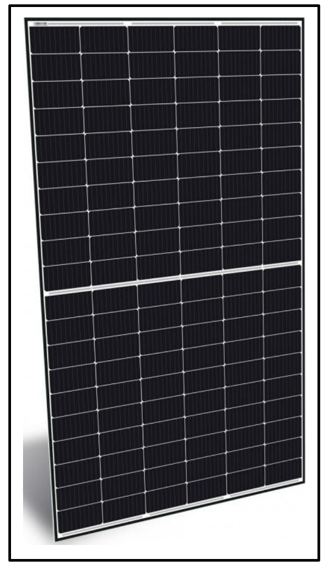


Figure 4.2.4. Image of the AxSun M-108[4]

Manufacturer Choice & Conclusion

Table 1: Total Panel Costs

Panel Models	Heliene Module	Risen Module	AxSun Module
Price Per Unit	$375.67	$254.21	$467.96
Total Units	3627	3627	3627
Total Price	$1,362,555	$922,020	$1,697,291

Table 2: Watts Per Dollar

	Materials Cost	Total Output	Cost Per Watt
Heliene Module	$1,814,256	1.70MW	$1.07 / W
Risen Module	$1,373,721	1.65MW	$0.83 / W
AxSun Module	$2,148,992	1.47MW	$1.46 / W

Total price comes from Table 1 values plus the rest of the material costs in Table 3. The rest of the material costs will be broken down in Chapter 5.

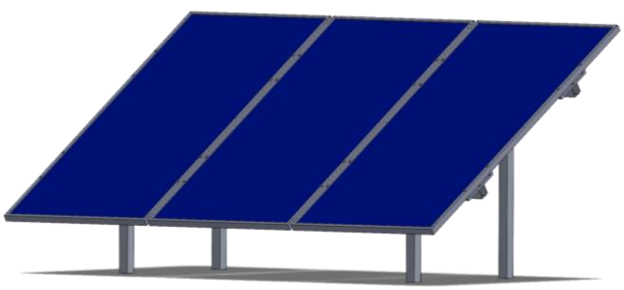
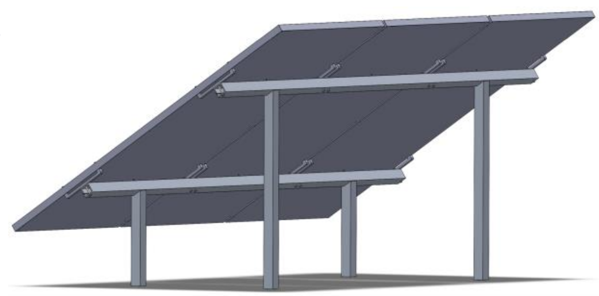
Ultimately, the American module from Heliene proved to be the best fit for our purposes. While the Chinese Risen module provides a significantly better cost for the electricity produced, it is hard to justify the short lifespan of their panels. Because our project purpose is to help provide long-lasting change in the Israeli energy sector, it would go against our goal to choose the Risen module simply because of its price. On the other end, the German modules are significantly more expensive. While German modules are known for their quality, the manufacturer's warranty suggests it's not significantly better than Heliene's module.

5: Deliverables

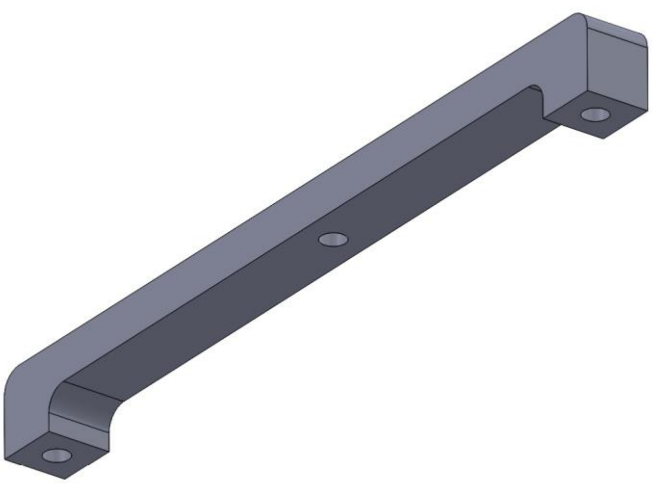
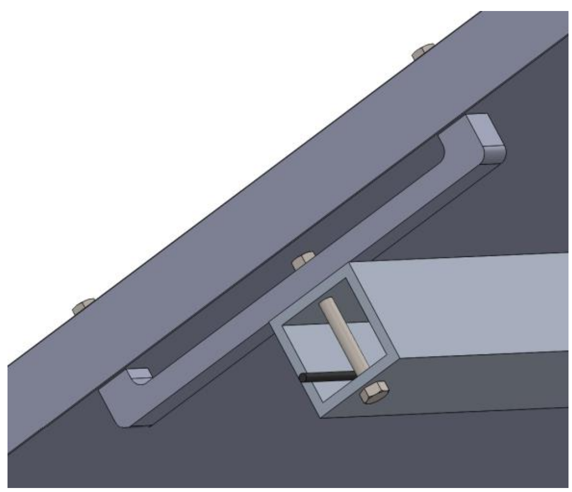
Using the American solar panels and the original conditions of the project, a one-hectare solar farm model in a desert region was created using SolidWorks. The complete equipment list, cost breakdown, and labor requirements for the design were also generated.

5.1: Solar Farm Design

The mount design holds three panels together in one unit. Four custom-milled aluminum handles shown in Figures 5.1.3 and 5.1.4 attach to the underside of each panel, which attach all three panels to two lateral beams, held up on four posts supported in concrete pilings. The beams used are 6mm-thick 60mm by 60mm square tubes of aluminum 6063 T5. Aluminum 6063 is the standard material for use in solar panel construction due to its natural rust-resistance and its ability to withstand corrosive weather. The T5 variant is one of the strongest alloys, which will be necessary for holding up this massive 112 kg module.

Figures 5.1.1 and 5.1.2. Front and back views of the three-panel mounting module.
Figures 5.1.3 and 5.1.4. Images of the custom-milled mount and how it attaches to the panel and beam.

The design for the Israeli desert features 3,627 panels across a 100m x 100m plot of land. These panels are angled at 33^{o}, matching the latitude they are being built at to maximize sunlight access. These panels are supported by a system of concrete pilings that extend three meters into the ground to hold the panels steady in the sand.

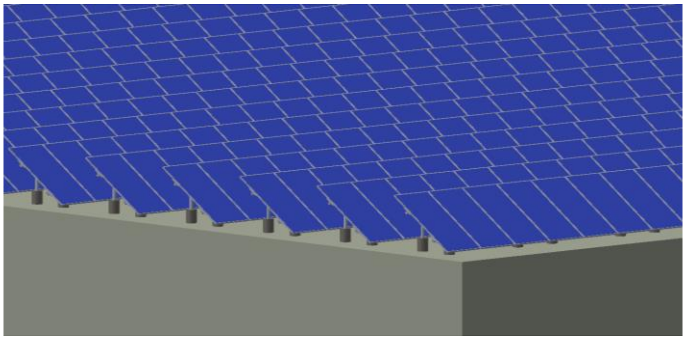


Figure 5.1.5. SolidWorks rendering of the full solar farm design.

5.2: Potential Locations in Israel

The Ayeklet Hashahar Kibbutz in northern Israel is one potential location for this solar farm. The soil in Ayeklet Hashahar is stronger than in southern Israel, meaning costs could be saved with shorter concrete pilings. The land is being sold for around 1 million USD per hectare.

The Arava desert would also make a prime building location for solar panels in southern Israel. The vast open terrain leaves lots of sunlight exposure, and cheap land prices reduce the startup cost of the project. The land costs only about 280,000 USD per hectare and is located near some other solar power plants.

5.3: Equipment Costs

As discussed in Chapter 2, inverters will be necessary to convert the DC panel current into AC current for the grid. The Growatt MIN10000TL-XH-US inverter was designed for solar panels and can manage up to fourteen Heliene panels each.[21] The cables used to transport the electricity from the inverters to the power lines will be aluminum cables to reduce theft. For theft prevention, these wires could optionally be surrounded by hardened steel cable, however this should be unnecessary, as aluminum cables are not worth stealing. Table 3 breaks down the total material costs, which comes to $451,701 without the panels.

