Sustainable Energy Assessment in Puerto Rico's Toll Stations Using Sustainable Rating Systems

By

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For my parents Eduardo & Julia

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Summary

The following document shows how sustainable rating systems can be applied and used to self-evaluate Puerto Rico's transportation infrastructure in terms of renewable energy viability. In order to do this a literary review was conducted on Puerto Ricos's energy cost, ratings systems available and renewable energy applied to transportation infrastructure. Currently the rating systems considered are: INVEST, Envision^{TM}, STARS and Greenroads. Energy consumption data was collected on several of Puerto Rico's toll stations which are the target infrastructure for this study. An energy assessment simulation, using the area available to place solar panels at toll sites was conducted to determine the energy subsidy possible and the cost savings. This in turn demonstrates the rate of return of the system in order to determine feasibility of implementation.

Resume

The present document demonstrates how to use rating systems to analyze Puerto Rico's toll stations and analyze how they stand up in terms of energy cost effectiveness. It has been known that Puerto Rico's energy cost per kilowatt is one of the highest within the United States with 25 cents per kilowatt-hour according to National Renewable Energy Laboratory (NREL). Looking to score points in the area of renewable energy source on rating systems is on the best interest on the island, its citizens and the government power distribution agency known as Puerto Rico Electric Power Authority (PREPA).

After a detailed evaluation on sustainable rating systems available in the construction industry, INVEST and ENVISION were chosen as adequate for certification based systems on renewable energy provided by the Institute for Sustainable Infrastructure and a system provided by the Federal Highway Administration. Using these rating systems the results of the energy assessment was measured in the renewable energy parameters and see how efficient running a solar grid on the infrastructure can be.

The results show that the implementation of photovoltaic systems is viable in economic and financial terms. Simulations show that the net present cost of using photovoltaic systems is less than just paying for electricity at its regular cost. Additionally, photovoltaic systems help prevent

the production of carbon monoxide. All different study cases showed favorable results while undergoing rating system evaluations.

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1 Introduction

Rating Systems in transportation are a new rising self-evaluation tools very similar to Leadership in Energy & Environmental Design (LEED) which is also a rating system although it is directed mainly towards civil infrastructure. The rating systems such as INVEST, Envision^{TM}, STARS and Greenroads have been developed and being used by an increasingly number of transportation agencies every day. Puerto Rico it's one of the top countries in the world with highest energy cost with a price of more than 20 cents per kilowatt since 2007, compare to an average of 13.2¢/kWh in the United States currently. Puerto Rico has inefficient grand scale public transportation such as trains or an island wide bus network. Because of this reason, highway civil infrastructure is of the outmost importance to the island as it is the major method of transportation which is used to daily work commute, emergency response vehicles and merchandise transportation. Up to date there is no public record of the use of these self-evaluation tools called rating systems in Puerto Rico's transportation infrastructure and the benefits that they can provide.

1.1 Justification

Toll road stations consist on a method of revenue for operation and maintenance of the same road in which they are located. Currently there is no public records that demonstrates the application of an assessment on Puerto Rico's toll roads that might show how efficient they are being operated using a transportation rating system as a reference for the assessment. There are 3 major points of improvement that this assessment will provide:

- Economically: With the intention of making more energy efficient toll road stations in Puerto Rico, a country with such a high energy cost, the goal of this project is to provide such an assessment from the point of view of a transportation rating system that can make toll road station much more energy efficient which will in turn translate to government funding savings and provide room for operational efficiency improvement.
- Environmentally: Energy consumption that comes from non-renewable sources such as solar, wind or thermal mainly come from fossil fuel. This holds true for toll stations. Changing their energy source to renewable, we can negate the carbon footprint that the use of fossil fuel would have left.
- Socially: Even though part of the highways on the Island are privately operated most are government operated and fundamentally all are government owned. It is on the best interest of the government agency in charge of operating and maintaining the country's highway to set an example to the people with such projects. Implementation of projects such as the simulations of the adding a photovoltaic system that will be presented on this document

1.2 Scope

The research project presented in this document consist of evaluating Puerto Rico's highway system. Among the types of transportation infrastructure, we are going to be analyzing toll stations. Inside the island toll station system, a few strategic locations are chosen to observe changes if any in the zones being studied. Particularly, conducting energy assessments in the chosen toll stations of Puerto Rico and applying the tools of rating systems, can provide a lot of insight and improvement to current practices being applied. We will be using a data collection methodology, to obtain values of energy load.

1.3 Description of Chapters

This document is originated with the following topics:

- Chapter 1: Introduction - description of project
- Chapter 2: Sustainable energy – definition and its relationship to construction
- Chapter 3: Power energy in Puerto Rico – reasoning for high power energy rates
- Chapter 4: HOMER Pro – description of software used for simulations
- Chapter 5: Rating systems – description of different rating systems with affinity for transportation infrastructure
- Chapter 6: Methodology – step by step description of work
- Chapter 7: Feasibility study – location study and possible restrictions to be aware of
- Chapter 8: Simulation walkthrough and results – Software input explanation

- Chapter 9: Synthesis of results and conclusions
- Chapter 10: References

2 Sustainable Energy and its Relationship to Sustainable Design in Construction

One or two generations ago engineers and the construction industry in general did not take into account many important details that can be called construction aftermath. Basically, infrastructure was thought out to last within a range of 30 to 40 years and after that, it became obsolete and planned to be demolished and rebuilt. As technological advances were applied to construction planning and construction aftermath analysis were made, people began to realize that construction was a high resource consumption activity and that it affects the environment in several ways. Because of this, Lifecycle Cost Analysis (LCA) and Environmental Impact Assessment (EIA) began to be part, and in some cases a requirement of infrastructure planning. Further analysis was made and revealed that infrastructure construction leaves a carbon footprint. A carbon footprint is the sum of carbon produced by all activities related to construction, operation and maintenance. As technology advanced and environmental awareness grew, the efforts to develop methods of mitigation and construction efficiency exponentially escalated. Of course, public opinion and environmental activist had their role to play to such a degree that their influence has stop projects such as the extension of road PR-66 from Rio Grande to Fajardo which was going to pass through the Yunque rain forest. One of the most common ways to make the operation and maintenance of infrastructure efficient and less resource consuming was the use of renewable energy.

2.1 Sustainable Energy

Sustainable energy is viewed as the engine for sustainable development. It can be defined as a dynamic harmony between the equitable availability of energy-intensive goods and services to all people and the preservation of the earth for future generations, or it can also be defined as the provision of energy development that meets the needs of the present without compromising the ability of future generations to meet their needs. The most important aspect of sustainable energy is that it must be clean energy. There are various form and applications for sustainable energy like hydroelectric plants that uses the falling pressure of the water column from a damn for its energy source, geothermal electricity produced from geothermal energy which is the thermal energy stored in the earth, wind power which produce power with a turbine that's being moved by the wind and photovoltaic energy generation which uses photovoltaic cells to harness the solar energy.

The focus of this project is the use of photovoltaic renewable energy. Solar power is one of the cleanest energy sources in the world if not the cleanest. Every hour, the sun provides the Earth with as much energy as all of human civilization uses in an entire year (Horn & Krupp, 2008). Thomas Edison once said: "I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait till oil and coal run out before we tackle that". The sun is an incredible source of energy but currently the humanity does not use much of that power due to the main problem being that the energy is distributed over a large area (the Earth, or rather half of it) and it needs to be concentrated in order for it to be useful. It is known that the energy that the sun provides on the Earth in a square meter is about 1,366 kilowatts denominated as the solar constant (this is not really constant, it varies 0.0002 kW/m^2 over an 11 year cycle). This translates to 180 quadrillion watts of energy to the outer atmosphere of the Earth (about 14,000 times our requirements for generating power to support the current world's needs). Of all that energy, due to the angle at which sunrays strike the Earth, the fact that only half of Earth surface receives energy at any given time, only about one fourth of the solar constant which is approximately 342 $watts/m^2$, is received by the atmosphere. Further loss of energy is due to 31% being reflected by the atmosphere so now only 69% reaches the Earth which is 236 $watts/m^2$ (Haugen, 2014). The quantities and percentages vary across the Earth due to weather conditions latitude, longitude, elevation and reflective properties (Haugen, 2012).

There are two forms of solar technologies which harness solar power into electricity or heat. Solar power can be converted directly using photovoltaic (PV) or indirectly by concentrating solar radiation (CSP), focusing solar energy on a receptor to provide high heat that is transformed into power. This project focuses on the use of photovoltaic power. The way a photovoltaic cell functions is that when semi-conductive material like certain types of silicon become expose to sunlight they release small amount of electricity, based on the photoelectric effect. The sunlight is made of photons or particles of solar energy. Practical commercial photovoltaic panels currently have a poor efficiency range of 12- 18%. This low percentage is due to the fact that photons contain different kinds of energy with different wavelengths. The material used for the PV cell only is compatible with a limited bandwidth of all the photon wavelengths and what happens is that when the cell is stroke by sunrays only a small amount is absorbed the rest bounces off or passes through. A PV system has several components including PV modules (groups of PV cells), which are commonly assembled into PV panels; one or more batteries; a charge regulator or controller; an inverter, when alternating current (AC) rather than direct current (DC) is required; wiring; and mounting hardware or a framework. When relating to photovoltaic systems there are 2 types, one is stand alone and the other one is grid connected system. The stand-alone system does not requires an inverter to convert direct current, which is the one provided by a photovoltaic panel to alternating current which is the one used by the utility grid. Having a grid connected system provides the option of net metering, which allows to sell back to the grid excess energy produced by the system. The installation of a PV system in a toll station will turn it partially into a Renewable Energy Infrastructure (REI) because the PV will only mitigate the electrical load partially.

2.2 Sustainable Design in Construction

A sustainable building is a structure that is designed, built, renovated, operated, or reused in an ecological and resource-efficient manner. It is notable to mention that the design, construction, and operation of facilities have a major impact on the proliferation of greenhouse gases. Energy inefficiency in the operation of a building leads to overuse of fossil fuels used for energy generation. The materials used in buildings such as wall and floor surfaces, paint, laminates, manufactured boards, and refrigerants are contributors to pollution as well, to the extent that they are designed to be environmentally friendly. Buildings account for one-sixth of the world's fresh water usage, one-quarter of its wood harvest, and two-fifths of its material and energy flows (Roodman and Lenssen, 1995). Initiatives such as Leadership in Energy and Environmental Design (LEED) established by the U.S. Green Building Council (USGBC), Energy Star and others promote green architecture and sustainable construction. These initiatives serve as a guide and reference for building owners, designers, and builders to ensure that future buildings increasingly incorporate the best practices that will in time, lead to a sustainable environment for all. According to studies by the U.S. Green Building Council (USGBC, 2007), in the United States buildings account for (Forbes and Ahmed, 2010):

- 65.2% of total U.S. electricity consumption
- >36% of total U.S. primary energy use
- 30% of total U.S. greenhouse gas emissions
- 136 million tons of construction and demolition waste (approximately 2.8 lbs. / person/day)
- 12% of potable water
- 40% (3 billion tons annually) of raw materials used globally

Buildings are vertical structures and are limited to their foot print area to implement sustainable systems such as photovoltaic on the roof but they are huge and constant energy consumers. Taking that into account and comparing to infrastructure like roadways that go for miles, they have a bigger environmental impact when built but are low energy consuming so given its broader area it haves bigger opportunities to implement sustainable systems.

To take into account all aspects of design and construction and energy efficiency LCA are now used more and more for creating sustainable buildings and sustainable infrastructure. LCA is a method used to evaluate the total costs incurred in the useful lifetime of a structure, increasing energy consumption efficiency and insuring Return of Investment (ROI). To perform an LCA one must take into account the acquisition cost of land, cost of construction materials and disposition of structure at end of useful lifetime, efficient operation use, maintenance and rehabilitation if reusing an existent structure. An LCA is of great utility when various design approaches are presented as viable options that meet basic requirements but vary in initial construction costs and maintenance and operation. LCA were originally performed for a useful life structure of 50- 60 years, but now they analyze up to 100 years or more. LCAs have 2 main stages including planning period that comprehends from initial design of structure and its construction until it becomes operational and the service period that comprehends from the moment that facility becomes operational until the end of the analysis period. Sometimes these two stages can overlap. An example is RealCost version 2.5.2 (FHWA 2009) is used in the BE2ST-in-Highways system to determine the life-cycle cost of a highway, including both agency costs and work zone user costs, for initial construction and rehabilitation events over the lifetime of the highway (Lee, Edil, Benson, and Tinjum, 2013). Renewable energy plays a big part in making a structure cost efficient during its operation phase. Rating systems such as LEED and INVEST are great tools that facilitate the design and construction of a sustainable infrastructure. They provide guides and goals during the design construction and operations phases of a project lifetime.

3 Power Energy in Puerto Rico

Puerto Rico is an island, which means that it is surrounded by water in all directions geographically speaking. "Puerto Rico is one of the jurisdictions with highest energy cost" (Cortés, 2017), this is directly correlated to the fact of its geographic limitations of bring an island. "More than 50% of the energy production of Puerto Rico is tied to the volatile prices of oil" (Cortés, 2017). Figure 1 shows percent energy sources for Puerto Rico

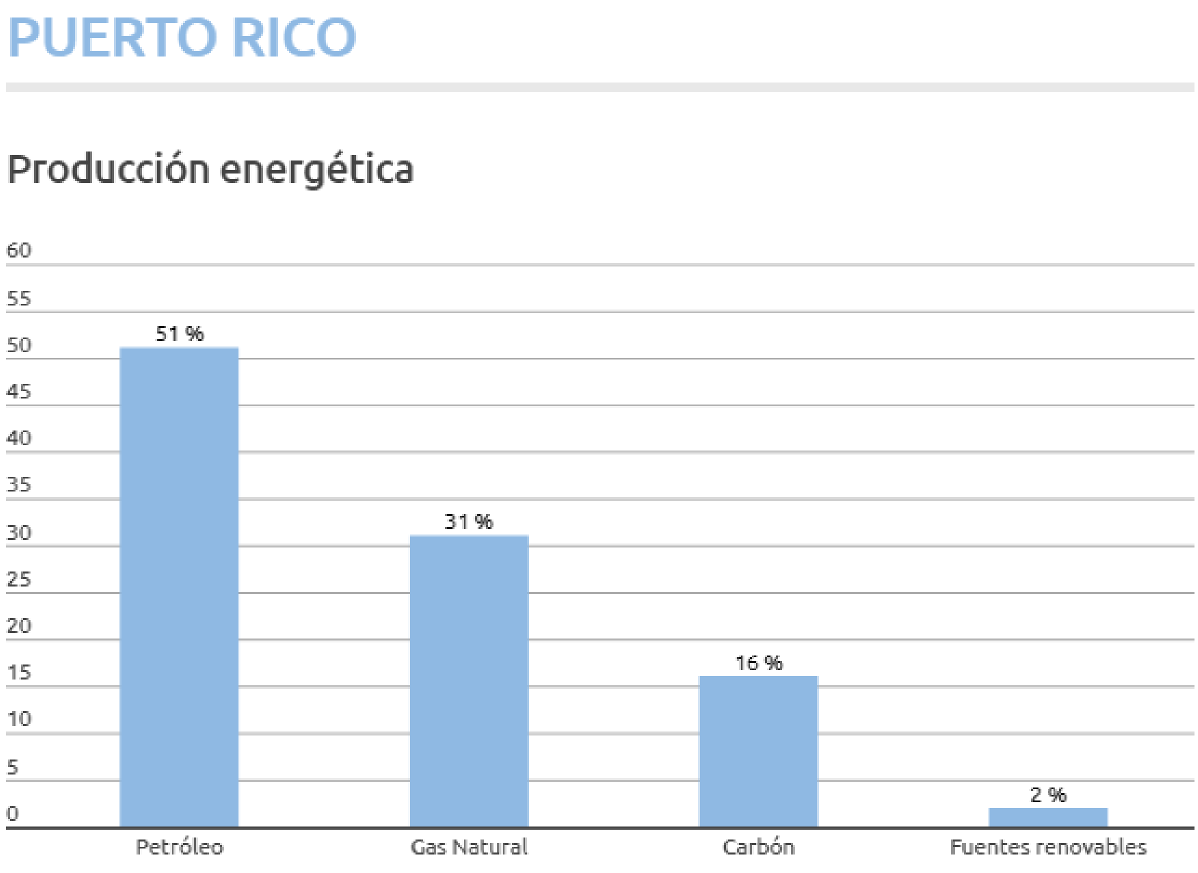


FIGURE 1 - PUERTO RICO ENERGY SOURCES 2017

Current prices for kilowatt-hour for the island are second only to Hawaii out of all the states. In Figure 2 we can observe a comparison between the Energy Prices for Puerto Rico compared to some other states and other countries with similar qualities.

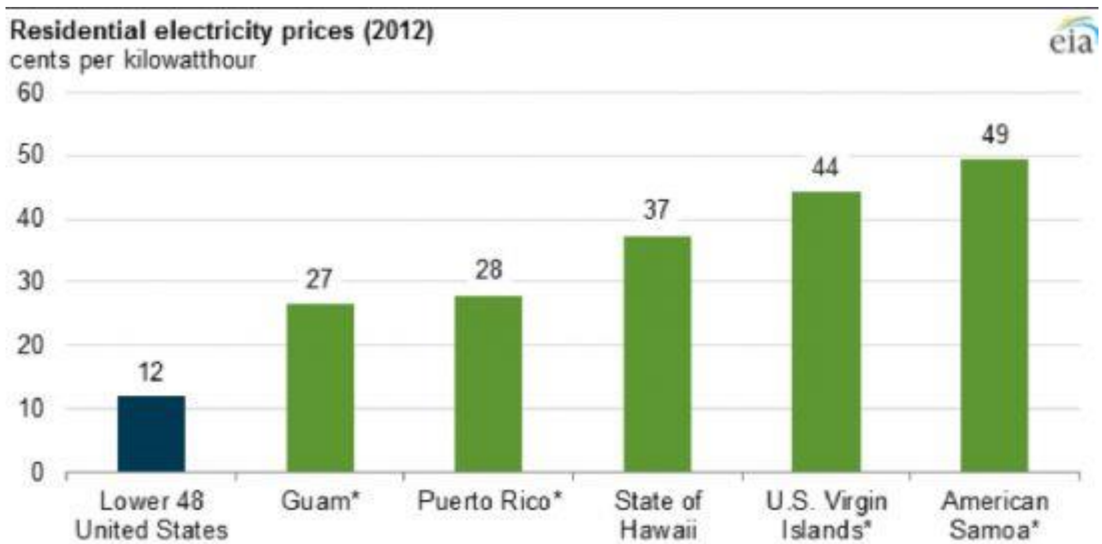


FIGURE 2 – ENERGY PRICES COMPARISON 2012

The US government presented a solution, it was considered to interconnect Caribbean islands with submarine cables to create a bigger grid (Cortéz 2017). This would allow more renewable energy sources to be integrated, lower energy costs and provide more grid stability. Despite this being an alternative it was not considered on the Integrated Resource Plan of the government owned electric distribution agency known as "Autoridad de Energía Eléctrica" or AEE for short. Analysis show that this solution comes at high cost and will have a severe impact on marine environment. Additionally the infrastructure would have a low resiliency that would be subjected to atmospheric events such as hurricanes. The agency current plans include a rise in the tariff that can reach 25 cent per kilowatt hour for residential consumers. This is close to the 2012 energy prices when the oil barrel was more than 100 dollars a shown on figure 3.

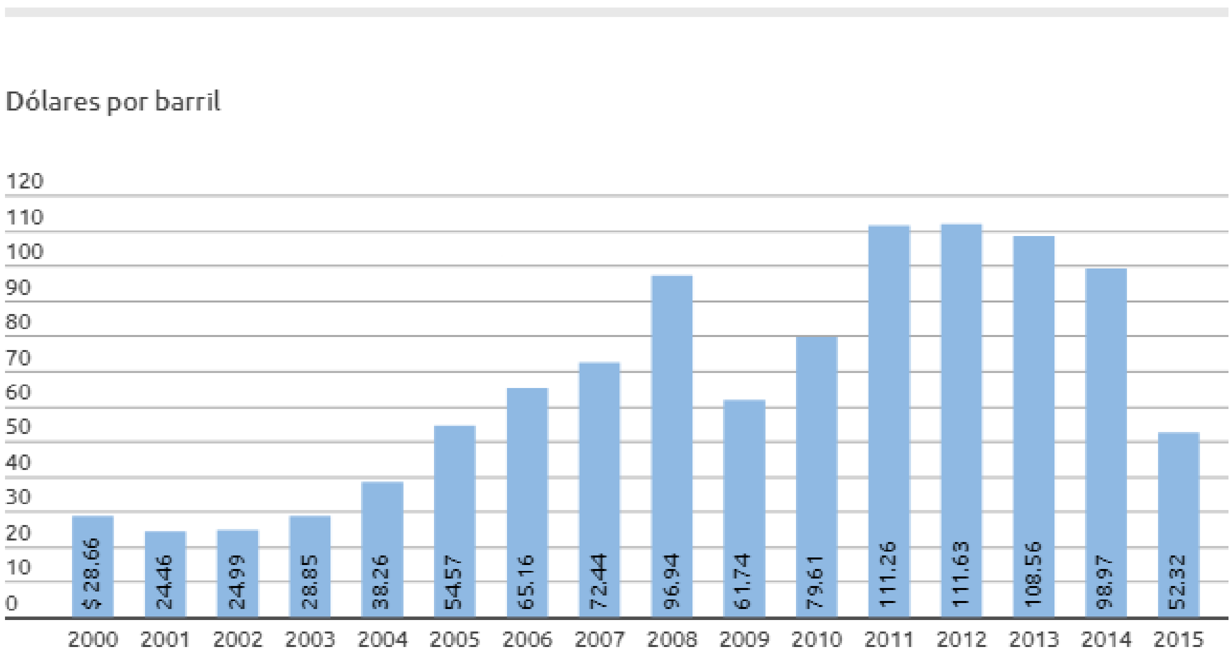


FIGURE 3 - OIL BARREL PRICE PER BRENT INDEX

The island has high prices for electricity and on top of that the atmospheric phenomenon the island is subjected to makes the grid unreliable. This has led to finding alternative power sources such a photovoltaic renewable energy systems. On Figure 4 we can see Puerto Rico Electric Power Authority (PREPA) Operational Profile

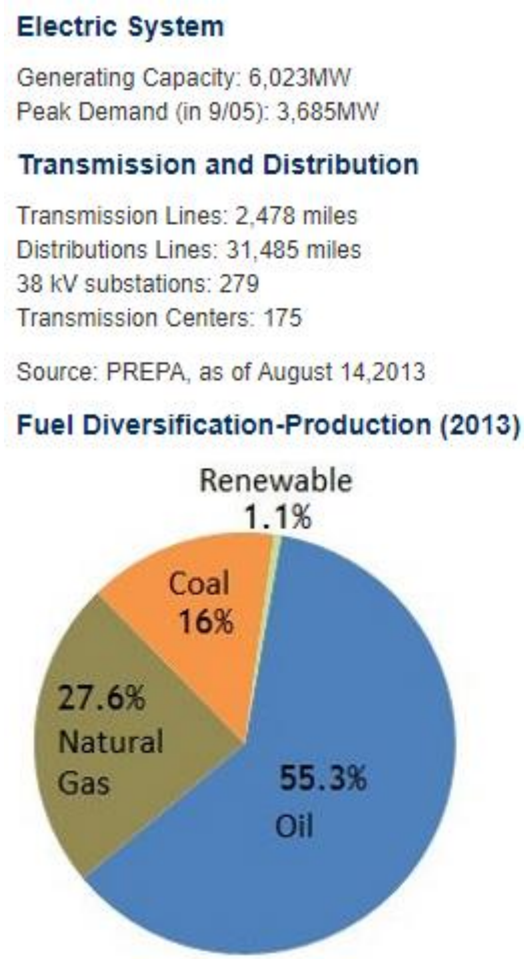


FIGURE 4 - PREPA OPERATIONAL PROFILE 2013

3.1 Highway Infrastructure in Puerto Rico

Puerto Rico has 26,862 kilometers of roadways, of which 454 kilometers are highways. “According to the FHWA, around 75 km of road are in good state, 227 km are acceptable, and

100 km are in a very bad state" (Cortés, 2016). The island of Puerto Rico is ranked 51st in the road roughness index, which serves as an indicator of the road network conditions. Below we can see a map on Figure 5 that indicates the major roadway network in Puerto Rico.

FIGURE 5 - MAJOR ROADWAYS IN PUERTO RICO

Due to the humid environment composed of high heat and rains of the island, the roadways here require above average maintenance. Roadway maintenance requires funds which can be collected through taxes and tolls. Puerto Rico has 2 major highways which are toll roads being PR-22 and PR-52. PR-22 ranges from the town of San Juan (Puerto Rico's capital) to Hatillo and is privately operated through a Private Public Partnership with *Metropista*s an Abertis company. *Metropistas* also operates PR-5, which connects Bayamón to the metropolitan area of San Juan. Another concessionaire of Abertis, "Autopistas de Puerto Rico" (APR), operates the 2 kilometer toll bridge "Teodoro Moscoso" that connects Isla Verde and San Juan by crossing the San José Lagoon. Abertis takes care of operation and maintenance of the highway and keeps toll revenue in return. Pr-52 highway is government operated, but similarly uses a portion of toll revenue for operation and maintenance of the highway.

4 Homer

Homer^{TM} is a Computer software that can run simulations of the operation of a renewable energy system. It is distributed by the National Renewable Energy Laboratory (NREL) of the US Department of Energy. Homer^{TM} is able to provide and compare the cost of energy of different simulations and is recommended for its capability to incorporate a microgrid system with different combination of elements. For example it can be used to evaluate photovoltaic systems, thermal energy, aeolic energy, hydraulic energy or any combination between these. This can even include non-renewable energy sources such as generators that use fuel as well as adding storage capability such as batteries. The energy balance can be simulated specifically by the hour and this allows for peak load analysis.

Homer^{TM} determines the viability of the desired system configuration in terms of how much energy the system is able to supply against how much it needs. Homer^{TM} incorporates the economic and financial factor into the analysis. After providing pricing information the simulation can include cost analysis about installation, operation, maintenance and replacement using net present value through the life cycle of the project. A detailed explanation regarding an analysis on the viability study will be provided.

5 Rating Systems

The application of rating systems is a new rising methodology for creating sustainable and efficient transportation infrastructure. Currently, environmental infrastructure contributing to the sustainability of concrete pavements can be assessed by the use one of the emerging rating systems based loosely on the Leadership in Energy and Environmental Design (LEED) green building rating system produces by the United States Green Building Council (USGBC). Examples of these rating systems are Green Roads for pavements under development at the University of Washington and GreenLITES a certification program instituted by the state of New York (Sabnis, 2011). Several studies like NCHRP PROJECT 25-25 TASK 64 have been made linking sustainable energy to transportation infrastructure.

5.1 Rating Systems

Rating systems have been used since the early 80s and have a wide range of applications. Some examples would be home energy rating systems, rating system for a utility rehabilitation, shale durability rating system based on loss of shear strength, dynamic thermal line rating system among many others. More than 600 sustainability assessment rating systems are available worldwide. Due to the objectives of this project, sustainable transportation rating systems was focused. The most commonly used in the USA are describe on the following sections.

5.1.1 Envision™

Envision™ system is the collaborative product of the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School and the Institute for Sustainable Infrastructure (ISI), and was launched in 2011 (Bahrevar, 2013). It consists on a project check list and sustainable rating system. Envision was originally funded by the American Society of Civil Engineers (ASCE), the American Public Works Association (APWA), and the American Council of Engineering Companies (ACEC).

5.1.2 INVEST

Infrastructure Voluntary Evaluation Sustainability Tool (INVEST) was launched by the Federal Highway Administration's sustainability system group in October 2012 (Bahrevar, 2013). INVEST considers the full life cycle of a project and has 3 major categories with 60 criteria included, which include: System Planning, Project Development and Operation and Maintenance. This rating system has several versions and it's still improving. The first version was known as Federal Highway Authority (FHWA) Sustainable Highways Self-Evaluation Tool. It was by the second version launched by October 2012 that it was known as INVEST and it was the collective product of local agencies, federal and state government officials, in collaboration with faculties from university and others. As INVEST is a self-evaluation tool it is not required or mandatory and it is free to use to help evaluate project sustainability. INVEST does not count with a certification system.

5.1.3 Green Roads

Greenroads sustainable highway rating system is presently managed by the Greenroads Foundation, but there were several other parties who helped in its creation. As with invest, there were several versions, including a 'Green Roads' edition in 2006 promoted by the Green Highways Partnership (GHP). GHP focused on advancing sustainable transportation as well as improving this industry's environmental performance. While GHP recognized the Washington DOT as the source of this 'Green Roads' strategy, much the same process planning effort (i.e., with nearly identical rating categories) was underway at the same time at the University of Washington. The exact sequence and due degrees of credit for these initial steps with 'Green roads,' 'Green Roads,' 'Greenroads' development 95 remains a bit clouded. The early versions collectively kick started the continuing evolution of the eventual 'Greenroads' system (i.e., with versions V0.95 in 2009, V1.5 in 2011, and V2.0 upcoming in 2014), where these later versions were initially spearheaded by the University of Washington and CH2MHILL, and more recently managed by the Greenroads Foundation.

5.1.4 GreenPAVE

GreenPAVE is Ontario's first Pavement Sustainability Rating System. The Ministry of Transportation in Ontario (MTO) is considered a leader in pavement technology with a history of 20 years of research, development and implementation of green initiatives including warm mix asphalt, pervious pavement of both concrete and asphalt in-place pavement recycling, and others. GreenPAVE is a point-based Rating System and it assesses the how sustainable is a road or its "greenness" that is primary based on LEED but also was influenced by GreenLites, Green Roads and Green Guide for Roads. Table 1 explains the point system different categories. Table 2 is an example of a category further broken down. Figure 6 shows GreenPAVE entire scheme.

