TOTAL ELECTRICITY DEMAND COVERAGE WITH SOLAR ENERGY SYSTEMS IN LA GUAJIRA-COLOMBIA.

A techno-economic case study.

Bolivar Pimienta, Carlos Mario
c.m.bolivarpimienta@students.uu.nl

MASTER IN ENERGY SCIENCE

Master Thesis

Total Electricity Demand Coverage with Solar Energy Systems in La Guajira-Colombia. A techno-economic case study.

Carlos Mario Bolivar Pimienta

Student Number: 6882277

Email: c.m.bolivarpimienta@students.uu.nl

Universiteit Utrecht

Faculty of Geoscience

GEO4-2510

First reader:	Prof. dr. Wilfried van Sark, w.g.j.h.m.vansark@uu.nl
Second Reader:	Dr. ir. Jesús Rosales Carreón, j.rosalescarreon@uu.nl

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Abbreviations

AC	Alternating Current.
BOS	Balance of System.
CNM	National Monitoring System. Centro Nacional de Monitoreo in Spanish.
DANE	National Administrative Department of Statistics. Departamento Administrativo Nacional de Estadística in Spanish.
DC	Direct Current.
IPSE	Institute of Planning and Promotion of Energy Solutions for the Not Interconnected Zones. Instituto de Planificación y Promoción de Soluciones Energéticas para las Zonas No Interconectadas in Spanish.
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
LCOE	Levelized Costs of Electricity.
LR	Learning rate
NPV	Net Present Value.
PV	Photovoltaic.
SAM	System advisor model.
SIN	Interconnected National System. Sistema Interconectado Nacional in Spanish.
SUI	Unique Information System of Domiciliary Public Services. Sistema Único de Información de Servicios Públicos Domiciliarios in Spanish.
TMY	Typical Meteorological Year.
UPME	Planification Unit for Mines and Energy. Unidad de Planeación Minero Enérgetica in Spanish.
ZNI	Not Interconnected Zones, Zonas no Inteconectadas in Spanish.

Abstract

Colombia has set several goals to improve its energy system. With the current National Energy Plan the country aims to increment the projects of renewable energy sources like solar and wind across its territory. But the implementation of this plan faces different social and technical challenges. La Guajira is a region in which these challenges are more prominent historically. From reliability to coverage, the electricity supply in the region has always been unstable.

This research aims to assess the possibility to cover all the electricity demand of La Guajira with the use of Solar PV applications with battery storage. This is done by first characterizing the residential electricity demand of the region, identifying the main uses of electricity by the different members of the population. Historic electricity demand is collected and then projected to the year 2050, that is the timeframe set for the current National Energy Plan.

The availability of the solar energy resource in the region is evaluated identifying the best position to locate solar farms, based on the total annual solar irradiance. With three different possible configurations for solar generation systems that include PV panels, Inverter, Microinverters, Single Axis Tracking System, and Battery System, a technical assessment is carried out. It is measured the technical performance of every possible configuration, and it is established the number of components needed to cover the electricity demand of La Guajira year by year from 2022 to 2050.

The research concludes with an economic assessment of the choices proposed. This analysis gives a similar LCOE for two of the configurations that are kept as final alternatives for the region. The configuration that includes the Single Axis Tracking System was left out, as it had a higher LCOE than the values currently used in the market.

1. Introduction

As part of its strategy against climate change after joining the Paris Agreement in 2015 (United Nations, 2015), Colombia published its updated National Energy Plan in December 2019 (Unidad de Planeación Minero Enérgetica [UPME], 2019). This plan consolidates the country's policy framework on energy and the environment for the coming years, with an important focus on the use of renewable energy sources.

Across the national territory, the implementation of the National Energy Plan faces different technical and economic challenges (UPME, 2019). Taking one of the regions in the country where these challenges are more prominent, La Guajira, this study offers a techno-economic analysis to cover all the residential electricity demand inside the territory, using Solar Energy Applications as the main source. Figure 1 shows La Guajira inside the mainland map of Colombia.

Figure 1

La Guajira inside the Colombian mainland map.

Note: From La Guajira in Colombia (mainland).svg, by Milenioscuro, December 2017, Wikimedia Commons (https://commons.wikimedia.org/wiki/File:La_Guajira_in_Colombia_(mainland).svg). CC-BY-SA-3.0. Image retrieved June 06, 2021.

1.1. Societal Background

Assuring reliability in electricity supply presents different challenges for developing countries like Colombia, such as: highly reliance on one predominant source (hydropower in this case), transmission congestion, weak interconnection and peak load after sunset (IRENA, 2018). Putting this in perspective, Colombia's main electric grid is the Interconnected National System (SIN in Spanish), that despite providing 99% of the total electricity supply of the country according to UPME (2016), it does not cover its entire territory. There are the Not Interconnected Zones (ZNI in Spanish) that even though have low demand with around 4% of the total country's population (UPME, 2016), account for up to 52% of the country's territory, with electricity on them supplied by a variety of choices, both renewable and non-renewable.

Not by chance, the regions on the ZNI are the ones with lowest scores on the competitivity assessments performed by different governmental entities in Colombia (Ramírez & de Aguas, 2015). La Guajira is part of this group, with a consistent low performance over the years. Several issues affect the territory, from hunger in its population of indigenous communities (the wayuus), to the lack of complete coverage of electricity demand, and scarcity of clean water among other problems, all of which have been exacerbated with the COVID-19 pandemic (Pan American Health Organization [PAN] & World Health Organization [WHO], 2021). The need for more flexible and reliable electricity supply sources is clear, with solar applications presenting an important possibility as the biggest desert of the country is in the region.

1.2. Scientific Background

Even though solar energy applications accounts for only 0.01% of the total electricity supply of Colombia , several projects of different sizes have been already deployed along the country, with around 126 new projects approved for the near future (UPME, (2018). In matters of research and innovation, the country has done different efforts starting with the Atlas of Radiation published by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM in Spanish) after an extensive analysis performed during 2014 and 2015 (*Atlas Interactivo - Radiación IDEAM*, 2014, n.d.-a). Different studies have been also carried out about renewable energy sources, with the most recent ones covering integration and optimization of large solar energy projects in the country's energy systems (Henao et al., 2019; Pupo-Roncallo et al., 2019), as well as solar PV generation status and future potential (López et al., 2020; Rodríguez-Urrego & Rodríguez-Urrego, 2018), all of which showed La Guajira as one of the more suitable regions for this type of projects. Despite this, there is a lack of literature about both economic and technological requirements for large-scale solar energy projects that could cover the demand of complete towns in the territory, less about covering the demand of the whole region.

1.3. Problem Definition

Based on the socio-economic status of La Guajira and the goals set for Colombia in the energy sector, this research is focused on the timeframe set for the current National Energy Plan to 2050, aiming to answer the next main research question:

What are the techno-economic requirements to cover all the residential electricity demand of La Guajira in Colombia with Solar Energy applications by 2050?

To answer this question, the next sub-questions divide the problem in smaller research units that will allow to get a complete picture of the assessment to undertake:

Sub-question 1: What is the present electricity demand in La Guajira and how will it evolve up to 2050?

Sub-question 2: Based on this demand, what are the technological requirement to cover it with solar energy applications and energy storage?

Sub-question 3: How will the investment and operation costs for both solar applications and energy storage evolve up to 2050 to cover the demand of La Guajira?

This research addresses each of the sub-questions in a sequential order, aiming to combine at the end all the results for the main research question. To do so, a theoretical background is first established in relation to the assessment of solar energy applications and their combinations with energy storage, both in economic and technological perspectives. That information is then used to build the methodology used to get the results presented, which are then discussed, closing with a conclusion for the research. Each section is addressed in individual chapters.

2. Theoretical Background

The information needed to develop an answer for each of the sub-questions established (and so the main research question) is presented in the next sections, covering first the analysis over the demand to cover, the solar energy source to use to generate electricity for such purpose, the technical components of solar energy applications, and later the economic assessment of such components.

2.1. Electricity demand forecasting

Electricity consumption in a group subject of study (small town, city, country, etc.) is directly related to its population growth and additional behavioral factors of the individuals that are difficult to predict. In general, electricity demand is ruled by a set of variables called “electricity demand determinants”, that change based on the nature of the projection undertaken (Mir et al., 2020). In this sense, electricity demand or load forecasting can be divided based on the timeframe in *Long-Term load forecasting (LTLF)* when several years are considered; *Medium-term load forecasting (MTLF)*, for a time frame of a couple of years; and *Short-Term load forecasting (STLF)* when no more than two weeks are considered for the analysis (Berk, 2015).

With a timeframe selected, different forecasting models are available to make the projection of the electricity demand. The choices vary between each other with different level of complexity and mathematical considerations and calculations, going from statistical-based or traditional methods, to time series methods, up to artificial intelligence (AI) base methods. (Berk, 2015; Elakrmi & Shikhah, 2016).

On a pragmatic approach that will be more suited for this research for LTLF, Mir et al., (2020) and Steinbuks et al., (2017) suggest to combine the economic indicators available (GDP for the case of countries) for medium to big size population (at least 500,000 users), with historic electricity demand and population growth under a statistical-based models to get a general projection of the demand. A data set of at least 20 years is recommended for this purpose with the highest frequency possible. In the case of scarcity of data, Mir et al., (2020) indicates that practitioners use more simple heuristics methods that allows then to create a rough model for the forecasting, always monitoring how well it fits with the data set available.

The statistical-based methods are *Linear*, *Polynomial*, *Selected-model function* and *Multi-variable* or *Multiple Linear variables*. Each method takes the electricity determinants as inputs (GDP and population for this case) and combines them using different exponents and relationship to create a model with the best fit possible. The model could underfit in which case it does not match enough points from the data set available; or it cut overfit matching almost all the points of the given data set, for which it might generate unacceptable responses (negatives values or too big demands) for future periods. The accuracy of a model is measured with performance metrics (error measurement) with different choices available to analyze the generated data by the model (Botchkarev, 2018).

2.2. Solar energy resource

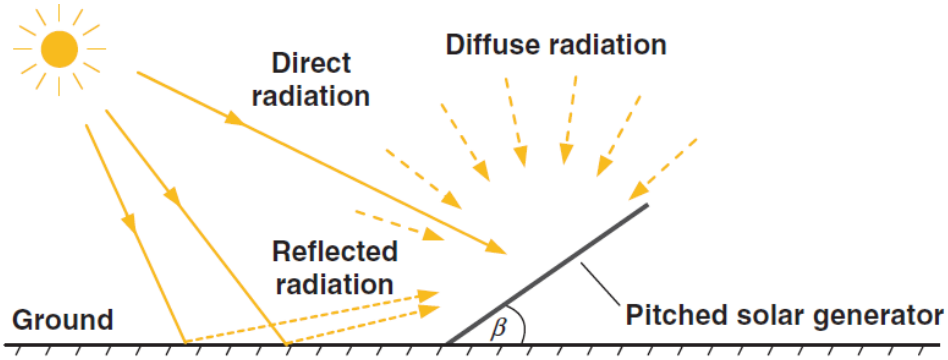
To properly evaluate a solar energy project, it is indispensable to measure the available solar radiation or irradiance at the final project location, as well as the weather patterns. The solar energy that hits the earth, travels from the sun as an electromagnetic radiation that gets absorbed, reflected, and divided in different components as it moves across the atmosphere, touching the different surfaces along the way as represented in Figure 2 (Perez, R., Scott, R., Arbogast, C., and Scott, 1986; Thorpe, 2017). To measure the performance of Solar Photovoltaic (PV) panels, the radiation components mostly used are Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI), (Thorpe, 2017).

The available radiation at a specific location on the globe (latitude, longitude, and height above sea level) can be estimated through different mathematical models that account for the temperature on the site, the airmass, pressure, and the angle of incident of the sun (azimuth angle). These models are categorized in different groups capable of providing a wide range of information for a specific site under study, as it is extensively covered in Zekai, S. (2008). Based on the available data from measurements taken on the site, the results provided by a model can be assess with the same performance metrics (error measurement) previously mentioned.

To analyze large size applications over long periods of time as in this research, it is common to use a Typical Meteorological Year (TMY) that consolidates the historic measurements of irradiance and weather conditions for a site. The TMY is used for each year in the lifecycle of the analysis carried out, as the input to the PV panels modelling. To built the TMY local measurement, satellite images and mathematical models are normally used (Reinders et al., 2017).

Figure 2

Solar radiation components over tilted surfaces like solar panels. (Mertens, 2018)



2.3. Large-Scale Solar Energy Systems

As a rule of thumb, the next core components constitute a solar PV energy system used to generate electricity directly, either stand-alone or connected to the grid, disregarding the size (Foster et al., 2009; Reinders et al., 2017):

- Solar PV Panels
- Hardware Balance-of-System (BOS): Solar PV Panels Concentrator, Controller and Ground-Fault Protection System.
- Inverter DC/AC
- Load or Grid connection panel.