Table 3: Total Material Costs

Materials	Inverter	Concrete	Cables	Al Tubing	Milled Al	80mm Bolt	50mm Bolt	Hex Nut
Price Per Unit	$1299.00	$117	$0.55	$2.75/kg	$1.96/kg	$0.49	$0.66	$0.23
Total Units	260	948	5250	40,654 kg	1168 kg	14,508	29,016	14,508
Total Price	$337,440	$110,916	$2888	$111,798	$2,290	$7,153	$19,057	$3,399

5.4: Labor Costs

The average salary of a construction worker in Israel is 32,400 USD/year. With around 20 construction workers, this project should take around two years to complete.[28] Estimating each mount module takes around three hours to install, two to three modules will be installed per day, taking just over two years to install 3,627 panels. Thus, the total labor cost comes out to 1,296,000 USD.

5.5: Total Cost Breakdown of Project

The total cost of the solar farm is 3,390,256 USD in the southern location, and 3,669,721 USD in the northern location, making the southern location 280,000 USD and 7.63% cheaper than the northern location.

6: Conclusions and Recommendations

6.1: Summary of Findings

Through our research, we found that the three main countries for solar panels manufacturers each had their strong suits. Chinese manufacturers Risen and Renogy, while inexpensive, suffered from short lifespans and poor warranties. German manufacturer AxSun had the longest lifespans for their solar panels, but the costs were significantly higher. The American Heliene panels managed a lifespan similar to that of AxSun at a cheaper price and greater output, proving itself to be the best panel.

6.2: Recommendations

All our recommendations were compiled into an open-source handbook that anyone can use. It features a complete step-by-step guide on how to construct a farm of any size using our design. When making the handbook, our main goal was to have clear, concise writing to avoid any possible confusion within it. One of the key objectives of the project was accessibility, and the concise writing of the project was done intentionally to make potential translation be as accurate as possible.

One of the most expensive aspects of the farm is the concrete. It is strongly recommended that suitable soil be found to reduce costs spent on concrete.

Bibliography

1. 144HC M6 monofacial module. HELIENE. (2022, August 2). Retrieved March 25, 2023, from https://heliene.com/144hc-m6-monofacial-module/

2. Admin. (2021, March 1). *Metric sized metals and steels: Metric metal: Parker Steel*. Metric Metal. Retrieved March 25, 2023, from https://www.metricmetal.com/

3. *Amazon.com : Poyasilon Wireless Cameras for home/outdoor security, 3MP* ... (n.d.). Retrieved April 30, 2023, from https://www.amazon.com/Poyasilon-Security-Cameras-Wireless-Detection/dp/B0BG39NWNF

4. *Axsun - German solar modules with character*. AxSun Solar GmbH & Co. KG. (n.d.). Retrieved March 25, 2023, from https://www.axsun.de/en/

5. Benhadji Serradj, D. E., Sebitosi, A. B., & Fadlallah, S. O. (2022). *Design and performance analysis of a parabolic trough power plant under the climatological conditions of Tamanrasset, Algeria*. International journal of environmental science and technology : IJEST. Retrieved February 26, 2023, from https://www.ncbi.nlm.nih.gov/pmc/articles /PMC8105702/

6. Box, T. (2022, November 3). *Doral Renewables Launches Next Phase of $1.5B solar farm in Northwest Indiana*. WBIW. Retrieved February 20, 2023, from https://www.wbiw.com/2022/ 11/03/doral-renewables-launches-next-phase-of-1-5b-solar-farm-in-northwest-indiana/

7. Brothers, P. by: D. (n.d.). *Going solar on the farm: Basic Components & System Coordination*. Alabama Cooperative Extension System. Retrieved February 26, 2023, from https://www.aces.edu/blog/topics/crop-production/going-solar-on-the-farm-basic-components-system-coordination/

8. Comello, S., Reichelstein, S. The emergence of cost effective battery storage. Nat Commun 10, 2038 (2019). https://doi.org/10.1038/s41467-019-09988-z

9. *Concentrating solar power in the United Arab Emirates: SHAMS 1 project secures financial close*. KW10 | Concentrating solar power in the United Arab Emirates: Shams 1 project secures financial close - SolarServer. Retrieved February 26, 2023, from https://web.archive.org/web/20110313173055/http://www.solarserver.com/solar-magazine/solar-news/current/2011/kw10/concentrating-solar-power-in-the-united-arab-emirates-shams-1-project-secures-financial-close.html

10. Crowell, C. (2015, July 23). *Flexible cable in Conduit wins an award for Missouri Solar Farm*. Solar Builder Magazine. Retrieved March 25, 2023, from https://solarbuildermag.com/news/flexible-cable-conduit-solar-farm-missouri/

11. Dash, D. (2022, April 11). *Sungrow, Doral Inks Contract for Israel's first DC-coupled liquid-cooled ES project*. Emerging Technology News. Retrieved February 20, 2023, from https://etn.news/buzz/sungrow-doral-inks-contract-for-israel-s-first-dc-coupled-liquid-cooled-es-project

12. Doral Energy. (2020, July 22). *Solar energy*. Doral Energy. Retrieved February 20, 2023, from https://doral-energy.com/en/solar-energy/

13. Doral Energy. (2022). *ESG report 2021 - Doral Energy*. DORAL ESG Report. Retrieved February 20, 2023, from https://doral-energy.com/wp-content/uploads/2022/05/ESG- DORAL-2021-report.pdf

14. Ebhota, W. S., & Tabakov, P. Y. (2023). Influence of photovoltaic cell technologies and elevated temperature on photovoltaic system performance. Ain Shams Engineering Journal, 14(7) https://www.sciencedirect.com/science/article/pii/S2090447922002957?pes=vor

15. Electrical Technology. (2023). Components of Solar Power Plant. Retrieved February 9, 2023, from https://www.electricaltechnology.org/2021/07/solar-power-plant.html.

16. *EU market outlook for Solar Power 2021-2025*. EU Market Outlook for Solar Power 2021-2025 - SolarPower Europe. (n.d.). Retrieved February 25, 2023, from https://www.solarpowereurope.org/insights/market-outlooks/eu-market-outlook-for-solar-power-2021-2025

17. European Solar Panel Market Research and Analysis 2015-2022: Key Players are Canadian Solar, First Solar, Yingli Green Energy Europe, Trina Solar, Energy Panel, S.L. and Sharp Solar. (2017). M2 Presswire.

18. Fastenal.com. (2022). Retrieved March 25, 2023, from https://www.fastenal.com/product/details/1138615

19. *Francisco Pizarro Solar Power Project, Spain*. NS Energy. (n.d.). Retrieved February 26, 2023, from https://www.nsenergybusiness.com/projects/francisco-pizarro-solar-power-project/#

20. Gendy, M. E., & Gendy, O. (2018, November 16). *Analysis of piled raft of Burj Khalifa in Dubai by the program ELPLA*. Retrieved April 30, 2023, from https://www.researchgate.net/publication/328649931_Analysis_of_Piled_raft_of_Burj_Khalifa_in_Dubai_by_the_program_ELPLA

21. Growatt 10kw grid-tie inverter: MIN10000TL-xh-US. Signature Solar. (n.d.). Retrieved April 3, 2023, from https://signaturesolar.com/growatt-10kw-grid-tie-inverter-min10000tl-xh-us/

22. Hafez, Yousef, A. M., & Harag, N. M. (2018). Solar tracking systems: Technologies and trackers drive types – A review. *Renewable & Sustainable Energy Reviews*, *91*, 754–782. https://doi.org/10.1016/j.rser.2018.03.094

23. IEA. “Defining Energy Access: 2020 Methodology – Analysis.” *IEA*, https://www.iea.org/articles/defining-energy-access-2020-methodology.

24. IEA, (26 October 2022). Evolution of solar PV module cost by data source, 1970-2020, IEA, Paris https://www.iea.org/data-and-statistics/charts/evolution-of-solar-pv-module-cost-by-data-source-1970-2020, IEA. License: CC BY 4.0

25. *Israel's new roadmap targets 40% of renewable power generation by 2030*. Enerdata. (2022, February 17). Retrieved April 30, 2023, from https://www.enerdata.net/publications/daily-energy-news/israels-new-roadmap-targets-40-renewable-power-generation-2030.html

26. *Israel: The Building Codes Assistance Project*. The Building Codes Assistance Project | Dedicated to the adoption, implementation and advancement of energy codes. (2016, October, 27). Retrieved February 6, 2023.