TABLE 1 - GREENPAVE CATEGORIES DESCRIPTION AND POINTS

Category	Goal	Points
Pavement Design Technologies	To optimize sustainable designs. These include long life pavements, permeable pavements, noise mitigating pavements, and pavements that minimize the heat island effect.	9
Materials & Resources	To optimize the usage/reuse of recycled materials and to minimize material transportation distances.	14
Energy & Atmosphere	To minimize energy consumption and GHG emissions.	9
Innovation & Design Process	To recognize innovation and exemplary efforts made to foster sustainable pavement designs.	4
	Maximum Total:	**36**

TABLE 2 - PAVEMENT DESIGN TECHNOLOGIES OBJECTIVES EXAMPLE

PAVEMENT DESIGN TECHNOLOGIES	
Description	**Points**
PT-1: Long-life Pavement	4
PT-2: Permeable Pavements	1
PT-3: Noise Mitigation	2
PT-4: Cool Pavements	2
Maximum Points Available	**9**

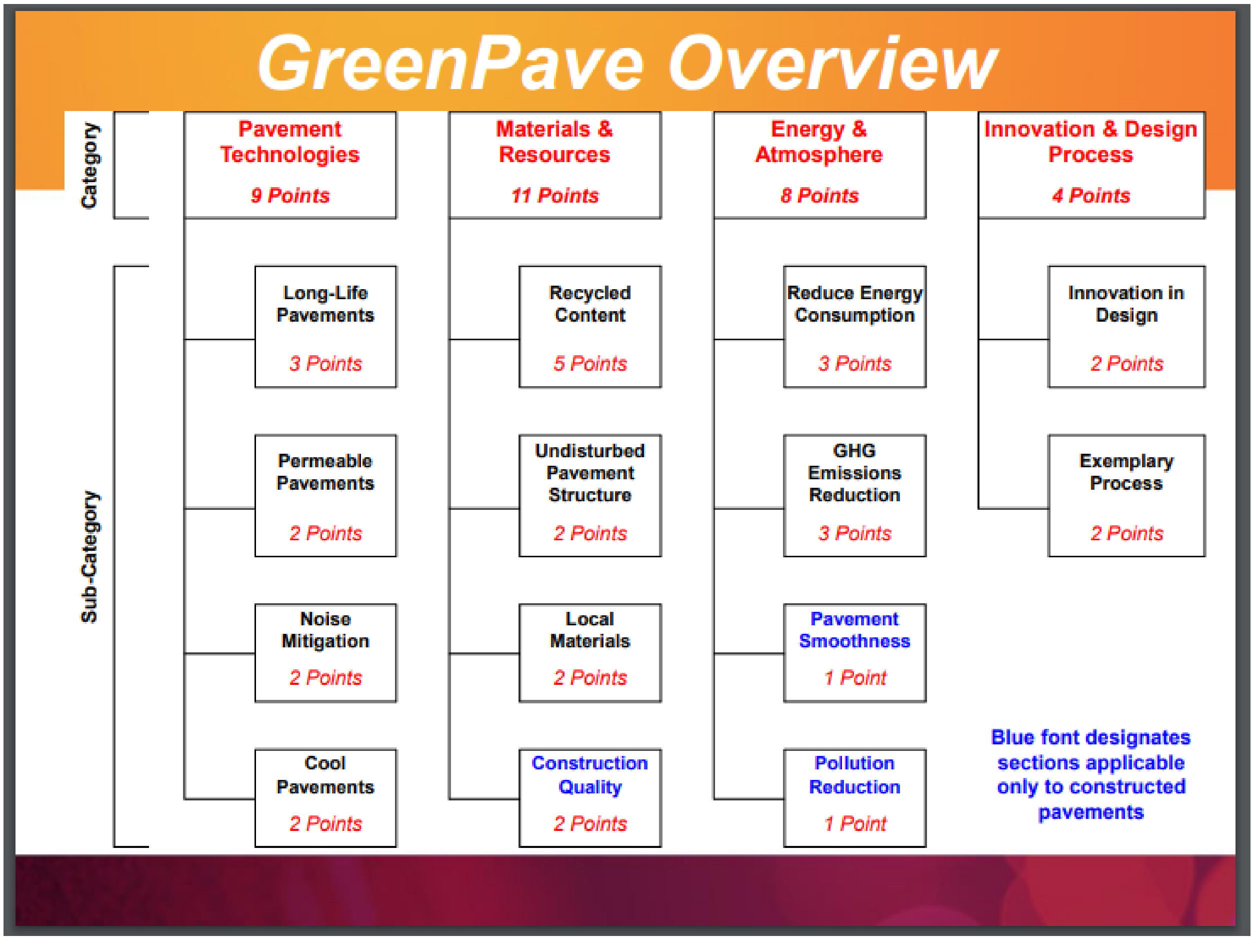


FIGURE 6 - GREENPAVE FULL SCHEME

6 Methodology

6.1 Introduction

The following section fully describes the methodology used on this research study. Presenting a documented process of the steps followed to accomplish this research it's an important part of it as this describes and explains the procedure used and enables and facilitates further research on the area of this study. Prior to explaining this research study it's important to indicate theoretical bases of the research point of view.

6.2 Methodology Definition

Methodology is the theory of organization of an activity (Novikov & Novikov 2013). This definition though very simple is also precise as it refers to the procedure of accomplishing an activity. Research in common parlance refers to a search for knowledge (Kothari 2004). Researchers study and develop designs and methods for research as well as instruments of measurement in order to advance in their respective field, and can have different approaches such as qualitative, quantitative or mixed. Combining the above mentioned one can say that research methodology is to organize an activity in order to search for knowledge using a determined approach. A good researcher must possess the qualities shown on Figure 7:

FIGURE 7 - LIST OF ATTRIBUTES OF A RESEARCH SCHOLAR (TRUNCELLITO ADAPTATION)

Methodology is described as well as an action plan utilized to complete our study. It is important to analyze the logic used in choosing the methods as in this manner we can explain them better. Detail is the key when describing the steps on the methodology used as this provides reader of the research with precise idea of the action plan. If possible providing a list will help with visualization and understanding the process.

6.2.1 Epistemology

Epistemology is known as the study of knowledge. The term “epistemology” comes from the Greek "episteme" meaning "knowledge" and "logos" meaning, roughly, "study, or science, of”, (Truncellito). There are a number of task that concern epistemology and they can be divided in 2 categories which are the *nature* of knowledge and the extent of human knowledge. The nature can be described as the basis of determining how can one know something or do not know something. The extent of human knowledge refers to how much do we know, how much can we learn, what is it the we are trying to learn, does it have limits and if there are unknowable aspects. Philosophers tend to use the word "know" in a factual sense, so that one cannot know something that is not the case, (Truncellito). Knowledge have different uses even in factual applications, one can know a place or a person known as an *acquaintance knowledge* or one can know how to do something known as *procedural knowledge*. Another type of knowledge, which is one focused by philosophers, can be expressed in a declarative sentence and can either be true of false (it does not need to be a fact), this is known as *propositional knowledge.* The method used on this research is *Procedural Knowledge* and it is factual.

Now that we know that we want that we want to stablish a procedure on how to do something we ask what else is needed. For this project we require data collection on the subject matter, and it can be obtained by measurement or acquirement of already existing data on this case it was the later. There are 2 types of data: qualitative and quantitative. Qualitative refers to a state of being of some parameter for example asking a person how they feel which can be subjective. Quantitative refers to measurable parameters such as how much water is in the glass, which is objective and factual.

6.3 Description of Methodology

This study is concentrated in renewable energy. With this in mind we chose to concentrate in the area of photovoltaic systems and its application to abate energy consumption in transportation infrastructure. Toll stations were chosen as transportation infrastructure as these are well distributed all around the island of Puerto Rico. This facilitates the observance of solar irradiance variation that may occur at different cardinal locations around the island. We search for a method to apply rating systems to the energy assessment of the toll stations which haven't been done previously in Puerto Rico. Previous research showed that photovoltaic systems have been used to power up different types of Renewable Energy Installation (REI) and that other form transforming solar power into energy is by concentrating it to produce heat into a device that will transform heat into power. Further study revealed that some rating systems, which are self-evaluation tools that can be certified (but not necessarily), have sections which account for renewable energy utilization. Therefore, the main purpose of the study became on performing photovoltaic system simulations in transportation infrastructure and what score the simulation can attain in the area of renewable energy utilization using the rating systems.

6.3.1 Methodology Steps

The following Figure 8 presents the procedure followed in order to complete this research study:

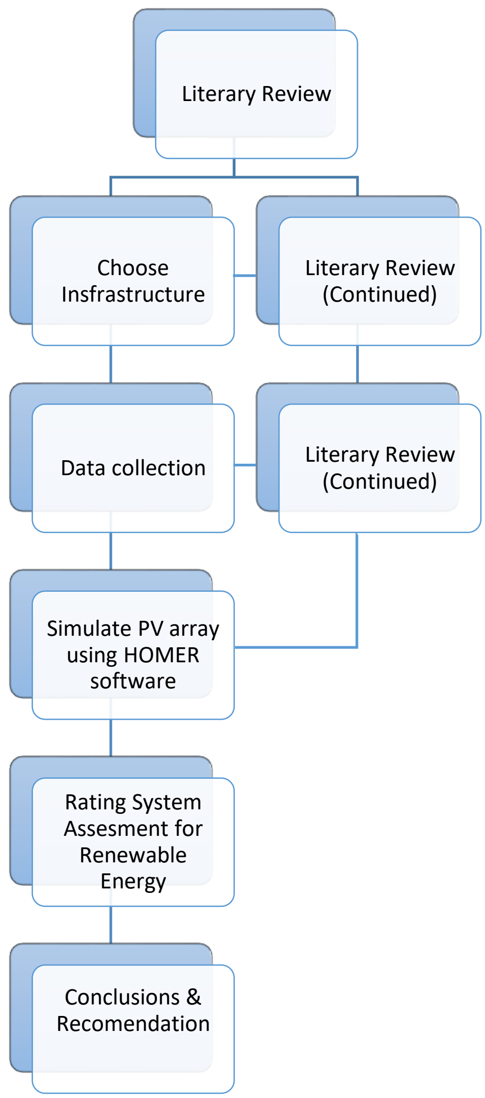


FIGURE 8 - METHODOLOGY FLOW CHART

- Determine which transportation infrastructure was going to be utilized to perform the study:
    - After careful thought toll stations was chosen as the transportation infrastructure as they are located at representative spots all around the island of Puerto Rico in which solar irradiance variation can be observed
    - Redact visit letters to different toll stations in order to receive permission to analyze the premises onsite.
    - The site visit will allow for better understanding of the equipment that the facilities use in order to make sense of the electric load that they need.
    - After permission was received by both public and private entities that run different toll stations around the island, visit dates were set.
- Collect onsite data of the facilities
    - When the visits were made a tour of the facilities was offered in which they explained how the facilities were operated.
    - Information about electric work load was requested for the facilities for a whole year in order to run the simulations as well as estimate the return of investment time defendant on the area available to install the photovoltaic system.
    - Determine the area available for the photovoltaic systems installation.
    - Using Google Earth, the roof area of the facilities was estimated.
    - This in turn provided the number of photovoltaic panels that can be installed.
- Simulation of photovoltaic system

    - With the data collected for electric load and the area available for the PV system, the simulations were performed using Homer software which is a microgrid optimization tool.
- Rating system scoring
    - The results of the simulation provided how much of the electrical load can be abated by the PV system.
    - The percentage of efficiency of the PV system was analyzed using 2 different rating systems.

7 Feasibility Study

In order to create a feasibility study it is important to first determine the factors that must be known to perform it. First we must determine the electrical load of the user that will be abated. In this case the user will be the different toll stations selected being the Buchanan toll station located in San Juan of PR-22 seen on Figure 9, the Ponce toll station of PR-52 seen on Figure 10 and the Juana Diaz toll station of PR-52 seen on Figure 11.

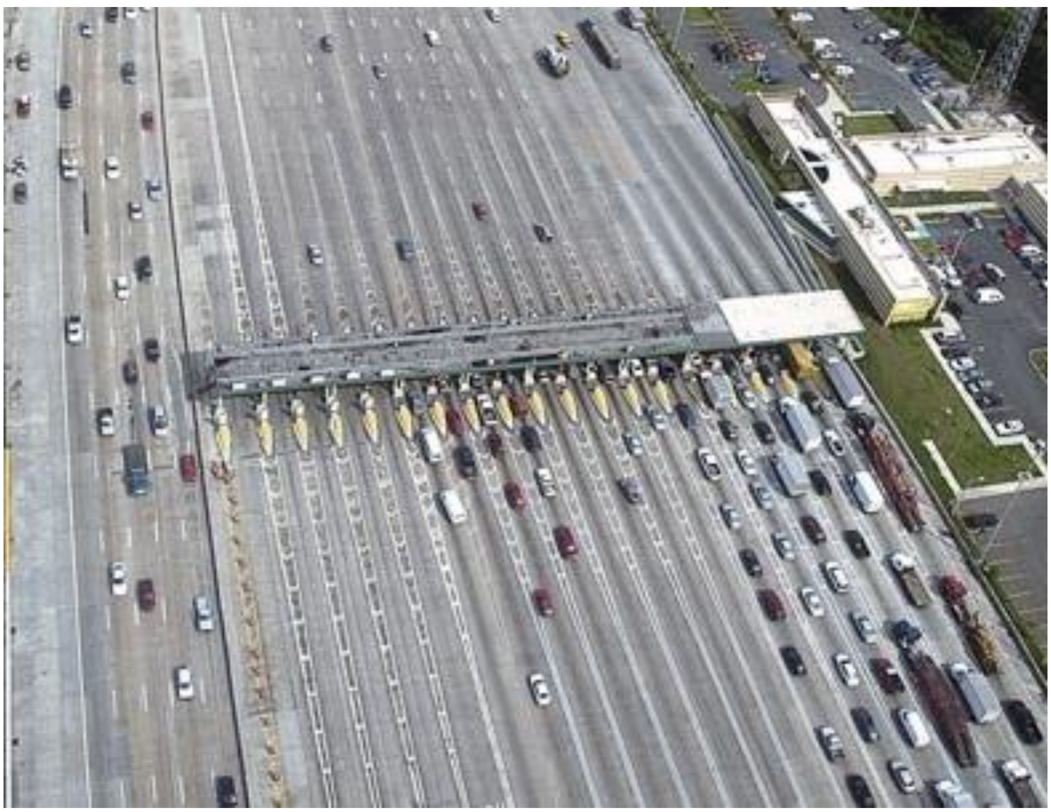


FIGURE 9 - BUCHANAN TOLL STATION (PASCUAL)

FIGURE 10 - PONCE TOLL STATION (GRAFAL)

FIGURE 11 - JUANA DIAZ TOLL STATION

Choosing these toll station as transportation infrastructure allows us to observe the variations of solar irradiance by location along the island. If the load is unknown then the use of specialized load measuring equipment is required such as a multimeter. After the load of the user is known, then it is important to know if there are limitations on the system such as area available for installation.

7.1 Location Study

To study the location and its surroundings it's very important to determine the viability of the system. With this information we can determine what area we have available for the installation of the system. Another factor that must be determined is the connection type. For this we have to access the available infrastructure, for example, the type of power available for a net metering system in which it is possible to sell back the excess energy produced by the system to the utility entity providing the power service. Other detail to consider is the addition of a storage system such as batteries. Another factor to consider is the needs of the user due to the location. We must see if the area has a constant supply of power or if it has constant black outs in which case a system with energy storage capacity would be needed. We have to keep in mind that adding energy storage capacity to the system will affect the total cost and the initial capital investment.

Grid interconnected systems have more options than off-grid standalone systems. When the system is interconnected to the grid we can decide if we are going to cover the energy demand completely or only partially. Off-grid systems do not have the option of deciding to cover the load partially they need to cover the load entirely. For all cases, it is recommended to use efficient and low consuming equipment along with demand response strategies.

Space availability can limit the renewable energy system size and consequently the amount of energy it can produce. The distance of the equipment is also an important factor as bigger cables will be required to compensate for energy loss with distance. The system should be located as close as possible to the area requiring the energy. Solar panels require at least 4 peak hours of sunlight to be effective and be used at maximum capacity (Energy Sage). “The term "peak sun hours" refers to the solar insolation which a particular location would receive if the sun were shining at its maximum value for a certain number of hours” (average solar irradiation), this refers to average daily solar insolation in units of kWh/m2 per day. We can observe an example on Figure 12.

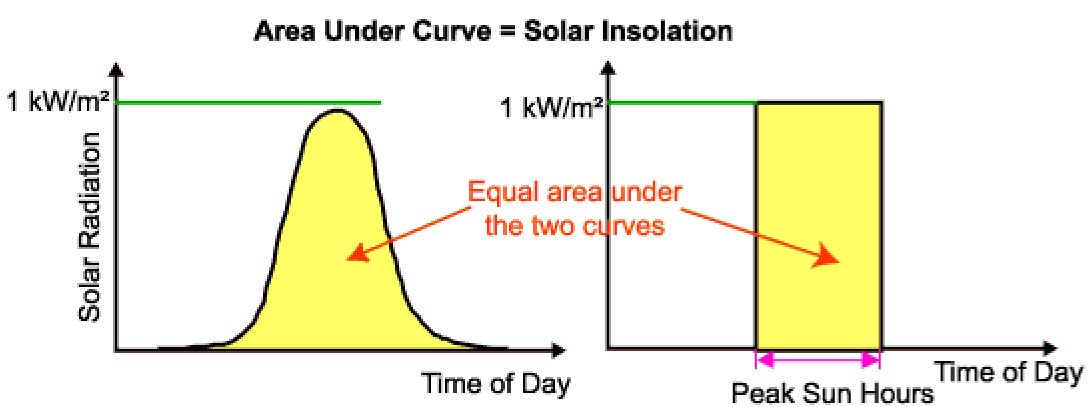


FIGURE 12 - SOLAR RADIATION OVER TIME OF DAY EXAMPLE

The location must be analyzed for possible blockage of objects casting their shadow on the panels as this will diminish the capacity of the solar panels to receive peak sunlight hours. The location must also be secure preferably. Puerto Rico is an island subject to atmospheric phenomenon such as hurricanes. High velocity winds might damage the installation so it is convenient if the system equipment such as inverters and batteries are located in an enclosed room which would also protect against robbery or vandalism.

7.2 Preliminary Design of System Load

With the requirements for the system already stablished and knowing the limitations of the system, the analysis of the system follows. For toll station cases, area available is a limiting factor that will determine the size of the possible photovoltaic array. As stated previously, the loads for a whole year of the facilities were provided by the management so there is no need to calculate the power load that the facility demands. The loads for all stations can be found on Appendix

7.2.1 Converters

There are a wide variety of converters nowadays sold by several manufacturers around the world. They range from 1 to hundreds of kilowatt capacity. These can have the capacity to do net metering, charge batteries or both. Converters capable of battery charging as well as net metering cost more as they are more complex and possess the capacity of supplying the load, charge the battery system and determine when to use battery charge. Systems that are connected to the grid require devices capable of detecting failures on the grid and stop AC electricity production, this will make it safe for utility repairs as it will not energize the power line. Another variable to be known is the voltage required. Direct Current voltage input will range from 12 volts to 600 volts and the AC output voltage will be in the range from 120 volts to 480 volts depending on the load requirements and system design. We must also know the required watts output in order to select the converter capacity and quantity.

7.2.2 Solar Panels

Like converters, solar panels come with a variety of specifications and are produces by different manufacturers. If there is no initial capital investment restriction, a panel with the best efficiency possible will yield better results while providing in the long run a better return of investment. They vary in efficiency, voltage, wattage, sizes, colors and even shapes. We can see examples of triangular shape on Figure 13, cone shape on Figure 14 and flexible film on Figure 15

FIGURE 13 - TRIANGULAR SHAPED SOLAR PANEL

FIGURE 14 - CONE SHAPED SOLAR PANEL

FIGURE 15 - FLEXIBLE SOLAR FILM

Price may limit the purchase of the highest efficiency equipment available. When there is unlimited space available for equipment installation, the most economic option may be the panel with best dollar/ kilowatt ratio available. Typically these panels are bigger. Something that can help to lower the price of panels is to buy them in bulk in order to obtain rebates. Now-a-days a 5 kW array can be as low as 2.3$/W 22% efficiency. Price comparison between brands is always wise when buying any type of merchandise, solar panels and photovoltaic systems are no different. Renown brands might charge more for same quality equipment. Typical warranties for solar panels vary but it is common that they reach 25 years.

Solar panel installation is of the outmost importance. They are typically mounted on roof tops but can be mounted on several other locations. Below we can see examples of a wall mounted solar panel on Figure 16, a roof mounted solar panel on Figure 17 and a ground mounted solar panel on Figure 18.

FIGURE 16 - WALL MOUNTED SOLAR PANEL

FIGURE 17 - ROOF MOUNTED SOLAR PANEL

FIGURE 18 - GROUND MOUNTED SOLAR PANEL

When mounting solar panels on roof top is convenient to install mounting brackets, as they help with the optimal panel inclination needed to receive sun rays as perpendicular as possible. Puerto Rico being an island located in the Caribbean, is subjected to hurricanes and tropical storms, which are accompanied by high velocity winds. Mounting brackets help secure the panels to the installation location protecting your investment and most importantly, preventing the panels to become projectiles and become damaged. The code design indicates that they should withstand wind of up to 145 miles per hour. On light of this it is recommended to leave a safety spacing on building roof edges where the wind speeds are strongest.

7.2.3 Wind turbine

Wind turbines are less common than photovoltaic panels but they are a very good source of renewable energy. Using wind, a free nature resource, as propelling force, they produce electric energy. The design is relatively simple as these come with a performance curve indicating how much power it can generate according to the wind speed available. The factor that needs to be known is what the wind speed profile of the location desired is. Below on Figure 19 can observe an example of the *wind turbine performance curve* which provide information to optimize efficiency with the wind speed.

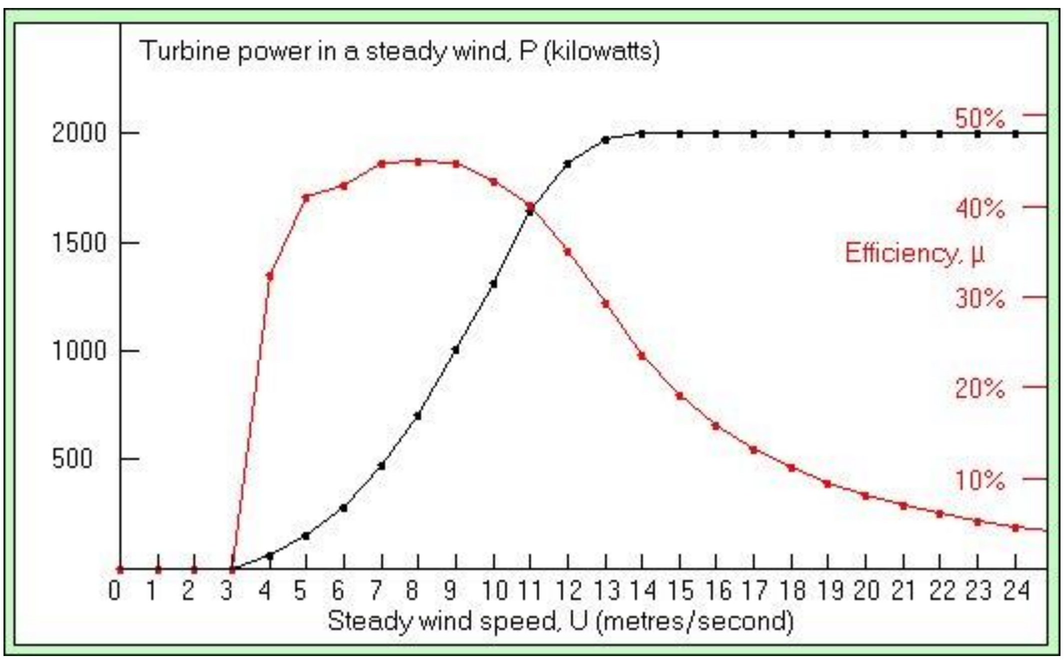


FIGURE 19 - WIND TURBINE PERFORMANCE CURVE

They are very convenient for windy locations but they also have disadvantages. Wind turbines are large and heavy. Soil must be analyzed on the installation location to see if it is stable enough and can handle the load weight. The specifications indicate the clear zone that the fan blades must have to be safe. Also wind turbines need to be far away from live power distribution lines for safety. Another issue is the vicinity of airport landing and takeoff zones. Like with solar panels it is recommended to compare prices and brands to find the best on the market for the required need. Matching the wind profile in the area with the proper wind turbine is important. On this project the use of wind turbine was not considered due to the limited area available on toll stations and the open space requirement they need.

7.2.4 Batteries

Batteries store energy and serve as a secondary power supply in case of a power outage due to a power grid failure, lack of solar panel energy in a photovoltaic system or lack of wind in an wind generator. There is certainly an advantage in having the security of an interrupted power supply but adding the battery component to the system will significantly increase the cost and lower system efficiency. The added system for storage adds control devices to manage battery charging.

Batteries need to have two major characteristics which are power rating and capacity. Power rating is the amount of electricity that the battery is capable to provide instantly. Capacity refers to the amount of power it can store. A battery with high power rating and low capacity can run an entire home for limited periods of time. Batteries with high capacity and low power rating are capable of providing power to a few crucial appliances for long periods of time. When we choose a battery it is important to have in mind the purpose and need for it. Batteries function in cycles of charge and discharge. Most batteries need to retain some charge due to their chemical composition, we can see an example on Figure 20. Discharging a battery completely can lead to severe damage to the battery useful life. Some Batteries can be discharged up to a maximum of 90% without getting damaged, these are known as deep cycle batteries.

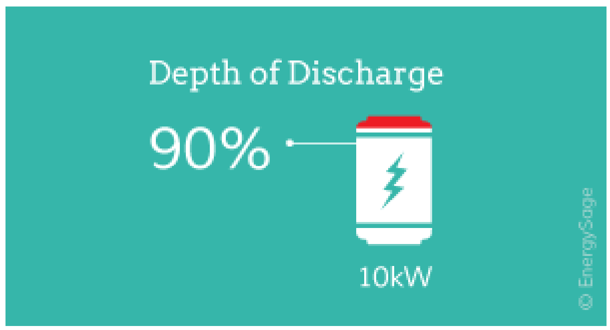


FIGURE 20 - MAXIMUM DEPTH OF DISCHARGE

Batteries used in home energy storage typically are made with one of three chemical compositions: lead acid, lithium ion, and saltwater. Lithium ion batteries are the best option for a solar panel system in most cases but they are more expensive. We can compare on Figure 21.

- Lead acid batteries have been used for decades in off-grid renewable energy systems. These are the cheapest in the market due to their low depth of discharge and shorter life span.
- Lithium ion batteries are lighter and more compact than lead acid ones. These have higher depth of discharge, relatively more capacity and linger life span. All those factor make them more expensive.

- Saltwater batteries are relatively new to the industry and they differ from other by not having heavy metals and using saltwater electrolytes instead. These can be easily recycle unlike batteries containing lead acid and lithium ion, which need a special process to be disposed.

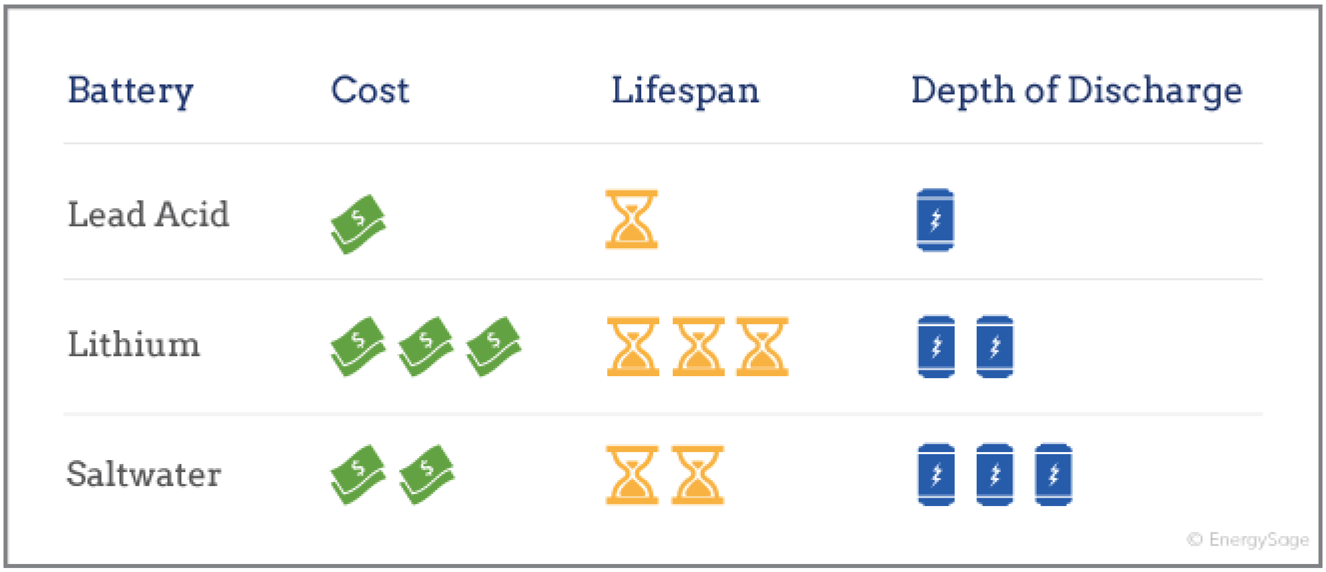


FIGURE 21 - BATTERY CHEMICAL COMPOSITION COMPARISON

Choosing a battery depends on several factors:

- space available to store them
- available capital to invest
- amount of storage power required (off-grid systems require more)

Like with all other components, it is advisable to compare prices and manufactures to get the best particular option. Batteries are not being considered on this project. Due to the size of the electrical load of the facilities studied and the amount of storage they would require.

7.2.5 Cable Sizing

There is a wide range of electrical cables and connection types used in renewable energy systems. To facilitate the process and safety of the equipment and the user, manufacturers specify the connection type pertinent to the installation of the equipment. Cables must be resistant to heat, ultraviolet rays and humidity, as it is possible that they will be exposed to the elements. Cable color coding is specified by the National Electric Code (NEC®) 200.6(A) and NEC 250.119. Ground cables are green color coded and they go to ground, AC neutral lines can be white or grey and any other color for AC live lines. Similarly, DC cables are green for ground, negative lines white, black or grey and any other color for positive lines. For safety measures the NEC dictates that all cabling must be able to carry 125% of the design load and another 125% for all connections from solar panels to batteries or inverters for a total of 156.25% the design load. Another aspect to consider is the energy loss on the wires due to its resistance and the current flowing through it. This is the voltage drop, which also depends on the length of the cable run. The voltage drop formula is computed as shown below

$$VD = \frac{2\ x\ L\ x\ R\ x\ I}{1000}$$

VD = Voltage Drop

L = length of cable in feet

R = cable resistance in ohms by 1000 feet

I = current of the electric load in ampere

The NEC has tables for ease of use ranging from 1 to 150 amperes for cables # 12, #10, #8, #4, #2, #1/0, #2/0, #3/0, #4/0 (from slimmer to thicker), and for voltages of 12, 24, 48, 60, 120, 240 & 480 with maxim voltage loss of 2-5%.

7.3 Feasibility Study of Using Solar or Wind Power for Transportation Infrastructure – Case Study

In March 2011 the Louis Berger Group Inc. published the study known as NCHRP PROJECT 25-25 TASK 64. The primary objective of this study was to develop technical data and case studies of wind or solar energy use as an alternate energy source for transportation infrastructure. For this purpose, feasibility studies for implementation of Renewable Energy Installation (REI) can be determined. The purpose is to develop a tool for the use of transportation agencies for technological integration of innovative applications of transportation with concentration in REIs. The interest to accomplish this was concentrated into four tasks.

- Task 1: Execute surveys in DOTs to develop data and talk to REIs installers within the DOTs to gather knowledge of which technologies have a higher demand.
- Task 2: Find necessary information sources for feasibility evaluation.
- Task 3: Detailed interview with survey participants.
- Task 4: Describe design approach for REIs.

Several analysis and technological reviews were considered. The conditions for the implementation of new technologies must be adequate for the location. For example, wind turbines in urban areas are feasible only if the wind is strong enough. In general wind current maps are not very accurate, hence an anemometer and a wind vane are needed to assess the resource. Also, the proximity to populated areas and noise generation of turbines must be considered. Finally, the power curve of the turbine must be certified in order to avoid performance ambiguity.

Information sources must be double checked in other for them to be accurate and up to date. Project feasibility depends highly on resource availability hence the first step in a project of renewable energy must be to determine if the location has solar or wind potential. With that information considered, technical specifications and economic and financial feasibility is determined. A good source of information would be, for example, NASA's page on solar energy and meteorology. For preliminary feasibility, energy generation and installation options must be estimated for solar and wind energy, with analysis tools such as Retscreen or HOMER. To stay actualized, one can visit the DOE, Solar Energy Technologies Program and DOE, Wind and Water Power Program.

Financing frequently comes from different options including public-private partnership (PPP). Additionally, in the private sector the Energy Purchase Agreements are used, which are based on generation and purchase of energy. This energy is sold based on energy generation and not in a lump sum payment in advance for the energy generation system. For this type of agreement, buyers and investors have long term fixed prices, some time with a percentage annual increment, which will benefit both parties.

7.3.1 Data Collection

To collect the data for the assessment in project NCHRP PROJECT 25-25 TASK 64, surveys were sent to the participating DOTs through e-mail. A total of 23 states participated and they were given a month to complete. The results show that the solar resource stands atop other alternatives. The most common REI were located in highway infrastructure. The most common application of renewable energy projects already implemented was in messages signs. The majority of the participating states reported a total of 10 to 100 projects that used solar energy. For the interviews a more select group representative of the participants was chosen according to their answers to the survey. Different factors were utilized for the selection process like the use of solar or wind systems, geographic diversity, size and quantity of projects, infrastructure and economical success. Table 3 includes an example of the states that participated along with the person interviewed and their position, the renewable energy solution used and their most common application.