For large-scale applications (i.e. bigger than 1MW according to Gevorkian, [2012]), also known as solar farms, energy storage systems are needed to supply electricity constantly, with several configurations possible. A consolidation of the main configurations proposed in Foster et al., (2009) Gevorkian (2012), Reinders et al., (2017), and Mertens, (2018) can be found in **Error! Reference source not found.**. Each one of these authors provided an equivalent version of the types of solar farms in Figure 3, with different variations in details about design considerations and installation. The PV system configurations in Figure 3 are:

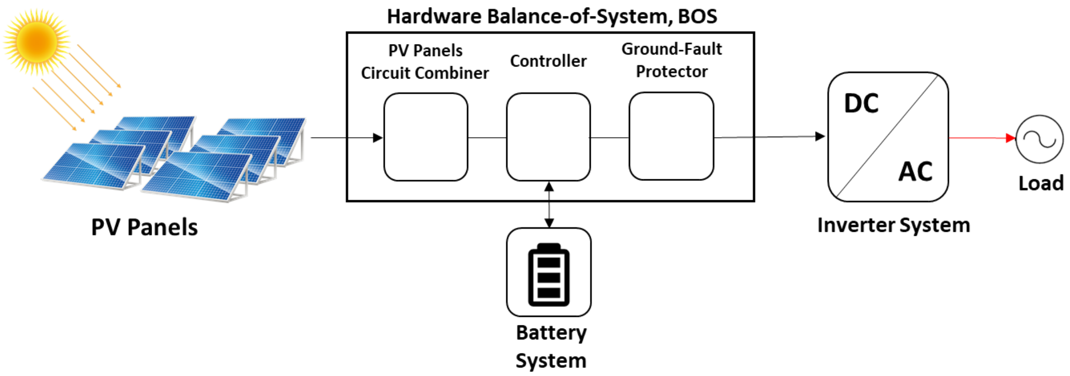
1. Standard Design: The solar farm is design based on the peak demand that the system will cover, with a straightforward approach of *Electricity Generation – Consolidation – Conversion – Supply*, accomplished respectively with: *PV Panels Array and Battery System – Hardware BOS – Inverter – Load Connection*. The operation of the battery system is aligned with the times slots of PV panels low performance.

2. Optimization of performance with sun tracking systems: The standard design is adjusted by adding tracking systems to the PV panels to increase their performance and reduce the use of the Battery System, and if possible, its size as well.

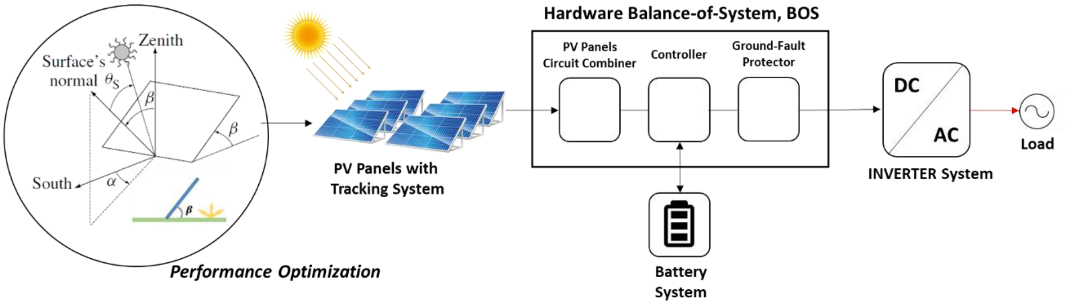
3. Individual DC/AC conversion per PV Panel: DC to AC conversion is split in one system for the Battery System, and small inverters for each of the panels. This allows the implementation of different operation strategies for the solar farm, that might come handy along the life cycle of the project to withstand quality problems caused by the load like increments in the presence of harmonics and parasite currents. Based on the performance of the farm along its life cycle, and the changes in the load, some additional components might need to be considered to balance further the power supply like DC-DC converters and LC filters (Reinders, et al., 2017). There is another type of configuration that adds small DC to DC converters per panel, to adjust their power output to the DC line requirements, considered for cases with low power output. (Foster, et al.,2009; Reinders, et al.,2017)

Figure 3

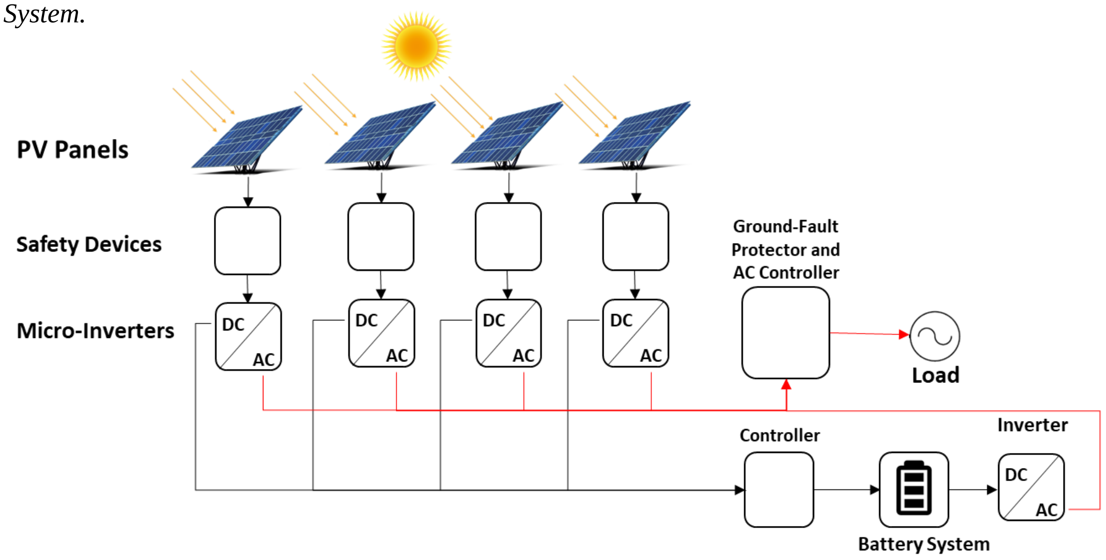
Large-Scale Solar PV Systems configurations: a) Standard Design; b) Performance optimization with sun tracking systems; c) Individual DC-AC converter per PV panel. DC lines in black, AC lines in red. Schematics adapted from configurations proposed in Bernsen et al., (2020), Foster et al., (2009), Gevorkian (2012), Reinders et al., (2017), and Mertens, (2018).



a) *Standard Design. Large-Scale solar PV system with energy storage. Large-size Hardware Balance-of System and Inverter System*



b) *Performance optimization with sun tracking systems. Large-size Hardware Balance-of-System and Inverter System.*



c) *Individual DC-AC converter per PV panel. Micro-inverters for the PV panels and large-size inverter for the Battery System*

2.3.2 Storage

The PV systems shown in Figure 3 use a Battery System as the main storage solution, to provide electricity on the times of the day where the PV panels are not generating power. But batteries are not the only storage solution available for this purpose. The references used to build Figure 3 discussed different choices, and IRENA consolidated the characteristics and current market presence of the most use technologies in their report Electricity Storage and Renewables: costs and markets to 2030 (IRENA, 2017), with extended details in their more recent report Electricity Storage Valuation Framework (IRENA, 2020). From the mechanical choices of storage are discussed: Pumped Hydro, Compressed Air and Flywheels; while for electrical choices are analyzed: Lithium-ion Batteries, Lead-Acid Batteries, High-Temperature Batteries, and Flow Batteries. For the case of solar farms, the Lithium-Ion Batteries are the technology more used, with the biggest growth projection in the future, so they are the choice for the analysis carry out in this research.

To analyze the battery system next to the PV panels, the main parameters used to evaluate battery performance are: State of Charge (SoC), Minimum State of Charge (SoCmin), Maximum State of Charge (SoCmax), Discharging Efficiency and Charging Efficiency. Additional parameters related to the effects of temperature over the batteries are considered in more detailed analyses, but the parameters enlisted are the most commonly used for assessment like the one carried out in this research. (Mertens, 2018)

2.4. Economic assessment of electrical power generation systems

In an economic perspective, the feasibility assessment of electric power generation projects follows the same methodology applied for other investment projects. Based on the product or service to offer and the timeframe of the project, first the calculation of the investment costs takes place followed by operation and maintenance costs, and income (cash flows) per period of time (normally in years). This is followed by the calculation of the investment criteria commonly used for the investment company (some companies used more than one) like Net Present Value (NPV), Pay Back Period, Average Accounting Report, or Internal Rate of Return (IRR), in order to weight the investment choices available to the company. An additional measurement used for projects in the energy sector is the Levelized Cost of Electricity (LCOE).

When the technological choices selected, a cost-benefit analysis can be performed. The benefits are tied to the performance or efficiency of the technology to generate units of electricity; while the costs are split in two, the investment costs and the operation and maintenance costs. The investment or initial costs, generally include: cost of equipment, costs of buildings, costs of land, engineering costs, installation costs, customization of equipment costs, among others (Blok, K. Nieuwlaar, 2020; Ross et al., 2016). A method to compare different configurations of solar energy applications and energy storage, that is commonly used in the energy market to compare different electric power generation technologies, is the LCOE that is defined by equation (1). LCOE is the cost or price of the electricity produced by which the costs are compensated with the benefits throughout the lifetime of the project (Blok & Nieuwlaar, 2020; Reinders et al., 2017).

$$\mathrm{LCOE} = \frac{\alpha \cdot \mathrm{I} + \mathrm{OM} + \mathrm{F}}{\mathrm{E}} \qquad (1)$$

where:

LCOE = Levelized costs of Electricity (e.g. € per kWh or MWh), also known in a wider approach as Levelized Cost of Energy for other energy applications.
α = capital recovery factor.

I = initial investment or capital costs
OM = annual operation and maintenance costs.
F = annual fuel costs (this is zero for the case of solar applications).
E = annual electricity energy production.

When the benefit and costs are not constant, which is normally the case for renewable energy applications, equation (1) must be adapted properly (Reinders et al., 2017). Depending on the nature of the elements, costs of pure technical components like solar panels or batteries might be subjected to learning curves which will affect the behavior of their costs over time. In a straightforward approach: “A learning curve expresses that the costs decrease by a constant fraction with each doubling of the total number of units produced”(Blok, K. Nieuwlaar, 2020; Junginger & Louwen, 2019), and can be consolidated with equation (2).

$$C_p = C_1 \cdot P^b \qquad (2)$$

where:

C_P = cost per unit after the cumulative production of P units
C_1 = cost of the first unit
b = experience index

An equivalent parameter supplied by studies is the Learning Rate, which can be used to find b in the previous equation. The learning rate is defined by equation (3):

$$Learning\ Rate = LR = 1 - 2^b \qquad (3)$$

To determine future prices for technological components, P in equation 2 is replace by the ratio between the projected units on the year that the price is needed, and the cumulative units reported in a specific time with the price C_1.

Additionally, based on the geography location of the project, local regulations should also be considered for additional incentives or tax exceptions that might applied. (Blok, K. Nieuwlaar, 2020; Gevorkian, 2012).

3. Methodology

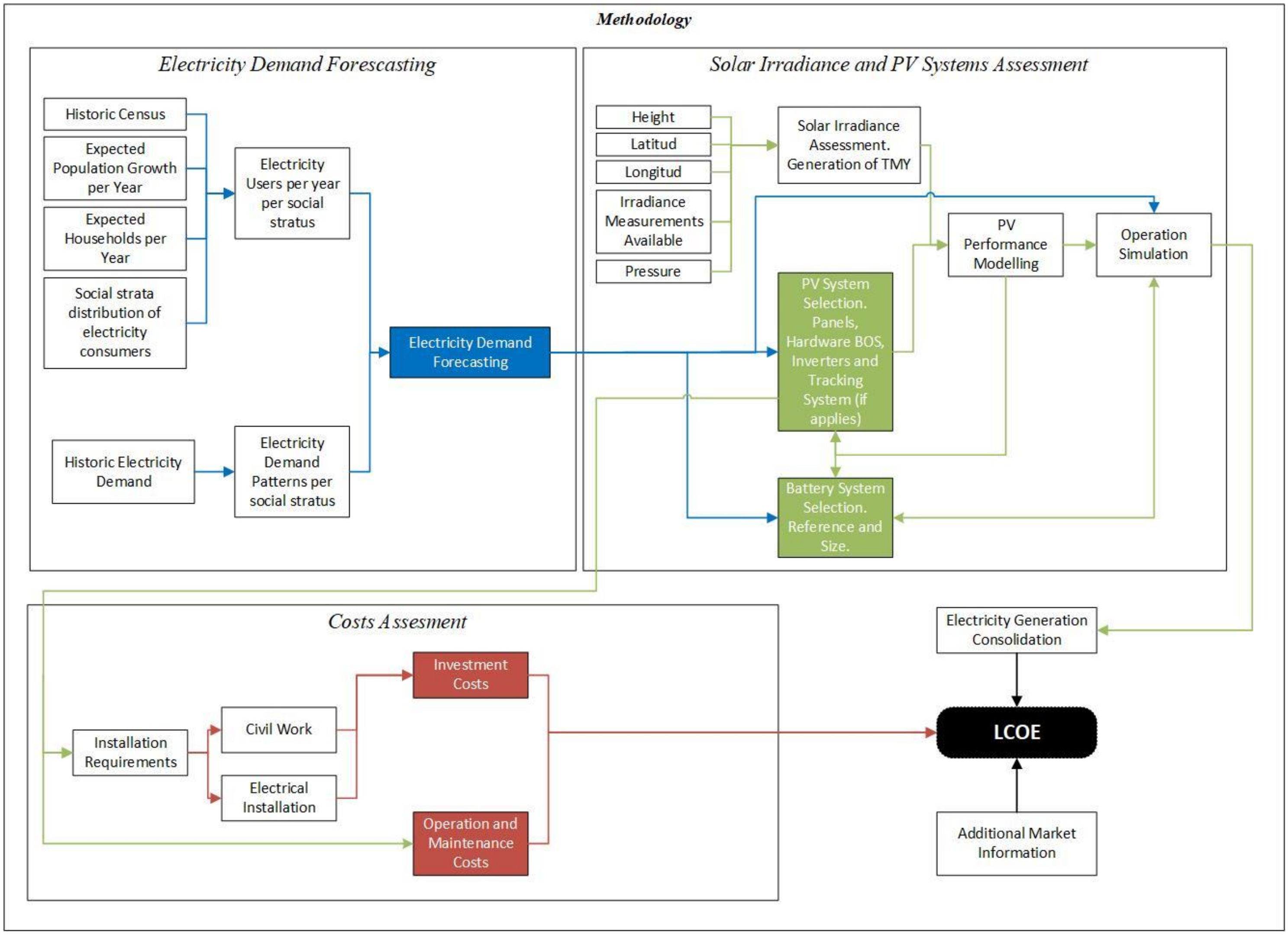
The sub-questions in section 1.3 were answered in a sequential order. Each step of the analysis generated results that were used as input for the subsequent stages of the research as needed. Mainly quantitative analyses were carried out to generate the results presented in the next section, using mainly Excel spreadsheets and the programming language Python as main tools.