27. J.R.G. Ross and Smokler, Ross, J. R. G., Smokler, & Ross, R. G. (n.d.). *Nominal operating cell temperature*. PVEducation. Retrieved March 25, 2023, from https://www.pveducation.org/pvcdrom/modules-and-arrays/nominal-operating-cell-temperature

28. Kilgore, G. (2022, November 11). Solar Farm income per acre calculator: See profit margin, costs, money made. 8 Billion Trees: Carbon Offset Projects & Ecological Footprint Calculators. Retrieved April 3, 2023, from https://8billiontrees.com/solar-panels/solar-farm- income-per-acre/

29. Lane, C. (2018, March 27). *What is a solar tracker and is it worth the investment?* Solar Reviews. Retrieved February 26, 2023, from https://www.solarreviews.com/blog/are-solar-axis-trackers-worth-the-additional-investment

30. Liao, Tianjun et al. "Thermoradiative–Photovoltaic Cells." *IEEE transactions on electron devices* 66.3 (2019): 1386–1389. Web.

31. Li Jie. (2020). Sun-tracking type solar panel movable support easy to install.

32. Liu Xiaozhi, & Wang Ziyan. (2013). *Closed-loop linkage type single-axis solar battery panel tracker*.

33. Loesche, D. (April 11, 2018). Developing Countries Invest More in Renewable Energy [Digital image]. Retrieved February 09, 2023, from https://www.statista.com/chart/13491/worldwide-new-investment-in-the-renewable-energy-sector/

34. Ltd., E. N. F. (2005). ENF Ltd.. ENF Solar. Retrieved March 26, 2023, from https://www.enfsolar.com/pv/panel-datasheet/crystalline/3473?utm_source=ENF&utm_medium=panel_profile&utm_campaign=enquiry_company_directory&utm_content=147

35. *Melech*. Melech Concrete | Concrete Services Tel Aviv | Israel. (n.d.). Retrieved March 25, 2023, from https://melechconcrete.com/

36. Melo, Aurélio Gouvêa et al. "Development of a Closed and Open Loop Solar Tracker Technology." *Acta scientiarum. Technology* 39.2 (2017): 177–183. Web.

37. Kelsey Misbrener. (2016) PSEG Solar Source Acquires Solar Power Project in North Carolina, US from BayWa r.e. Solar Projects for USD12.2 Million. In GlobalData Deals. GlobalData plc.

38. *Mono Risen Energy - RSM144-7-455M*. Secondsol der Photovoltaik Marktplatz. (n.d.). Retrieved March 25, 2023, from https://www.secondsol.com/en/anzeige/32537//risen-energy/rsm144-7-455m

39. National Renewable Energy Laboratory (2022). Shams 1 CSP Project. *NREL: Concentrating Solar Power Projects.* Retrieved February 25, 2023, from https://solarpaces.nrel.gov/project/shams-1.

40. Pepermans. (2017). Sino-European Solar Panel Dispute: China's Successful Carrot and Stick Approach Towards Europe. Journal of Contemporary European Research, 13(4). https://doi.org/10.30950/jcer.v13i4.831

41. *Parabolic trough collector: Working, benefits, and drawbacks*. Solar Square Blog. (2022, October 20). Retrieved February 26, 2023, from https://www.solarsquare.in/blog/parabolic-trough-collector/

42. Ren Zongying, Ye Shuangli, & Ma Lisheng. (2011). Automatic sun tracking double-shaft moving system for solar panel.

43. Robertson, J. (2020) Types Of Energy Ranked By Cost Per MegaWatt Hour. Types of energy ranged by cost per megawatt hour - solar power guide- infographic.

44. Sabas, M. (2016, February 18). *History of Solar Power*. Institute for Energy Research. Retrieved April 26, 2023, from https://www.instituteforenergyresearch.org/renewable/solar/history-of-solar-power/

45. Shuanglong Machinery. (2021, April 2). *Precast concrete pile: Advantages and disadvantages [sizes & cost]*. Shuanglong Machinery. Retrieved March 25, 2023, from https://www.machinesl.com/precast-concrete-pile/

46. *Solar panels*. Renogy. (n.d.). Retrieved March 25, 2023, from https://www.renogy.com/solar-panels/

47. *Solar Star Projects, Antelope Valley, California, USA*. NS Energy. (n.d.). Retrieved February 26, 2023, from https://www.nsenergybusiness.com/projects/solar-star-projects-california/

48. SunPower. (2022, August 3). *How much do solar panels cost?* SunPower. Retrieved April 30, 2023, from https://us.sunpower.com/solar-resources/how-much-do-solar-panels-cost

49. Sunrun. (2023, January 10). *Do solar panels work in cold weather?* Sunrun. Retrieved February 25, 2023, from https://www.sunrun.com/go-solar-center/solar-articles/do-solar-panels-work-in-cold-weather

50. Tervo et al. (2020). Solar Thermal Radiative-Photovoltaic Energy Conversion. Cell Reports Physical Science, 1(12), 100258. https://doi.org/10.1016/j.xcrp.2020.100258

51. U.S. Department of Energy. (2023). Solar integration: Solar energy and storage basics. Office of Energy Efficiency & Renewable Energy. Retrieved February 9, 2023, from https://www.energy.gov/eere/solar/solar-integration-solar-energy-and-storage-basics

52. U.S. EIA (2017). More than half of utility-scale solar photovoltaic systems track the sun through the day. *Asia News Monitor*.

53. Wang, J. M., & Lu, C. L. (2013). Design and implementation of a Sun tracker with a dual-axis single motor for an optical sensor-based photovoltaic system. *Sensors (Basel, Switzerland)*, *13*(3), 3157–3168. https://doi.org/10.3390/s130303157

54. Weinberger, D. (2023, January 5). *Here are the different types of solar panels you should consider for your home*. Forbes. Retrieved February 26, 2023, from https://www.forbes. com/home-improvement/solar/types-of-solar-panels/

55. Worcester Polytechnic Institute. (1970, February 21). Retrieved February 6, 2023.

56. Wu, Bennett, D. H., Lee, K., Cassady, D. L., Ritz, B., & Hertz-Picciotto, I. (2012). Feasibility of using web surveys to collect time-activity data. *Journal of Exposure Science & Environmental Epidemiology*, *22*(2), 116–125. https://doi.org/10.1038/jes.2011.23

Appendix A: Research Instrument

Survey

Consent script

Why is this study being done?

This study will be done to help us have more insight into the experiences of people who use solar panels so that we know what aspects we need to consider when recommending others to use solar energy.

What is involved with this research study?

This survey will take approximately 15 minutes to complete. In the survey, we will ask about your experience having solar panels installed in your home and your opinions on them.

What are the risks of participation?

There are no participation risks. These questions should not invoke discomfort, and your privacy will remain protected.

How will my privacy be protected?

Your identity will remain anonymous and your answers will be pooled with others to ensure complete privacy.

Who can participate?

You may be eligible to participate if you are at least 18 years of age, and you have had solar panels installed either at your home or at your place of business.

What are the benefits of participating?

The benefits will be that the answers to these survey questions can help aid future recipients of solar panels. These answers can help new recipients through hurdles and challenges of having a resource like this. Through this individual help, it can aid in the standardization of solar panels used for renewable energy. As well as interpreting the social perception of such technology.

Consent questions

1. Do you consent to participate? (If yes, then 2; if no, then leave)
    a. Yes
    b. No

2. Are you 18 years old or more? (if yes, then 3; if no, then leave)
    a. Yes
    b. No

Study Description

Israel has committed to increasing its total renewable energy usage to 30% by the year 2030. To help achieve this goal, this project aims to develop a guide for building solar panels for aspiring entrepreneurs interested in building solar energy stations for people who do not have access to renewable energy. There are several reasons to promote having access to renewable energy. The first is having access to any sort of energy also means having access to many different life-changing things. If a place does not have access to energy that means they can not do any medical procedure that involves light, monitors, scans, electronic medical records, or any other device that requires electricity. Along with the medical factors, they cannot get efficient access to clean water, transportation, or even reliable lighting. Today there are roughly 2.7 billion people who do not have access to reliable electricity, which is about a third of the world's population. Solar technology can be life-changing for these areas.