TABLE 3 SUMMARY OF STATES AND RENEWABLE ENERGY APPLICATION

States	Interviewed	Renewable	Application
WI	ITS Engineer & ITS R&D Rep	Solar	Portable Changeable Message Signs (PCMS), microwave detectors
VT	Connect Vermont Director	Solar	Variable Message Sign (VMS)
TX	DOT Engineer & DOT Electrician	Solar	Flashing beacons, navigational lighting
IA	ITS Rep & 2 Transdata Reps	Solar /Wind	PCMS, cameras, advisory radio, speed sensors (wind and solar)
SD	DOT Maint. Engineer	Solar / Wind	Road Weather Information System (RWIS)
PA	DOT Director Maint/Ops & Div. Chief Facilities Mgmt	Solar	Stockpile buildings (pilot projects), VMS, flashers
UT	DOT Maintenance Engineer	Solar/Wind	Maintenance Station
ME	ITS Manager & ITS Comm. Tech	Solar	Variable Message Board (VMB), RWIS

7.3.2 Summary of Interviews

In accordance with the feasibility intent, there were different methods for determining the return of investment (ROI) in the different states with REIs but this highly depends on the energy cost of the state in question and the use of the REI. Using federal subsidies, the ROI can be met much faster. In terms of future development, several states mentioned plans for expansion in their solar systems and the addition of wind systems. Noticeably, Pennsylvania considers the utilization of wind system by using the wind produced by trucks in the highway to produce energy with wind turbines. In conclusion most states are satisfied with the utilization of REIs and have expansion plans. The implementation barriers diminish a technology advance. A recommendation given in the study was that states that are new to the use of REIs use small projects first to gain experience from them.

7.3.3 Results of Interviews for Installers or Manufacturers

A methodology used was to ask which technologies had most demand in transportation facilities and which technologies were pending preparation. DOTs were asked to include information about installers or manufacturers that worked with them and from there the most frequent ones were selected. In the case of sings and temporary signs the DOT engineers determined the requirements for each projects and prepared specifications for temporary projects using solar applications. Depending on necessity the photovoltaic panels change in size and power. In the case of portable LED signs of solar energy, it came to light that they were mostly used in arrow signs, messages or speed radars. This type required that the batteries last 10 days.

The equipment had warranty of 5 years and 2 for the battery charger. These contain an internal monitoring system that verifies voltage and amperage so that the batteries are not overcharged. In the case of fixed solar mounts connected to the grid, it was concluded that the systems mounted on ground require extensive engineering analysis and go according to the climate and soil type. If strong wind is present, special installation are required. Fixed mounts have more durability than mobile units. In the theme of grid connected highway lightning it came to light that lighting poles are utilized to place panels which in turn feed the grid. They possess an inverter to turn DC (direct current) to AC (alternate current). These units have little maintenance because they are designed with angle so that the wind and ice don't get to be so detrimental and the rain acts as a cleanse agent. In the case of solar-wind hybrid units it was said that where there are both resources a hybrid system could be used in which the panels are typically between 50 and 250 watts and the wind turbines are 300 watts. The standard batteries charged by this system can last between 3 and 5 days. The maintenance is the same as the standard for solar panels because the turbines are small and do not require any special maintenance. This type of system has a life time of 10 years and the batteries of 5 years.

The interviews with the installers and manufacturers provided knowledge of the differences between REIs systems and the factors that affect them. The mayor difference is between the mobile units and the grid connected fixed ones. The grid connected ones provide different options and generate bigger quantities of energy which provides more stability and security for the grid about the expected energy production. With advancing technologies, the batteries for these systems must become more and more reliable and allow for storage of up to 6 days currently.

7.3.4 General Design Approach

It has been concluded that in order to place a REI close to the road the security of motorcyclists and pedestrians must be taken into account. For this the Manual on Uniform Traffic Control Devices (MUTCD) is used, which is the standard for all Traffic Control Device (TCD) installations in any place. It is also advised to consult the AASHTO roadside design guide which helps independent agencies to develop their own politics. For the REIs, the roadside design guide does not mention particularly the REI which need to be addressed at some point which can be an opportunity for further research. The initial concepts include the limitations of an object to be near the road to reduce serious consequences if an errant vehicle gets off the road. A lot of options are available like redesign, remove, relocate, use a breakaway base or barrier placement. Additionally, a clear zone must be taken into account which will allow a vehicle to recuperate its stability without any obstacles. The design criteria include permanent placements for which supports must be adequate for signs and lighting and when possible must be place behind existent barriers. It also includes portable signs which are used for climate conditions or season or zones where high animal activity is present. These must be equipped with an alternate energy source in case the main one fails. Finally, REIs must be placed behind existent barriers or out of the clear zone. Temporary placements and work zones are addressed by part 6 of the MUTCD which includes design principles for TCDs in work zones. The clear zone can be applied to work zones but its width must be case specific. Table 4 includes a list of the most common REIs and the corresponding design approaches that must be considered. For the purpose of this investigation project the location considered was to install renewable energy in an already existing structure, turning it partially into a REI. An example structure can be found in Figure 22 which are the framework model type.

FIGURE 22 - MODERN AUTOMATED TOLL STATION WITH FRAMEWORK MODEL

TABLE 4 - COMMON REIs AND RESPECTIVE DESIGN APPROACH

Most Common Systems	General Design Approach				
	Locate outside of Clear Zone	Make Breakaway	Protect with Guiderail	Provide crash cushion or barrier	Delineate reflective devices
Permanent VMS/RWIS		x	x	x	
Temporary VMS/PCMS and RWIS			x	x	x
Traffic data collection (speed counters, etc.)	x		x		
Luminaries		x	x		
Call Boxes		x	x		
Traffic Signals		x*	x	x	
Utility poles or other poles used to mount solar units			x		
Overhead Signs			x	x	
Large roadside signs	x	x	x	x	
Small roadside signs		x			

The case study shows a variety of uses in mobile and low scale renewable energy installation. This document will implement a renewable energy installation at a large scale as well as medium scale.

8 Toll Station PV System Simulation and Rating System Assessment

8.1 Development of a New Simulation

We are using HOMER due to its microgrid capability to implement several components as well as incorporate economic and financial factor. HOMER has a simple and easy to use user interface seen in Figure 23. It is an extremely reliable tool that can even optimize through iterations within the simulation. When opening the latest version of HOMER PRO, you can see the following window. In this main window we can start building a system to simulate.

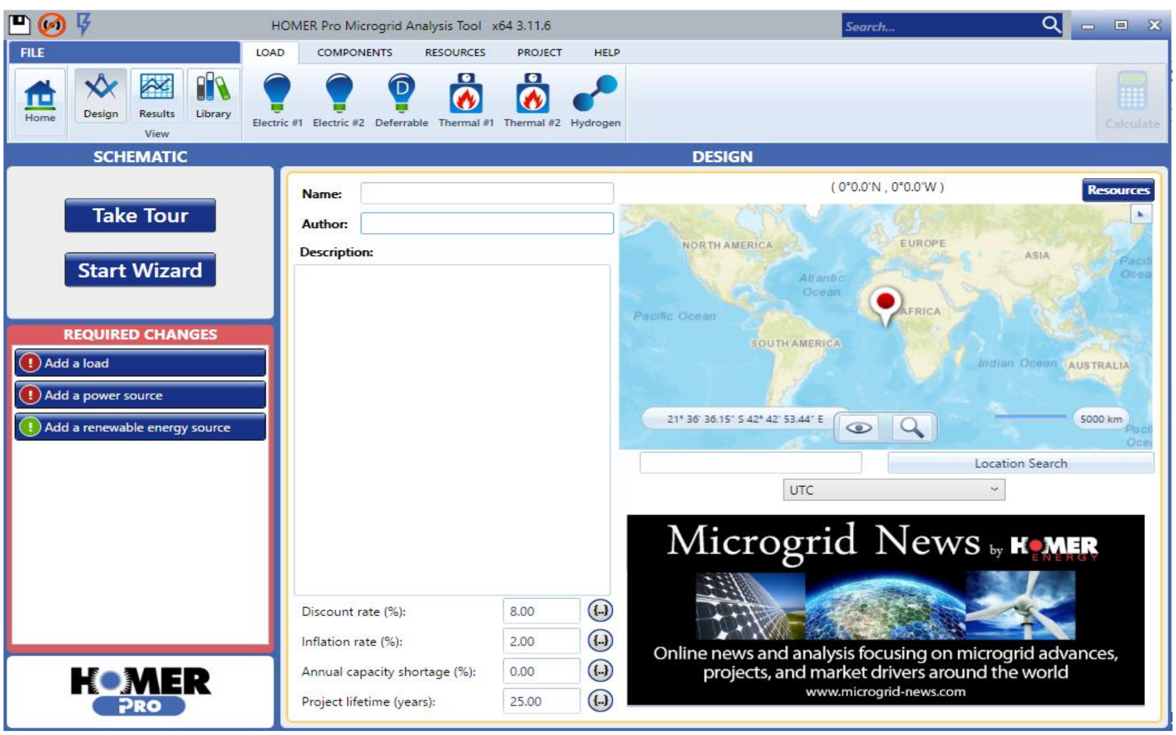


FIGURE 23 - HOMER PRO MAIN WINDOW

A new file is created automatically, and it can be saved at any point of design. In the simulation one can indicate a title for the system simulation a title and description. Following the middle column down one can enter 4 financial variables:

- Discount rate: The real discount rate is used to convert between one-time costs and annualized costs. HOMER calculates the annual real discount rate (also called the real interest rate or interest rate) from the "Nominal discount rate" and "Expected inflation rate" inputs. HOMER uses the real discount rate to calculate discount factors and annualized costs from net present costs.
- Inflation rate: A measure of how fast a currency loses its value. That is, the inflation rate measures how fast prices for goods and services rise over time, or how much less one unit of currency buys now compared to one unit of currency at a given time in the past. For Puerto Rico the inflation rate was 1% percent in 2014 when the load data was collected (Trading Economics).
- Annual capacity shortage: A capacity shortage is a shortfall that occurs between the required operating capacity and the actual amount of operating capacity the system can provide.
- Project life time (years): This will be the period of years for which the economic and financial variables will be calculated such as Net Present Cost (NPC) & Return of Investment (ROI).

The map rectangle to the right is a zone locator. Putting the map cursor where your renewable energy system will be installed HOMER PRO automatically connect via internet with the National Renewable Energy Lab and gathers data for the location such as solar irradiance and average wind speed, taking them into account in the simulation. At the left column of the window, the system schematic will be shown. Since the system has not been defined, we can observe the buttons of Take a Tour and Start Wizard. Take a Tour will guide the user through the basics of the software.

8.1.1 Start Wizard

Start Wizard will pop up a series of windows for beginners asking the basic components of a renewable energy system as seen on Figure 24.

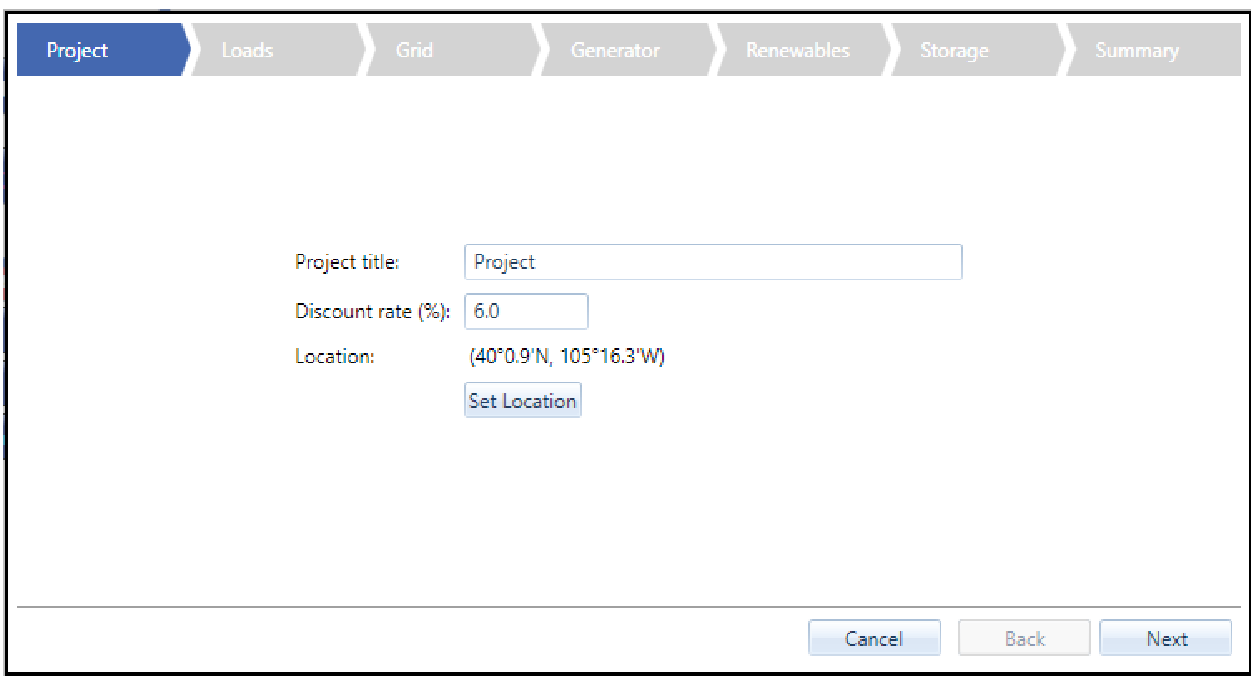


FIGURE 24 - PROJECT WINDOW

In Figure 24 we enter the Project title, discount rate and location.

In Figure 25 it shows how to enter the average daily load, indicate if there is a peak month and choose between a preset of possible load profiles.

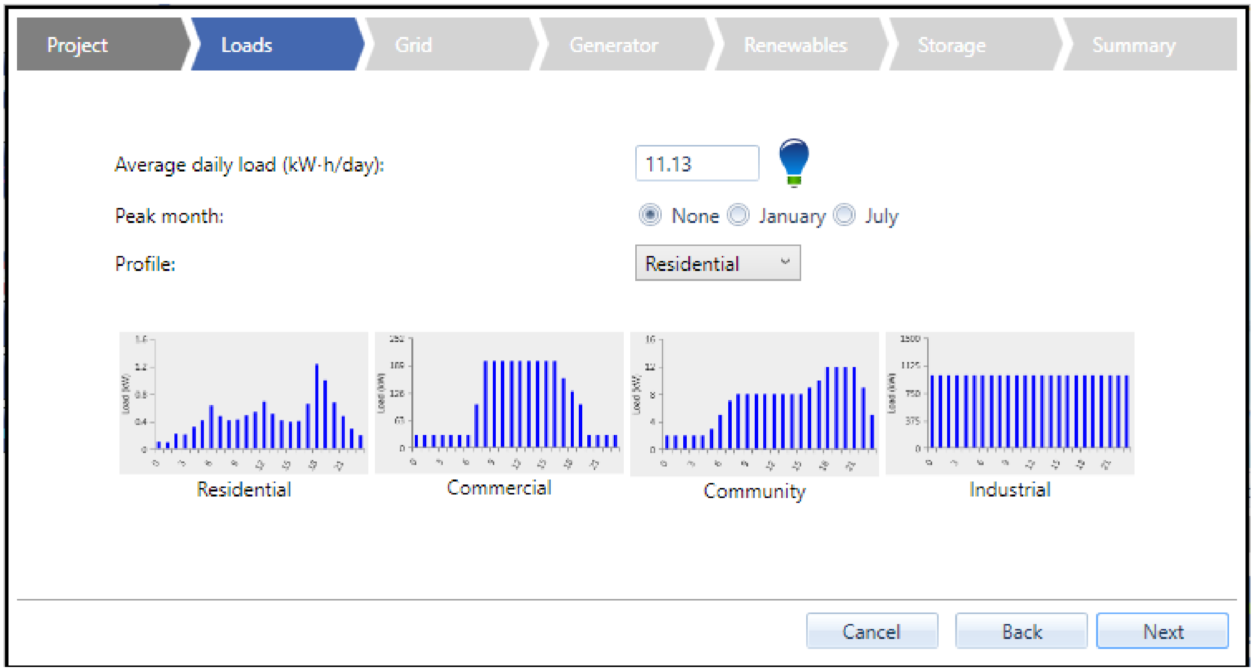


FIGURE 25 - LOAD WINDOW

In Figure 26 we can HOMER weather or not we are connected to the power grid, indicate price of energy in cents by kW-h and the rate at which excess energy can be sold back to the grid by net metering.

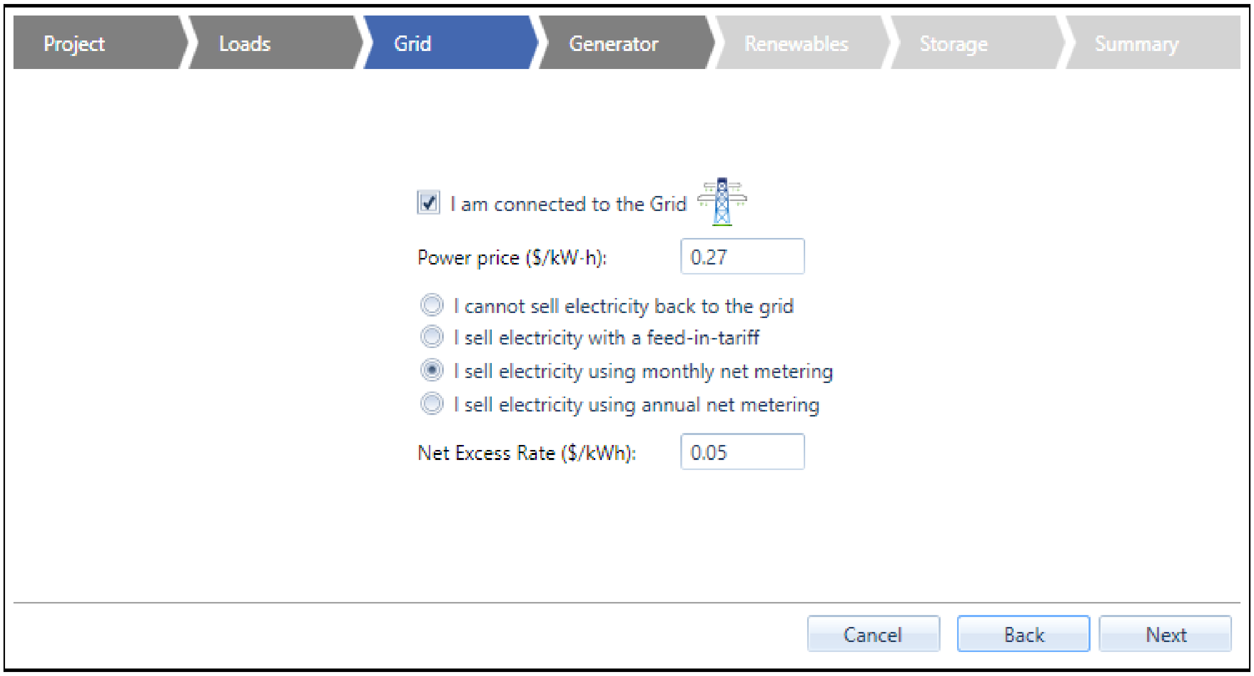


FIGURE 26 - GRID WINDOW

In Figure 27 we can enter the generator cost and the cost of the fuel that is going to be consumed by it. Generators were not considered for these simulations. HOMER includes this as a fixed component because it considers all combinations of systems with or without generator, finding the most feasible array.

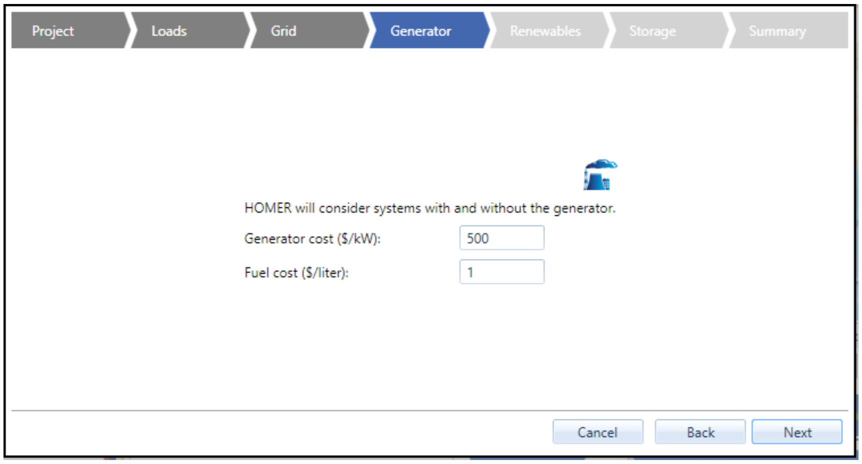


FIGURE 27 - GENERATOR WINDOW

In Figure 28 we indicate which renewable component we are going to use for the simulation and their cost.

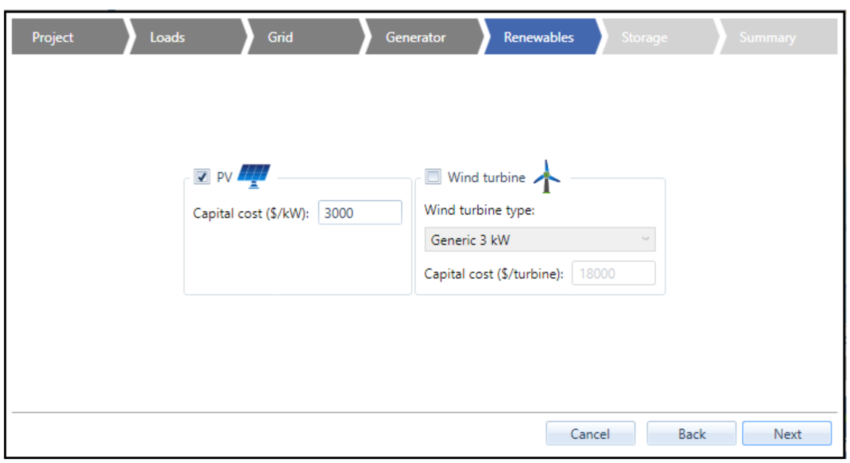


FIGURE 28 - RENEWABLE WINDOW

In Figure 29 we can choose if we want to add batteries to the system. HOMER PRO has a built in database of brands with specifications for all components and additionally allows to add and save a custom component to the library for later reuse.

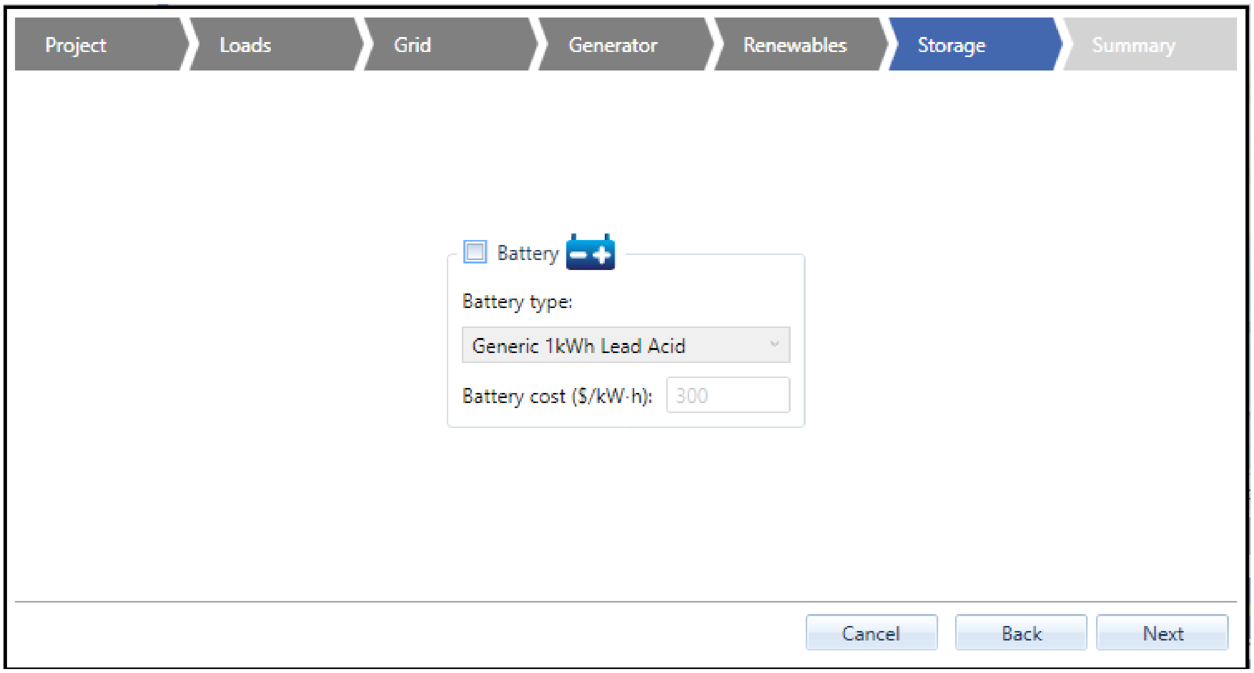


FIGURE 29 - STORAGE WINDOW

In Figure 30 we can revise all the information that was entered regarding the schematic of the simulation. After verification we can hit calculate and obtain optimization results from HOMER PRO.

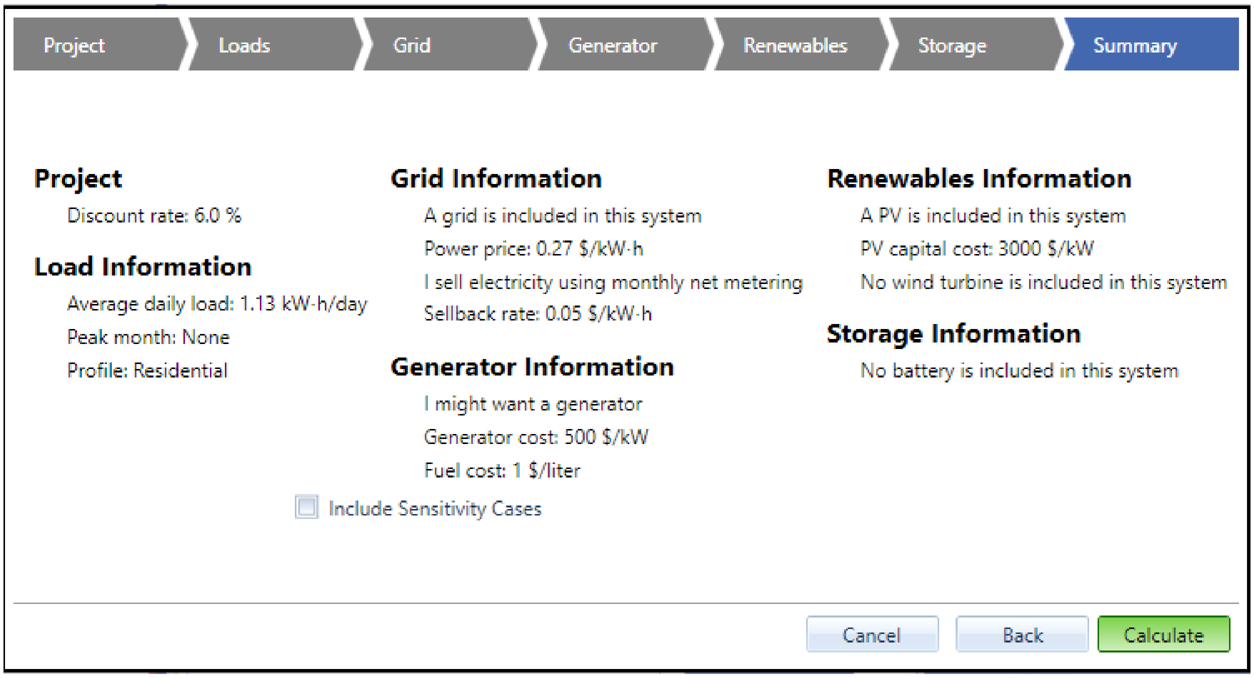


FIGURE 30 - SUMMARY WINDOW

8.2 Manual Entry of Components

Besides running the wizard there is also the manual way. Experienced users can just determine by themselves the components their systems need and run the simulation.

8.2.1 System Load Ribbon

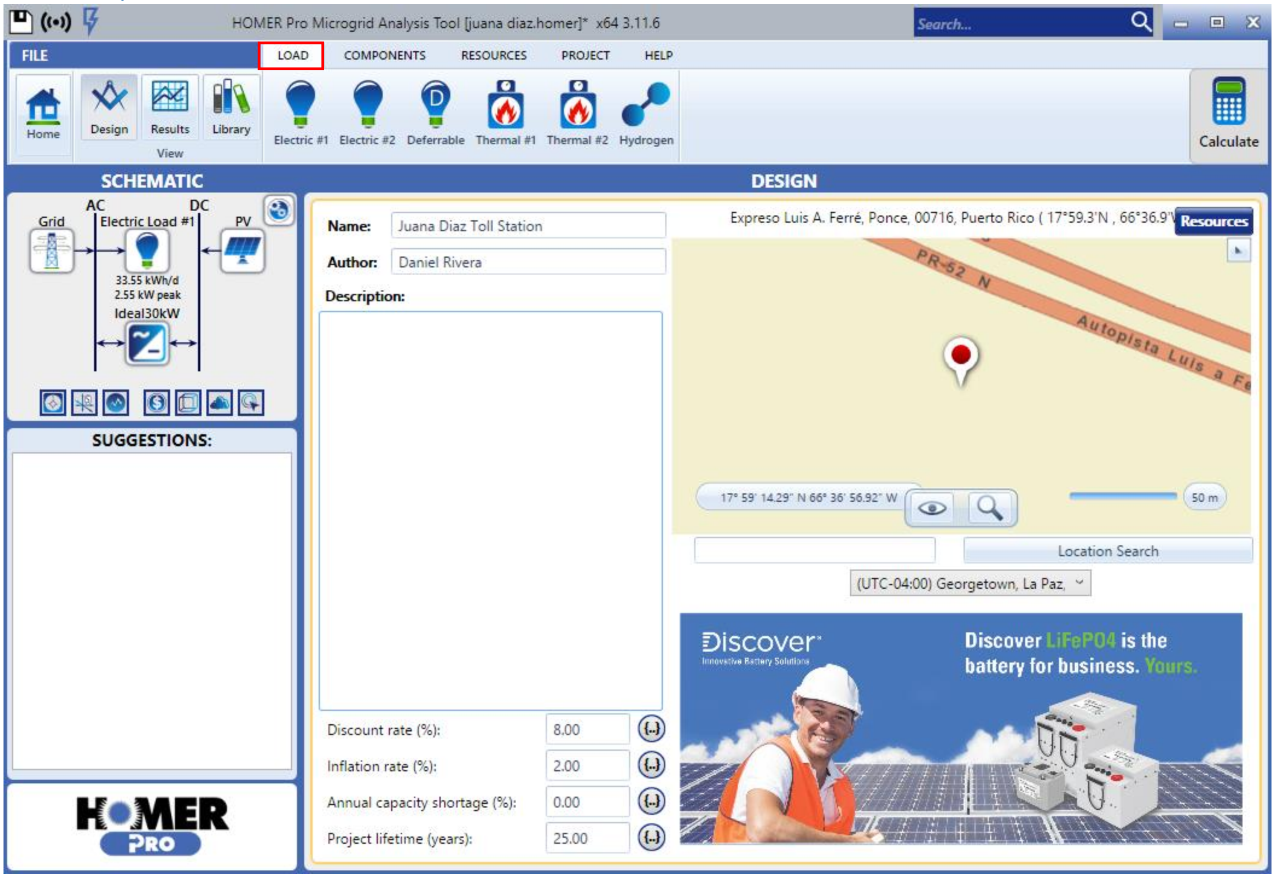


FIGURE 31 - LOAD RIBBON

For the toll station simulations the only load is electrical but HOMER Pro can also include Deferrable loads, Thermal loads and Hydrogen loads as seen on Figure 31. We can analyze 2 separate load profiles for the same system but we only need one. By clicking on electric load # 1 as seen on Figure 32 the load profile window will appear allowing access to enter load values. We can observe graphs such as daily, seasonal (monthly), and yearly profiles. By pressing the “show all month” profile a new window will appear in which we can input data for the whole year as shown in Figure 32. To simplify the analysis we distributed the daily load evenly among the 24 hours since peak load analysis requires specialized equipment and measurement for long periods of time.