3.1. Overview

Figure 4 shows the consolidated summary of the methodology used. First a forecasting of the electricity demand if performed up to 2050, followed by an assessment of the solar radiation available in the region and solar energy application needed to cover the demand projected per year. All this information is then used to performed the economic assessment.

Figure 4

Research methodology overview



3.2. Electricity demand forecasting

An initial data collection process was carried out, to consolidate the electricity determinants for the region, using official governmental sources. The available information about population, number of households and social strata was gathered first. In matters of economic information, the historic behavior of the GDP of Colombia cannot be directly extrapolated to the region based on the historic social background of La Guajira previously described in the introduction. Instead, it was collected the electricity demand based on the socio-economic strata of the population inside the region, as reported by the respective governmental entity.

The electricity demand forecasting for La Guajira was then done on pragmatic and heuristic approach as recommended in section 2.1 using machine learning techniques for two main statistic-based methods: Multiple Linear Variable and Polynomial. Each method was used to create a mathematical model capable of predicting the data collected, and then use to create a Long-Term load forecasting from 2022 to 2050. Both methods are defined as (Elakrmi & Shikhah, 2016 and Montgomery, D. C., Peck, E. A., & Vining, 2021):

3.2.1 Polynomial method

$$\mathrm{L_k} = \sum_{\mathrm{m}=0}^{\mathrm{p}} \mathrm{a_m t_k^m} \qquad (1)$$

The unknow parameters are estimated using:

$$\begin{pmatrix} a_0 \\ a_1 \\ \vdots \\ a_p \end{pmatrix} = \begin{pmatrix} N & \sum_{k=1}^{N} t_k & \cdots & \sum_{k=1}^{N} t_k^p \\ \sum_{k=1}^{N} t_k & \sum_{k=1}^{N} t_k^2 & \cdots & \sum_{k=1}^{N} t_k^{p+1} \\ \vdots & \vdots & & \vdots \\ \sum_{k=1}^{N} t_k^p & \sum_{k=1}^{N} t_k^{p+1} & & \sum_{k=1}^{N} t_k^{2p} \end{pmatrix}^{-1} \begin{pmatrix} \sum_{k=1}^{N} L_k \\ \sum_{k=1}^{N} L_k t_k \\ \vdots \\ \sum_{k=1}^{N} L_k t_k^p \end{pmatrix} \qquad (2)$$

where,

L_k is the kth estimated load
t_k is the time of the load
a's are the model unknows
k is the index of data = 1,2,3,4

3.2.2 Multiple linear variable method

$$\mathrm{L_k} = \mathrm{b_0} + \mathrm{b_1 X_1} + \mathrm{b_2 X_2} + \ldots + \mathrm{b_p X_p} \qquad (3)$$

where,

L_k is the kth estimated load
X_i are the independent variables, i=1,2,….,p
and the b's are the 'regression coefficients' to be estimated

The models generated by each method were analyzed with two main performance metrics. First with R^2 coefficient of determination, that takes values between 0 and 1, where 1 is a perfect fit. And second the Mean Absolute Error, MAE, that is the standard deviation of the residuals, and provides an indication of how far off are the points of the model from the real values; with a perfect fit for a value of 0.0. The combination of both metrics, with a graph aid (scatter plot) provides a perspective of the models under analysis with enough information to either accept or reject them. This process was done twice, first for the electricity users, and then for their electricity demand.

In Appendix 1 can be found the flow diagram used to build the code in Python (Van Rossum, G., & Drake Jr, 1995) for the electricity demand forecasting.

3.3. Solar irradiance

Different specialized software and sources in solar energy information were considered to obtain a TMY for La Guajira. From Meteonorm (https://meteonorm.com/), Solargis (https://solargis.com/), NASA Prediction of Worldwide Energy Sources (https://power.larc.nasa.gov/data-access-viewer/), National Renewable Energy Laboratory NREL (https://maps.nrel.gov/nsrdb-viewer/), and Solcast (https://solcast.com/about-us/), the last one was selected. Solcast offers a wide range of solar and weather data sets with different time frames and formats, with free access for university students.

Following the theoretical background, the solar irradiance data available from the Colombian governmental entities for La Guajira, was used to compare the data obtained from Solcast. The same performance metrics discussed for the electricity demand forecasting were used to evaluate the accuracy of the data obtained. The data is valid if there is a high R^2 coefficient of determination (at least 80%) with a low MAE in contrast with the average and maximum values of the data sets.

With the data source validated, three points of maximum solar irradiance were selected for La Guajira based on the data reported. Solcast was used to get a TMY data set with the next variables with their respective units: GHI (W/m^2), DNI (W/m^2), DHI (W/m^2), Temperature (°C), Wind Speed (m/s), and Pressure (hPa).

3.4. Solar PV Systems: Techno-economic assessment.

3.4.1 Technical assessment

With the locations selected, each scenario proposed in Figure 3 can be then evaluated to cover the demand for the region, found in the first stage of the research. Using the package pvlib from python (*Pvlib Python*, 2021) the performance of the solar PV panels were analyzed to find the best physical arrangement for each scenario, based on the general guidelines for simulation with this library provided in Stein, (2012), *PVPMC,* (2018), Holmgren et al., (2017) and *Pvlib Python*, (2021).

For Scenario 1: Standard Design, and Scenario 3: Individual DC/AC conversion per PV Panel; it is first determined the best tilt and orientation for the PV panels to optimize their exposure to the solar irradiance on each point selected. The TMYs from Solcast were used for this purpose, in combination with the next instructions from pvlib, executed in the order enlisted:

pvlib.solarposition.get_solarposition
pvlib.atmosphere.get_relative_airmass
pvlib.atmosphere.get_absolute_airmass
pvlib.irradiance.aoi
pvlib.irradiance.get_total_irradiance

With the best tilt and orientation for the PV panels it was then determined how much energy a single PV panel can produce in a year. The System Advisor Model (SAM, https://sam.nrel.gov/) is used to selected a PV panel from the market, with the instruction *pvlib.pvsystem.retrieve_sam*.

Then, the instructions *pvlib.pvsystem.sapm_effective_irradiance*, *pvlib.temperature.sapm_cell* and *pvlib.pvsystem.sapm* were used subsequently, to get the generation values in DC. With the value of generation per panel, the demand was then analyzed to determine the amount of PV panels and the size of the battery system, while assuming a fixed efficiency for the inverter in the system based on market information. Several iterations were done in Pyton for this process.

Scenario 3 was analyzed keeping the same sequence and set of instructions for Scenario 1. An additional reference of inverter was selected in the same way done with the PV panels, from the SAM database. Then, the additional instruction *pvlib.pvsystem.snlinverter* was used to get the generation values of the PV panels in AC. Taking then the demand, it was determined the amount of PV panels and inverters, and the size of the battery system.

For Scenario 2: Optimization of performance with sun tracking systems, the approach is very similar to Scenario 1. The only difference in this case is related to the tilt and orientation analysis of the PV panels, as now a Single Axis Tracking system is added. This system was model with the instructions *pvlib.tracking.SingleAxisTracker, pvlib.tracking.singleaxis, and tracker.get_irradiance*.

Deployment strategy

For each scenario, the analysis to cover the electricity demand of the region was done under the same approach. The systems were sized and selected focusing on assuring a ***high reliability*** of the electricity supply. This is, that no matter the conditions, the system under analysis will always be able to provide the electricity required in the region. The next rules guide the programming code for the electricity demand coverage:

1. **Deployment over time***:* The timeframe set for this research from 2022 to 2050, is divided in smaller units based on the average lifecycle of the main components of the systems for the different scenarios: *Battery System (Lithiom-ion), 5 years; PV Panels, 25 years; Inverters, 10 years* (Gevorkian, 2012; IRENA, 2017, 2021). Then, the demand is analyzed for periods of 5 years, with a last period of 4 years from 2047 to 2050. In every one of these periods is established the amount of panels needed, as well as the size of the inverter and the battery systems.
2. **Battery system operation:** When the PV panels are generating less than 30% of their maximum capacity, the battery system will come into operation. This reduces the amount of PV panels needed at low generation times of the day to cover the demand. This value of 30% was determined after several iterations in Python, from 5% to 50%, on the different scenarios.
3. **Amount of PV Panels:** To determine how many panels are needed in the system, first from the TMY of each location analyzed, it is selected the points (hours) where the PV panels produce around 30% of their maximum capacity. The maximum demand in such points is selected. Then, that demand is divided by the energy generated for a panel in that hour, to get the number of panels needed to cover such demand properly. It is then validated if the amount found can cover the electricity demand in all the times of the TMY where the PV panels are generating more than 30% of their maximum value, and the amount of PV panels is adjusted if needed.
4. **Battery sizing:** It is consolidated the amount of energy needed in every period of the TMY where the PV Panels are generating less than 30% in a dataset. Then, the maximum value for such dataset divided by the efficiency of the inverter, will become the size of the battery system.
5. **Additional PV Panels to charge the battery system:** With the high reliability perspective set for the analysis, the charging of the battery system will rely on additional PV Panels to avoid compromising the coverage of the electricity supply. The process to determine the additional PV panels is similar to the one carried out before. It is determined the amount of energy produce for one panel every day of the TMY, then diving the size of the battery system by the lowest value from that dataset, the additional amount of PV panel is found.
6. **Inverter sizing:** the big size inverter or inverter system is selected based on the maximum value of the demand in the period analyzed. This value of demand is divided by the average efficiency of inverters of 80% (IRENA, 2021), to get the value for the inverter.

7. **Single Axis Tracking System:** the electricity to operate this system is provided by additional PV panels for the Scenario 2. The number of panels is determined considering that the system works one time per hour, for 1 min to adjust the angle of the PV panels that controls.

This strategy will for sure oversize the components under assessment as covering the electricity demand on the lowest time of production acceptable for the PV panels without the battery system will demand an amount of PV panels that will generate excess of electricity on other times or regular production.

3.4.2 Economic assessment

The economic assessment was done in a straightforward approach applying the equations provided in the theoretical background to calculated first the investment costs for each scenario proposed, and then to determine the LCOE on each of the geographic locations considered for the region. For the investment costs, the needed market information was collected to project the prices of the different elements to 2050 by year. Excel spreadsheets was the main tool use for this analysis.

4. Results

The results obtained after applying the methodology described are presented for each stage of the research. Each section of this chapter starts with a data collection process that provides the inputs for the respective quantitative analyses needed to get the results presented.