Survey Questions:

Solar Panel Installation:

1. How long ago were your solar panels installed?
    a. Less than a year ago
    b. Between 1-5 years ago
    c. Between 5-10 years ago

d. Over 10 years ago

2. How much of a role did the following categories play in your decision to install solar panels?

Scale	1 (none)	2	3	4	5	6	7 (Main reason)
Environment							
Cost							
Ease of Use							
Other:							

3. Were there any aspects that were a deterrent in your decision to install solar panels?

Scale	1 (Not a concern)	2	3	4	5	6	7 (Biggest Deterrent)
Appearance							
Cost							
Maintenance							
Other:							

4. How long did the installation process of installing your solar panels take?
   a. Hours
   b. Days
   c. 1-month

d. Over a month

5. How satisfied were you with your installation process?

Scale	1 (Extremely Dissatisfied)	2	3	4	5	6	7 (Extremely Satisfied)
Satisfaction Level							

6. How likely would you be to recommend solar panel installation to a friend?

Scale	1 (Extremely Unlikely)	2	3	4	5	6	7 (I already have)
Likeliness to Recommend							

7. After having solar panels for a period of time, which aspects would you now say is the biggest deterrent from recommending solar panels to someone?

Scale	1 (Not a concern)	2	3	4	5	6	7 (Biggest Deterrent)
Appearance							
Cost							
Maintenance							
Other:							

Solar Panel Maintenance:

8. How many times have your solar panels needed maintenance?
   a. Zero
   b. 1-3
   c. 3-5
   d. Over 5

9. How much of a burden has the following aspects of the maintenance caused?

Scale	1 (None)	2	3	4	5	6	7 (Huge Burden)
Time							
Cost							
Losing Electricity							
Other:							

10. For each category, how much benefit have you received from your solar panels?

Scale	1 (Big detriment)	2	3	4 (No difference)	5	6	7 (Big benefit)
Electric bill payments							
Electricity reliability							
Other:							

11. For each category, where would you like to see the most improvement?

Scale	1 (Doesn't need improvement)	2	3	4	5	6	7 (Needs major improvement)
Installation time							
Installation intrusiveness							
Value for money							
Other:							

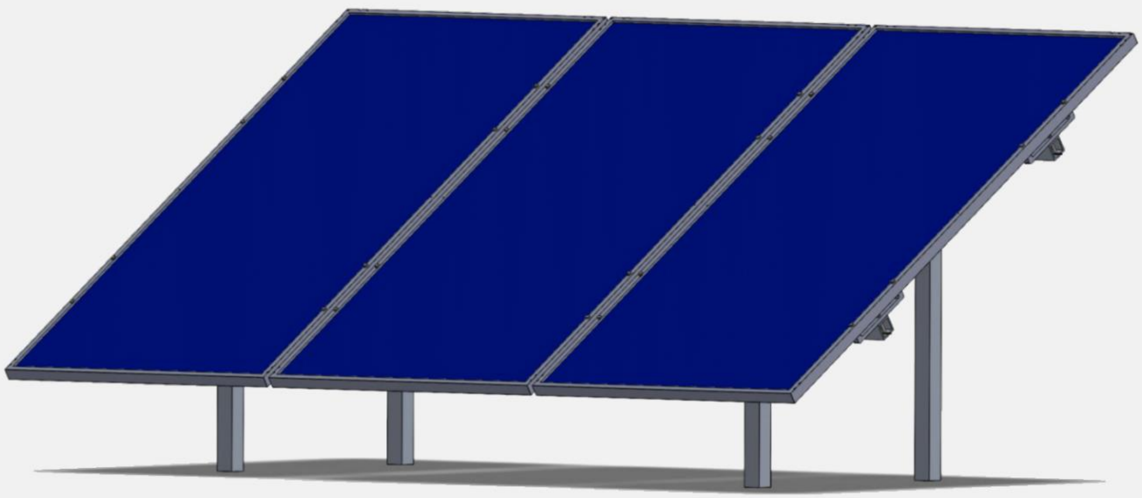
12. Lastly, if you have any concluding thoughts that you feel are worth sharing, please write them on this page. Thank you for your participation.

Socioeconomic:

13. What is your age?
    a. 18-25
    b. 25-50
    c. 50-75
    d. Over 75
14. How much money do you make in a year?
    a. Below 50,000 ILS
    b. Between 50,000-100,000 ILS
    c. Between 100,000-150,000 ILS
    d. Above 150,000
15. Anything you feel needs to be mentioned that has not been covered regarding your solar panel installation?

Appendix B: Handbook

SOLAR FARM **CONSTRUCTION MANUAL**



A **complete** construction guide for a one-hectare solar farm designed for any environment.

This manual was made possible by Worcester Polytechnic Institute, the University of Haifa, Ort Braude College of Engineering, and the Mityaalim Foundation.

Table of Contents

Introduction

Why Solar Power?

A solar farm of this size can be very beneficial to a community. Such farms, while requiring funding to build, have the ability lower the cost of power bills from the main power company. A solar farm like this is also able to allow more remote and less developed cities to have a reliable source of energy that requires minimal maintenance. Solar farms like this design are able to reduce the demand of power from the larger power plants that utilize fossil fuels and other non-renewable methods to produce electricity. Compared to other forms of renewable energy solar panels require much less money and maintenance to continue operating. This design has very few proprietary parts meaning that if some pieces need to be replaced or repaired, there are several options for substitutes that are not OEM (original equipment manufactured) parts. Lastly compared to other forms of renewable energy, Solar farms are far more modular and can continue to run if specific portions of the farm are damaged or broken.

Important Details

Please note that we are *not* responsible for any potential liabilities with undertaking this project. Please approach this project with caution and care.

This guide is meant for the construction company.

The goal of this handbook is to eliminate your need for hiring engineers to design your solar farm. However, the assembly process requires professional work to ensure material safety and stability. The mounting assembly requires welding, and the ground support requires a secure concrete foundation. A qualified construction company should be hired to build this plant.

This solar farm is modular and changeable.

The design provided here accommodates 3627 panels on a single hectare of land. However, this can be scaled up or down to any size.

Additionally, this farm was designed for building in northern Israel. See the Appendix for details on adjusting the solar panel angle for different latitudes. Assuming the location receives 6 hours of sunlight per day, this farm will generate 7616.7 kWh or roughly 1.2 MW of power.

Material Breakdown

Material List

01	Heliene 144HC M6 Monofacial Solar Module
02	60mm x 60mm x 6mm Aluminum 6063 Square Tubing
03	Custom-milled Aluminum 6063
04	M8-1.25x80mm 8.8 Hex Cap Screw
05	M8-1.25x50mm 8.8 Hex Cap Screw
06	M8-1.25 A4-80 Hex Nut
07	M20-M40 Concrete
08	Growatt 10kW Grid-Tie MIN10000TL-XH-US Inverter
09	USE-2 Aluminum Underground Service Cables
10	(Optional) Galvanized Aircraft Cable

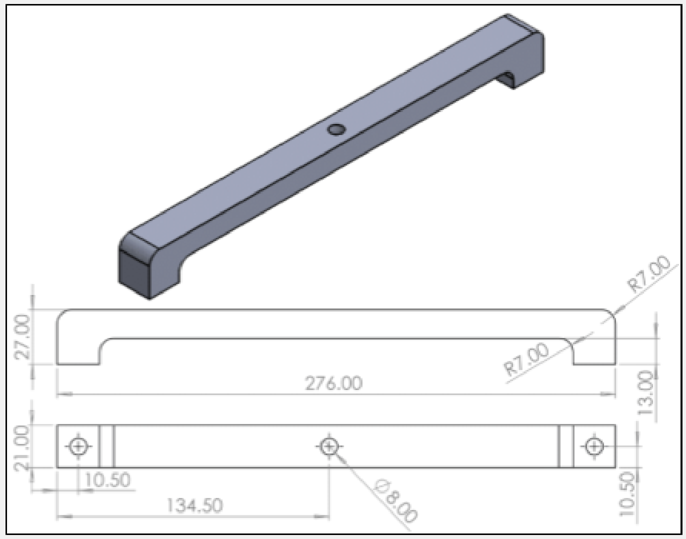
Important Notes

Material	Notes
Hardware (hex bolts and nuts)	Finish color does not matter, however it is important that the material type chosen is rust-resistant. Stainless steel is recommended.
Aluminum	6063-T5 is the recommended alloy of aluminum. However, most types of 6063 aluminum should be fine.
Concrete	M20-M40 grade concrete should be used to ensure stability.
Service Cables	Copper cables can be used, however aluminum cables are advised to deter cable theft.