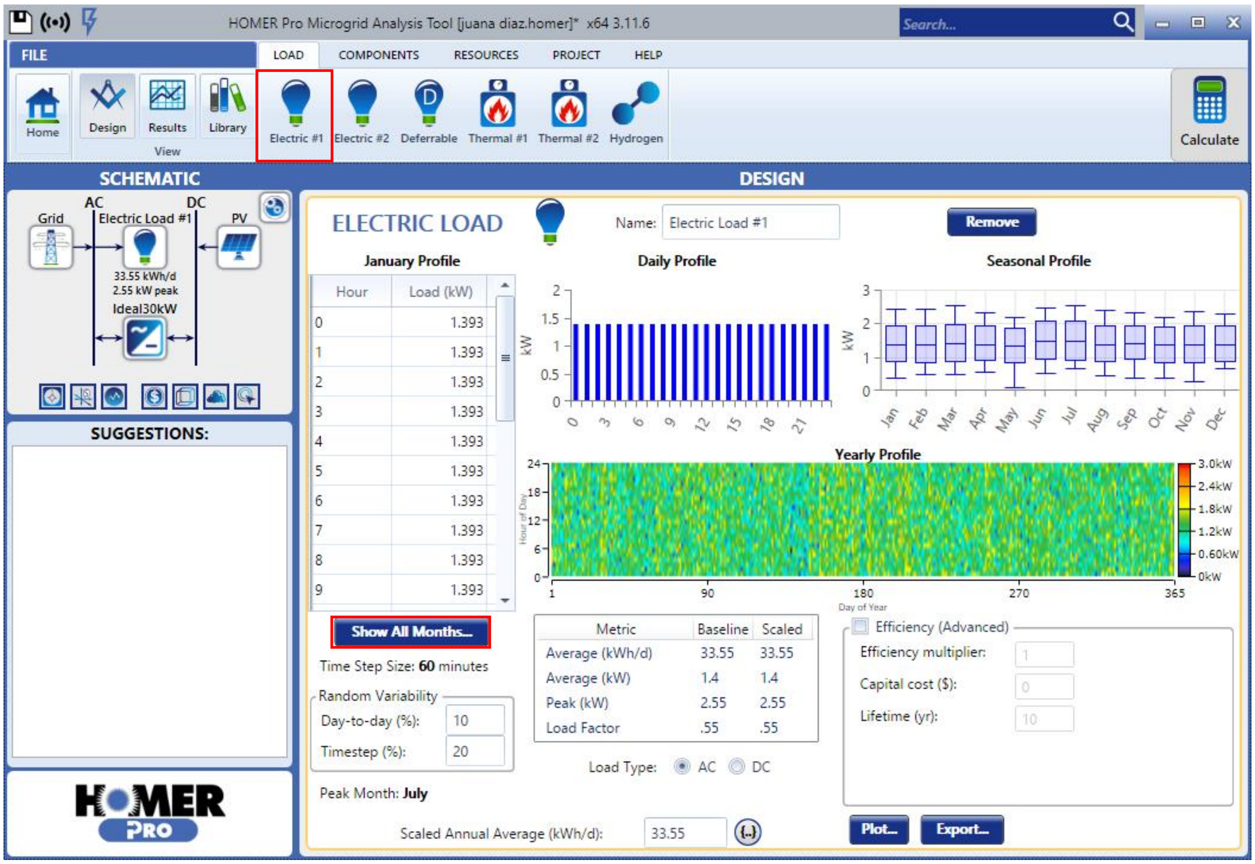
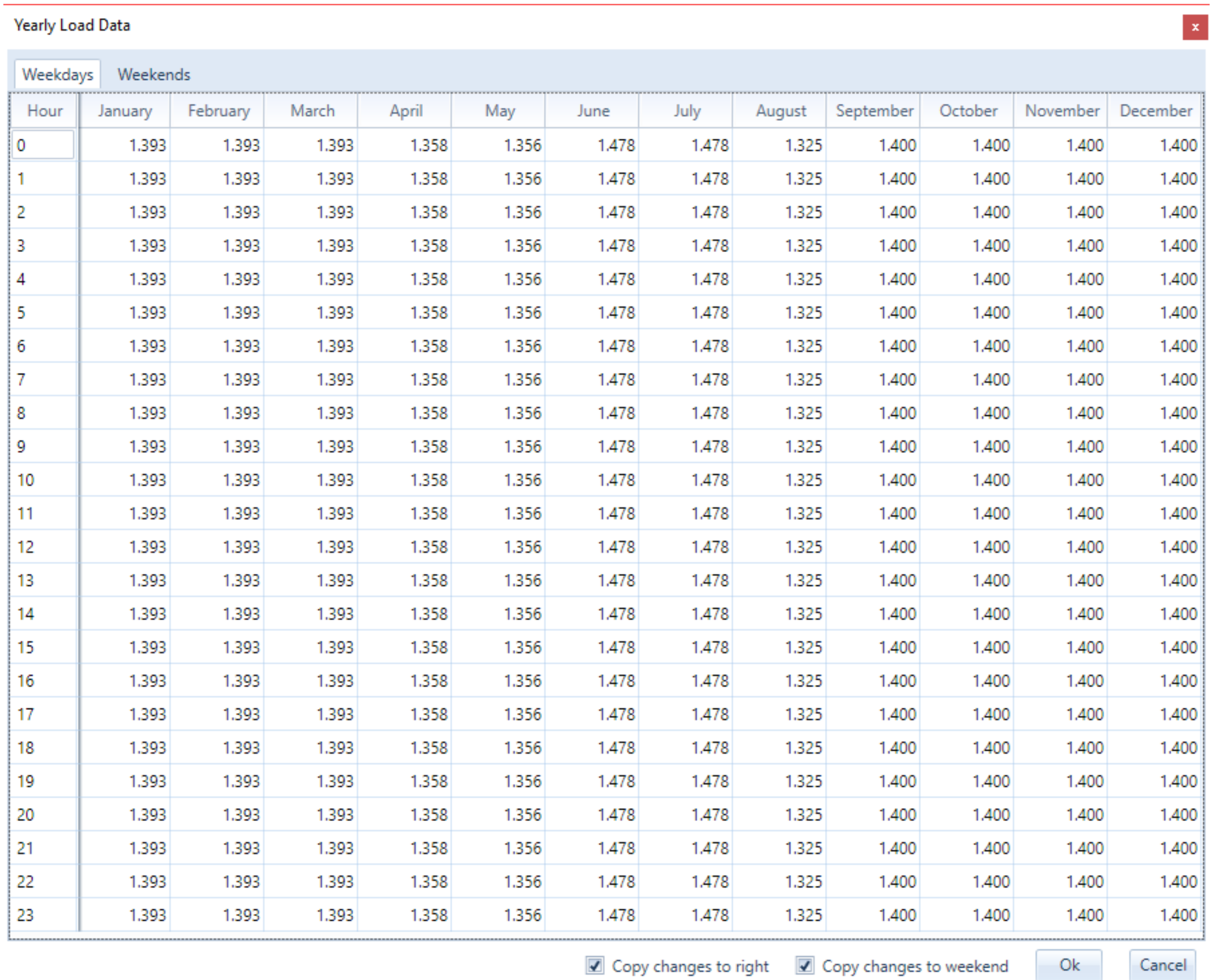


Figure 32 - Electric Load Profile

In Figure 33 we can observe an example of a complete year load for all hours on the day. There is an option to enter a different load for weekends as this can vary depending on the user. An example of this is a business operating on week days and have the offices closed during the weekend has a lower weekend load while a household in which most members either work or go to school during the week have a higher weekend load where the entire household is there all day long.



Hour	January	February	March	April	May	June	July	August	September	October	November	December
0	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
1	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
2	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
3	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
4	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
5	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
6	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
7	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
8	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
9	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
10	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
11	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
12	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
13	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
14	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
15	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
16	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
17	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
18	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
19	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
20	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
21	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
22	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
23	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400

FIGURE 33 - YEARLY LOAD INPUT

8.2.2 Components Ribbon

Opening the components ribbon we can see all the components available to add to the renewable energy system as shown on Figure 34.

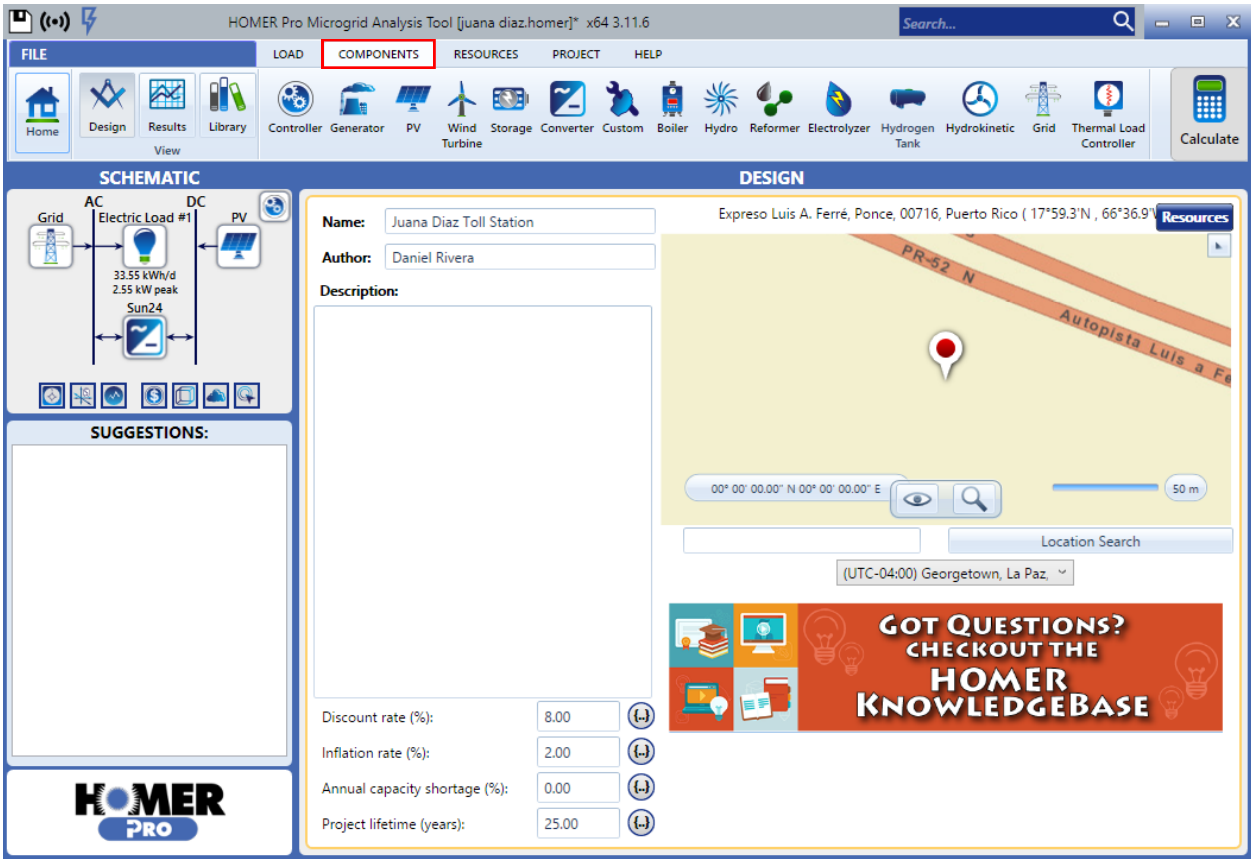


Figure 34 - Component Ribbon

The basic ones are the controllers, generators, photovoltaic, wind turbine, storage, converter and grid. Advance components in the current version include, boiler, hydro, reformer, electrolyzer, hydrogen tank, hydrokinetic and thermal load. Most of the advanced components require additional licenses in order to use them.

8.2.2.1 Grid Component

When we have an interconnected renewable energy system connected to the grid we add this component.

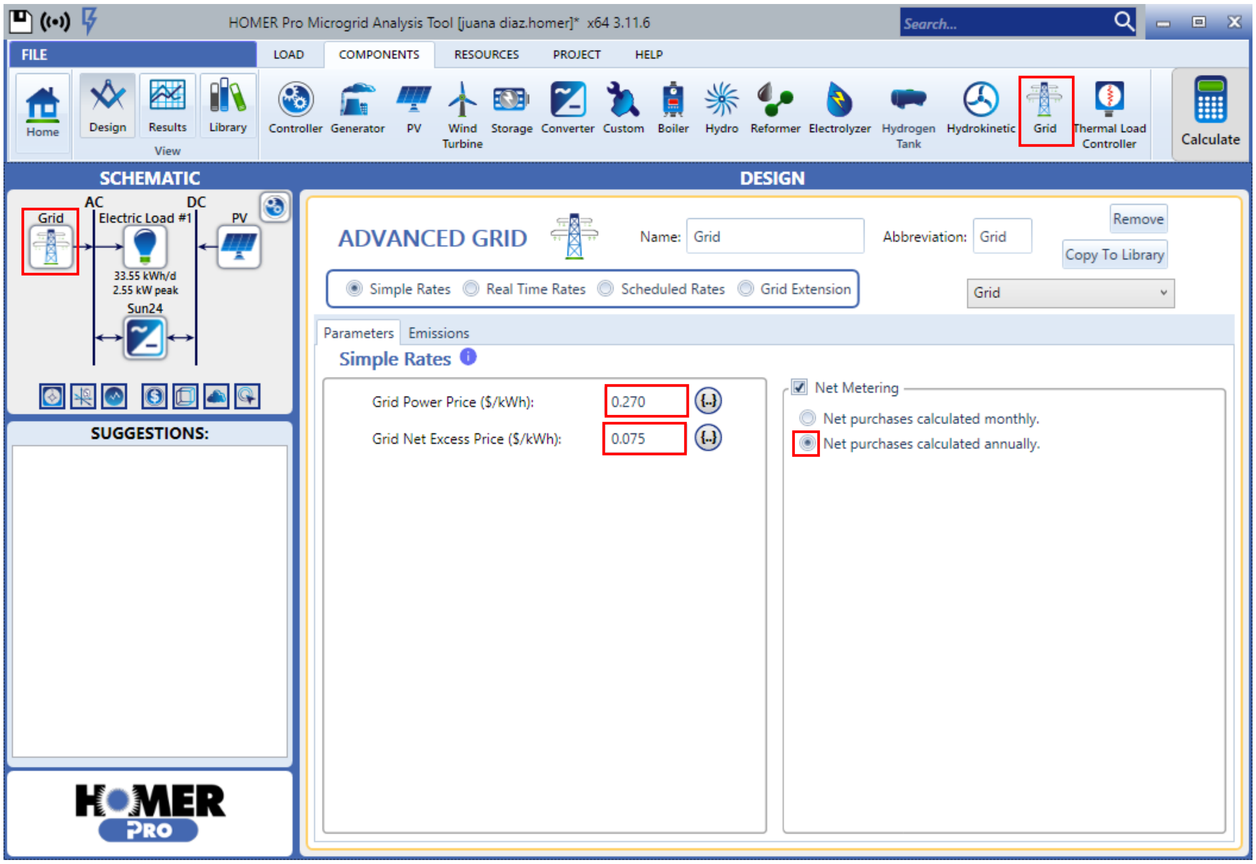


FIGURE 35 - GRID COMPONENT

When we click on the grid button, a grid icon will appear in the schematic as shown on Figure 35. In order to be able to sell back excess energy produce by the system to the grid we select the net metering checkbox to the right and select *Net purchases calculated annually*, this is the option that applies to the system in evaluation since in Puerto Rico it is legislated as so. We can enter the price per kilowatt-hour in the top blank box which is 0.27$/kW-hr in Puerto Rico for commercial users such as the toll stations. This is a sensitivity variable and several prices can be compared at once. We can also enter the rate at which we can sell back to the grid which for this study will be $0.075/kW-hr as stated in PREPAS Rule Book for Interconnecting Energy Generators with the Grid Distribution System and Participate on Net Metering Program.

8.2.2.2 Converter Component

By clicking the converter component, the following window will appear as shown on Figure 36. We can select an inverter on the list that comes with HOMER Pro or we can add our own. We can also select complete catalog and download more options. If we have a predetermined photovoltaic array size then we have to choose search space option. In here we include a 0 for the analysis to have a base case scenario. With a baseline of no renewable energy system we can compare economics when the results of the simulation are available.

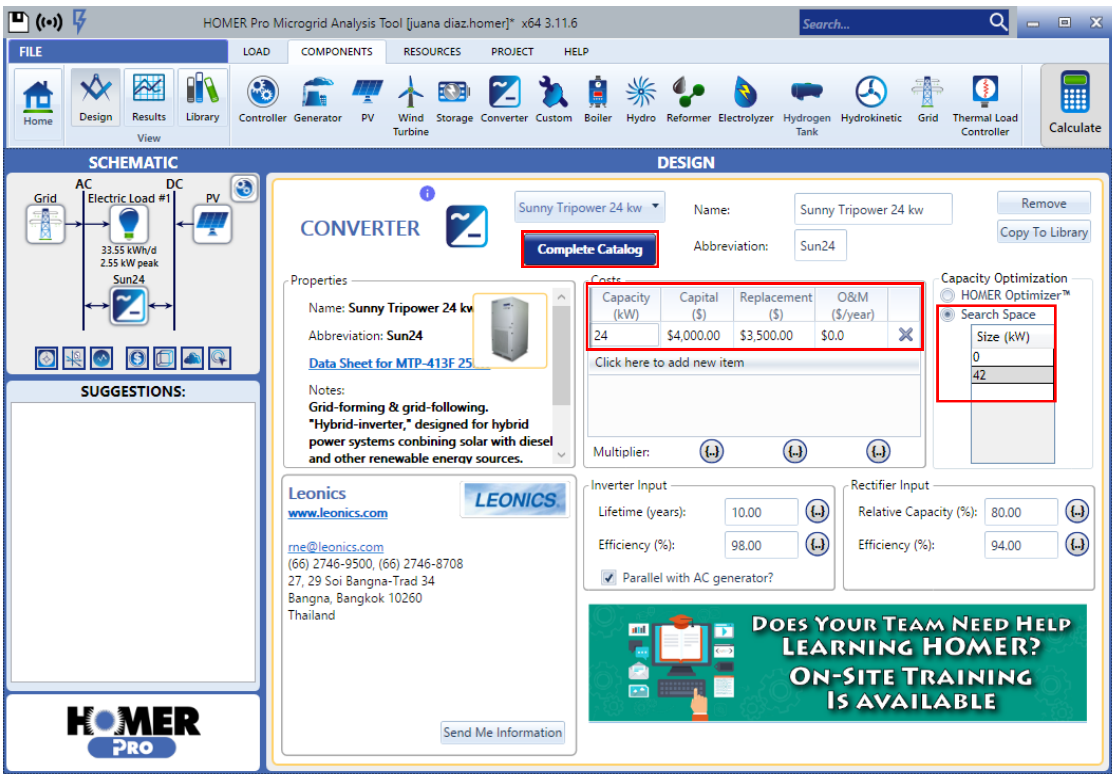


FIGURE 36 - CONVERTER COMPONENT

8.2.2.3 Photovoltaic component

When we select the PV component button the window on Figure 37 will appear.

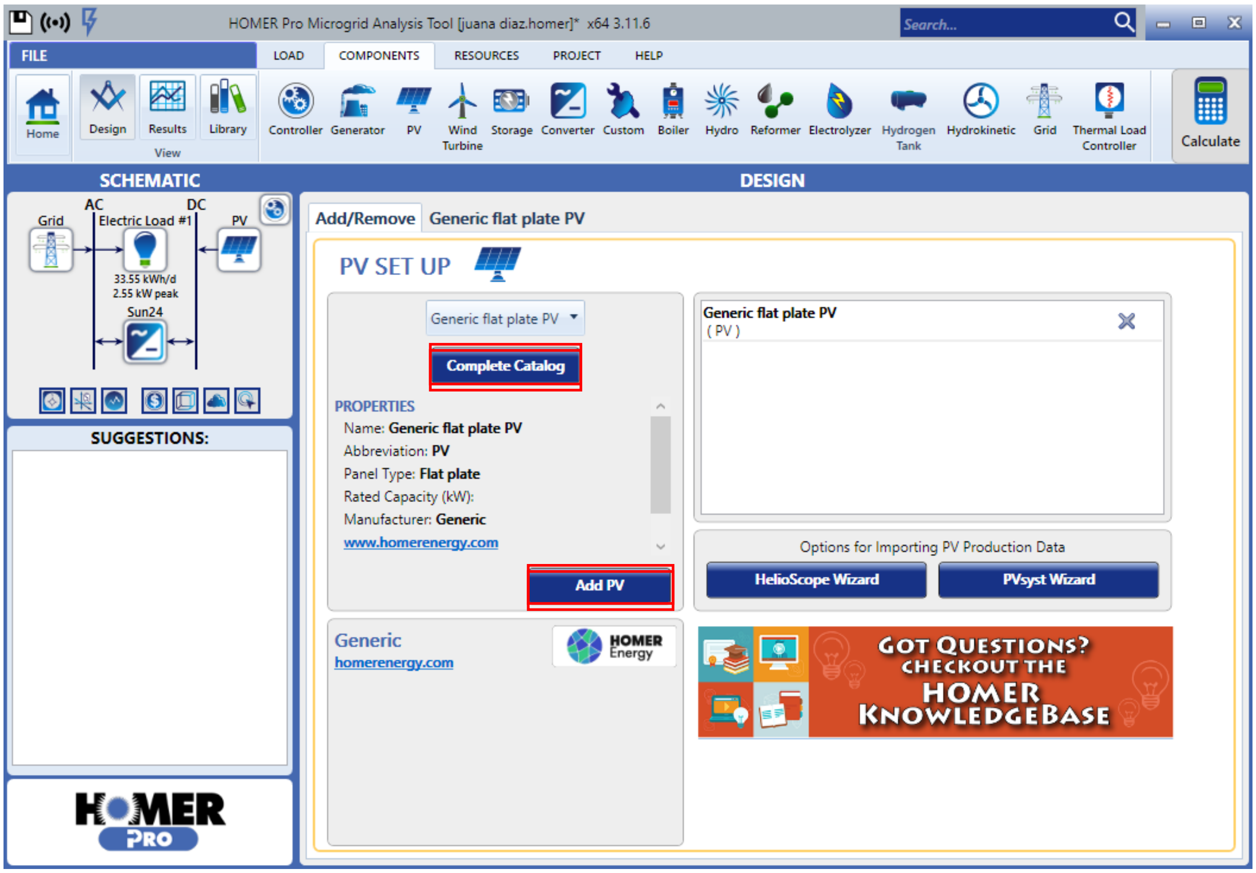


FIGURE 37 - PV COMPONENT SET UP

In this window we can select from a list of panels already included in complete catalog or chose generic to input our own. When we have decided on our selection we click on the add PV button and a new window will appear in which we can enter the prices for the panel similar than with the Converter and a PV icon will appear on the system schematic.

In Figure 38 we show the potential options we can modify using the PV component. This window is similar to the converter one in which we input the capacity of the panel as well as the cost, the replacement cost, the operation and maintenance cost and the replacement time. There are advanced options that take into account tracking system technology which is a motorized mount that follows the sun in order to maintain the most perpendicular angle available at all times. We also choose the search space option if we have a determined photovoltaic array size.

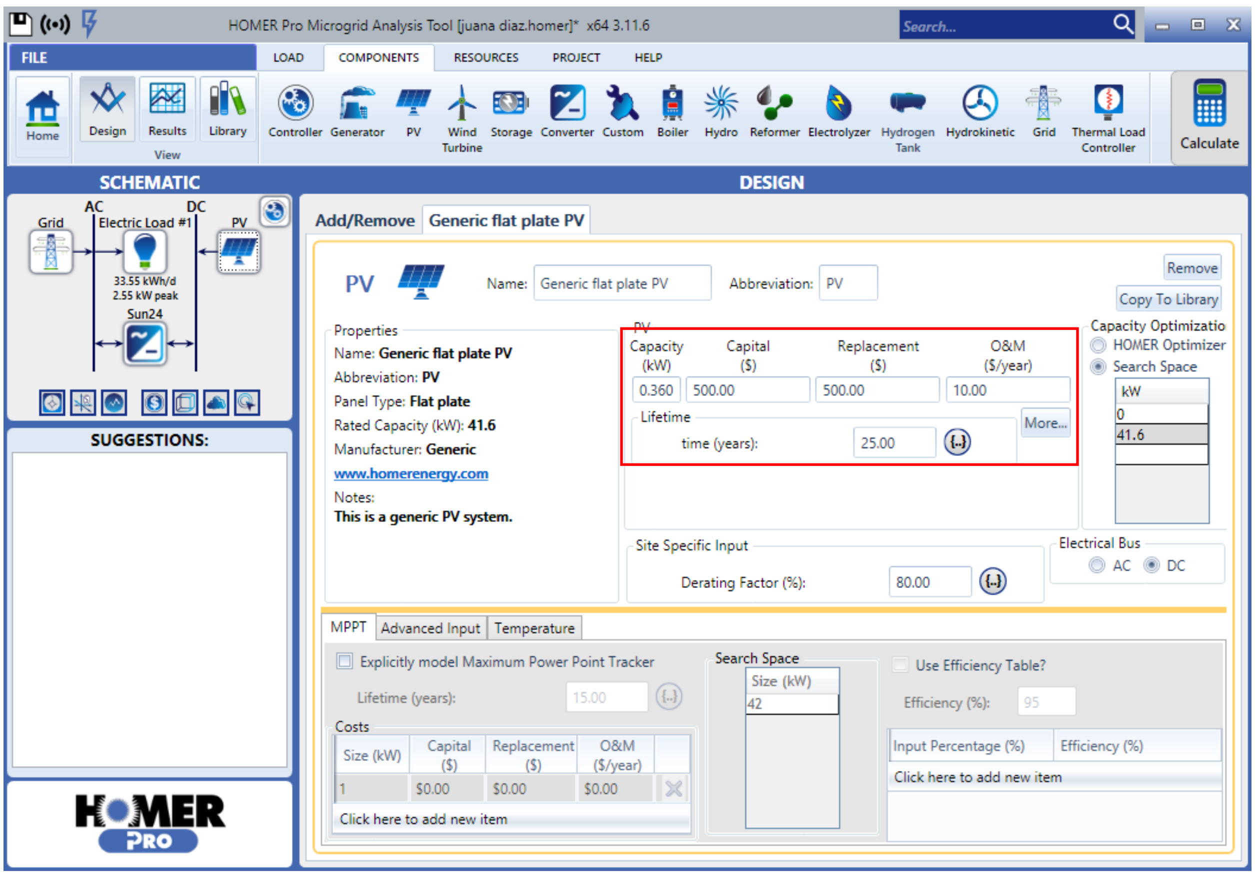


FIGURE 38 - PV COMPONENT

8.2.2.4 Wind turbine component

Very similar to adding a PV array we do so with a wind turbine. By clicking on wind turbine a window like in Figure 39 will appear where we see the complete catalog and add wind turbine button.

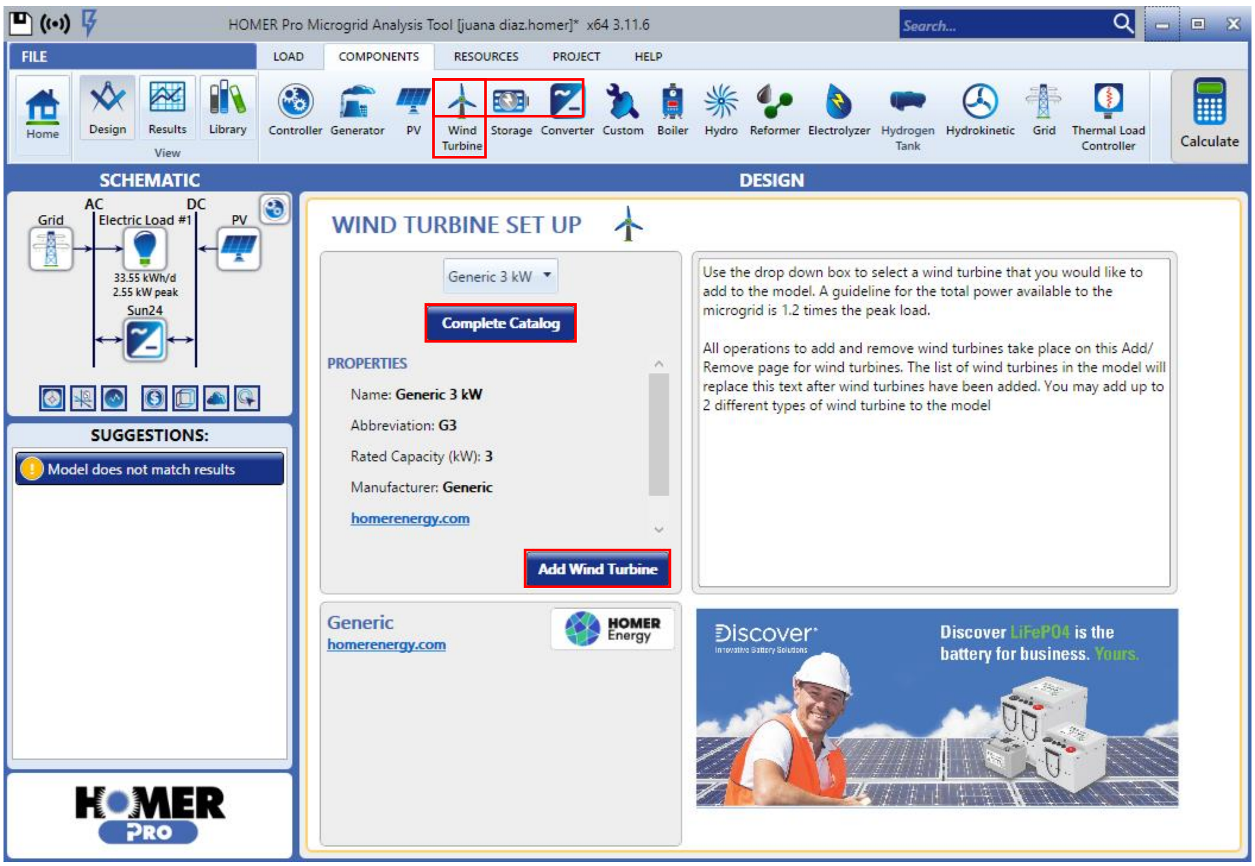


FIGURE 39 - WIND TURBINE SET UP

After pressing add the window will change to the one on Figure 40.