4.1. Residential electricity demand forecasting

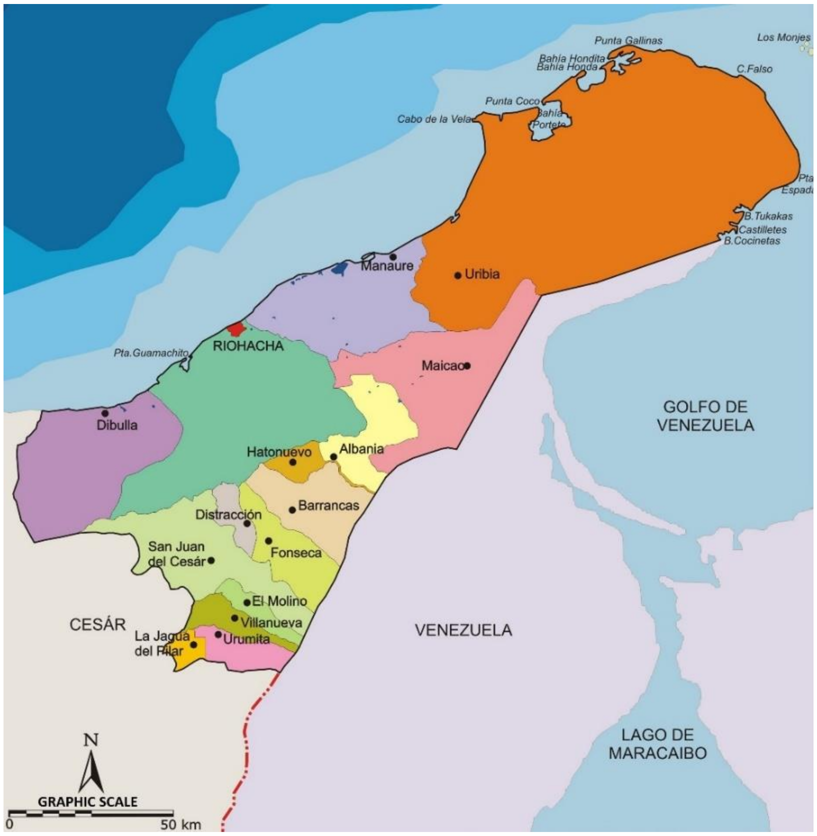
4.1.1 Data collection

a. Population growth

La Guajira covers a territory of 20,848 km^2. It is located between the latitudes 10º 23´00´´N and 12º28´00´´N, and between the longitudes 71º06´00´´W and 73º39´00´´W. There are 15 main municipalities in the territory as shown in the map in Figure 5. The area for each municipality specified covers the town and its respective rural areas. (*Sociedad Geográfica de Colombia [SOGEOCOL], La Guajira*, n.d.)

Figure 5

La Guajira. Administrative and Political divisions map. Adapted from (SOGEOCOL, La Guajira, n.d.)



Note: An additional subdivision is used for the territory, in three big areas as follows: Upper-Guajira (Alta Guajira in Spanish) for Uribia; Medium-Guajira (Media-Guajira in Spanish) for Albania, Maicao, Manuaure, Riohacha and Dibulla; and Lower-Guajira (Baja Guajira in Spanish) for the rest of the municipalities.

According to the census of Colombia for population and housing of 2018 (Departamento Administrativo Nacional de Estadística[DANE], 2021), the reported total population of 825,364 habitants for that year is distributed inside the territory as summarized in Table 1. The projection for both population and housing up to 2050 given in the same census are shown in Figure 6 (A table with the data used for the graphs can be found in Appendix 1).

Table 1

Colombian Census 2018. Main Population Indicators for the Department of La Guajira.

Parameter	**Colombian Census 2018**
Population	
Total	825,364
Urban areas	391,901
Rural Areas	433,463
Men	49%
Women	51%
Indigenous	394,683
Households	
Total	227,367
Urban areas	114,060
Rural areas	113,307

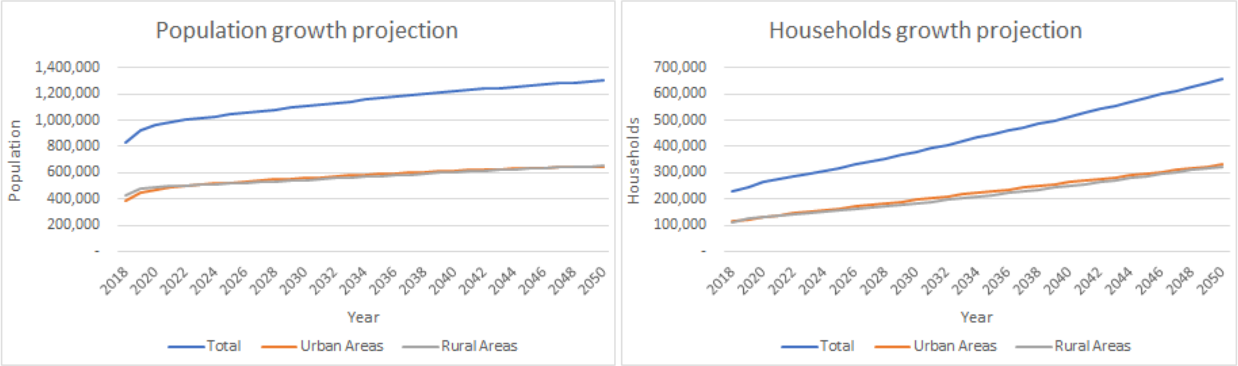
Note: Urban Areas correspond to the geographic delimitation “Municipal Areas” in the census, which are the main towns of the department with an established city hall. Rural areas covered the geographic locations “Populated Centers” and “Dispersed rural” with the households near and far of the stablished towns, inside their delimitated areas in Figure 5.

[a] The indigenous people are distributed 39.27% in the Upper Guajira, 47.07% in the Medium Guajira, and 13.66% in the Lower Guajira. In the case of the Upper Guajira, they account for 96.38% of the total population in that part of the region.

The households’ information reported is related to the houses that are occupied or have temporary occupation for 2018 as well as the projections up to 2050. The census does report empty houses in La Guajira and they account for an additional 5.9% of the total number of houses in the territory. These empty houses were left out of the analysis carried out.

Figure 6

Population and number of households growth projections for La Guajira. Census 2018. (DANE, 2021)



b. Electricity demand determinants

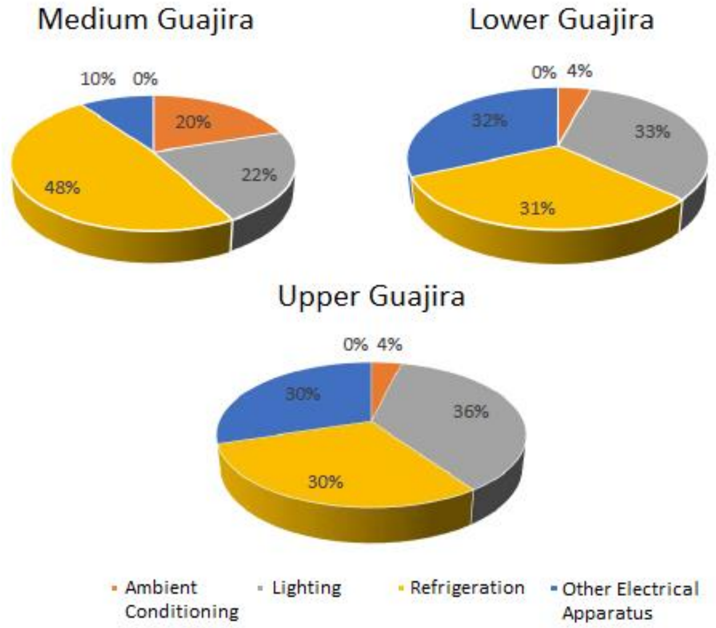
Colombia has carried out several studies to characterize the energy demand across the country through different governmental entities. In 2006, UPME published a study with the Universidad Nacional with an analysis for different cities of the country, consolidating the energy consumption patterns of the main energy sources (Unidad de Planeación Minero Energética UPME et al., 2006). For the case of electricity, the study revealed that the average consumption per household per month for the lower social strata (three out of six strata in the country) was between 111.0 and 176.2 kWh/month/household for the biggest cities across the country. It also showed how the average consumption per person was higher for higher social strata.

Under the same methodology, an study focused on La Guajira was done in 2016 under the energization plan of rural areas by the same entity (UPME, Servicio Nacional de Aprendizaje [SENA], 2016). According to this study, the residential electricity consumption in the region is characterized as follows:

1. **Coverage:** The total electricity coverage of the region is 60.7%. Only 15% of the houses in the Upper Guajira are connected to the SIN, 82% for the Medium Guajira, and 72% for the Lower Guajira.
2. **Stability:** The electric system in the region is anything but stable. There are blackouts of different durations, along the year, across the whole territory. Around 45.38% of the total households experience power outage of random duration, in a frequency between 1 and 5 days. While the same happens for around 17% of the total households every day.
3. **Main usages:** Electricity is consumed in La Guajira mainly for ambient conditioning, refrigeration, lighting, and other electrical apparatus (domestic and non-domestic appliances).
4. **Electricity demand distribution per usage:** Figure 7 shows the consolidation of electricity consumption in La Guajira according to its main usages.

Figure 7

Electricity consumption patterns across La Guajira. Figure translated from (UPME , SENA, 2016)



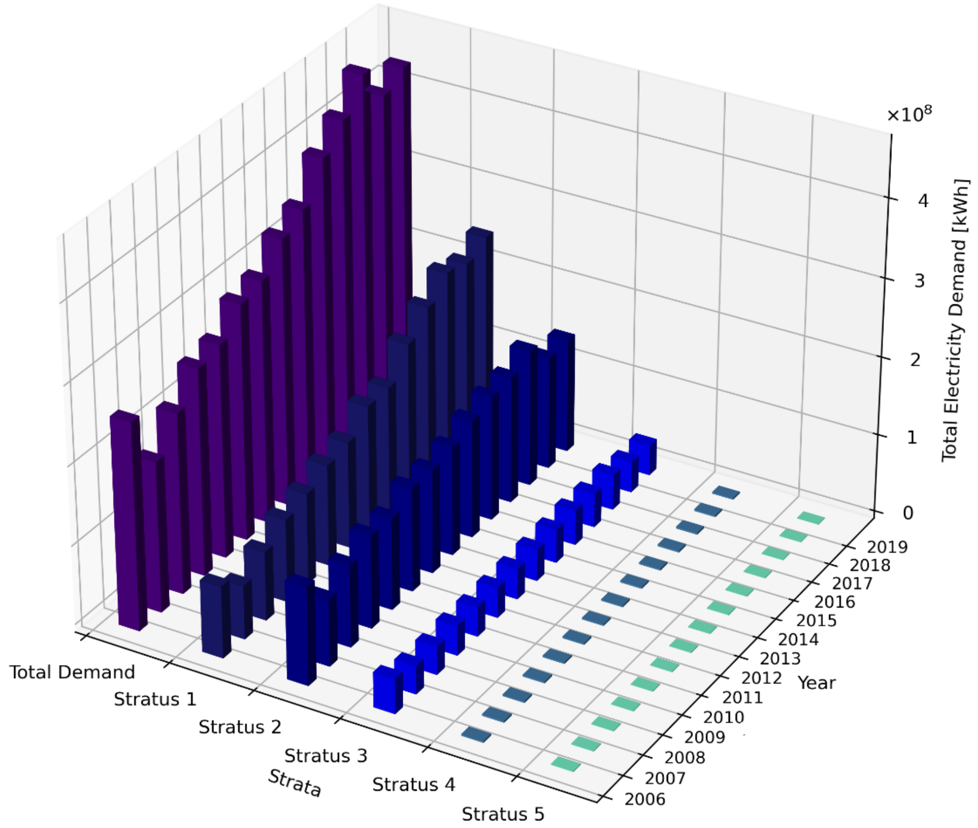
5. **Total consumption:** The average electricity consumption in La Guajira is 29,371,916 kWh/month according to the data from the Unique Information System of Domiciliary Public Services, SUI in Spanish. Contrasting this with information provided in Table 1, the consumption of the region is around 35.59 kWh/person/month and 129.18 kWh/household/month. This consumption is distributed 16% in the Upper Guajira, 52% Medium Guajira and 16% Lower Guajira.

Accounting for economic factors, the energy consumption in La Guajira is distributed in 5 out of the 6 social strata established for the country. The strata are proportional to the amount of wealth of the households. Hence, stratus 1 defines the poverty line with the users with the lowest income level, and next to strata 2 and 3, receive one form of subsidies from the government for different services. La Guajira reflects the same behavior observed in the big cities of the country, with higher average consumption per households and person for the higher social strata.

The electricity consumption or demand, as well as the main services provided and/or monitored by the Colombian government**,** are reported with a monthly resolution by the SUI (SUI [Sistema Único de Información de Servicios Públicos Domiciliarios], n.d.). In Figure 8 is consolidated the annual electricity demand for La Guajira from 2006 to 2019, where it can be clearly seen that the lowest social strata represent the highest electricity demand.

Figure 8

Historic annual electricity demand for La Guajira. Graph generated with the SUI data for the region.