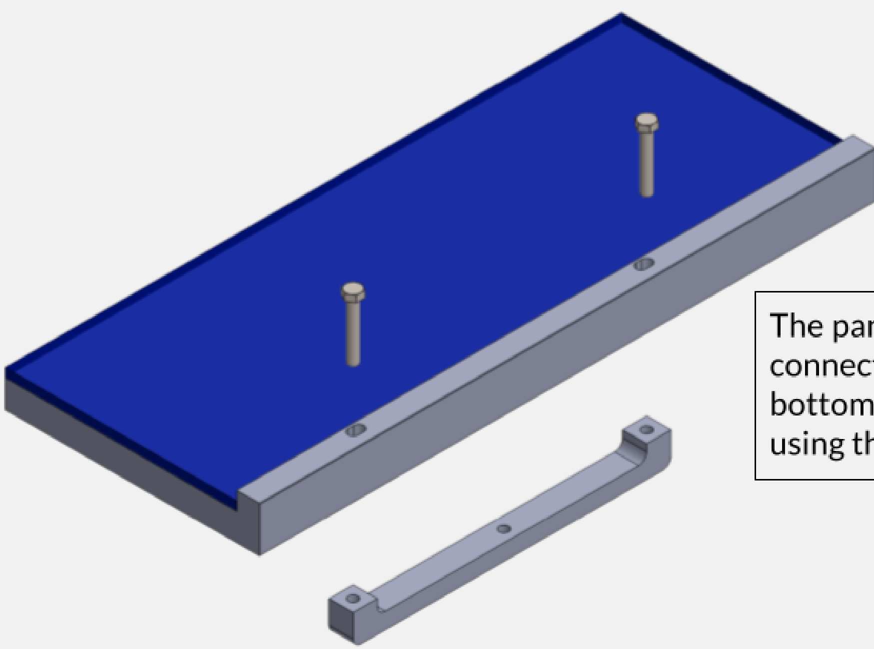
Assembling the Mount

1. Panel Handles

The panel handles need to be **custom CNC-milled** to fit the Heliene solar panels. The full part drawing for these handles can be found in the appendix. **Four** of these handles will need to be attached to **every solar panel**. It should be noted that the two bottom holes must be **threaded**.



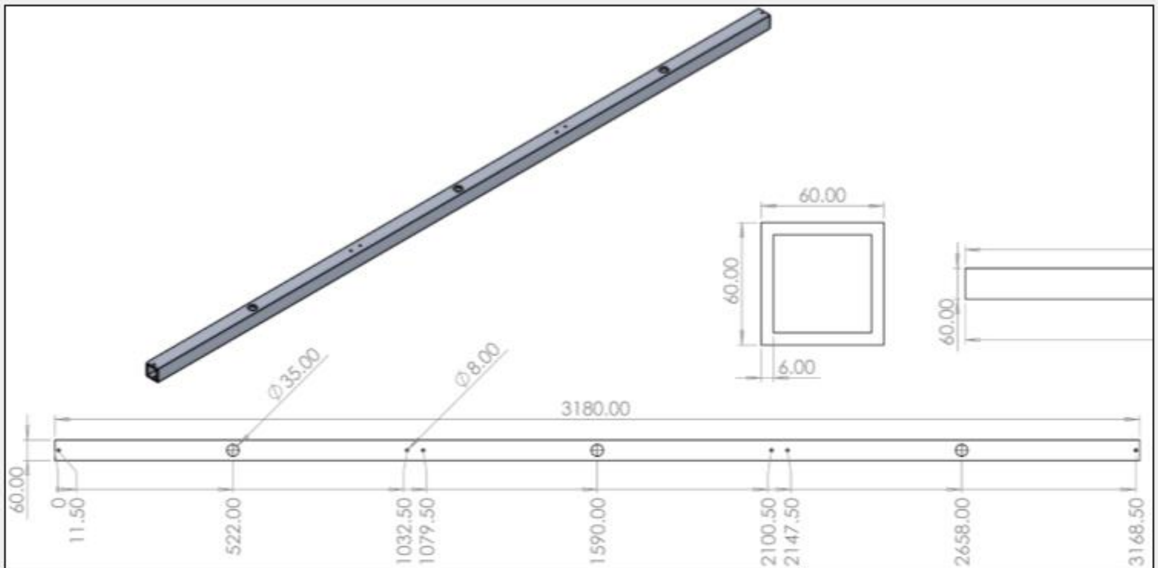
FULL PARTS DRAWINGS available in the appendix.



The panel handles are to be connected **underneath** the bottom of the panel frame using the **50mm bolts**.

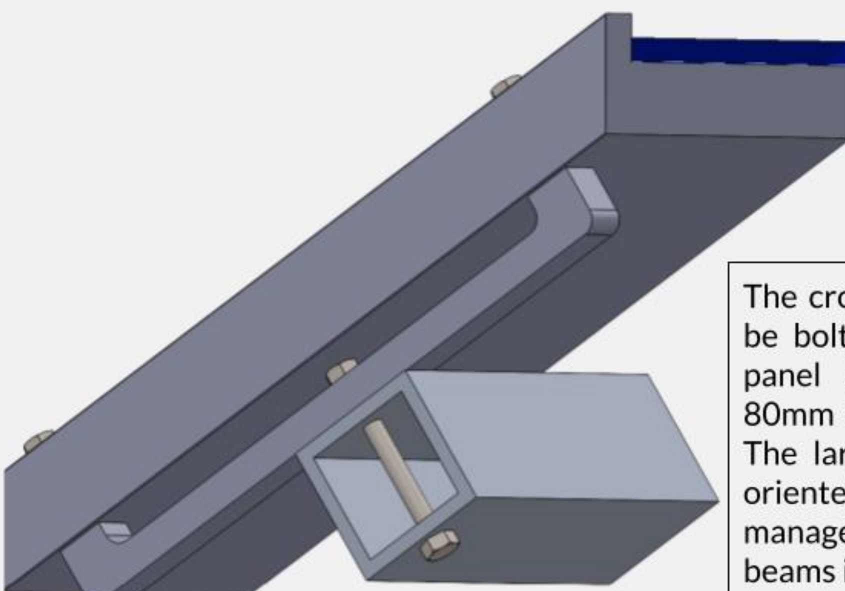
Assembling the Mount

2. Cross-Panel Beam



The cross-panel beams connect three panels together, and are to be made with the square aluminum tubing. The full part drawing for these handles can be found in the appendix. **Two** of these beams will need to be attached to **every triple-panel rig**.

FULL PARTS DRAWINGS available in the appendix.



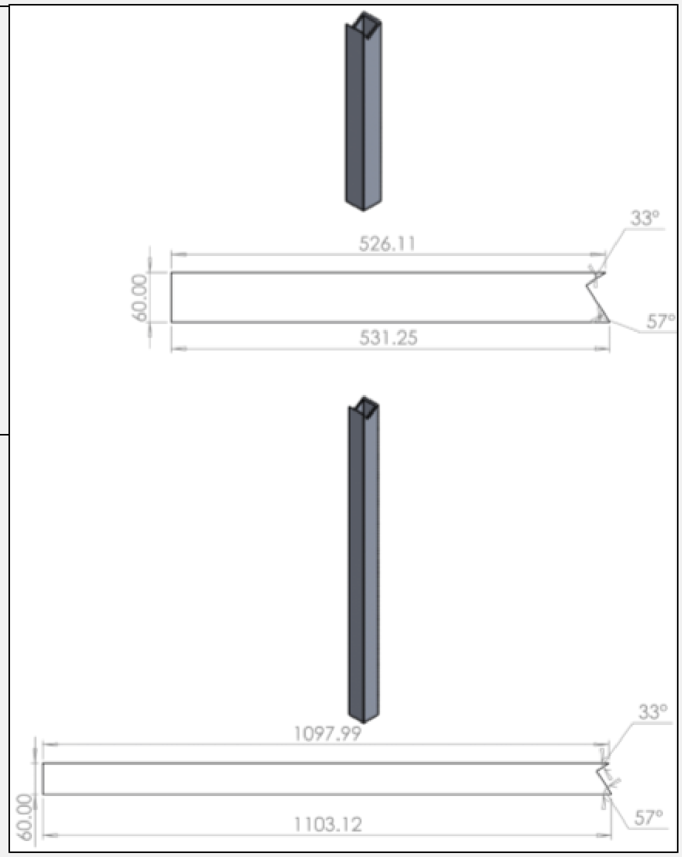
The cross-panel beam is to be bolted **underneath** the panel handles using the 80mm bolts and a hex nut. The large holes should be oriented **upwards** for cable management through the beams if desired.