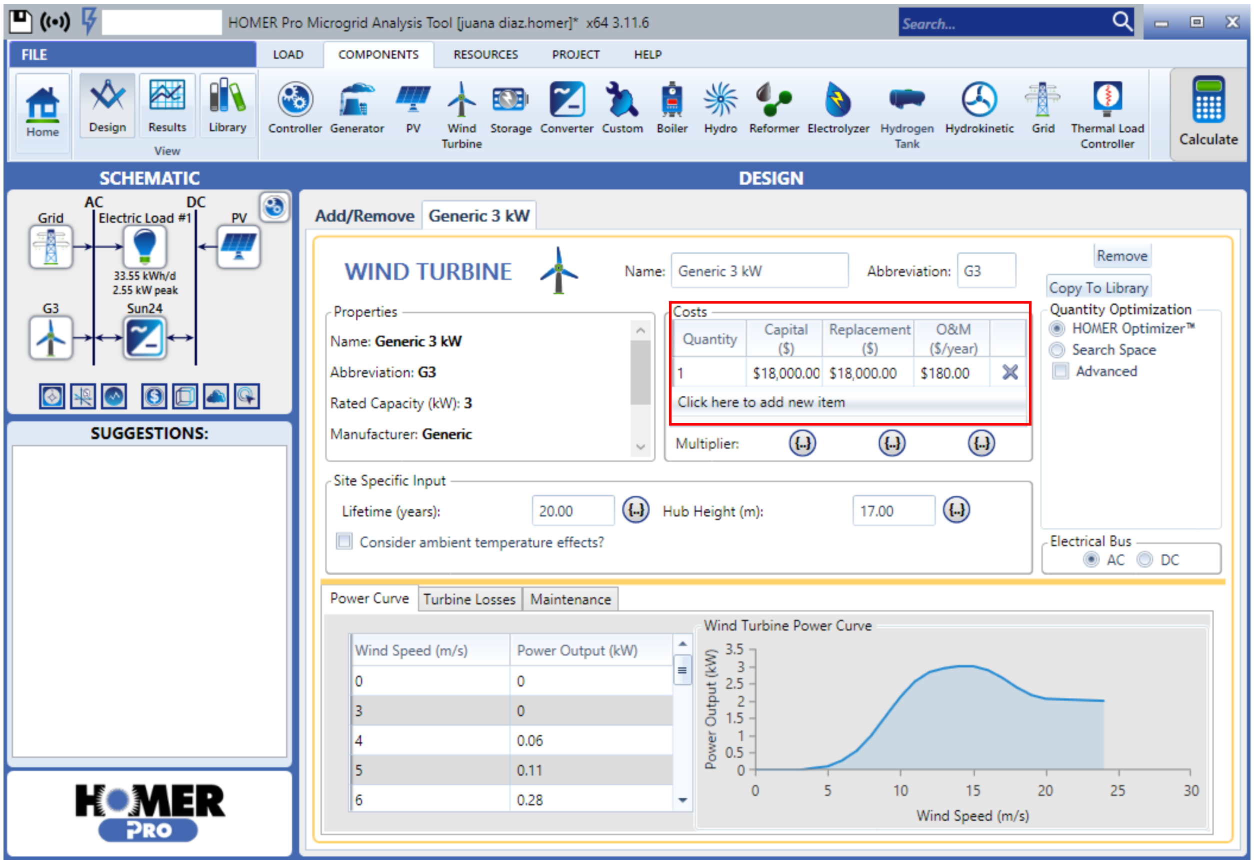


FIGURE 40 - WIND TURBINE COMPONENT

On this window we can make similar changes like in the PV and converter windows but here we can observe the power curve graph. Wind turbines are not being considered for the toll stations.

8.2.2.5 Storage component

The storage component to be used are batteries. When we select the storage icon a window like the one below on Figure 41 will appear.

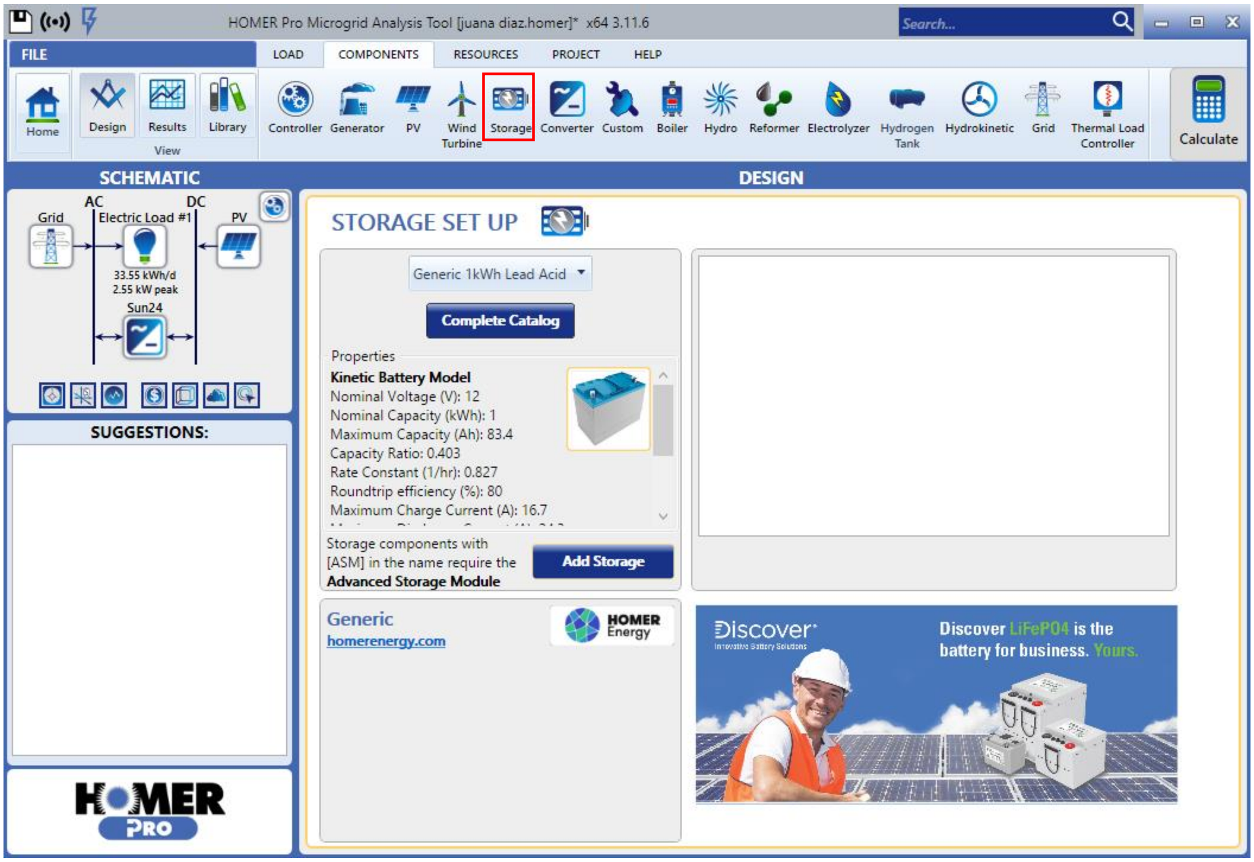


FIGURE 41 - STORAGE SET UP

After choosing from the catalog or creating a battery we press the add storage button and a new window like the one on Figure 42 will appear. In this new window we can observe we have slight different required inputs boxes such as battery quantity and string value. The string size is the amount of batteries that will be connected in series.

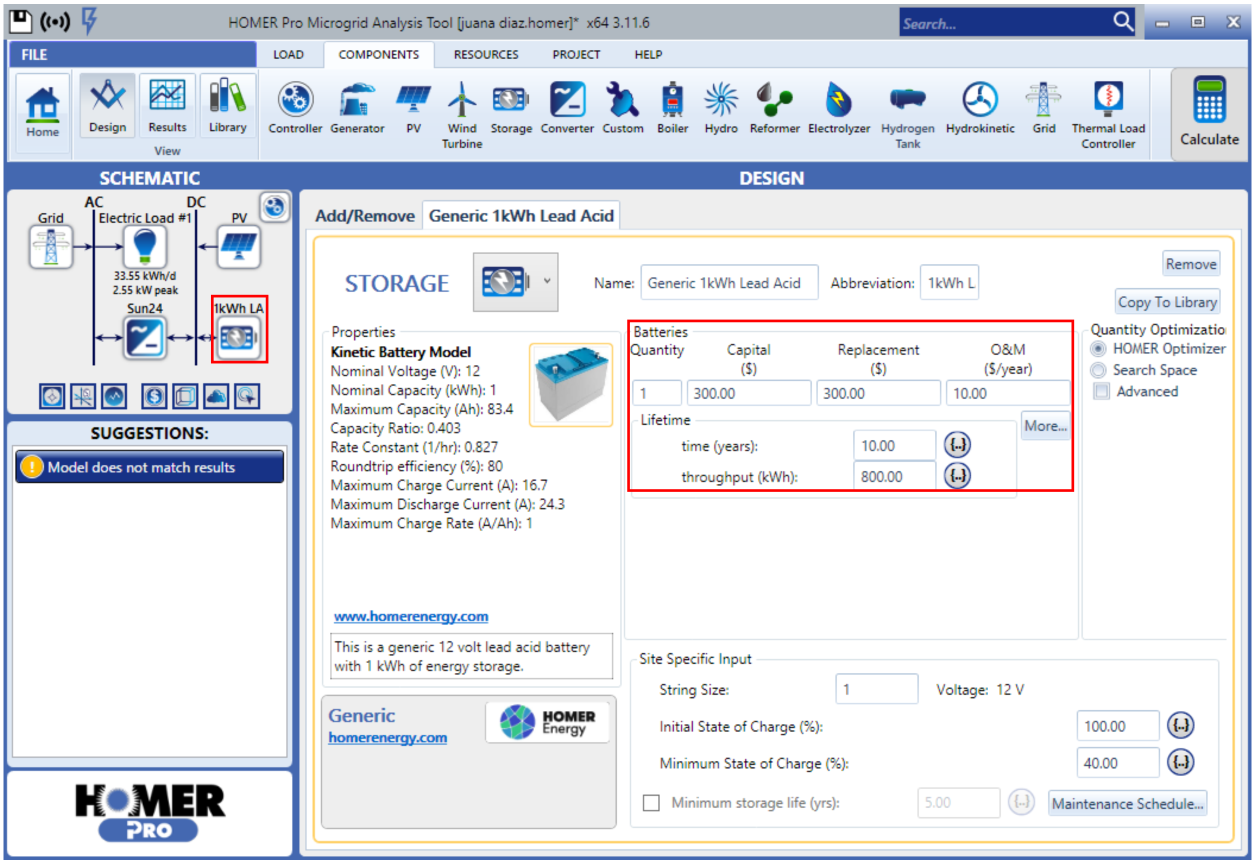


FIGURE 42 - STORAGE COMPONENT

8.2.2.6 Controller component

Selecting the controller component will open the window shown on Figure 43. Here we can choose between 2 main options which are Cycle Charging or Load following, both refer to how a generator operates at full capacity and uses surplus energy to charge the storage or operate only as required to supply the load required and leaves low priority objectives such as charging the storage strictly to the renewable part of the system. For the simulations to be performed we will not be taking into account generators so the choice is not relevant.

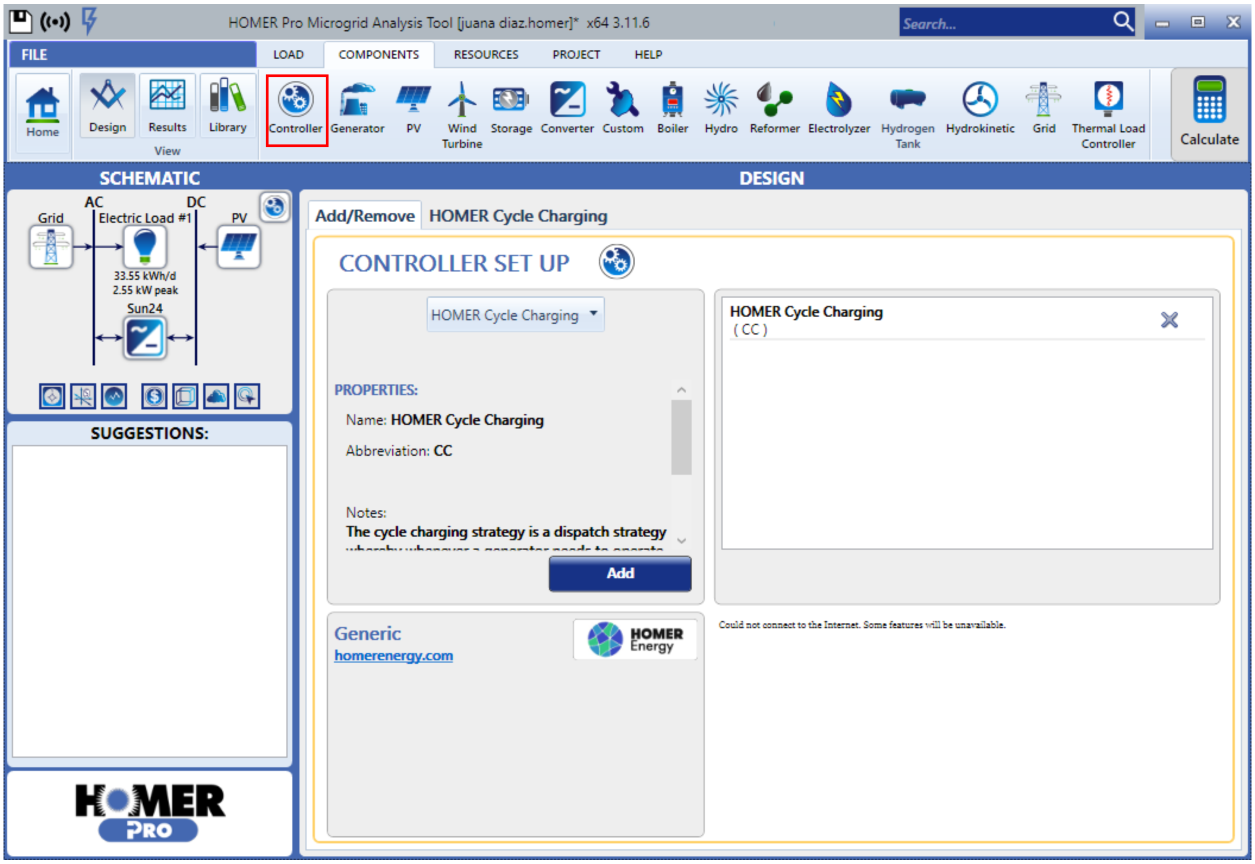


FIGURE 43 - CONTROLLER SET UP

In order for the simulation to run, we still need to add a controller. By pressing the add button the window on Figure 44 will appear. As stated previously, a generator will not be considered for the toll station simulation, because of this we can leave the default values as they are.

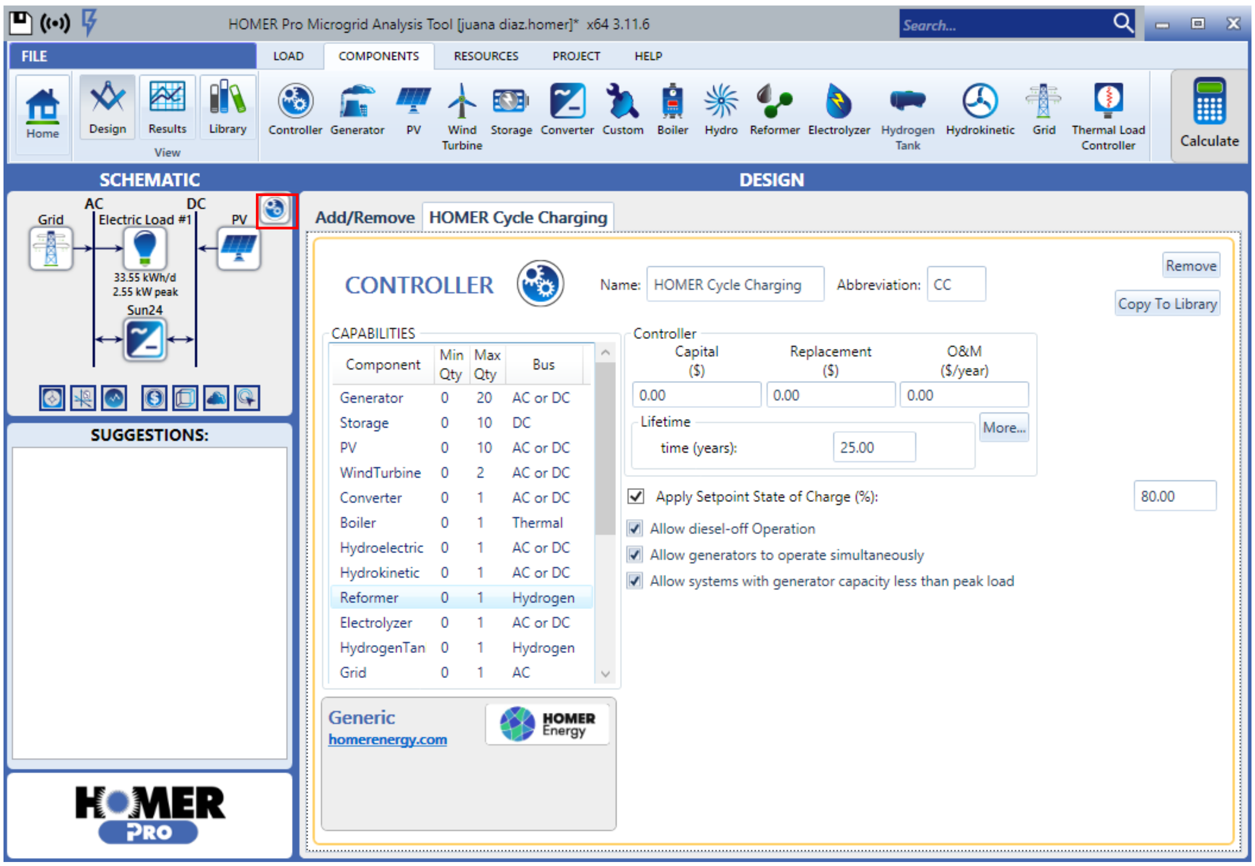


FIGURE 44 - CONTROLLER COMPONENT

8.2.3 Resource ribbon

The third ribbon in the HOMER Pro software is the Resource ribbon. The most common resources are solar and wind. Other resources such as temperature, hydrokinetic and biomass are part of an advanced license of HOMER Pro and the simulations performed on this analysis will not include components requiring such resources.

8.2.3.1 Solar GHI Resource

When pressing the first available component the following window on Figure 45 will appear.

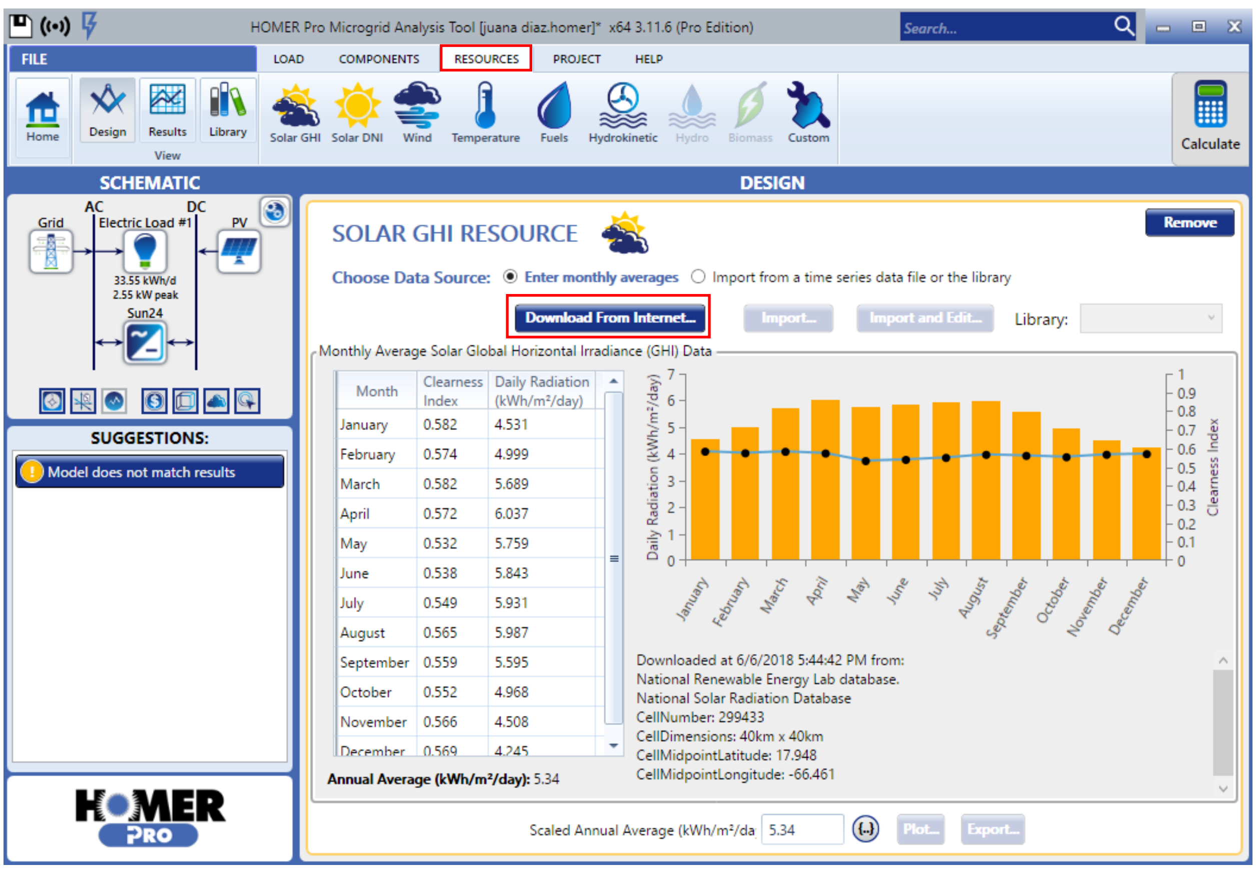


Figure 45 Solar Resource - Global Horizontal Radiation

GHI stands for global horizontal irradiation which is the sum of beam radiation (also called Direct Normal Irradiance or DNI), diffuse irradiance, and ground-reflected radiation. We can observe these in Figure 46.

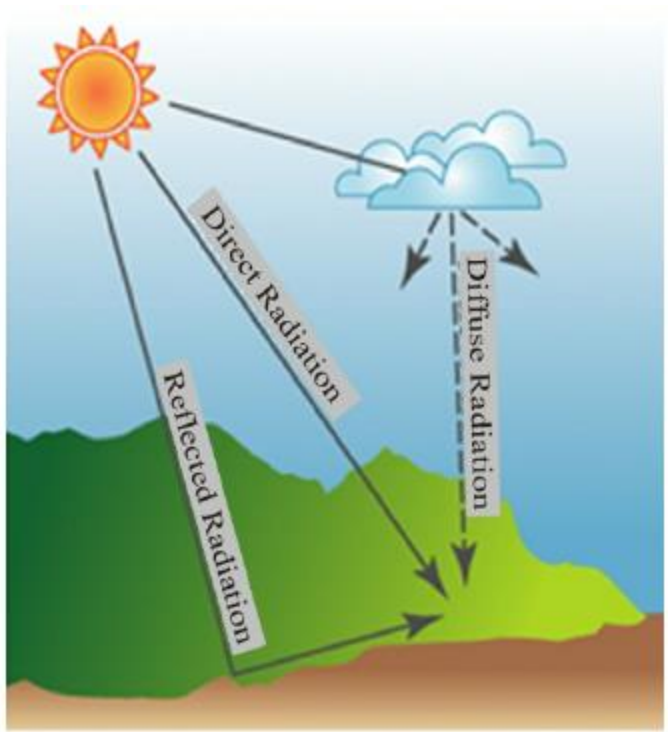


FIGURE 46 - SOLAR RADIATION TYPES

After selecting our location on the map we can simply press the download from internet button and the calculations will take into account specific solar irradiance.

8.2.3.2 Wind resource

Wind resource window works very similar to the solar GHI one. After specifying our location on the map, pressing the download from the internet button will gather the average wind speed at the location for the month as seen on Figure 47.

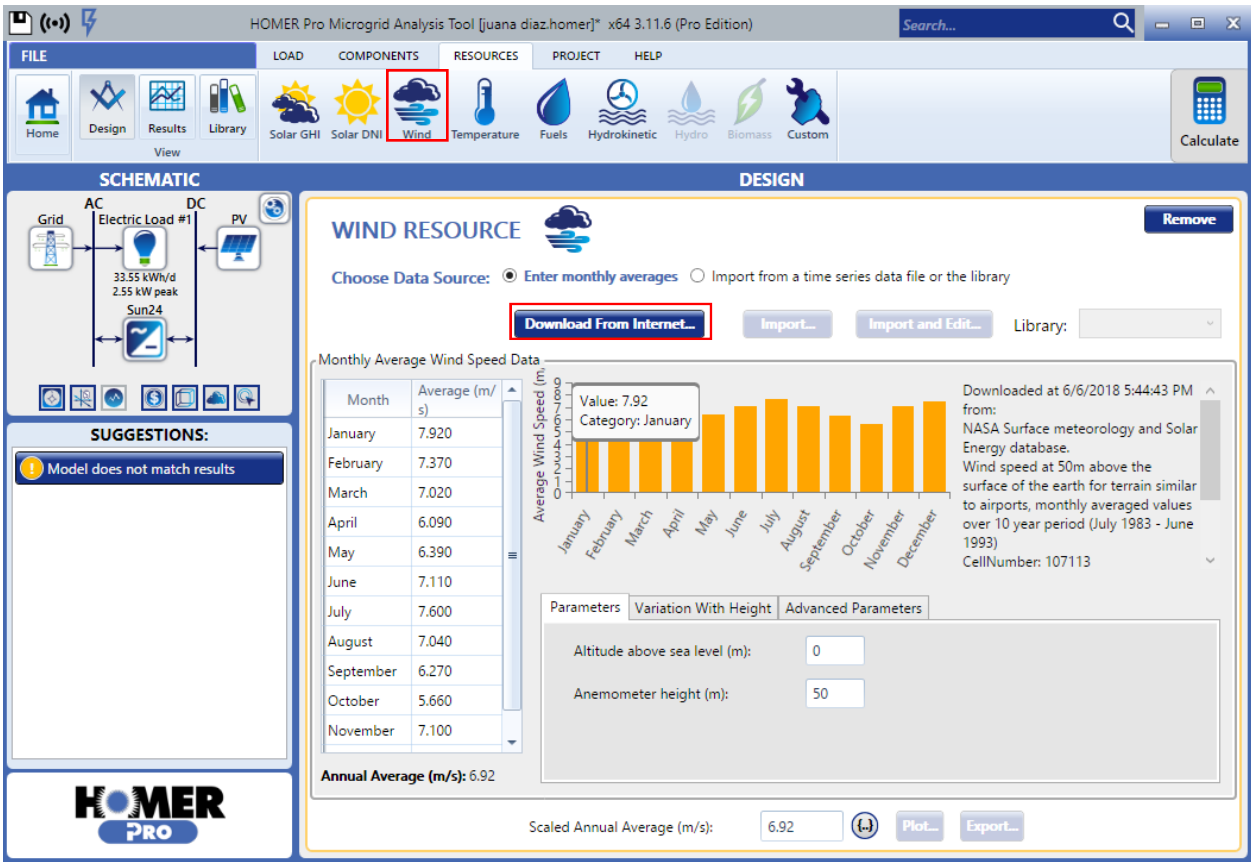


FIGURE 47 - WIND RESOURCE DATA GATHERING

8.2.4 Project ribbon

In here we can observe various aspects of the project implementation side of things. As shown on Figure 48.

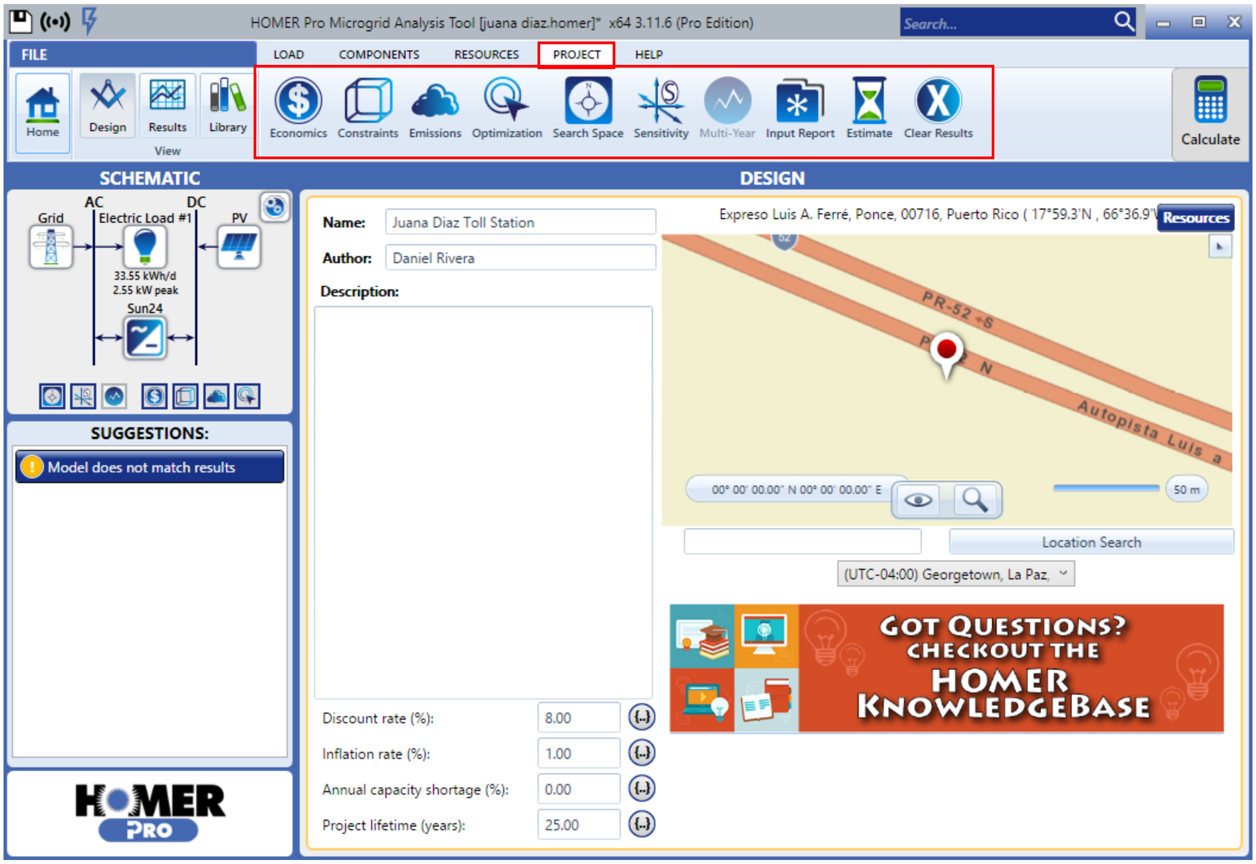


FIGURE 48 - PROJECT RIBBON

8.2.4.1 Economics

HOMER includes an input window where the user can alter variables such as the interest rate and the life cycle of the project as shown on Figure 49. Choosing a period of 25 years for the simulation is recommended as widening the time period of project life cycle might not represent truthful results as technology advances and prices change over time.