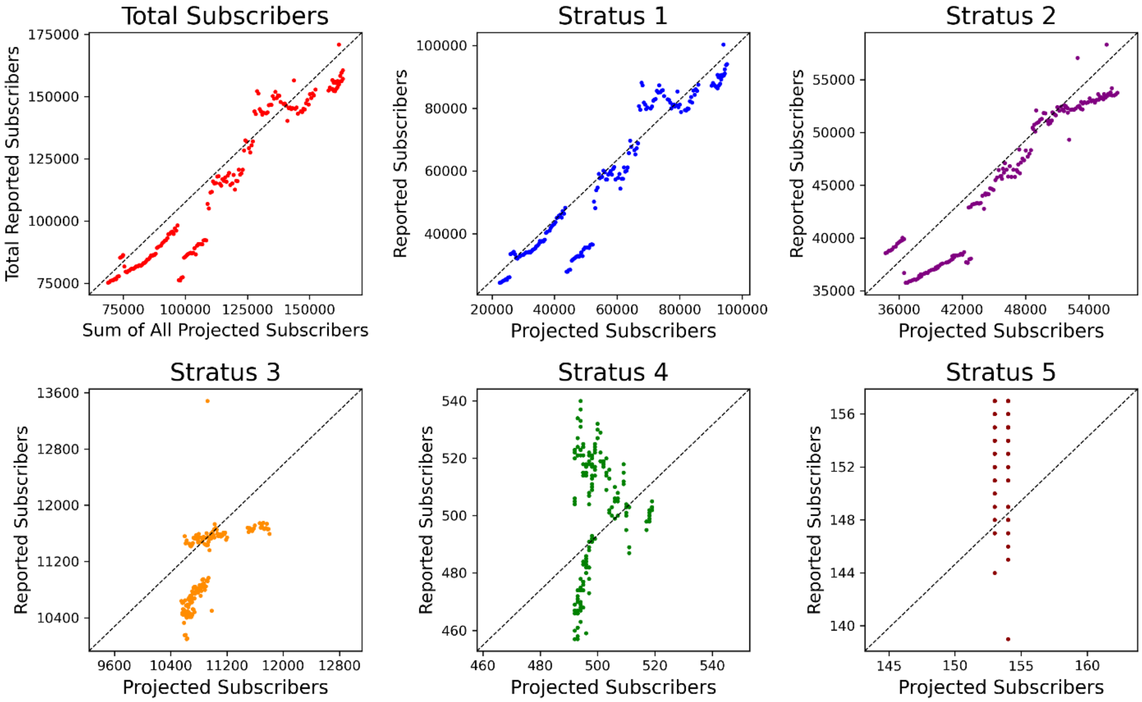
4.1.2 Forecasting

The main challenge for the forecasting process was the availability of data about the electricity demand of the region. The SUI database provided information back to 2006 in a monthly basis, so there were not at least 20 years of information as recommended in the theoretical background. Despise this, and under the lack of any other better sources, both statistical-based methods (Multi Linear Variable and Polynomial) were run using the library Scikit-Learning (Pedregosa et al., 2011) in Python. First, the number of users were forecasted and later the electricity demanded for such users or subscribers (connected households to the grid) as referred to by the SUI. In both cases, the results for the Polynomial method gave a better coefficient of determination R^2, but when use to forecast the subscribers and electricity demand to 2050, it provided negative values, which is an indication of overfitting (Montgomery, D. C., Peck, E. A., & Vining, 2021). This kept on happening after many iterations, with different exponents. Based on this, the results for the Multilinear Linear Variable method were kept instead.

Figure 9 shows the scatterplots of the models obtained to determine the subscribers per social stratus with the Multi Linear Variable method. The graphs show the difference between the values provided by SUI and the ones forecasted with each model. As both axes have the same scale, a 45° line will indicate a perfect fit between the two data sets. When comparing at the end the projection of the total users, with the sums of the individual strata, the highest value of R^2 coefficient was found. For these models, the ***historic population*** and ***number of households*** were used as input, to get the ***electricity subscribers*** reported from 2006 to 2019.

Figure 9

Scatterplots for the Multiple Linear Variable models of the electricity subscribers of La Guajira. 45º lines added as guidelines to the different graphs.



In Table 2 is summarized the final models and their performance indicators. It can be seen how for the models with R^2 coefficients under 80% the MAE is low enough in comparison to the maximum value of the datasets, to accept the performance of the models. For the case of Stratus 3, the MAE is higher than the other cases as a couple of the points are locate far off the diagonal of the model, as can be seen in Figure 9, where these points are in the upper part of the graph for that stratus.

Table 2

Performance metrics for the subscribers' models per social stratus.

Stratus	Model Generated $y = a_0 + a_1x_1 + a_2x_2 + a_3x_3$ y = subscribers x_1 = time(month) x_2 = households x_3 = population	R2 Coefficient $R^2 = 1 - \frac{\sum_{i=1}^{n}(A_i - P_i)^2}{\sum_{j=1}^{n}(A_j - \bar{A}_j)^2}$ A_i values from SUI P_i values forecasted	MAE $MAE = \frac{1}{n}\sum_{i=1}^{n}\lvert A_i - P_i\rvert$ A_i values from SUI P_i values forecasted
Stratus 1	a_0= 40462.444933 ; a_1=382.922 a_2= 0.166947 ; a_3=-0.058614	0.897	5449.340
Stratus 2	a_0= 46950.186062 ; a_1=160.186 a_2= -0.0166435 ; a_3=-0.0162117	0.905	1606.47
Stratus 3	a_0= 11680.931723 ; a_1=-12.525 a_2= 0.0368338 ; a_3=-0.00761408	0.287	307.17
Stratus 4	a_0= 632.253405 ; a_1=-0.202401 a_2= 0.000939475 ; a_3=-0.000357	-0.0006	18.94
Stratus 5	a_0= 153.819673 ; a_1=-0.006568 a_2= 0.000023 ; a_3=-0.0000046	-0.0422	2.27
Total subscribers (sum of all strata)		0.91	6117.57

Adding the number of subscribers per stratus to the analysis, as an additional input with the values of historic population and number of households, the same process was done again for the electricity demand per stratus. The metrics for the models selected are presented in Table 3, and in Appendix 1 in Table A1. 2 can be found the final equations for the models.

Table 3

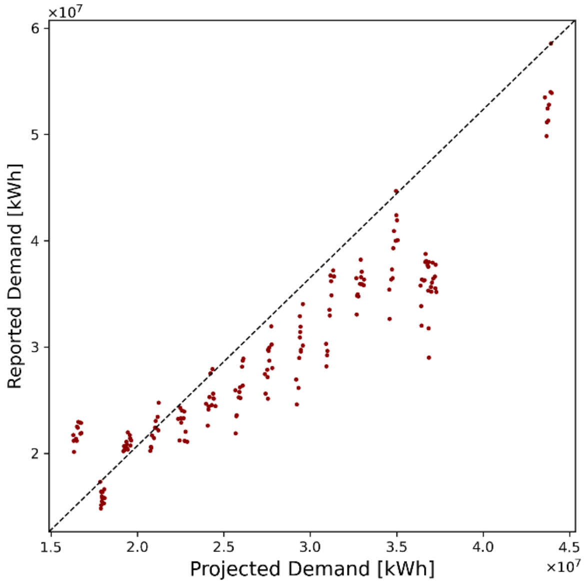
Performance metrics for the electricity demand models per social stratus.

Model	R2 Coefficient	MAE
	$R^2 = 1 - \frac{\sum_{i=1}^{n}(A_i - P_i)^2}{\sum_{j=1}^{n}\left(A_j - \bar{A}_j\right)^2}$	$MAE = \frac{1}{n}\sum_{i=1}^{n}\lvert A_i - P_i\rvert$
Stratus 1	0.84	1590233.68
Stratus 2	0.39	1169088.87
Stratus 3	-4.29	264307.37
Stratus 4	-9.22	17850.70
Stratus 5	-2.98	7742.13
Total Demand	0.83	2796556.04

Each stratus presented similar results to the analysis performed for the electricity subscribers. For the case of stratus 5, as the number of subscribers and electricity demand did not change considerably over the years (Figure 8), the values provided by the SUI per month were kept fixed up to 2050. Figure 10 shows the scatter plots of the total demand obtained by summing the values of all the strata together, which provide a high enough R² coefficient as seems in the final row of Table 3 to accept the results obtained.

Figure 10

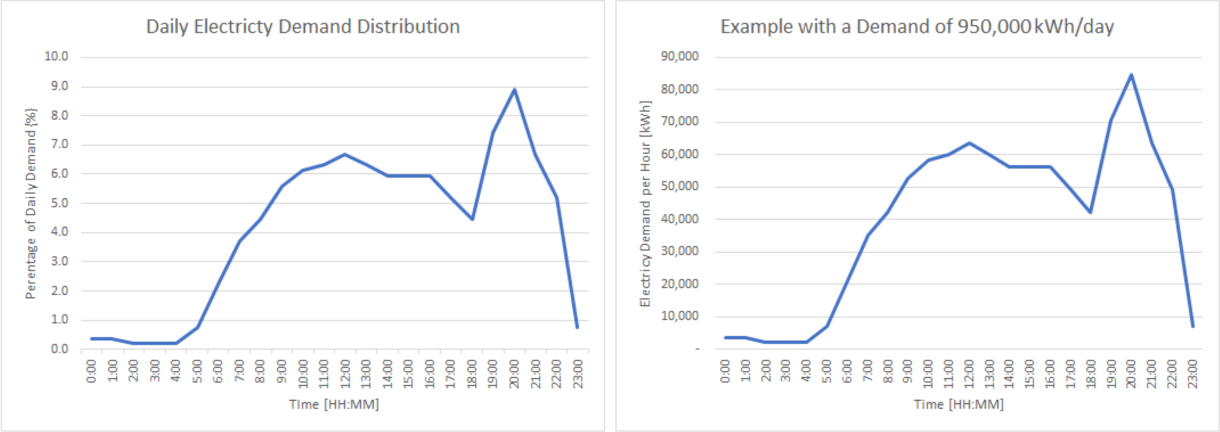
Scatterplot for the sum of all the results from the Multiple Linear Variable models of the electricity demand of La Guajira. 45° line added as a guideline to the graph.



The models selected were then used to forecast the electricity demand from 2022 to 2050 per month, creating a **base scenario** for the total demand of the region. In Appendix 1 can be found the population and households' projection data used for this purpose as input. On a simplistic approach, the projected values were then divided evenly per day on each month, and later per hour based on the daily profile shown in Figure 11. This profile was built based on the average daily consumption graph for Colombia. The table with the data to generate the graphs can be found in Appendix 1 (Table A1. 3)

Figure 11

Daily average electricity demand profile for La Guajira.



Note: Base profile in percentage and example of distribution for a 950,000 kWh/day demand.

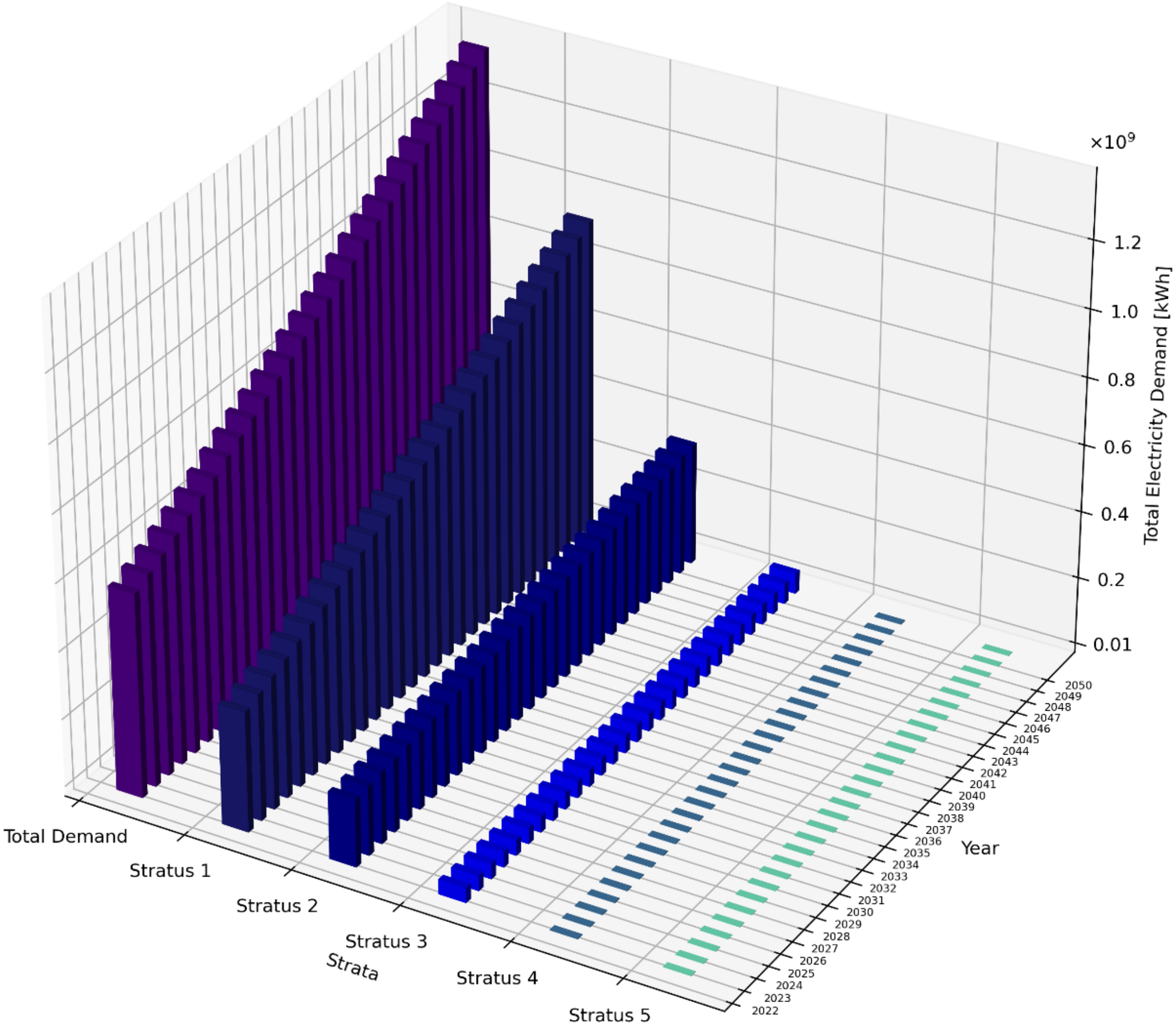
From the base model, there is a difference between the number of final subscribers and the total households in 2050, which reflects the current electricity coverage in the region. Aiming for a positive perspective on the development of the region, and additional model is considered where there will be a total coverage of all the households by 2050. This was done increasing the subscribers in Strata 1, 2 and 3 proportionally per month, from January 2022 to December 2050. These strata were selected as they have the biggest concentration of subscribers.