6

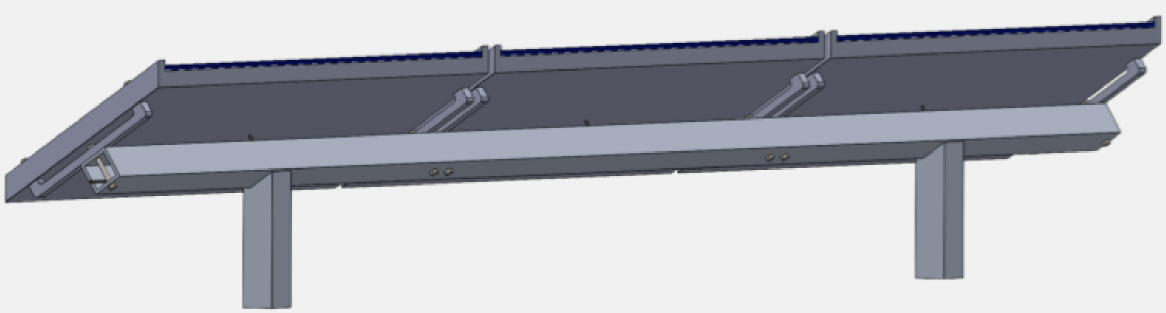
Assembling the Mount

3. Support Beams

These support beams hold up the rig, and are also to be made from the square aluminum tubing. The full part drawing for these handles can be found in the appendix. **Four** of these beams will need to be attached to **every triple-panel rig**, two of the **tall** ones and two of the **short** ones.



FULL PARTS DRAWINGS
available in the appendix.

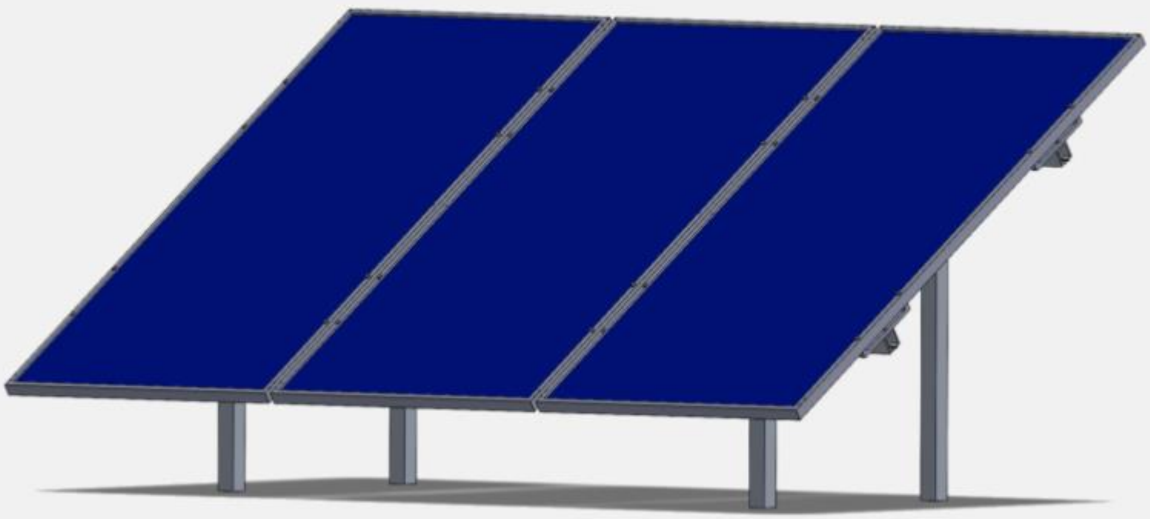


The support beams are to be welded to the support beams such that the panels are centered across the support beams. The tall support beams are to go on the back, as to angle the panels towards the sun.

Assembling the Mount

4. Completed Assembly

A full module should now be complete and ready to be mounted. There are a few checks that can be made to ensure that the module was built correctly. When level, the panels should make roughly a 33° angle with the ground. The panels should be centered between the support legs, and nothing should be free to move in any way.



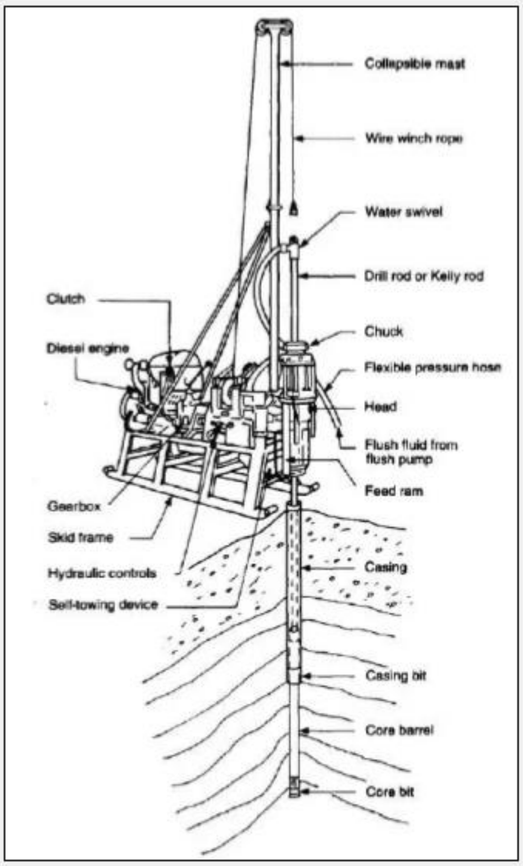
These are the total materials required for one completed assembly:

01	Solar Panel	3 count
02	Aluminum Square Tubing	9.63 meters
03	CNC-Milled Aluminum	2.9 kg
04	80mm Bolt	12 count
05	50mm Bolt	24 count
06	M8 Hex Nut	12 count

Mounting the Panels

1. Boring Holes

This step is very important to the longevity of the construction of this solar farm. Before any construction begins, a full soil analysis should be conducted by a geotechnical drilling engineering firm. The depth of the foundational piles under each panel will be determined by the type of soil. For locations with suitable soil and loam, holes should extend be 1.5 meters into the ground. For locations with weaker soil or sand, holes should be dug down to 3 meters. Additionally, for areas in colder climates, it must be insured that the piles extend below the frostline in order to prevent uplift. There will be 4836 holes.



Geotechnical drilling machine for **soil analysis**.

A mechanical auger would the most effective method for excavation before placing in the concrete form tubes. For adaptation to more remote areas or difficult terrain, a skid steer can be utilized with this auger, as shown in the image above.

Mounting the Panels

2. Setting Concrete Forms

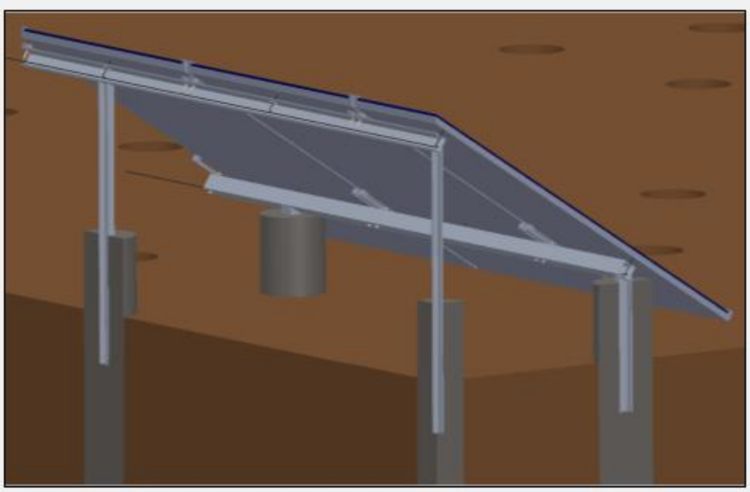
After all the holes have been mapped out and excavated, fiber laminated concrete form tubes can be placed in the holes. Hold the tube forms level and pour dirt into the hole on the *outside* of the tube to keep it vertical. The tube should also be protruding at least 30 centimeters above the ground level. Each tube will have a diameter of 250mm.