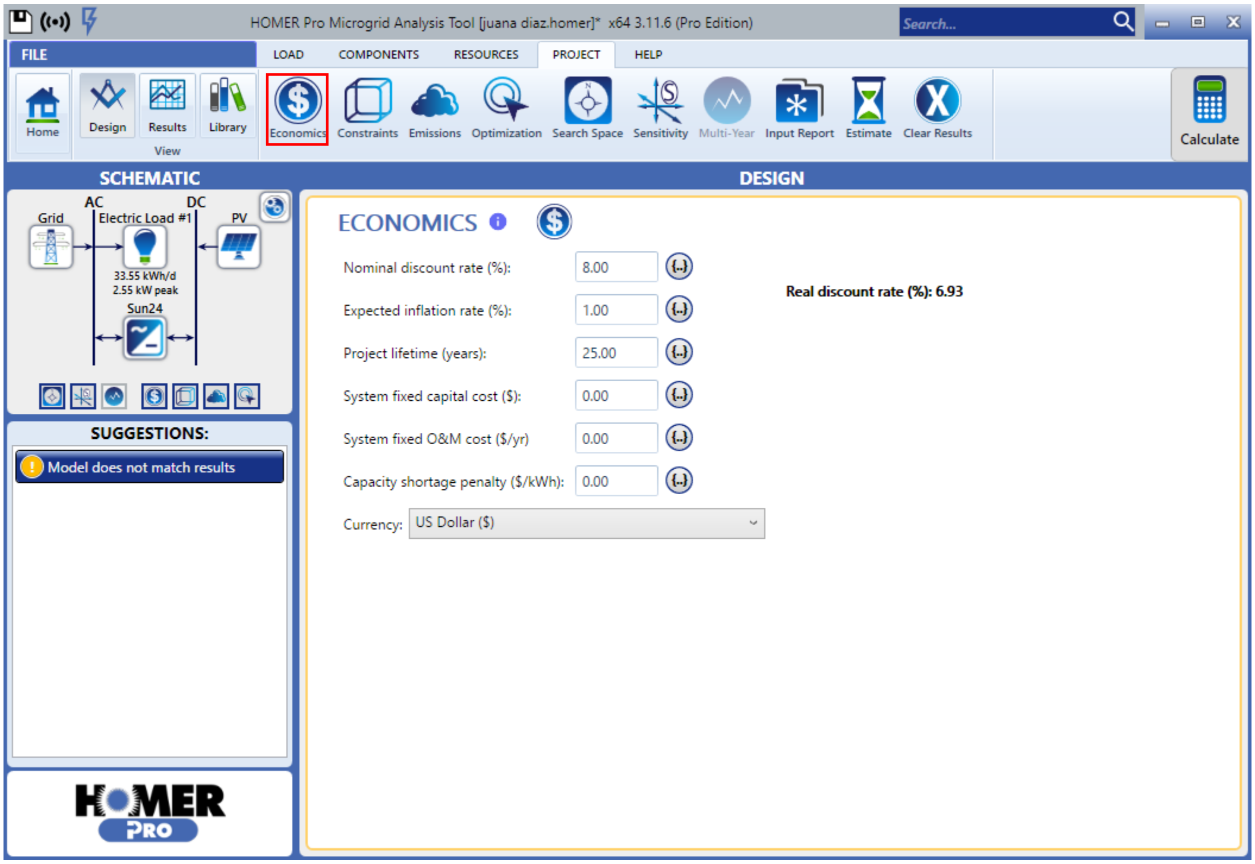


Figure 49 - Project Economics

If the project has a running generator using fuel then a carbon footprint will be produce. In this section we can add fines for producing too much CO_2 among other impurities.

8.2.4.2 Emissions

In project emissions we can add penalties for carbon monoxide production and other impurities. This will happen if the system includes a generator dependent of fossil fuel we can see the emission window on Figure 50.

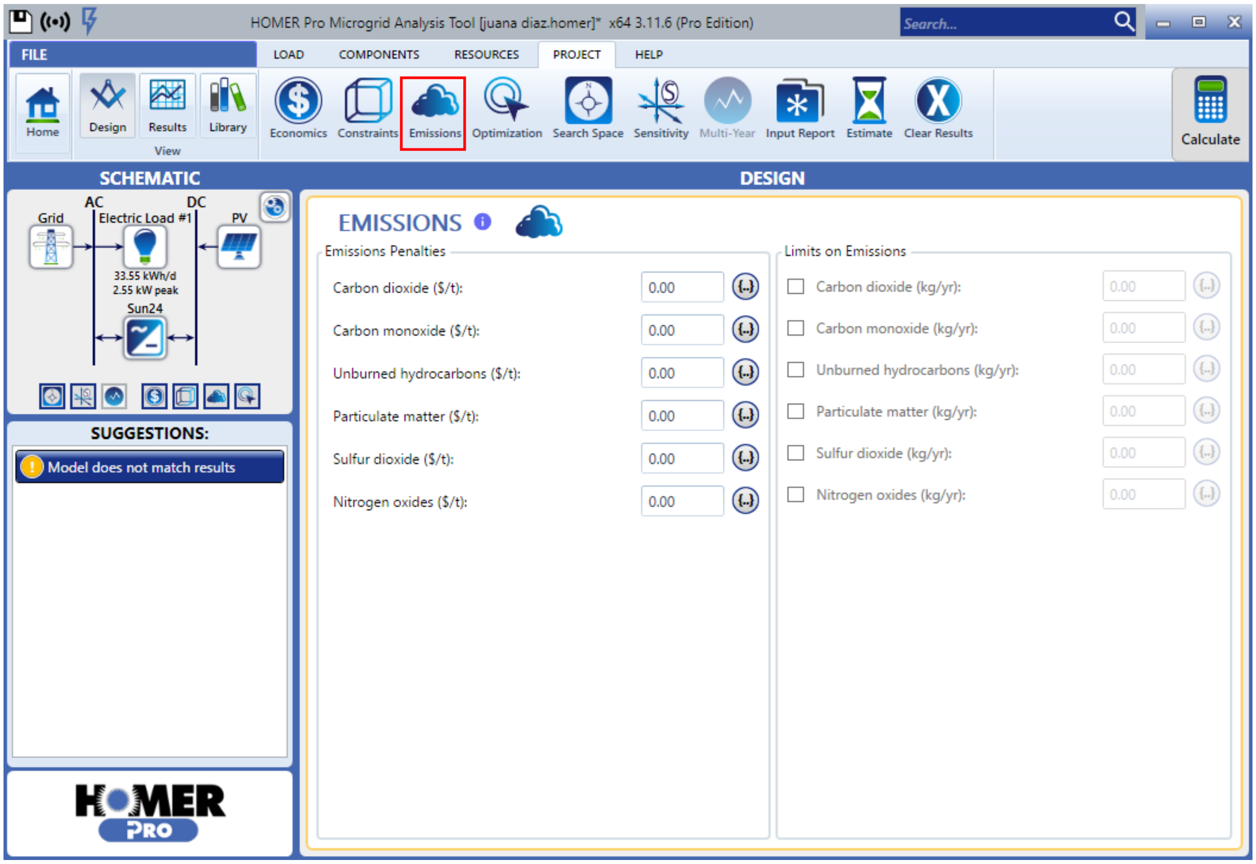


FIGURE 50 - EMISSION WINDOW

8.3 PV Array Simulation

Now that we know the steps necessary to use the HOMER Pro program we proceed to enter the data for each toll station and run the simulation for each one in order to perform the rating system scoring. A similar location with a PV array already installed was visited. This was the "Hospital de Veterano" in Mayagüez which is a LEED Platinum building. This building has a PV array of commercial level which does not run with any batteries only net metering. From this we can see that it is difficult to cover the entire load of commercial buildings and therefore the use of batteries would not be considered. According to Energy Sage, some of the top solar panel manufacturers can be observed in Figure 51.

SunPower vs LG, SolarWorld and other Solar Panel Manufacturers

SOLAR PANEL BRAND	AVERAGE EFFICIENCY (%)	AVERAGE COST ($/WATT)	PRODUCT WARRANTY (YEARS)
SunPower	20.6	3.79	25
LG	18.8	3.39	25
SolarWorld	16.7	3.20	20
Canadian Solar	15.7	3.05	10
Panasonic	19.6	3.26	25

FIGURE 51 - TOP SOLAR PANEL MANUFACTURERS

Due to the fact that we have a limited space, it is in the best interest of the simulation to go with highest efficiency panel as possible. Having a top efficiency is Sunpower, unfortunately they do not operate in Puerto Rico and their panels can't be bought individually. Panasonic is the runner up in efficiency and they are not far behind. "The Japanese electronics giant has become one of the most popular panel brands in the U.S., hitting the "sweet spot" between efficiency and affordability for many homeowners". We have chosen the panel Panasonic VBHN330SA16

330 Watt. This panel has efficiency of 19.7% one of the highest in the market and comes with a 25 year warranty matching that of Sunpower. It has an output decline of 3% on the first year and .26% subsequent years up to 25. This panel's dimensions are of 1590.0 mm in length and 1053.0

mm on width. We can see a physical presentation of the panel on Figure 52. For more information on the panel please refer to appendix A

FIGURE 52 - PANASONIC VBHN330SA16

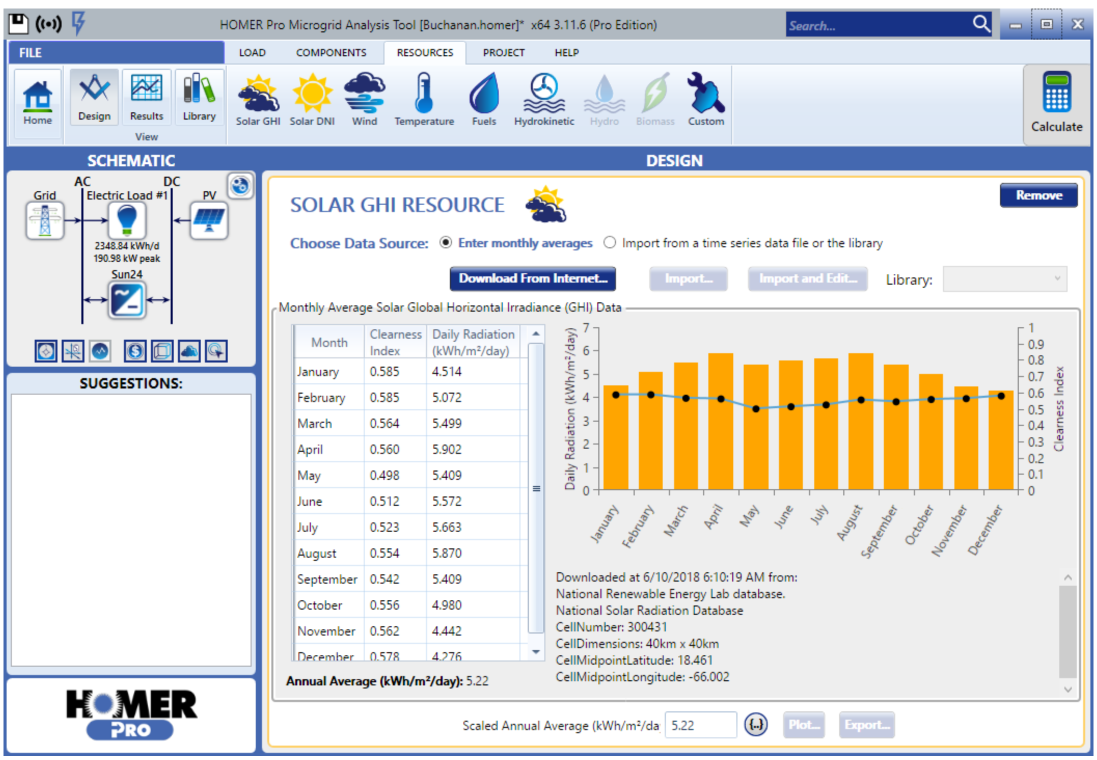
They can be bought for 366.40 dollars from Solaris putting it at 99 cents per watt. For the inverters we have chosen the same brand as the photovoltaic system that the LEED Platinum "Hospital de Veterano" has, the Sunny Tripower 30 kW string converter which can be bought for $5,875.00 from whole sale solar putting it at 20 cents per watt. This is a commercial 3 phase inverter with 98.6% efficiency, detailed specifications can be found in appendix A. In Puerto Rico the local contractors make quick estimates with a cost of 3 dollars for installed watt. The national average for the United States is 3.14 dollar per watt. To be conservative since we are using high end products we are going to distribute the cost per watt between $3.20 dollars. Our panel and inverter together have a cost of 1.19 dollars per watt leaving the panel to 83.19% of the cost. Taking the pondered weight into account out of the $3.20 dollars the installed price for the panel is $2.66 leaving the inverter at $0.54 per watt installed.

8.3.1 Buchanan Toll Station

The Buchanan Toll Station is located in Guaynabo. For this location 4 different areas were taken into consideration for panel installation including the Canopy area and 3 other building. The total area available was 14453.3 square feet for a total of 802 panel that can be installed. This area calculation is very conservative as we leave 2 feet spaces between rows for maintenance purposes and this takes into account panels that cannot be installed due to obstacles like roof equipment. With the amount of panels that we obtained and the power of 330 watt for each panel we can obtain a photovoltaic array of 264.660 kW. With this PV array size we would need 9 30kW converters for a total of 270kW. Proceeding into HOMER PRO we locate the Buchanan Toll Station as shown on Figure 53 below to obtain specific solar irradiance.

FIGURE 53 - BUCHANAN TOLL STATION LOCATION

We can observe a total solar irradiance of 5.22 kWh/m^2/day as seen on Figure 54.



Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.585	4.514
February	0.585	5.072
March	0.564	5.499
April	0.560	5.902
May	0.498	5.409
June	0.512	5.572
July	0.523	5.663
August	0.554	5.870
September	0.542	5.409
October	0.556	4.980
November	0.562	4.442
December	0.578	4.276

FIGURE 54 - BUCHANAN SOLAR IRRADIANCE

Now we proceed to enter the size and prices for the panels and the inverter as seen on Figure 55 and Figure 56.

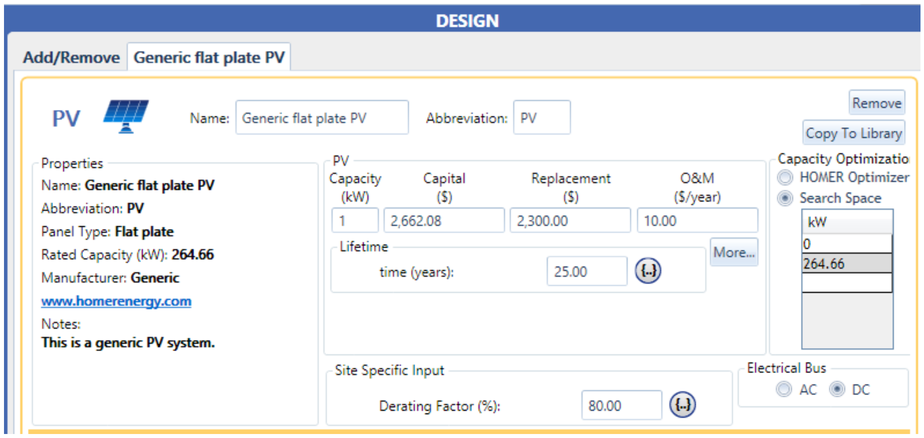


FIGURE 55 - BUCHANAN PV ARRAY SIZE

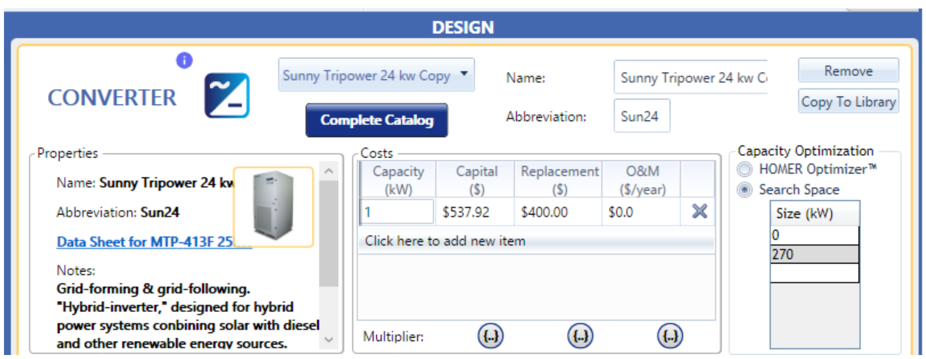
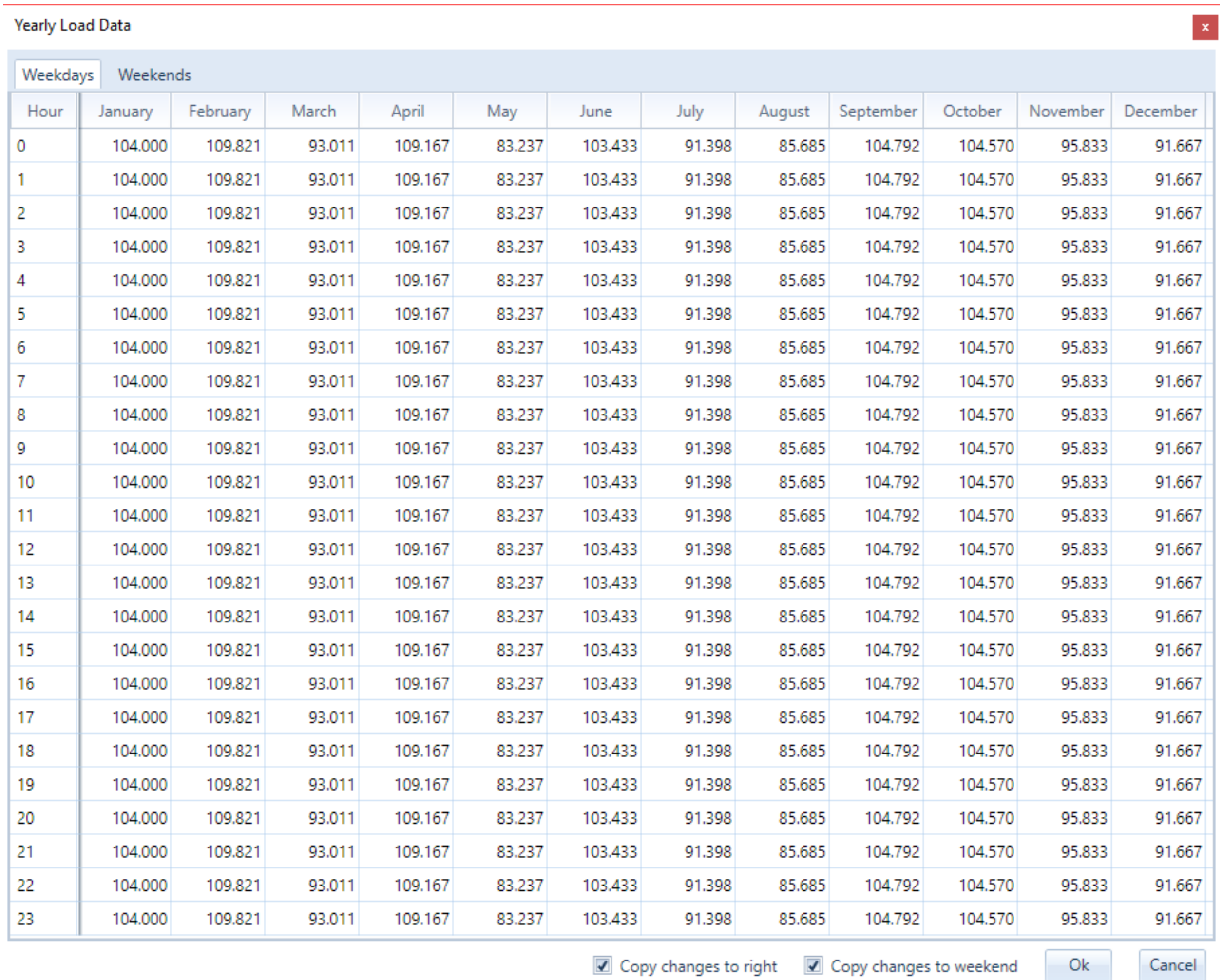


FIGURE 56 - BUCHANAN CONVERTER SIZE

Finally, we enter the load Profile as shown on Figure 57.



Yearly Load Data

Weekdays | Weekends

Hour	January	February	March	April	May	June	July	August	September	October	November	December
0	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
1	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
2	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
3	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
4	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
5	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
6	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
7	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
8	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
9	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
10	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
11	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
12	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
13	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
14	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
15	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
16	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
17	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
18	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
19	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
20	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
21	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
22	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667
23	104.000	109.821	93.011	109.167	83.237	103.433	91.398	85.685	104.792	104.570	95.833	91.667

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FIGURE 57 - BUCHANNAN YEARLY LOAD DATA

With all components in place we can use the calculate button to obtain the simulation results.

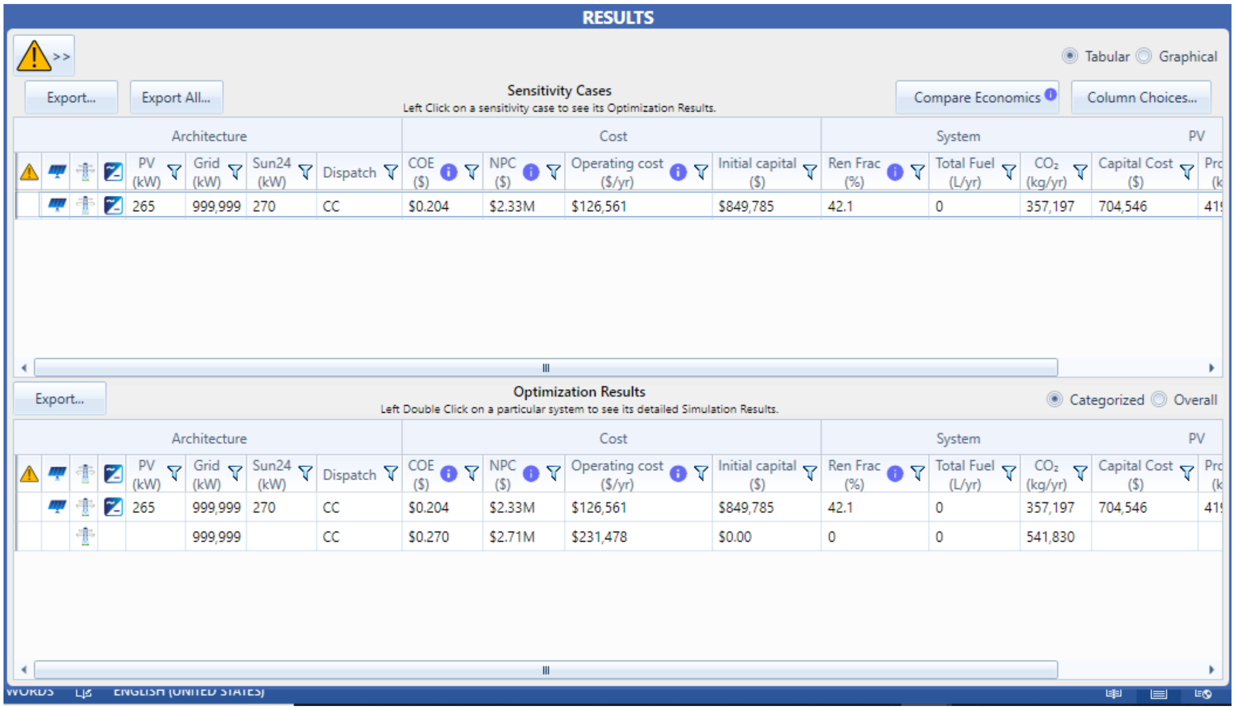

FIGURE 58 BUCHANAN SIMULATION RESULTS

The simulation result show that in the Buchanan toll station case, the renewable energy array is feasible as the net present cost is that of $2.33 million while no renewable energy costs $2.71 million dollars. During the life cycle of the project we can save $380 thousand dollars. Having limited size for components and Buchanan being the highest energy consuming toll station, we can only achieve a renewable fraction of 42.1%. The system will prevent a total of 184,633 kg/yr. of carbon dioxide (CO_2) from being produced. The return of investment is due on 7.84 years.

8.3.2 Ponce Toll Station

Located in the town of Ponce this toll station has less load demand than Buchanan but less area available as well. For this location, 4 different areas were taken into consideration for panel installation including the Canopy area and 3 other building. The total area available was 7352.85 square feet allowing a total of 408 panels that can be installed. This area calculation is very conservative as we leave 2 feet spaces between rows for maintenance purposes and this takes into account panels that cannot be installed due to obstacles like roof equipment. With the amount of panels that we obtained and the potency of 330 watt for each panel we can obtain a photovoltaic array of 134,640 kW. With this PV array size we would need 5 30kW converters for a total of 150 kW. Proceeding into HOMER PRO we locate the Ponce Toll Station as shown on Figure 59 below to obtain specific solar irradiance.

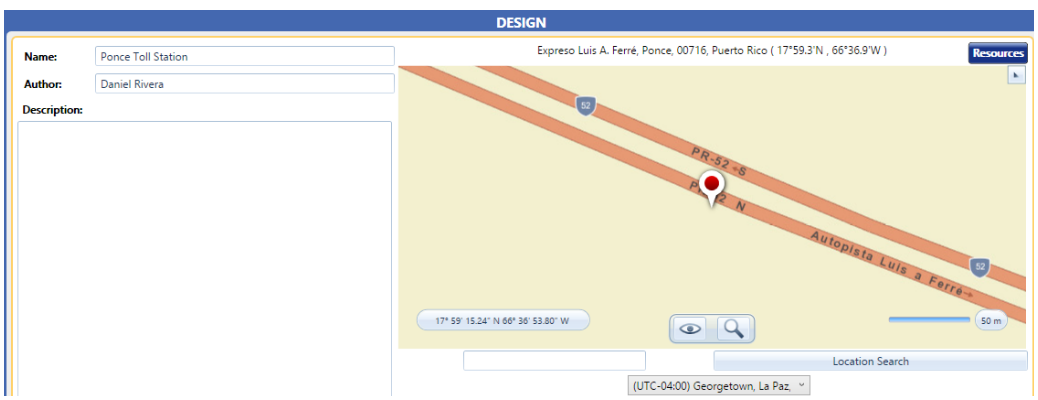

FIGURE 59 - PONCE TOLL STATION LOCATION

We can observe a total solar irradiance of 5.34 kWh/m^2/day as shown on Figure 60.

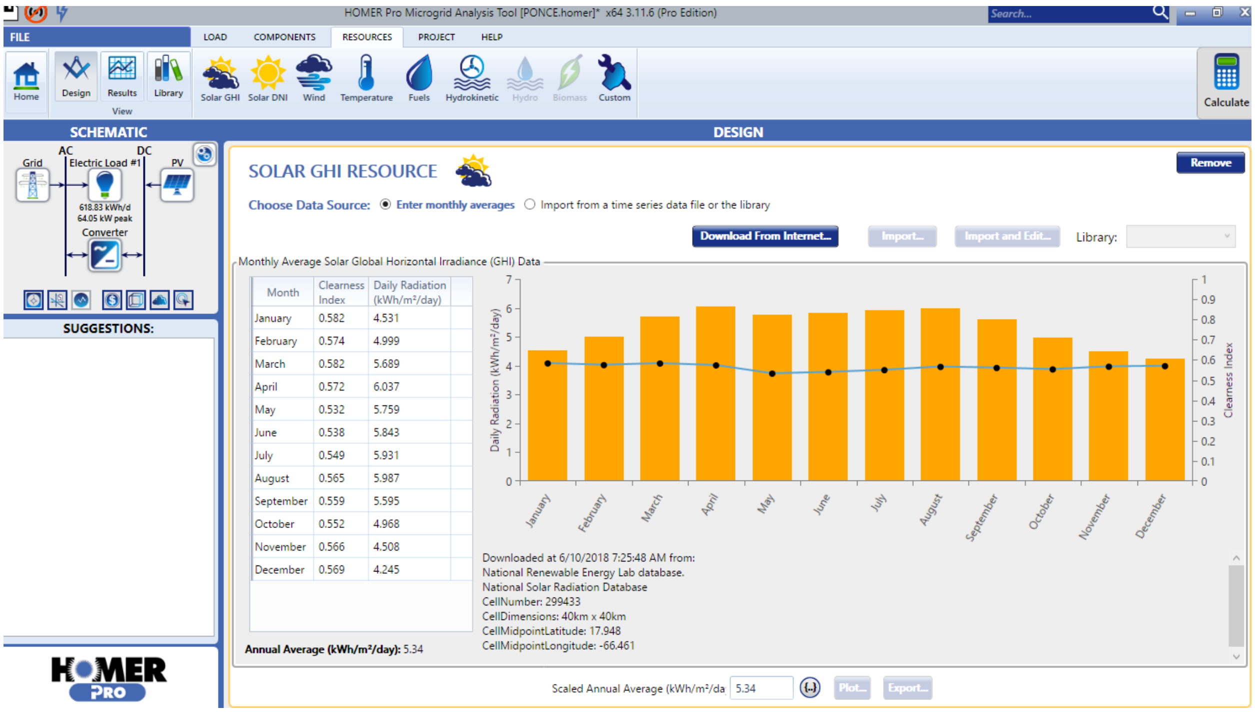

FIGURE 60 - PONCE SOLAR IRRADIANCE

Now we proceed to enter the size and prices for the panels and the inverter as shown on Figure 61 and Figure 62 respectively.

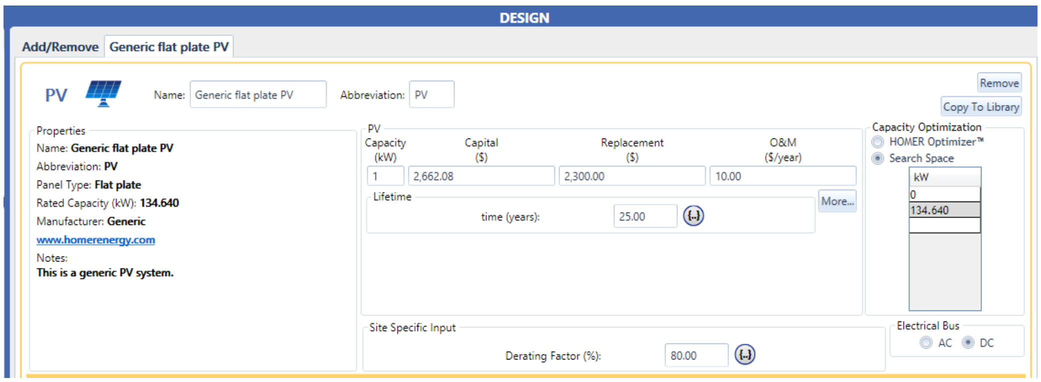

FIGURE 61 - PONCE PV ARRAY SIZE

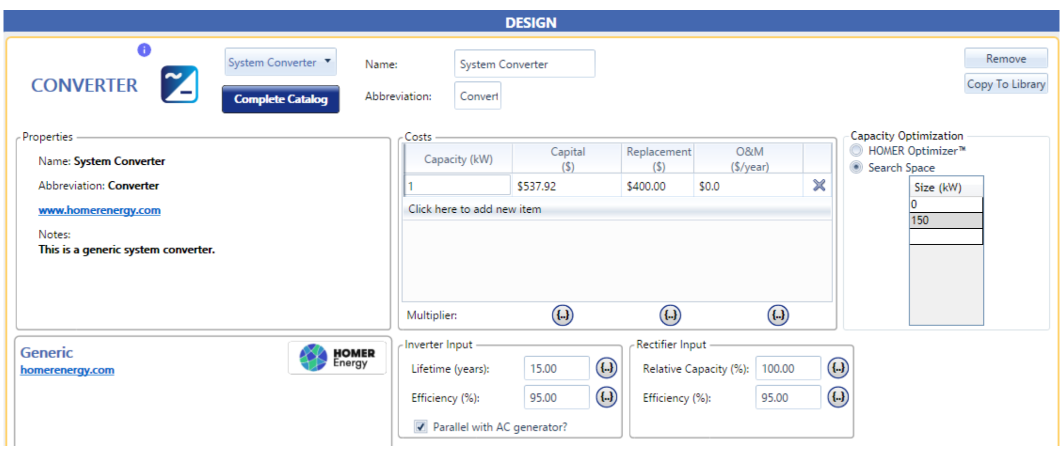

FIGURE 62 - PONCE CONVERTER SIZE

Finally we enter the load profile as shown on Figure 63.

Yearly Load Data

Weekdays | Weekends

Hour	January	February	March	April	May	June	July	August	September	October	November	December
0	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
1	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
2	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
3	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
4	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
5	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
6	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
7	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
8	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
9	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
10	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
11	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
12	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
13	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
14	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
15	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
16	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
17	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
18	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
19	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
20	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
21	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
22	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250
23	20.805	27.417	25.345	24.792	25.345	25.278	32.698	20.805	20.805	22.486	37.722	26.250

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FIGURE 63 - PONCE YEARLY LOAD PROFILE

With all components in place we can use the calculate button to obtain the simulation results which we can see on Figure 64.