Lastly, the transmission and distribution losses of the grid were also included in the analysis. According to Pirolli, (2016) the collective losses for distribution and transmission electric systems range between 7% and 10% for developed countries, while for developing countries they could reach up to 50%. The World Bank reported the last value of electric power transmission and distribution losses for Colombia in 11% back in 2014 (World Bank Group, n.d.), which is the additional value added to all the values forecasted.

The electricity demand forecasting is then concluded with a *Base Electricity Demand Model and a Model with Complete Coverage of Households*. Figure 12 shows the results for the Base Model without the addition of the losses of the grid.

Figure 12

La Guajira annual electricity demand projection for the base model, without additional modifications, from 2021



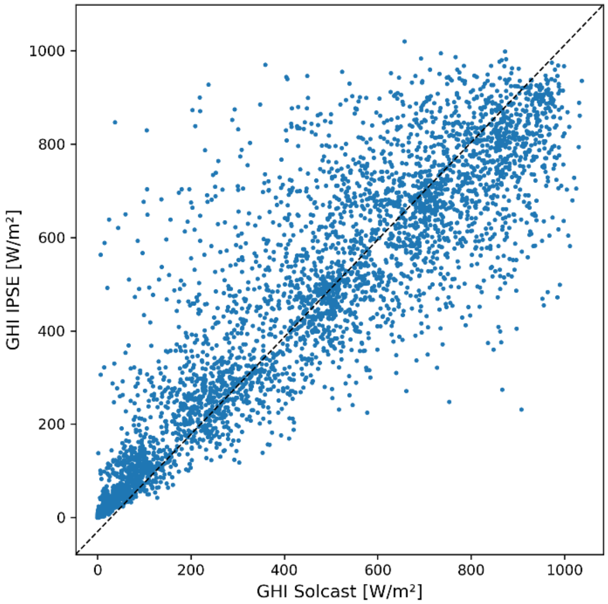
4.2. Solar irradiance assessment

In addition to the IDEAM in Colombia, the Institute of Planning and Promotion of Energy Solutions for the Not Interconnected Zones, IPSE (Instituto de Planificación y Promoción de Soluciones Energéticas para las Zonas No Interconectadas in Spanish, https://ipse.gov.co/) has several meteorological stations around the country to collect data about energy sources, demand, distribution, and transmission among other. One of these stations is in the Upper Guajira, in a small town inside the rural area of Uribia called Nazareth, in latitude 12,175104 and longitude -71,282503 as shown in Figure 15. It was requested to IPSE the available information for solar irradiance from that station. In response, IPSE provided values for GHI from April 2020 to April 2021 with a resolution of 1hour.

From the Solcast website (https://toolkit.solcast.com.au/historical/tmy-p50/request), and with the license enabled as a university student, a TMY was extracted from the location of the Nazareth Station of IPSE. The GHI from this TMY dataset was compared with the data from IPSE obtaining a high enough R^2 coefficient of determination of **0.89604**, and a very low MAE of **48.179 W/m²**, when considered the maximum value of the data set of 1036.4 W/m² and a mean of 232.78 W/m². This good performance of the data by Solcast can also be validated in the scatterplot presented in Figure 13, where most of the points are concentrated around the 45º line.

Figure 13

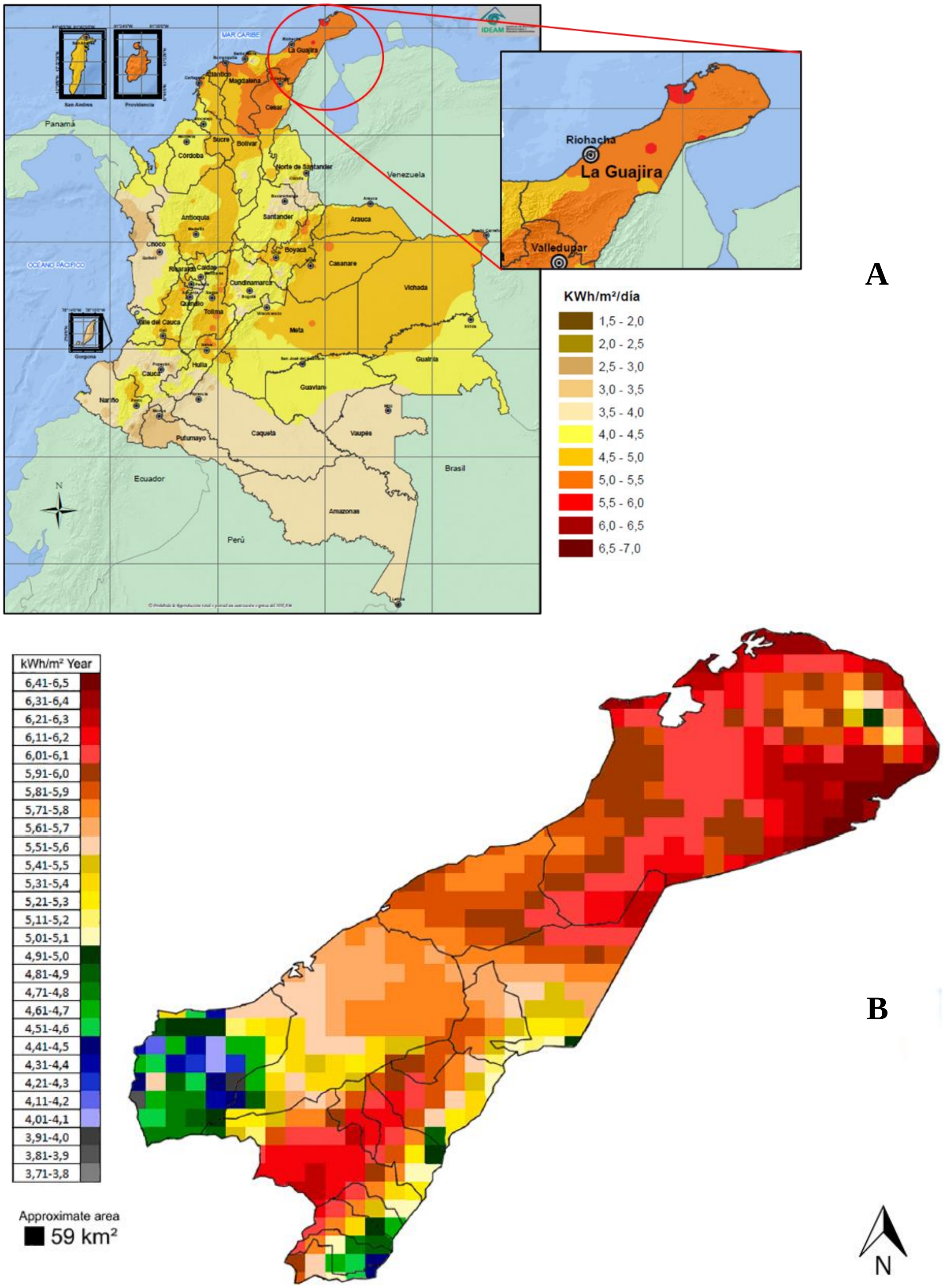
Scatterplot for the GHI provided by Solcast in contrast with the measured values on site by IPSE in the Nazareth Station. Latitude 12,175104 and longitude -71,282503.



With the Solcast data validated, three points were selected for the region to evaluate the PV panels based on the maximum annual irradiance. The points were positioned far apart inside the region, aiming to get different temperature profiles for the solar panels as well. This selection was done base on the work of Carvajal-Romo et al., (2019) and the Atlas of Radiation of the IDEAM (*Atlas Interactivo - Radiación IDEAM*, 2014 n.d.-b). Figure 14 shows the analysis of irradiance provided by these sources, while Figure 15 shows the three points selected. From each of these points, a TYM was generated from Solcast with the variables: GHI (W/m²), DNI (W/m²), DHI (W/m²), Temperature (°C), Wind Speed (m/s), and Pressure (hPa).

Figure 14

Global Horizontal Irradiance for La Guajira.



Note: (A) Global horizontal irradiance of Colombia, annual average. Adapted from *Atlas Interactivo - Radiación IDEAM*, 2014 n.d.-b based on figure in (Carvajal-Romo et al., 2019). La Guajira zoomed-in. (B) Global horizontal irradiance for La Guajira, recalculated with historic data and mathematical models with the software Solargis. Image taken from Carvajal-Romo et al., (2019).

Figure 15

Solar irradiance selected points for the analysis of La Guajira.

Note: Nazareth Station, latitude 12.175104 longitude -71.282503. Point A, latitude 10.999102 longitude -73.069799. Point B, latitude 11.354774 longitude -72.520483. Point C, latitude 11.618547 longitude -72.223852.

4.3. Solar PV systems assessment.

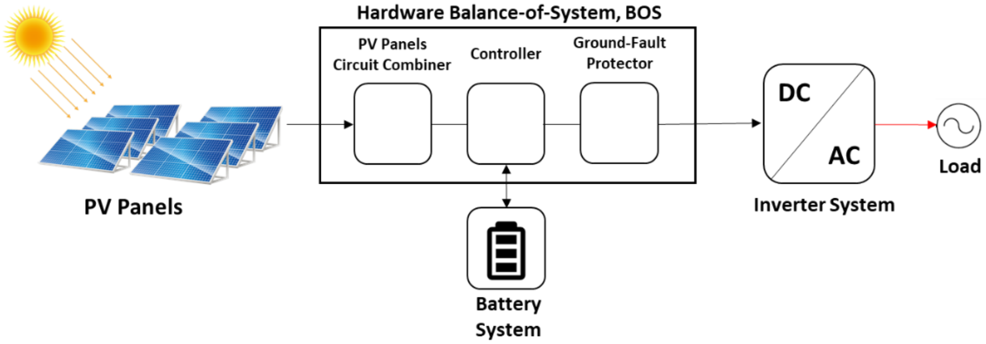
Each scenario proposed in Figure 3 was evaluated on the three points previously selected, obtaining the results presented next.

4.3.1 Scenario 1: Standard design

Figure 16 is an extract of Figure 3 with the architecture or configuration for the first scenario.

Figure 16

Scenario 1. Standard design for a solar farm with energy storage and a large size inverter.



Using the programming language Python(Van Rossum, G., & Drake Jr, 1995) and the library pvlib (*Pvlib Python*, 2021), the tilt and orientation of the PV panels are determined first. With tilt variations between 0º and 90º, and orientations between 0º and 335º (North=0º, East=90º, South=180º and West=270º). In Figure 17 can be seen the consolidated results of the total annual global irradiance for each combination of tilt and orientation. Table 4 shows the best of those combinations with their respective total annual global irradiance per geographic point, which are the final values selected.