Once the tubes are set in place, begin filling them with concrete. Shake the tube as it is being filled to prevent voids and air pockets. A concrete truck would be ideal for this job, however a secondary pumping truck (as shown above) could also work if the terrain is too difficult. Pouring by hand should be a last resort option.

Mounting the Panels

3. Setting Concrete Forms

Once the concrete has been poured into the tubes the vertical members of the panel assembly are placed into the wet cement. These posts should be 0.5 meters into the concrete to prevent shifting. Optionally brackets can be mounted into the concrete (shown on the right) compared to the entire post. These brackets allow further adjustment, removal or upgrades, but decrease durability.



A **cut view** of the inside of the concrete pilings.

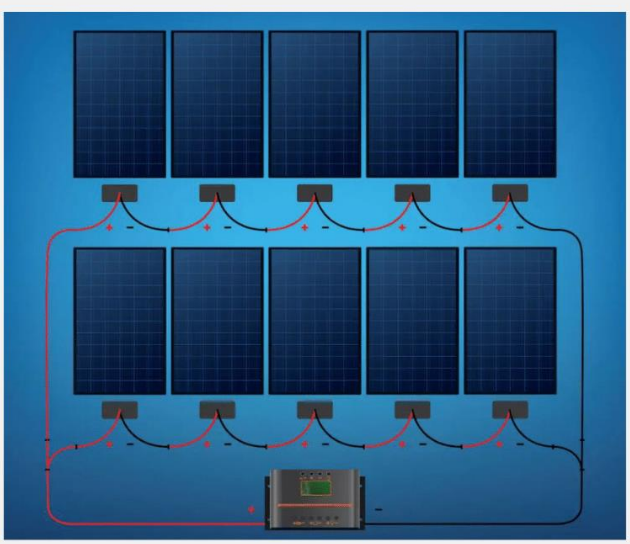
Once the vertical posts are determined to be level and perfectly straight, temporary wood bracing can be used to hold the structure level for the drying process. After about 2 days the temporary clamp structure can be removed and the concrete will fully cure after 28 days.

Wiring the Solar Panels

1. Panels to Inverters

On the underside of the panels are the output cables. These output cables allow each panel to directly connect to each other. Connect this panels together in chains of 14 panels each, as this is the maximum amount that the inverters can handle. Connect an inverter to the end of each one of these 14-panel chains.

(Left) Example of one of the Growatt string inverters used in this model



The panels in this wiring formation will reach the max operational capacity of these inverters. Along with being efficient, they are wired in such a way if that one panel is not functioning it can simply be bridged. By removing the faulty panel from the wiring system, the farm could still operate and this would suffice as a temporary fix. These cables should be buried to prevent theft and sun damage.

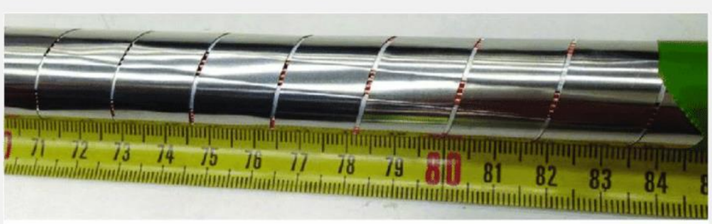
Wiring the Solar Panels

2. Panels to Substation

Once the system is connected with the inverters, run the wires together at the edge of the farm so the power company can easily connect to the grid The local power company purchasing the power will be responsible for connecting the plant to the grid/ distribution center. Once all the cables merge to at one point, the power company will install meters and connect the cables to main service lines. Any cable after the power meter is property of the power redistribution center and any maintenance will be their responsibility past that point.

A dual meter (seen right) keeps track of the usage of electricity as well as how much electricity is being generated and recorded through the meter

Optionally, these service cables can be spiral wrapped in galvanized (seen below) aircraft cable to prevent theft, though this is not necessary, especially if aluminum service cables are being used.



13

Appendix

Reference Materials

On the following pages, you will find the parts drawings for the custom cut and milled parts, along with an assembly drawing. Heliene's CAD drawings for the solar panel are also provided.

All the SolidWorks files have also been uploaded for your convenience here:

https://www.dropbox.com/s/gyd41nb6bayqhbt/Solar%20Farm%20Drawings%20.zip?dl=0

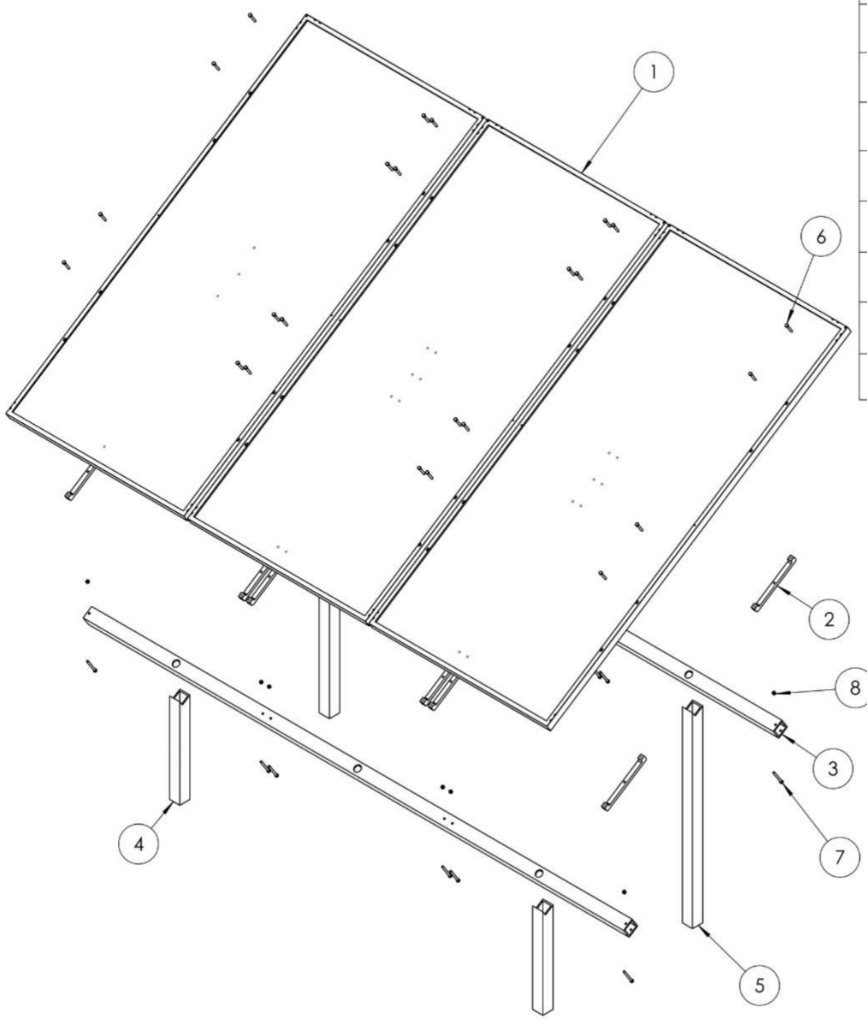
Adaptability

This design is made for usage in Israel. However, this design can be applied anywhere, as long as the angle is changed accordingly. The angle of the solar panels must match the latitude of the location for the best year-round results. Increase or decrease the height of the back legs in order to change the tilt accordingly.

Additionally, make sure to account for soil changes, as is discussed in the Mounting the Panels section.

Contact Us

Wish to contact us? Send us an email at gr-SolarC23@wpi.edu.