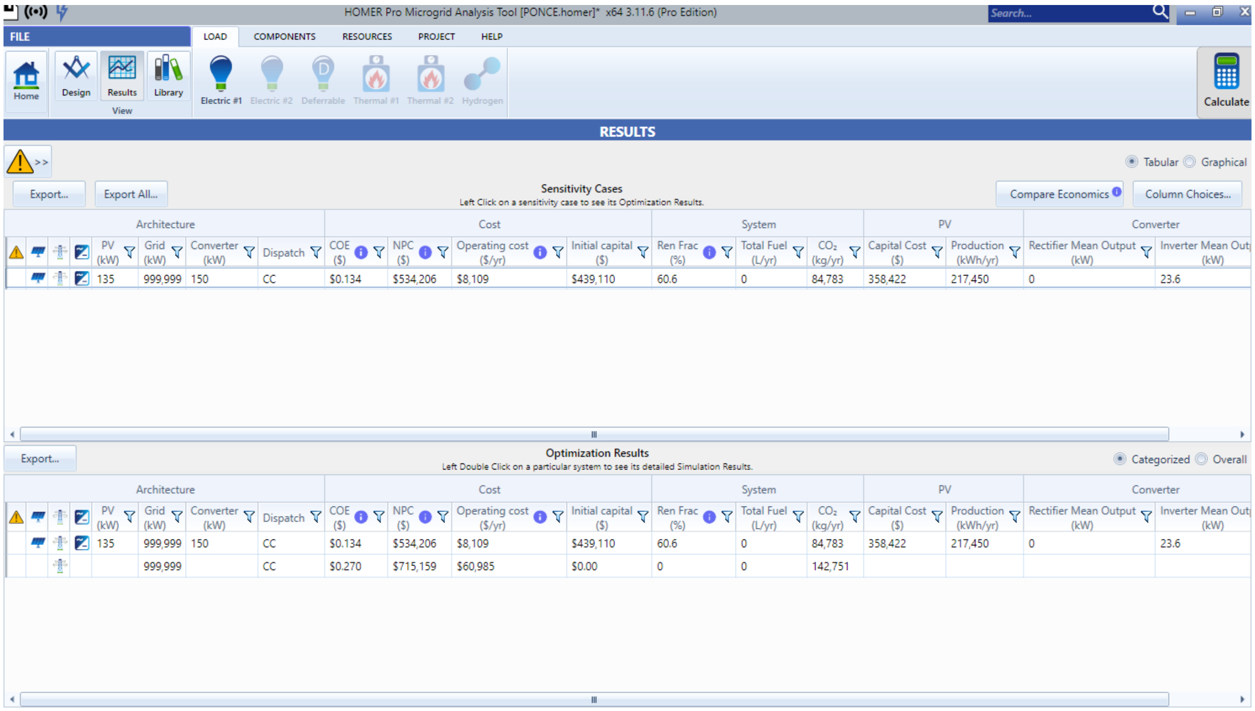

FIGURE 64 - PONCE SIMULATION RESULTS

The simulation result show that in the Ponce toll station case, the renewable energy array is feasible as the net present cost is that of $534,206 dollars while no renewable energy costs $715,159 dollars. During the life cycle of the project we can save $180,953 dollars. Having limited size for components and Ponce being the high energy consuming toll station, we can achieve a renewable fraction of 60.6%. The system will prevent a total of 57,968 kg/yr. of CO_2 from being produced. The return of investment is due on 8.07 years.

8.3.3 Juana Diaz Toll Station

Located in the town of Juana Diaz, this toll station has the smallest load demand and has the least area available as well. This is a special location as it is a completely different station called a framed toll station. A framed toll station does not require vehicles to stop or slow down in order to charge the toll. The toll fare is charged to the customer wireless via a unique transceiver specific to the car. In Puerto Rico this system is called “Auto Expreso”. Not having any building except for the recharge station lane there is little to no space available for photovoltaic system installation. The following is proposed for this particular case, create a roof like structure between frames where the panels will be installed. This area calculation is very conservative as we leave 2 feet spaces between rows for maintenance purposes. The total area available was 2342.82 square feet allowing a total of 130 panels that can be installed. With the amount of panels that we obtained and the potency of 330 watt for each panel we can obtain a photovoltaic array of 42,900 kW. Taking into account the load profile provided, which is similar to that of a regular size house we have more than enough power available. We will run the simulation with full capacity to observe the results. With this PV array size we would need 2 30kW converters for a total of 60 kW. Proceeding into HOMER PRO we locate the Juana Diaz Toll Station as shown on Figure 65 below to obtain specific solar irradiance.

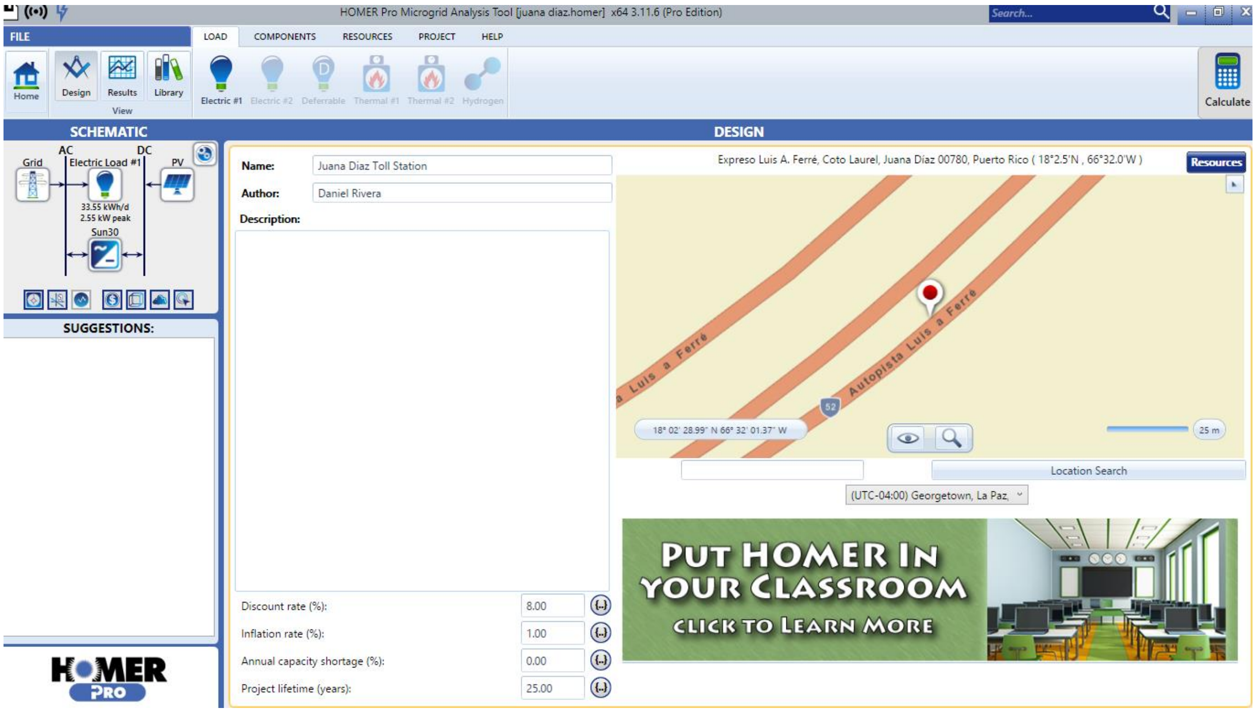

FIGURE 65 - JUANA DIAZ TOLL STATION LOCATION

We can observe a total solar irradiance of 6.21 $kWh/m^2/day$ as seen on Figure 66.

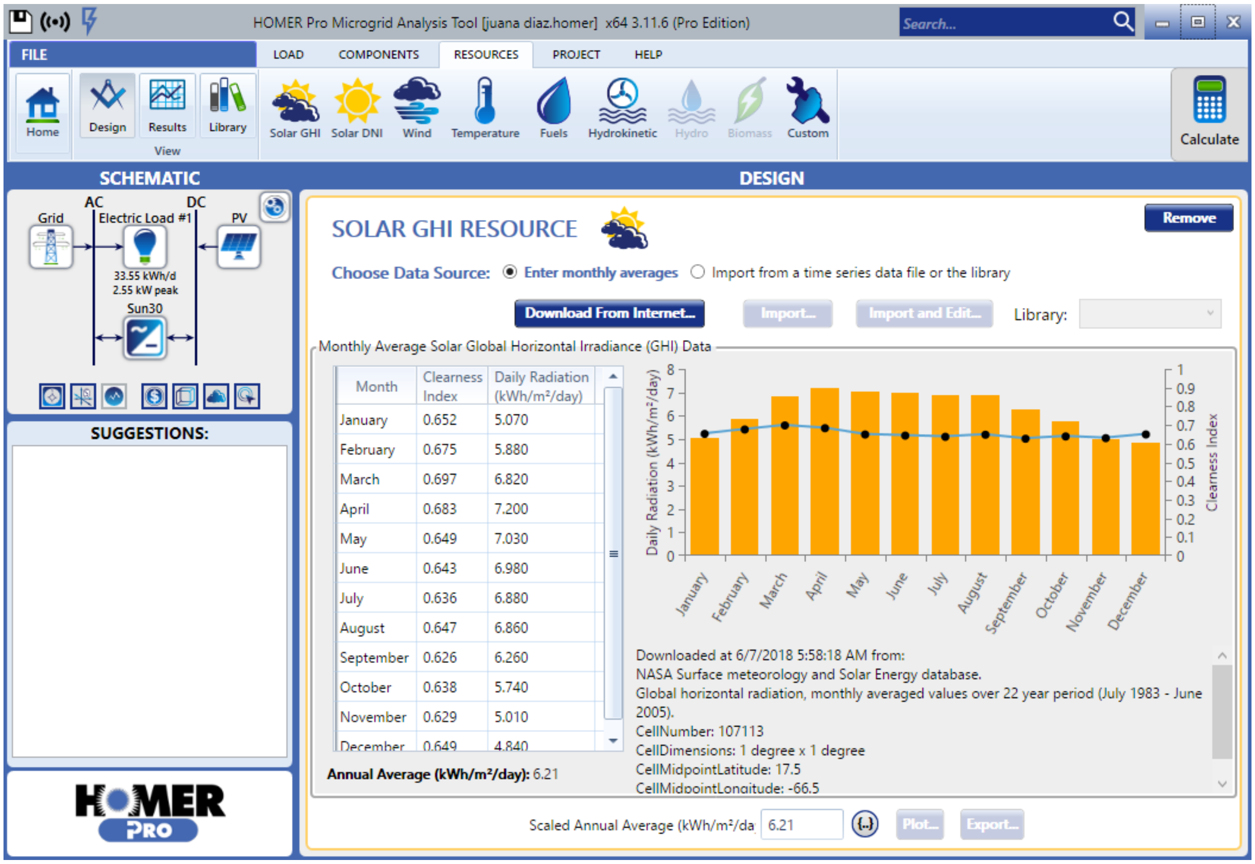

FIGURE 66 - JUANA DIAZ SOLAR IRRADIANCE

Now we proceed to enter the size and prices for the panels and the inverter as shown on Figure 67and Figure 68 respectively.

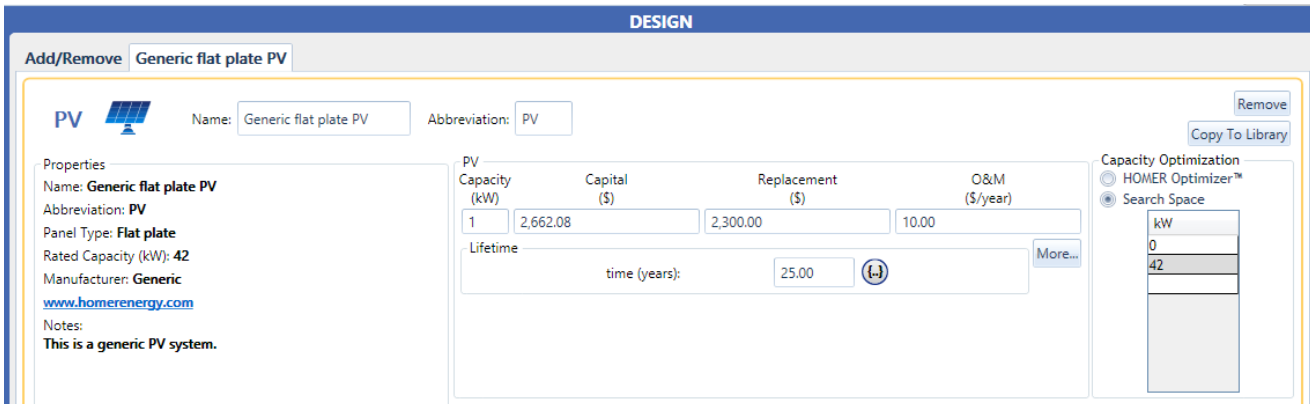

FIGURE 67 - JUANA DIAZ PV ARRAY SIZE

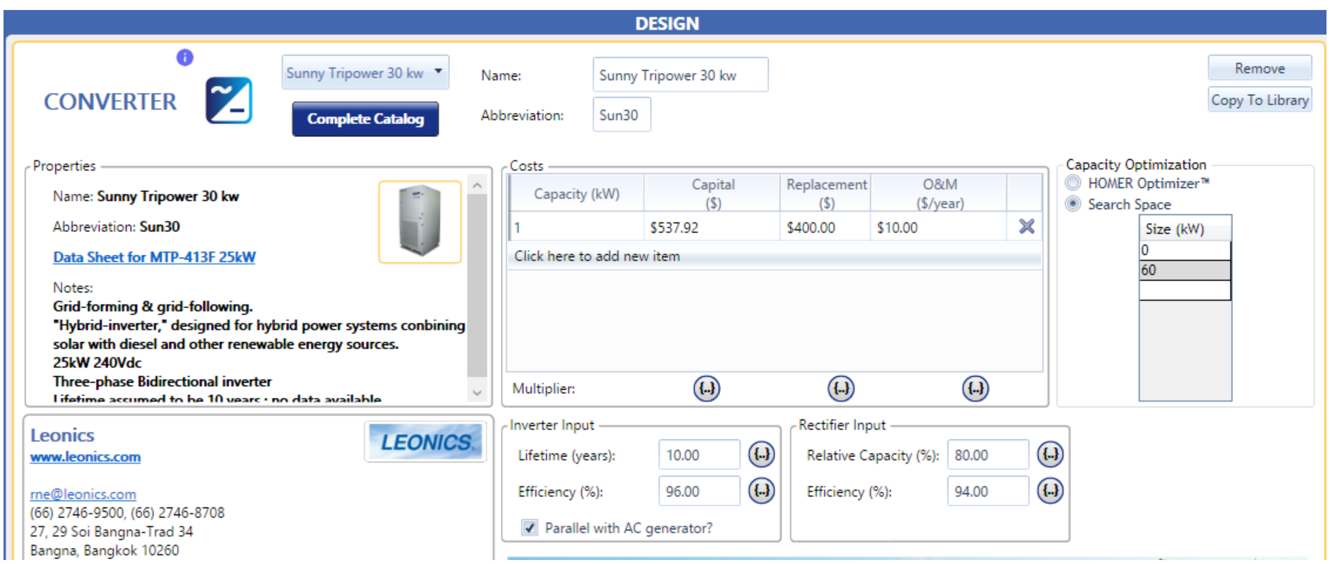

FIGURE 68 - JUANA DIAZ CONVERTER SIZE

Finally we enter the load profile as shown on Figure 69.

Yearly Load Data

Weekdays Weekends

Hour	January	February	March	April	May	June	July	August	September	October	November	December
0	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
1	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
2	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
3	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
4	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
5	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
6	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
7	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
8	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
9	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
10	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
11	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
12	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
13	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
14	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
15	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
16	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
17	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
18	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
19	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
20	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
21	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
22	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400
23	1.393	1.393	1.393	1.358	1.356	1.478	1.478	1.325	1.400	1.400	1.400	1.400

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FIGURE 69 - JUANA DIAZ YEARLY LOAD PROFILE

With all components in place we can use the calculate button to obtain the simulation results as shown on Figure 70.

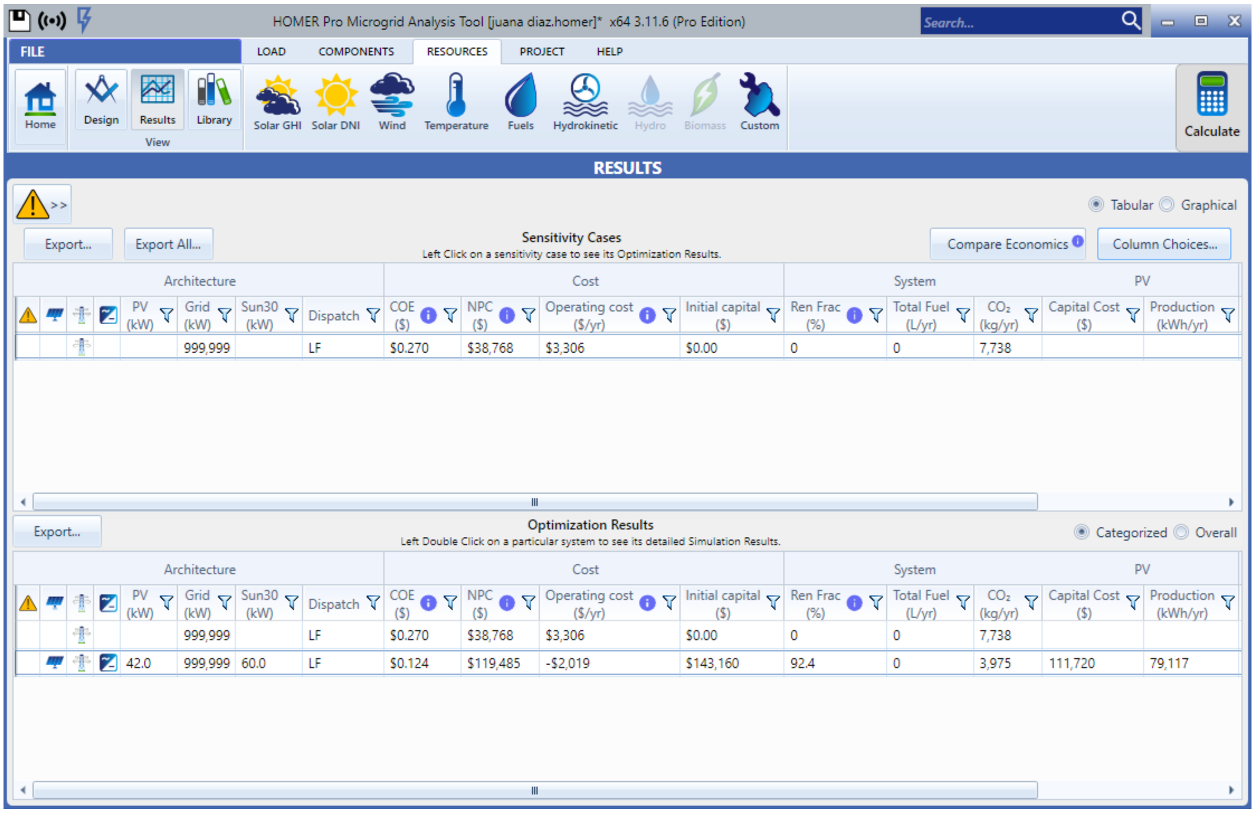


FIGURE 70 - JUANA DIAZ SIMULATION RESULTS

The simulation result shows that in the Juana Diaz toll station case, the renewable energy array is not feasible economically as the net present cost is that of $116,328 dollars while no renewable energy costs $38,768 dollars this is due to the fact that we simulated a photovoltaic system bigger than needed. During the life cycle of the project we will spend $77,560 dollars more by implementing a system as big as we possibly can. The space available is more than enough and with the net metering we are producing several times the demand load but the renewable fraction goes as far as 92.4%. This is due to the fact that the system is grid dependent and there will always be energy produced from the grid during the night. The system will prevent a total of 3,763 kg/yr of CO_2 from being produced. The return of investment would be due past the life time of the project.

Since this is the only non-feasible case economically, we proceed and use the HOMER Pro optimizing function to find out the ideal photovoltaic array with the least NPC for this location. We choose the optimizer function on both the PV and Converter elements as shown on Figure 71 and Figure 72 respectively.

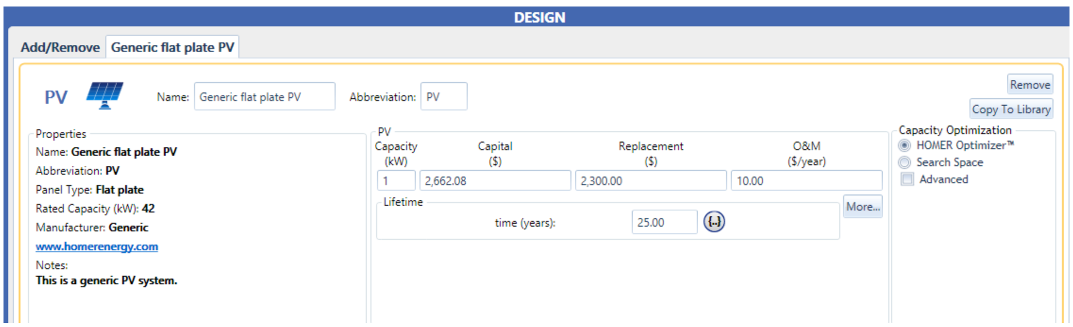


FIGURE 71 - JUANA DIAZ PV ARRAY (HOMER OPTIMIZER FUNCTION)

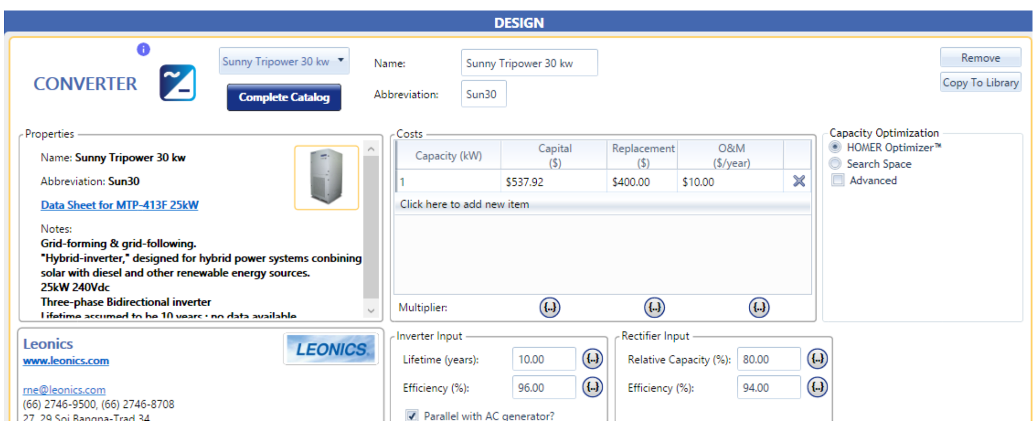


FIGURE 72 - JUANA DIAZ CONVERTER (HOMER OPTIMIZER FUNCTION)

We press calculate to obtain the results which we can see on Figure 73.

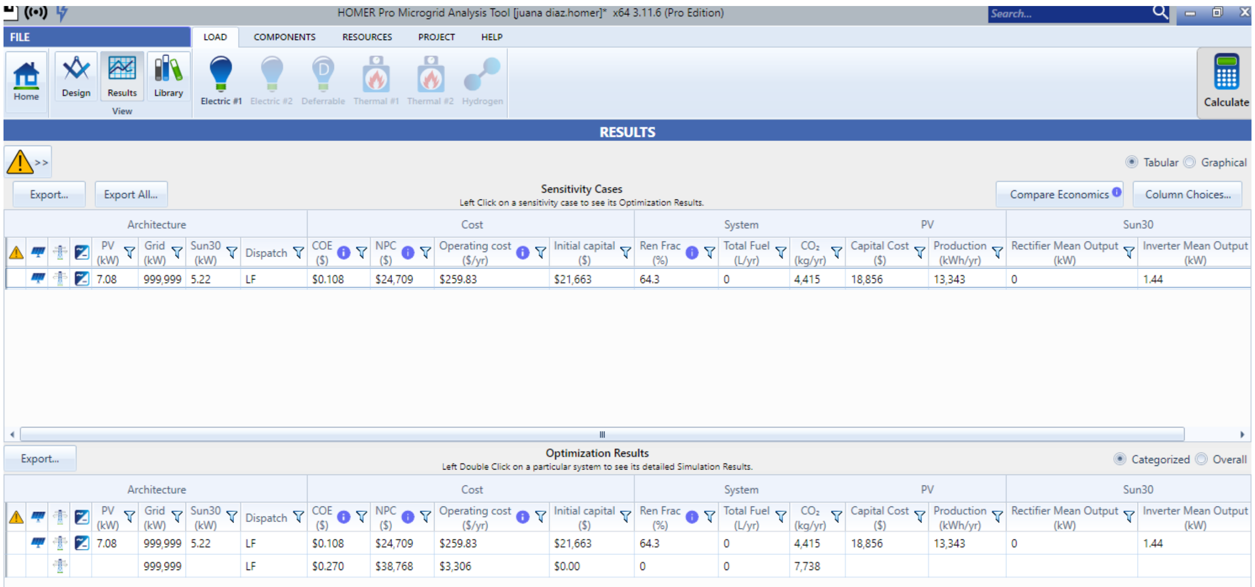


FIGURE 73 - JUANA DIAZ SIMULATION RESULTS OPTIMIZER FUNCTION

The optimizer shows that the best combination with the lowest NPC of $24,977 dollars, would be a photovoltaic array of 7.08 kW and an inverter of 5.22 kW, saving 13,791 dollars through the life cycle of the project. This system has a renewable fraction of 64.3% and 3,323 kg/yr of CO_2. Selecting this option would make the most economical and financial sense when analyze on its own but it all depends in the end what is the purpose of the installation. In this particular case we can implement a system that ends up being restorative in an environmental sense and also with the extra energy produce we can also counter some expenses in the Ponce toll station.

8.4 Rating System Scoring

As mentioned previously we will be using the rating system Envision by the ISI and INVEST by the FHWA. For ENVISION, it is currently on its third version. The energy scoring portion is located on the Resource Allocation section that has 14 credits in total. They divide the energy credits into 4 subcategories:

- RA 2.1 Reduce Operational Energy Consumption
- RA 2.2 Reduce Construction Energy Consumption
- RA 2.3 Use Renewable Energy
- RA 2.4 Commission and Monitor Energy Systems

ENVISION defines resources as assets that are need to build infrastructure and keep it running. We can observe the renewable scoring points for the use of renewable energy on Figure 74.

RESOURCE ALLOCATION: ENERGY

RA2.3 Use Renewable Energy

24

POINTS

INTENT

Meet operational energy needs through renewable energy sources.

METRIC

Extent to which renewable energy sources are incorporated.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A	A	A	A	A
(5) At Least 5%	**(10) At Least 15%**	**(15) At Least 30%**	**(20) At Least 50%**	**(24) Net Positive**
(A) The project meets: 5% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 15% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 30% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 50% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project generates a net positive amount of renewable energy.

FIGURE 74 - ENVISION RA2.3 USE OF RENEWABLE ENERGY

The INVEST rating system functions similarly to ENVISION with a scoring system but is much more rigorous. It is divided in 5 modules:

- System planning for states module
- System planning for region module
- Project development module
- Operations and maintenance module
- Innovation criterion

For the simulation assessment we will be using the *Project Development Module* as implementing a renewable energy system to an existing structure is being considered a project of its own. The energy portion is located on submodule PD-17: energy efficiency. In here we have:

- Requirement PD-17.1: 1 point evaluate energy needs and implement alternatives. This point we already have for the data collection of energy consumption for each toll station and by recommending the use of renewable energy systems.
- Requirement PD-17.2: 1-6 points reduce total energy consumption. We can achieve this by adding the renewable energy source already recommended or replacing equipment for more energy efficient counterparts such as LED lighting. We can see on Figure 75 the graph used to earn point on INVEST for this requirement.

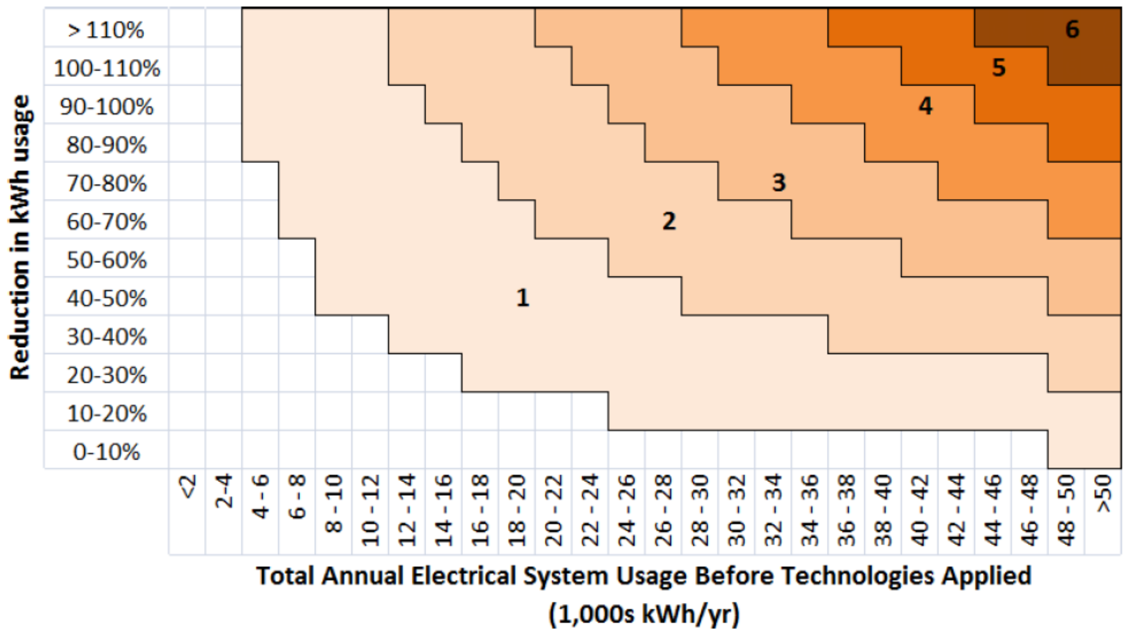


FIGURE 75 - PD-12.2.A POINTS EARNED FOR ENERGY EFFICIENT ELECTRICAL SYSTEM DESIGN

- Requirement PD-17.3 stablishing an audit plan: Establish a plan for auditing energy use after the project is complete, as part of operations and maintenance.

8.4.1 Scoring sources for INVEST

Any project is considered to have met the rating system criterion if the requirements above can be reasonably substantiated through the existence of one or more of the following documentation sources (or equal where not available):

1. Documentation of energy usage evaluation and reduction plan.

2. Calculations documenting energy usage if the roadway project was to be constructed with high-pressure sodium (HPS) luminaires and fixtures, the expected energy usage as designed, and the resulting energy savings as a percentage of calculation no. 1.

3. Contract documents and/or cut sheets of the luminaires being installed on the project.

4. Sample cut sheets and specifications for each technology installed on the project that shows the expected wattage of the component(s) used or generated.

5. Documentation of plan for auditing energy use after construction.

As stated before INVEST is a more rigorous scoring system that requires evidence in order to be eligible for certificate.

8.5 Rating system assessment

Now that we have described both rating systems and explained how to obtain points on each we finally take the photovoltaic simulations for the toll stations and assign the scoring. First off we will do the Envision scoring and subsequently the INVEST scoring for all 3 toll station cases.

8.5.1 Envision Scoring

- Buchanan toll station: reached a **superior level of achievement** as shown on Figure 76 with the PV system producing a total of 418,722 kWh/yr and the total load of the system being 858000 kWh/yr covering a 48.86% of the load. This gives 15 points out of 24.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A	A	A	A	A
(5) At Least 5%	(10) At Least 15%	(15) At Least 30%	(20) At Least 50%	(24) Net Positive
(A) The project meets: 5% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 15% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 30% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 50% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project generates a net positive amount of renewable energy.