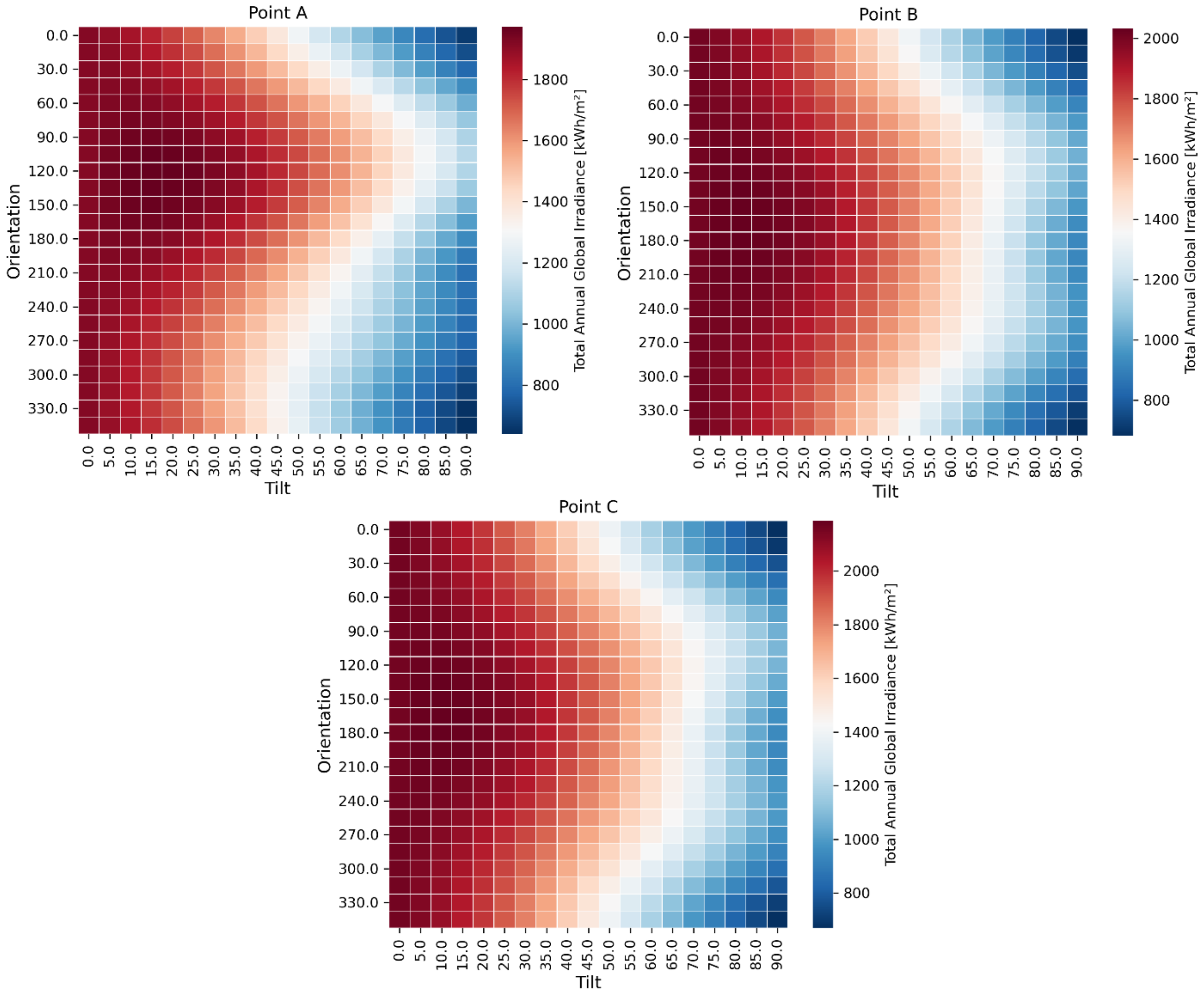
Table 4

Best configuration of tilt and orientation for PV panels in the three points selected for analysis, based on the annual global irradiance.

Point	Coordinates (latitude, longitude)	Orientation(º)	Tilt (º)	Total Annual Global Irradiance (kWh/m²)
A	10.999102 -73.069799	120	15	1972.306
B	11.354774 -72.520483	165	10	2032.394
C	11.618547 -72.223852	165	10	2186.934

Figure 17

Total annual global irradiance for different tilts and orientations on the three points selected for la Guajira.



Fixing then the positioning for the PV panels with the data in Table 4, the next commercial reference (Table 5) is used to assess the electricity generation on each site. This reference was selected based on the maximum power of generation in comparison with other references on the SAM Database.

Table 5

Module SunPower 128-Cell, commercial information.

Parameter	Value
Module Reference	SunPower 128-Cell Module [2009 (E)]
Area	2.144 m²
Material	c-Si
Cells in Series	128 Cells
Isco	5.87 A
Voco	85.3 V
Impo	5.49 A
Vmpo	72.9 V

For each geographic location, the panels can generate the amount of energy presented in Table 6, per year. The PV panels were assessed as established in the methodology, accounting for wind, temperature, and pressure effects, with the respective instructions in the pvlib library. It is included the maximum power reach by the panel, also known as Wpeak, as it is the parameter used for the economical assessment.

Table 6

Total annual energy generation per panel for the three points selected for Scenario 1.

Point	Total Annual DC Generation in a TMY (kWh/year)	Maximum Power Reach in a TMY (Wp)
A	707.56	360.33
B	721.56	345.48
C	778.12	356.38

With the two models of demand built in the first stage of the research, and taking into consideration the losses of the grid (11%), and the technical assumptions for the battery system and inverter in Table 7, the different elements of the system were designed. . Figure 18 and Figure 19 show the evolution of the sizing of the different components from 2022 to 2050 for both demand models. On the other hand, Table 8 shows the final sizing of the components in 2050. A detailed table per period of 5 years can be found in Appendix 2, with the amount of PV panels needed to achieve the solar farm size required based on the maximum power of the PV panels showed in Table 6.

Table 7

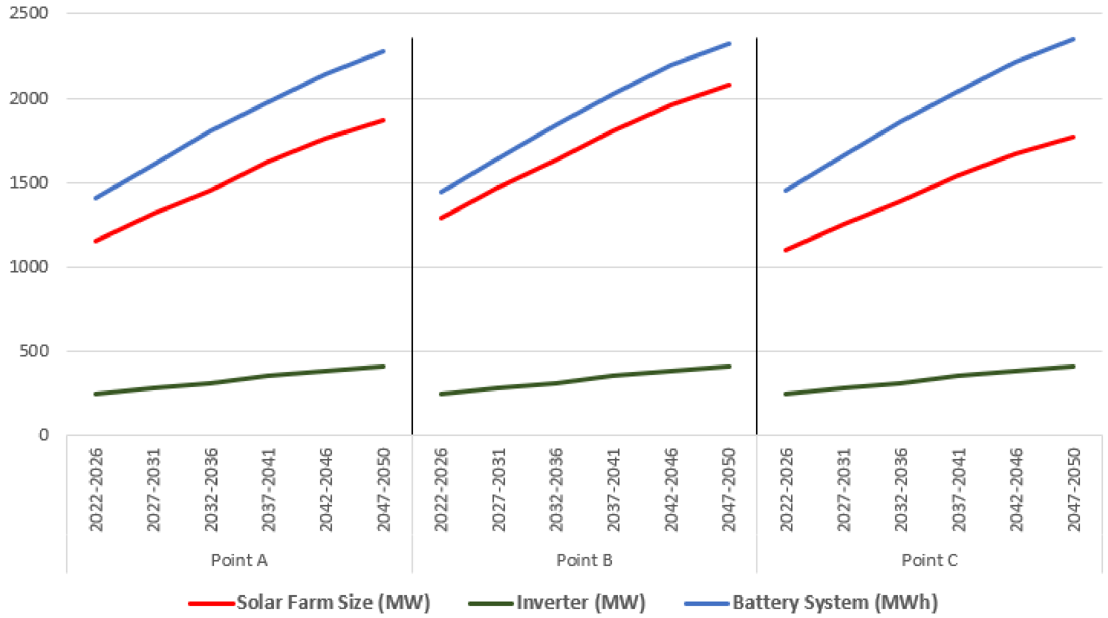
Technical parameters for the battery system and inverters.

Parameters	Value
Inverter	
Efficiency	80%
Battery System	
Minimum State of Charge (SoCmin)	10%
Maximum State of Charge (SoCmax)	100%
Discharging Efficiency	94 %
Charging Efficiency	94 %
Type of Battery	Lithium-Ion

Note: The parameters for the battery system are used for all the scenarios, while the efficiency of the inverter is used in Scenarios 1 and 3. Average values based on Gevorkian (2012); IRENA (2017, 2020b); and Mertens (2018)

Figure 18

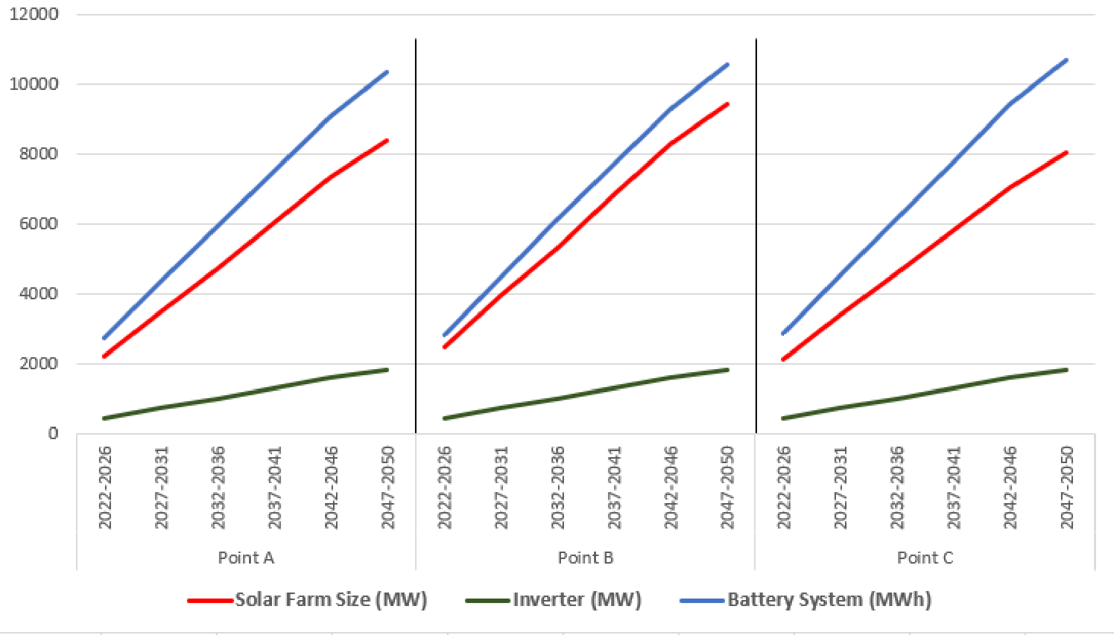
Scenario 1 Results. Evolution of the components sizing from 2022 to 2050 to cover the demand for the Base Model with installations on the different geographic locations.



Note: the components were analyzed on a period of 5 years that is the lifetime of the battery system.

Figure 19

Scenario 1 Results. Evolution of the components sizing from 2022 to 2050 to cover the demand for the Total Coverage Model with installations on different geographic locations.



Note: the components were analyzed on a period of 5 years that is the lifetime of the battery system.

Table 8

Scenario 1 final size of the different components in 2050 for both electricity demand models.

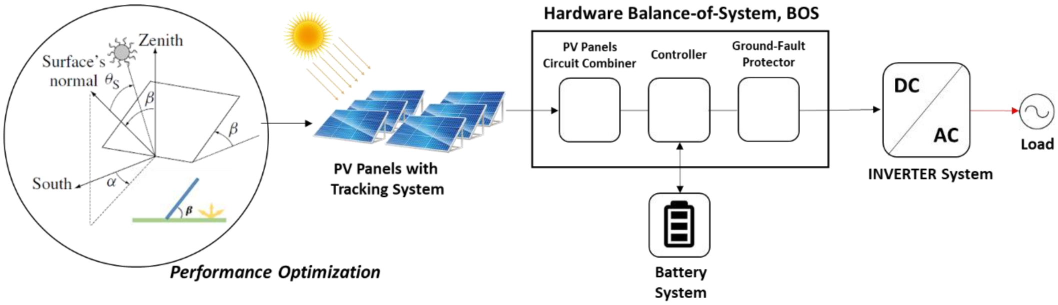
Point	**Base Model**			**Total Coverage Model**		
	Solar Farm Size (MW)	Inverter (MW)	Battery System (MWh)	Solar Farm Size (MW)	Inverter (MW)	Battery System (MWh)
A	1,868	407	2,274	8,396	1,828	10,366
B	2,082	407	2,324	9,449	1,828	10,604
C	1,773	407	2,347	8,041	1,828	10,730

4.3.2 Scenario 2: Optimization of performance with sun tracking systems

Figure 20 is an extract of Figure 3 with the architecture for the second scenario.

Figure 20

Scenario 2, optimization of performance with a single axis sun tracking system. Large-size battery system and inverter.



For this case, the single axis tracking system added to the architecture forced the PV panels to "chase" the sun, to increase the total irradiance absorbed. With the use of the respective instructions in Python, the PV panels were assessed with the orientation set for Scenario 1 as the starting point, and letting then the tracking system to modify their positioning as needed. Table 9 consolidates the annual performance of the PV panels, which has higher values than the ones reported in Table 6 for Scenario 1.

On the other hand, Figure 21 shows how the single axis tracking system behaves along a TMY. The results presented correspond to the geographic location of Point A, but the behavior is similar for the other two points. A simple way to grasp the graphs presented in the figure is to take the Single Axis Tracker Angle as the main guidelines for the tilt and orientation of the PV panels. When the red line is negative, the PV panels are facing South-East with the orientation set in Scenario 1, and the tilt indicated by the black line of the Surface Tilt in the zoomed-in graph. When the red line is positive, the PV panels are facing North-West at 180° from the original orientation, with the tilt once again indicated with the black line in the zoomed-in graph.