ITEM NO.	PART NUMBER	MATERIAL	WEIGHT (KG)	QTY.
1	Heliene 144HC M6 Solar Panel	N/A	25.00	3
2	Attachment Handle	6063-T5	0.24	12
3	Cross-Panel Beam	6063-T5	11.07	2
4	Front Support Beam	6063-T5	1.82	2
5	Back Support Beam	6063-T5	3.82	2
6	M8 x 1.25 x 50 Hex Head Screw	Steel	0.0027	24
7	M8 x 1.25 x 80 Hex Head Screw	Steel	0.0031	12
8	M8 x 1.25 Hex Nut	Steel	0.0047	12

SPONSORED BY:
Mityaalim Foundation

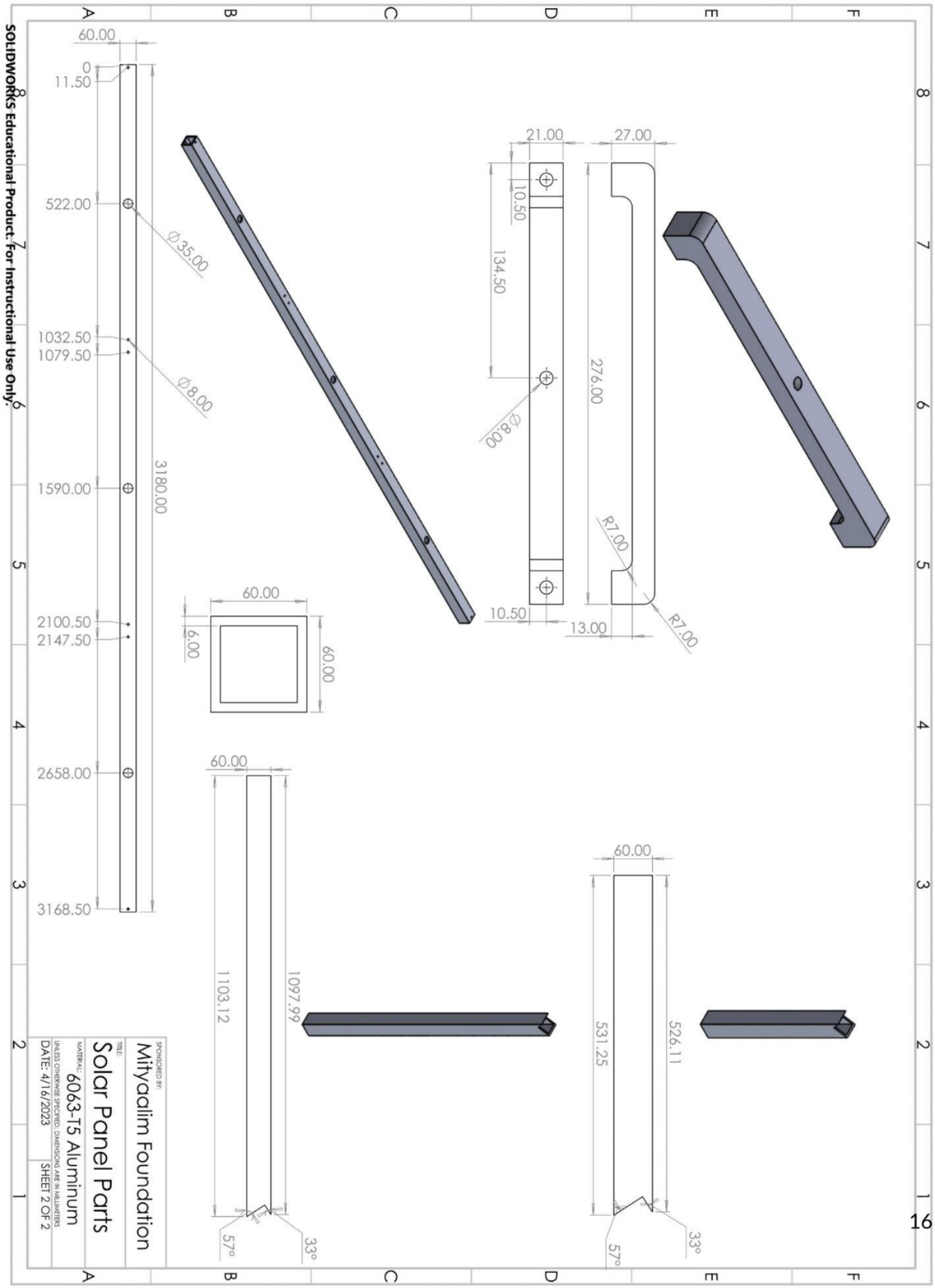
TITLE:
Three-Panel Rig

WEIGHT: 111.46 kg

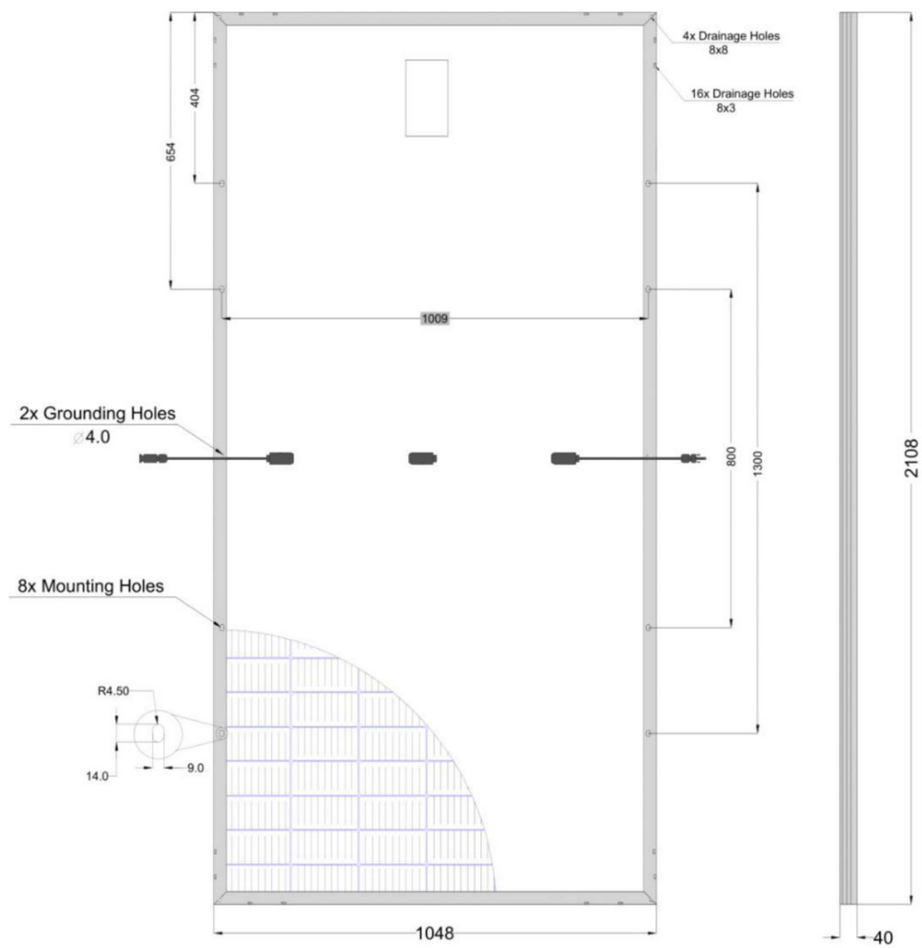
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS

DATE: 4/16/2023 | SHEET 1 OF 2

15


SOLIDWORKS Educational Product. For Instructional Use Only.
SPONSORED BY:
Mityaalim Foundation
TITLE:
Solar Panel Parts
MATERIAL: 6063-T5 Aluminum
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS
DATE: 4/16/2023
SHEET 2 OF 2
16

REV.	DESCRIPTION	DATE
00	INITIAL RELEASE	2021-03-25



NOTES:

ALL DIMENSIONS IN "MM" UNLESS SPECIFIED OTHERWISE.
FOR 1500V PRODUCTS, EDGE SPACING (LIVE PARTS TO THE ACCESSIBLE EDGE OF THE MODULE) NEEDS TO BE MORE THAN 15MM.
FOR 1000V PRODUCTS, EDGE SPACING (LIVE PARTS TO THE ACCESSIBLE EDGE OF THE MODULE) NEEDS TO BE MORE THAN 12.7MM.

HELIENE	DOCUMENT TITLE: HELIENE_144_M6_SPEC_REV.00	DRAWN BY: XINYAN BAI	DATE: 2021-03-25
	DRAWING NUMBER: N/A	REVIEWED BY: GLEN MARSHALL/ CONNOR COVERT	DATE:
REVISION: 00	TOLERANCES: REFER TO HELIENE LAYOUT DRAWING	APPROVED BY: RICARDO GUADARRAMA	DATE:
SCALE:	COPYRIGHT HELIENE: THIS DOCUMENT AND DATA DISCLOSED HEREIN OR HEREWITH IS PROPRIETARY AND MAY NOT BE REPRODUCED, USED OR DISCLOSED IN WHOLE OR IN PART WITHOUT WRITTEN PERMISSION FROM HELIENE.	THIRD ANGLE PROJECTION	UNIT: MILIMETER(MM)