FIGURE 76 - BUCHANAN ENVISION SCORING

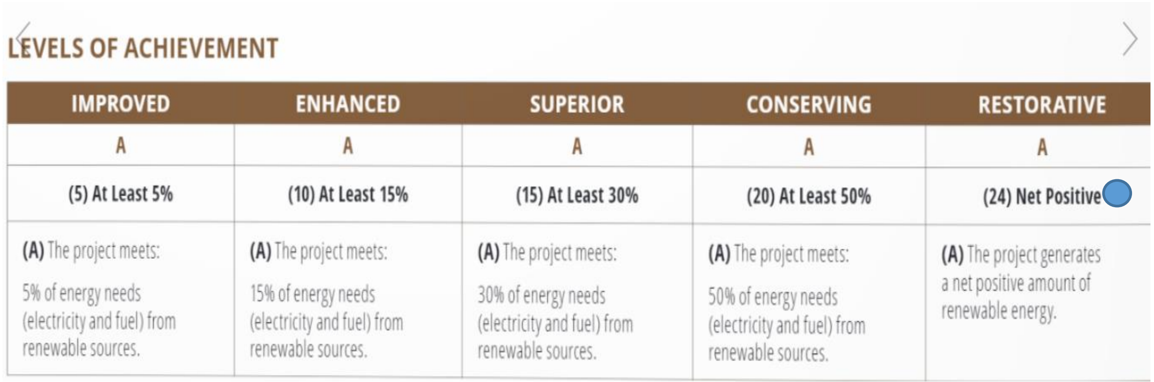
- Ponce toll station: reached a **conserving level of achievement** as shown on Figure 77 with the PV system producing a total of 217,450 kWh/yr and the total load of the system being 229,040 kWh/yr covering a 94.93% of the load. This gives 20 points out of 24

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A	A	A	A	A
(5) At Least 5%	(10) At Least 15%	(15) At Least 30%	(20) At Least 50%	(24) Net Positive
(A) The project meets: 5% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 15% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 30% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 50% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project generates a net positive amount of renewable energy.

FIGURE 77 - PONCE ENVISION SCORING

- Juana Diaz Toll Station: if the maximum allowed system is installed this toll station reaches a **restorative level of achievement** as shown on Figure 78 with the PV system producing a total of 79,111 kWh/yr and the total load of the system being 11,727.07 covering all the load and producing 674.60% of the load. This gives all the 24 points available.



LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A	A	A	A	A
(5) At Least 5%	(10) At Least 15%	(15) At Least 30%	(20) At Least 50%	(24) Net Positive
(A) The project meets: 5% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 15% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 30% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 50% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project generates a net positive amount of renewable energy.

FIGURE 78 - JUANA DIAZ ENVISION SCORING

8.5.2 INVEST Scoring

- Buchanan toll station: Gets one point in PD-17.1 for PV system simulation and data collection and analysis of the load. By using the Table PD-12.2.A we can locate this system that requires 858,000 kWh/yr in the X axis in the far end of the table above 50,000kWh/yr

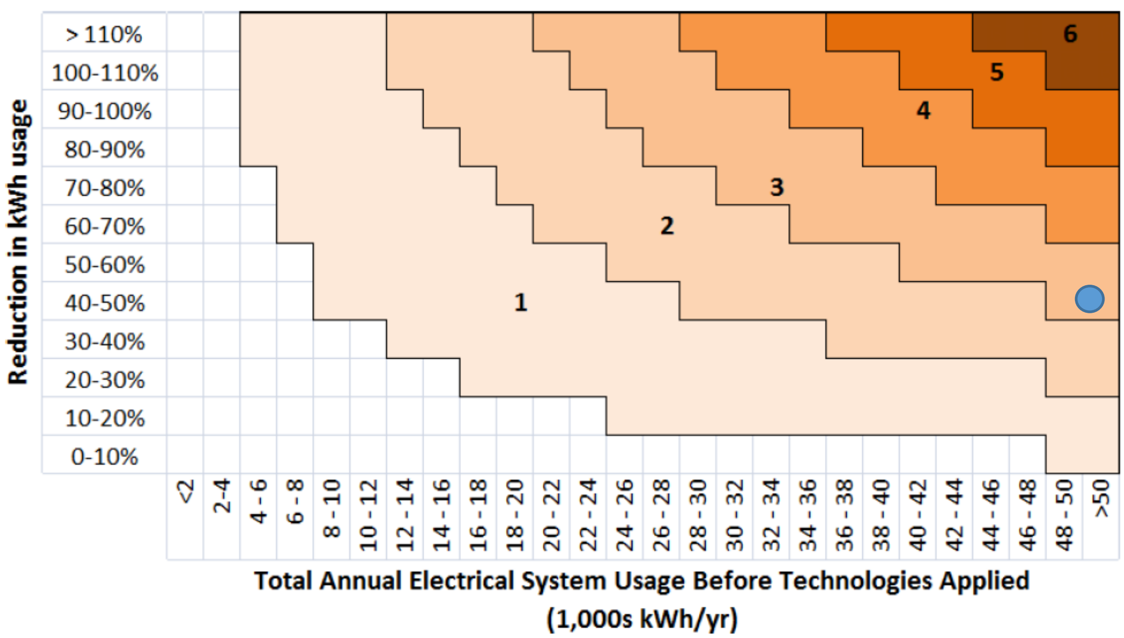


FIGURE 79 - BUCHANAN INVEST SCORING

The scoring achieved in this case is 3 out of 6. Finally we can get a point in PD-17.3 by auditing energy usage during the operation and maintenance. The total score is 5 out of 8.

- Ponce toll station: Gets one point in PD-17.1 for PV system simulation and data collection and analysis of the load. By using the Table PD-12.2.A we can locate this system that requires 229040 kWh/yr in the X axis in the far end of the table above 50,000kWh/yr.

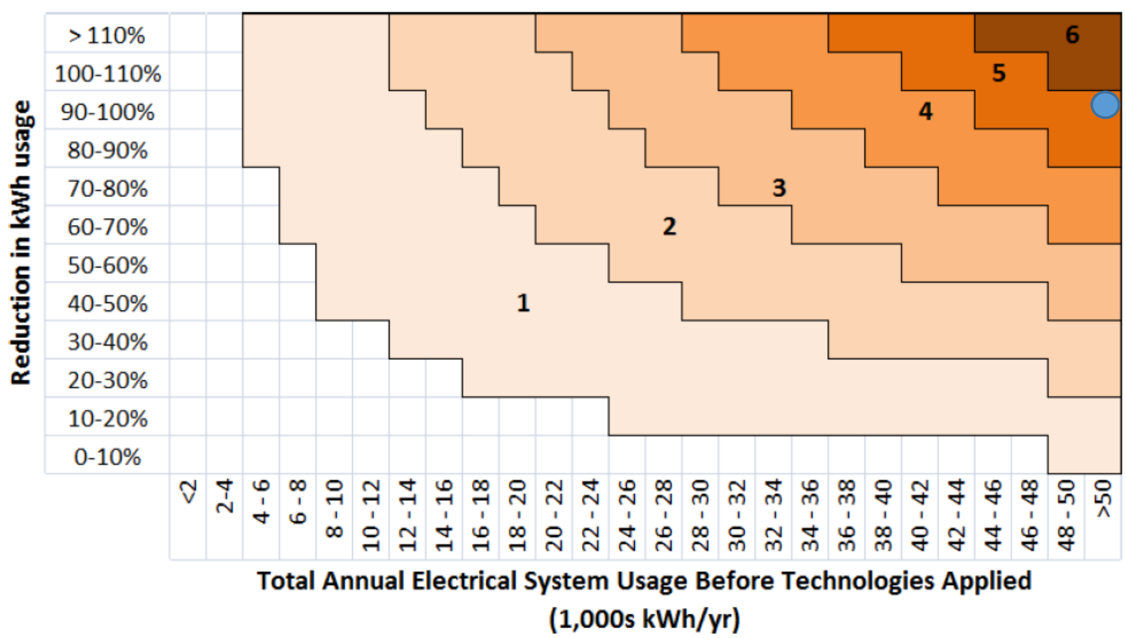


FIGURE 80 - PONCE INVEST SCORING

With a 94.93% of load covered the toll station is located in the 90-100% bracket. The scoring achieved is 5 out of 6. Finally we can get a point in PD-17.3 by auditing energy usage during the operation and maintenance. The total score is 7 out of 8.

- Juana Diaz toll station: Gets one point in PD-17.1 for PV system simulation and data collection and analysis of the load. By using the Table PD-12.2.A we can locate this system that requires 11,727.07 kWh/yr in the X axis in the beginning of the table in the 10,000-12,000 kWh/yr bracket as shown in Figure 81. The low size of the load required obtains 1 point out of 6 due to the fact that INVEST does not takes into account a reduction above 110%.

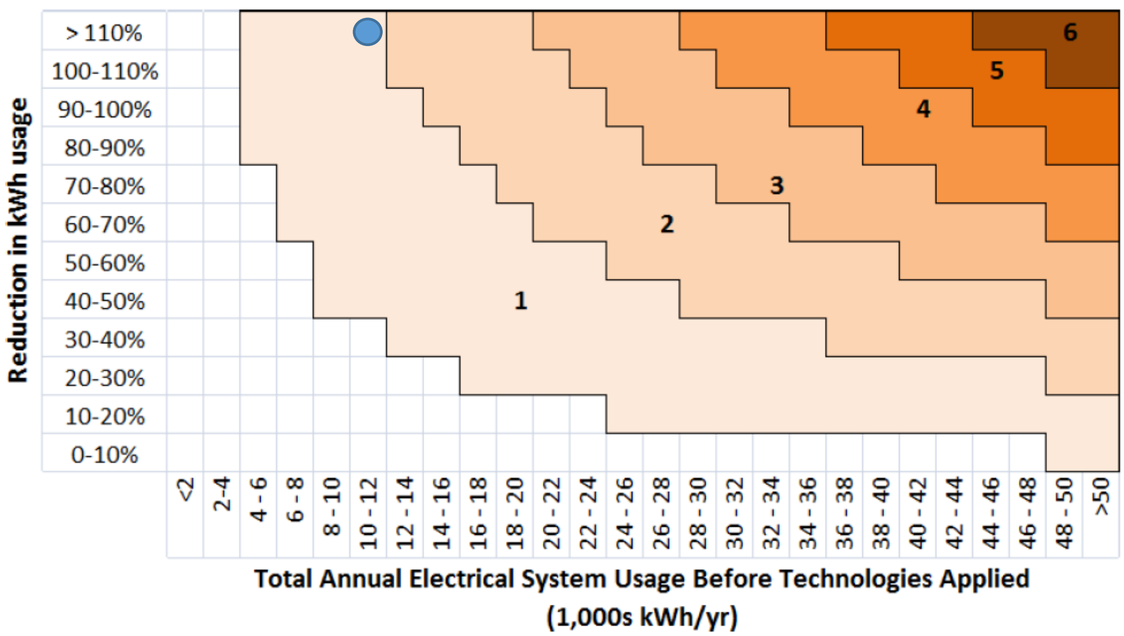


FIGURE 81 - JUANA DIAZ SCORING

Finally we can get a point in PD-17.3 by auditing energy usage during the operation and maintenance. The total score is 3 out of 8.

9 Results and Conclusions

The implementation of renewable energy systems in toll stations will yield several direct and indirect benefits. One of the most important benefits is the economic and financial feasibility. The photovoltaic system simulations demonstrated that all 3 toll stations studied have economically feasible options that will have simple return of investment in less than 10 years in general. All these options lower the cost of energy of 27 cents per kilowatt for commercial clients in Puerto Rico. As another benefit the emissions of carbon dioxide are greatly reduce which helps safe the environment as well as providing a better quality of life for people. With the simulations we deduced that renewable energy systems help reduce the leveled cost of energy up to an extent of the percent of the renewable fraction. The implementation feasibility of renewable energy system varies directly with the cost of energy of the grid. The higher the cost of energy of the grid, the more feasible renewable energy becomes as the implementation will have a fixed cost. Additionally as technology advances on the field of renewable energy, the systems will become more efficient and viable.

In the ENVISION parameters all simulation provided a superior level of achievement or better. The Buchanan toll station reached a superior level, the Ponce Toll station reached a conservative level and the Juana Diaz station also achieved a conservative level but is capable of achieving a restorative achievement level. The INVEST rating system is more strict than the INVEST, in terms of achieving scoring. The most favorable simulation in this case was the Ponce toll station followed by Buchanan and lastly Juana Diaz. Rating systems are a great tool for the planning and design of new infrastructure as it can help set specific goals to be integrated within the design. Although they have more diverse synergy with new designs they can also help to assess existing infrastructure such as adding a non-existing photovoltaic system to incorporate into an existing infrastructure which would be the design of a new small project, as well as to reduce the operational energy consumption. The implementation of rating systems helps to define goals at the time of designing new infrastructure in a way that will reduce economical cost while giving society a better quality of life with a sustainable environment.

We conclude that sustainable photovoltaic systems should be implemented on all toll stations in Puerto Rico as they are economically viable and they would prevent several thousands of kilograms per year of CO_2 from being produced. Rating systems should be implemented on all new infrastructure from the design phase.

Further research found on this project includes but it is not limited to:

- Implementation and analysis of photovoltaic systems in all toll stations island wide.
- Include Renewable Energy Installations on the AASHTO roadside design guide
- Compare the rigorousness of sustainable rating systems and understand their focus.
- Implementation of a sustainable rating system on all aspects for a new transportation infrastructure.

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11 Appendix A

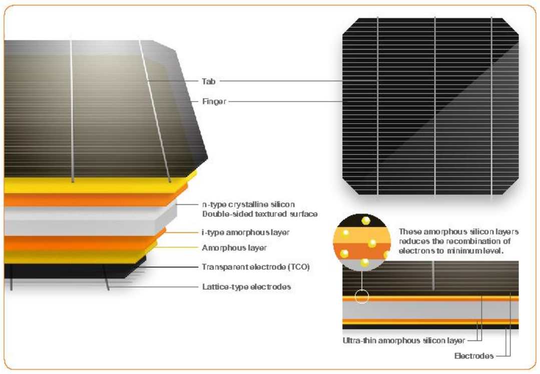
Specification Sheets

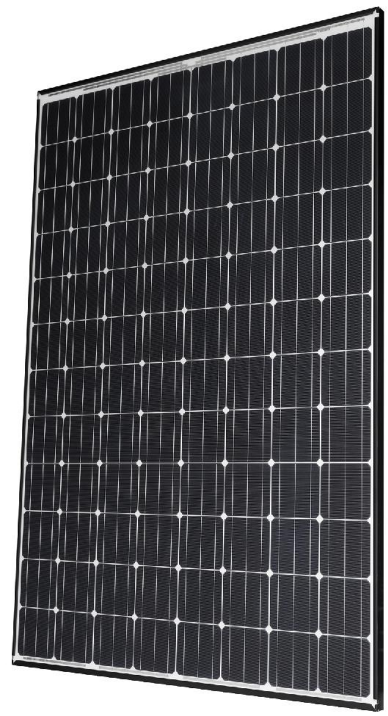
HIT.
Photovoltaic Module

Panasonic

N330/N325

Panasonic's unique heterojunction technology uses ultra-thin amorphous silicon layers. These thin dual layers reduce losses, resulting in higher energy output than conventional panels.





Advanced bifacial cell designed for increased energy output. The cell utilizes sunlight reflected back from the rear side material which captures more light and converted into energy.

Our competitive advantages

High Efficiency at High Temperatures
As temperature increases, HIT® continues to perform at high levels due to the industry leading temperature coefficient of -0.258% /ºC. No other module even comes close to our temperature characteristics. That means more energy throughout the day.

25 Year Product and Performance Warranty**
Industry leading 25 year product workmanship and performance warranty is backed by a century old company- Panasonic. Power output is guaranteed to 90.76% after 25 years, far greater than other companies.

Quality and Reliability
Panasonic's vertical integration, 20 years of experience manufacturing HIT® and 20 internal tests beyond those mandated by current standards provides extreme quality assurance.

Higher Efficiency 19.7%
Enables higher power output and greater energy yields. HIT® provides maximum production for your limited roof space.

Low Degradation
HIT "N-type" cells result in extremely Low Light Induced Degradation (LID) and zero Potential Induced Degradation (PID) which supports reliability and longevity. This technology reduces annual degradation to 0.26% compare to 0.70% in conventional panels, guaranteeing more power for the long haul.

Unique water drainage
The water drainage system give rain, water and snow melt a place to go, reducing water stains and soiling on the panel. Less dirt on the panel means more sunlight getting through to generate power.

HIT®
Photovoltaic Module

Panasonic

N330/N325

ELECTRICAL SPECIFICATIONS

Model	VBHN330SA16	VBHN325SA16
Rated Power (Pmax)¹	330W	325W
Maximum Power Voltage (Vpm)	58.0V	57.6V
Maximum Power Current (Ipm)	5.70A	5.65A
Open Circuit Voltage (Voc)	69.7V	69.6V
Short Circuit Current (Isc)	6.07A	6.03A
Temperature Coefficient (Pmax)	-0.258%/°C	-0.258%/°C
Temperature Coefficient (Voc)	-0.16V/°C	-0.16V/°C
Temperature Coefficient (Isc)	3.34mA/°C	3.32mA/°C
NOCT	44.0°C	44.0°C
CEC PTC Rating	311.3W	306.5W
Cell Efficiency	22.09%	21.76%
Module Efficiency	19.7%	19.4%
Watts per Ft.²	18.3W	18.0W
Maximum System Voltage	600V	600V
Series Fuse Rating	15A	15A
Warranted Tolerance (-/+)	+10%/-0%*	+10%/-0%*

MECHANICAL SPECIFICATIONS

Model	VBHN330SA16, VBHN325SA16
Internal Bypass Diodes	4 Bypass Diodes
Module Area	18.02 Ft.² (1.67m²)
Weight	40.81 Lbs. (18.5kg)
Dimensions LxWxH	62.6x41.5x1.4 in. (1590x1053x35 mm)
Cable Length +Male/-Female	40.2/40.2 in. (1020/1020 mm)
Cable Size / Type	No. 12 AWG / PV Cable
Connector Type²	Multi-Contact® Type IV (MC4™)
Static Wind / Snow Load	50 PSF (2400 Pa)
Pallet Dimensions LxWxH	63.7x42.2x65.4 in.
Quantity per Pallet / Pallet Weight	40 pcs. /1719 Lbs. (780 kg)
Quantity per 40' Container	560 pcs.
Quantity per 20' Container	240 pcs.

OPERATING CONDITIONS & SAFETY RATINGS

Model	VBHN330SA16, VBHN325SA16
Operating Temperature	-40°F to 185°F (-40°C to 85°C)
Hail Safety Impact Velocity	1" hailstone (25mm) at 52 mph (23m/s)
Safety & Rating Certifications	UL 1703, cUL, CEC
UL 1703 Fire Classification	Type 2
Limited Warranty	25** Yrs Workmanship and Power Output (Linear)***

NOTE: Standard Test Conditions: Air mass 1.5; irradiance = 1000W/m²; cell temp. 25°C

* Maximum power at delivery. For guarantee conditions, please check our guarantee document.

** Installation need to be registered through our website **www.panasonicusahitwarranty.com** within 60 days in order to receive twenty-five (25) year Product workmanship. Otherwise, Product Workmanship will be only fifteen (15) years.

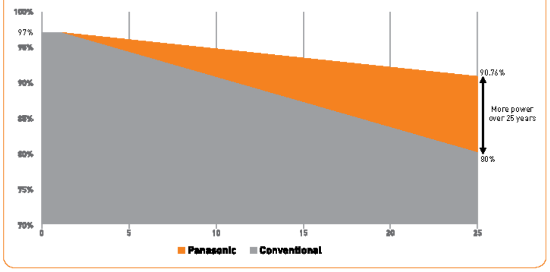
*** 1st year 97%, after 2nd year 0.26% annual degradation to year 25.

¹ STC: Cell temp. 25°C, AM1.5, 1000W/m²

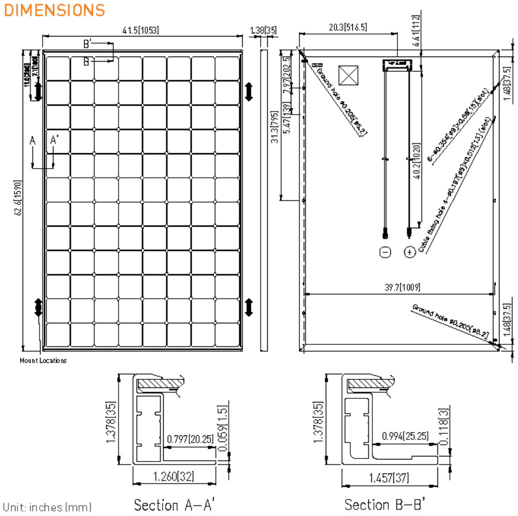
² Safety locking clip (PV-SSH4) is not supplied with the module.

NOTE: Specifications and information above may change without notice.

PERFORMANCE WARRANTY

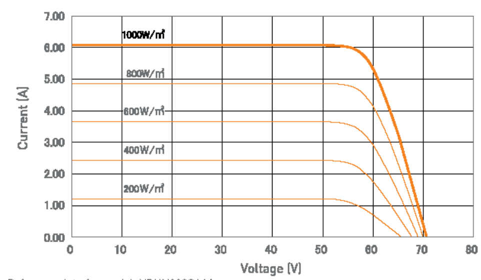


DIMENSIONS



Unit: inches (mm)

DEPENDENCE ON IRRADIANCE



Reference data for model: VBHN330SA16
(Cell temperature: 25°C)

⚠ CAUTION! Please read the installation manual carefully before using the products.

Used electrical and electronic products must not be mixed with general household waste. For proper treatment, recovery and recycling of old products, please take them to applicable collection points in accordance with your national legislation.

Panasonic

Panasonic Eco Solutions of North America
Two Riverfront Plaza, 5th Floor, Newark, NJ 07102
panasonicHIT@us.panasonic.com
business.panasonic.com/solarpanels

04/2017
RS17170_DS

SUNNY TRIPOWER 12000TL-US / 15000TL-US / 20000TL-US / 24000TL-US / 30000TL-US

Design flexibility

- 1000 V DC or 600 V DC
- Two independent DC inputs
- 15° to 90° mounting angle range
- Detachable DC Connection Unit

System efficiency

- **98.5% CEC, **98.6% Peak
- 1000 V DC increases system efficiency
- OptiTrac Global Peak MPPT

Enhanced safety

- Integrated DC AFCI
- Floating system with all-pole sensitive ground fault protection
- Reverse polarity indicator in combination with Connection Unit

Future-proof

- Complete grid management feature set
- Integrated Speedwire, WebConnect, ModBus interface
- Bi-directional Ethernet communications
- Utility-interactive controls for active and reactive power

SUNNY TRIPOWER 12000TL-US / 15000TL-US / 20000TL-US / 24000TL-US / 30000TL-US

The ultimate solution for decentralized PV plants, now up to 30 kilowatts

The world's best-selling three-phase PV inverter, the SMA Sunny Tripower TL-US, is raising the bar for decentralized commercial PV systems. This three-phase, transformerless inverter is UL listed for up to 1000 V DC maximum system voltage and has a peak efficiency above 98 percent, while OptiTrac Global Peak minimizes the effects of shade for maximum energy production. The Sunny Tripower delivers a future-proof solution with full grid management functionality, cutting edge communications and advanced monitoring. The Sunny Tripower is also equipped with all-pole ground fault protection and integrated AFCI for a safe, reliable solution. It offers unmatched flexibility with a wide input voltage range and two independent MPP trackers. Suitable for both 600V DC and 1,000V DC applications, the Sunny Tripower allows for flexible design and a lower levelized cost of energy.

www.SMA-America.com

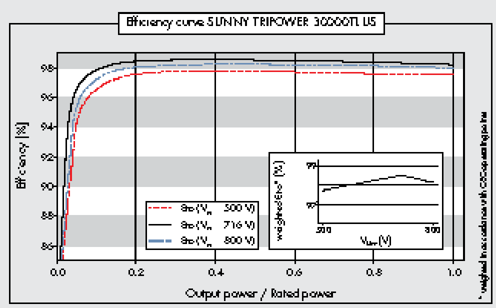
Technical data	Sunny Tripower 12000TL-US	Sunny Tripower 15000TL-US	Sunny Tripower 20000TL-US	Sunny Tripower 24000TL-US	Sunny Tripower 30000TL-US
Input (DC)					
Max. usable DC power (@ cos φ = 1)	12250 W	15300 W	20400 W	24500 W	30800 W
Max. DC voltage*	1000 V	1000 V	1000 V	1000 V	1000 V
Rated MPPT voltage range	300 V...800 V	300 V...800 V	380 V...800 V	450 V...800 V	500 V...800 V
MPPT operating voltage range	150 V...1000 V	150 V...1000 V	150 V...1000 V	150 V...1000 V	150 V...1000 V
Min. DC voltage / start voltage	150 V / 188 V	150 V / 188 V	150 V / 188 V	150 V / 188 V	150 V / 188 V
Number of MPP tracker inputs	2	2	2	2	2
Max. input current / per MPP tracker input	66 A / 33 A	66 A / 33 A	66 A / 33 A	66 A / 33 A	66 A / 33 A
Output (AC)					
AC nominal power	12000 W	15000 W	20000 W	24000 W	30000 W
Max. AC apparent power	12000 VA	15000 VA	20000 VA	24000 VA	30000 VA
Output phases / line connections	3 / 3-N-PE				3 / 3-N-PE, 3-PE
Nominal AC voltage	480 / 277 V WYE				480 / 277 V WYE, 480 V Delta
AC voltage range	244 V...305 V				
Rated AC grid frequency	60 Hz				
AC grid frequency / range	50 Hz, 60 Hz / -6 Hz...+5 Hz				
Max. output current	14.4 A	18 A	24 A	29 A	36.2 A
Power factor at rated power / adjustable displacement	1 / 0.0 leading...0.0 lagging				
Harmonics	< 3%				
Efficiency					
Max. efficiency / CEC efficiency	98.2% / 97.5%	98.2% / 97.5%	98.5% / 97.5%	98.5% / 98.0%	**98.6% / **98.5%
Protection devices					
DC reverse polarity protection	●	●	●	●	●
Ground fault monitoring / grid monitoring	●	●	●	●	●
All-pole sensitive residual current monitoring unit	●	●	●	●	●
DC AFCI compliant to UL 1699B	●	●	●	●	●
AC short circuit protection	●	●	●	●	●
Protection class / overvoltage category	I / IV	I / IV	I / IV	I / IV	I / IV
General data					
Dimensions (W / H / D) in mm (in)	665 / 650 / 265 (26.2 / 25.6 / 10.4)				
Packing dimensions (W / H / D) in mm (in)	780 / 790 / 380 (30.7 / 31.1 / 15.0)				
Weight	55 kg (121 lbs)				
Packing weight	61 kg (134.5 lbs)				
Operating temperature range	-25 °C...+60 °C				
Noise emission (typical) / internal consumption at night	51 dB(A) / 1 W				
Topology	Transformerless				
Cooling concept / electronics protection rating	OptiCool / NEMA 3R				
Derating at 277 V AC	45 °C...52 °C				**40 °C...>45 °C
Features					
Display / LED indicators (Status / Fault / Communication)	– / ●				
Interface: RS485 / Speedwire, WebConnect	○ / ●				
Data interface: SMA Modbus / SunSpec ModBus	● / ●				
Mounting angle range	15°...90°				
Warranty: 10 / 15 / 20 years	● / ○ / ○				
Certifications and approvals	UL 1741, UL 1998, UL 1699B, IEEE 1547, FCC Part 15 (Class A & B), CAN/CSA C22.2 107.1-1				
NOTE: US inverters ship with gray lids.	Data at nominal conditions.	*Suitable for 600 V DC max. systems	**Preliminary data		
● Standard features	○ Optional features	– Not available			
Type designation	STP 12000TL-US-10	STP 15000TL-US-10	STP 20000TL-US-10	STP 24000TL-US-10	STP 30000TL-US-10

Accessories


RS485 interface
DM-485CB-US-10


Connection Unit
CU 1000-US-10


SMA Cluster Controller
CLCON-10



12 Appendix B

Toll Station Load Profiles

Juana Diaz Electric Load Profile

Acuerdo de Servicio: 0727790588
Autoridad de Carreteras

Fecha Final	Días	UDM	Cantidad de Servicio Facturable	Cantidad de Servicio Diario Promedio
9/1/2014	31	Kilovatio hora	1042.00	33.61
8/1/2014	31	Kilovatio hora	986.04	31.81
7/1/2014	29	Kilovatio hora	1029.03	35.48
6/2/2014	31	Kilovatio hora	1100.00	35.48
5/2/2014	31	Kilovatio hora	1009.00	32.55
4/1/2014	29	Kilovatio hora	945.00	32.59
3/3/2014	28	Kilovatio hora	3744.00	133.71
2/3/2014	32	Kilovatio hora	0.00	0.00
1/2/2014	31	Kilovatio hora	0.00	0.00
12/2/2013	20	Kilovatio hora	0.00	0.00

Ponce Electric Load Profile

Acuerdo de Servicio: 0727790468
Autoridad de Carreteras

Fecha Final	Días	UDM	Cantidad de Servicio Facturable	Cantidad de Servicio Diario Promedio
9/20/2014	30	Kilovatio hora	14980.00	499.33
8/21/2014	30	Kilovatio hora	14980.00	499.33
7/22/2014	32	Kilovatio hora	18200.00	568.75
6/20/2014	30	Kilovatio hora	18200.00	606.67
5/21/2014	29	Kilovatio hora	17640.00	608.28
4/22/2014	32	Kilovatio hora	19040.00	595.00
3/21/2014	29	Kilovatio hora	17640.00	608.28
2/20/2014	30	Kilovatio hora	19740.00	658.00
1/21/2014	32	Kilovatio hora	21140.00	660.63
12/20/2013	28	Kilovatio hora	17640.00	630.00
11/22/2013	30	Kilovatio hora	27160.00	905.33
10/23/2013	32	Kilovatio hora	17269.00	539.66
9/21/2013	29	Kilovatio hora	18991.00	654.86
8/23/2013	31	Kilovatio hora	20300.00	654.84
7/23/2013	31	Kilovatio hora	21980.00	709.03
6/22/2013	31	Kilovatio hora	20580.00	663.87
5/22/2013	29	Kilovatio hora	18580.80	640.72
4/23/2013	33	Kilovatio hora	23419.20	709.67
3/21/2013	29	Kilovatio hora	20580.00	709.66
2/20/2013	32	Kilovatio hora	20160.00	630.00
1/19/2013	30	Kilovatio hora	18900.00	630.00
12/20/2012	31	Kilovatio hora	18900.00	609.68
11/19/2012	31	Kilovatio hora	18900.00	609.68
10/19/2012	30	Kilovatio hora	19180.00	639.33
9/19/2012	30	Kilovatio hora	19180.00	639.33
8/20/2012	30	Kilovatio hora	18340.00	611.33
7/21/2012	30	Kilovatio hora	20720.00	690.67
6/21/2012	30	Kilovatio hora	20720.00	690.67
5/22/2012	30	Kilovatio hora	21700.00	723.33
4/22/2012	32	Kilovatio hora	21700.00	678.13

Buchanan Electric Load Profile

Buchanan

Month	Grid Purchase (kW-h)	Days	Daily Average
1	77800	31	2509.677419
2	73800	28	2635.714286
3	69200	31	2232.258065
4	78600	30	2620
5	61928	31	1997.677419
6	74472	30	2482.4
7	68000	31	2193.548387
8	63750	31	2056.451613
9	75450	30	2515
10	77800	31	2509.677419
11	69000	30	2300
12	68200	31	2200