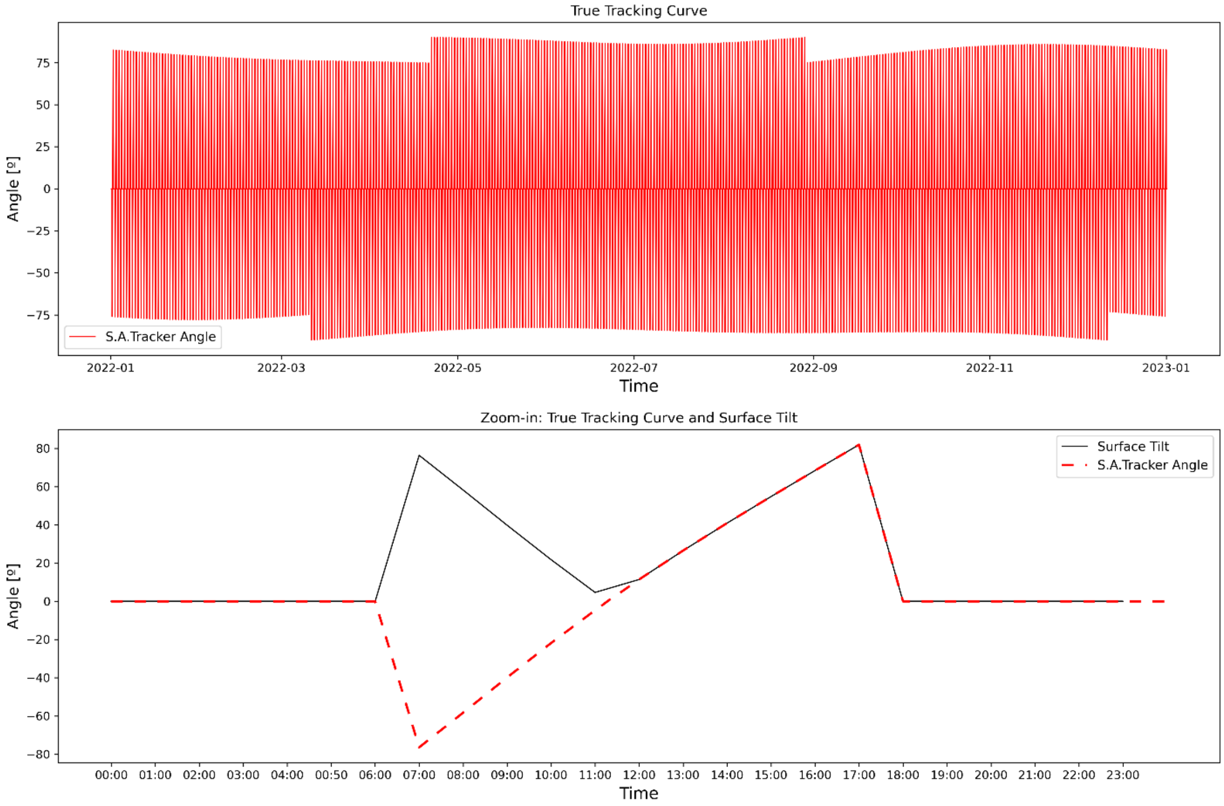
Table 9

Total annual energy generation per panel for the three points selected for Scenario 2.

Point	Total Annual DC Generation in a TMY (kWh/year)	Maximum Power Reach in a TMY (Wp)
A	755.06	368.63
B	862.19	353.73
C	946.16	349.41

Figure 21

Single axis tracking system movements in Point A, along a TMY and zoomed-in section for a day.



Note: [a] The angle reported for the Surface Tilt in the second graph corresponds to the absolute value of the PV Panels tilt with respect to the reference point of installation, while the Single Axis Tracker Angle (S.A. Tracker Angle) shows the full range of motion of the tracking system.

[b] The date selected for the second graph was 05 January 2020.

The deployment strategy was then applied, including the energy consumption to operate the single axis tracking system. For this, different commercial references were taken in consideration: from Soltec (https://soltec.com/) the models SFOne and SF7; from Powerwave (https://www.pvpowerway.com/) the models PowerFit-Plus and PowerFit-Blade; and from PVH (https://pvhardware.com/) the models Monoline and Axone. Table 10 consolidates the main assumptions established based on the commercial references for single axis tracking system.

Table 10

Single axis tracking system main assumptions based on marker information.

Parameter	Value
Operating power	150 W
Number of modules per tracking system	70 PV panels
Angle adjustment time	1 min
Frequency of angle adjustment	1 hour

Same as in Scenario 1, in **Error! Not a valid bookmark self-reference.** and Figure 23 can be found the different components sizing up to 2050, with a frequency revision of 5 years. Table 11 on the other hand, summarizes the final size of the components in 2050. In Appendix 2 can be found a more detailed table with the data used to present the results in this section.

Table 11

Scenario 2 final size of the different components in 2050 for both electricity demand models. The solar farm size includes the panels needed to supply power to the single axis tracking system.

Point	**Base Model**			**Total Coverage Model**		
	Solar Farm Size (MW)	Inverter (MW)	Battery System (MWh)	Solar Farm Size (MW)	Inverter (MW)	Battery System (MWh)
A	1,822	407	2,301.72	8,237	1,828	10,493
B	2,178	407	2,426.17	9,870	1,828	10,944
C	1,752	407	2,293.30	8,003	1,828	10,471

Figure 22

Scenario 2 Results. Evolution of the components sizing from 2022 to 2050 to cover the demand for the Base Model with installations on the different geographic locations. The solar farm size includes the panels needed to supply power to the single axis tracking system.

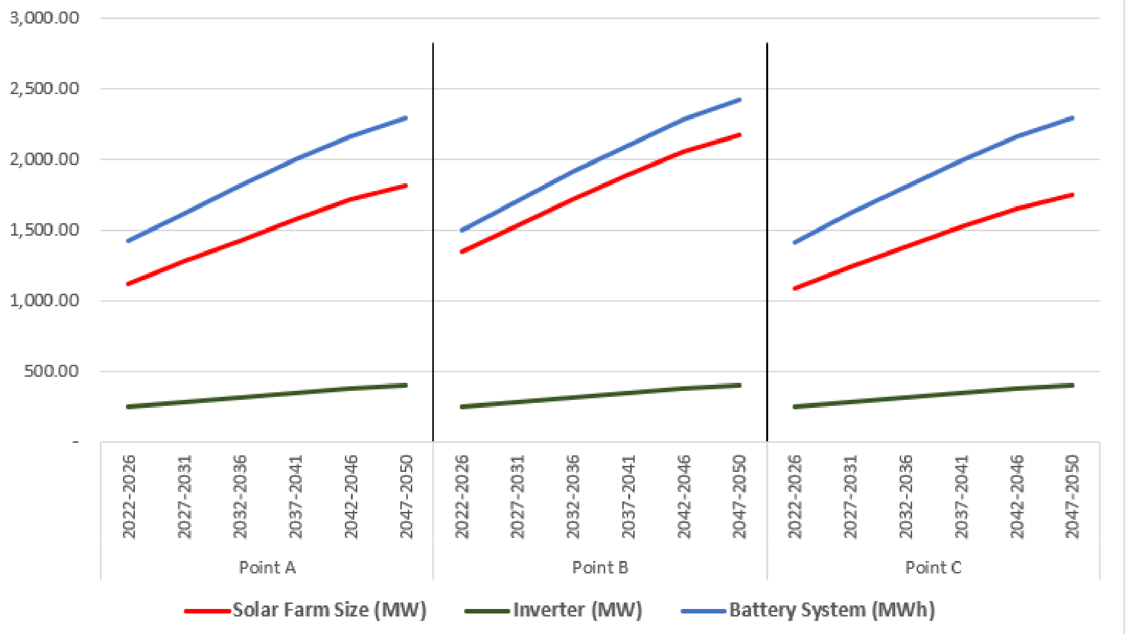
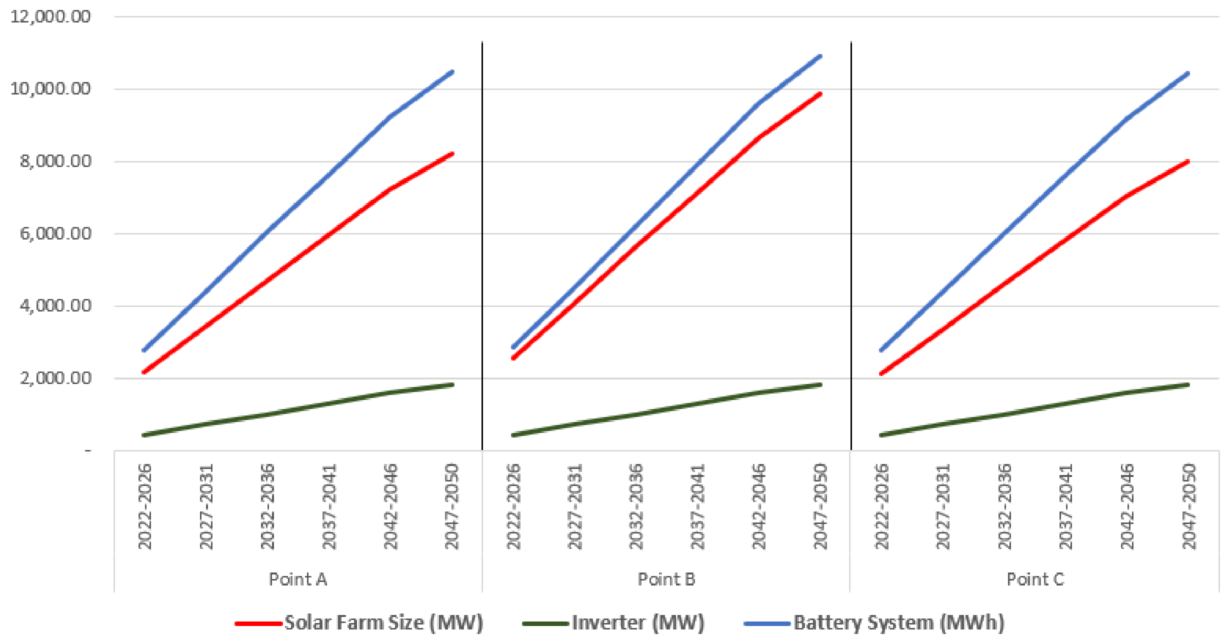


Figure 23

Scenario 2 Results. Evolution of the components sizing from 2022 to 2050 to cover the demand for the Total Coverage Model with installations on different geographic locations. The solar farm size includes the panels needed to supply power to the single axis tracking system.

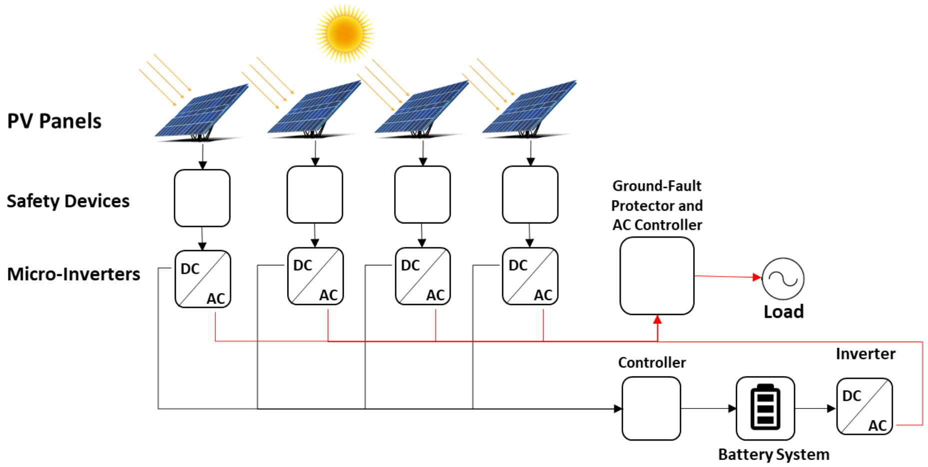


4.3.3 Scenario 3: Individual DC/AC conversion per PV Panel

Lastly, Figure 24 is an extract of Figure 3 with the architecture for the third scenario.

Figure 24

Scenario 3. Individual DC/AC conversion per PV panels.



The solar irradiance assessment for this case is the same as for Scenario 1, so the orientations and tils for the PV panels show in Table 4 were kept. Based on the performance of the panels in DC that is consolidated in Table 6, an inverter was selected to connect to each panel individually as presented in the architecture in Figure 24. Table 12 consolidates the technical information of the inverter selected.

Table 12

Commercial information of the inverter selected from the company Enphsase Energy.

Parameter	Value
Module Reference	D38-72-208 S1x
Vac	208
Paco	380.00
Pdco	401.30
Vdcmax	40.0
Idcmax	12.54

With the inverters added to the system, the respective instructions in Python were added to main code, to evaluate the performance of the duo PV Panels-Inverters. Table 13 consolidates the results obtained. While as before, Figure 25 and Figure 26 show the different components sizing up to 2050, with a frequency revision of 5 years. Table 14 on the other hand, summarizes the final size of the components in 2050. In Appendix 2 can be found a more detailed table with the data used to present the results in this section.

Table 13

Total annual energy generation per panel for the three points selected for Scenario 3, in AC.

Point	**Total Annual DC Generation in a TMY (kWh/year)**	**Maximum Power Reach in a TMY (Wpac)**
A	681.40	351.75
B	694.71	336.87
C	750.46	348.08

Table 14

Scenario 3 final size of the different components in 2050 for both electricity demand models. The solar farm size includes the panels and the inverters.

Point	**Base Model**			**Total Coverage Model**		
	Solar Farm Size (MW)	Inverter Battery System (MW)	Battery System (MWh)	Solar Farm Size (MW)	Inverter Battery System (MW)	Battery System (MWh)
A	1,734	407	2,340	7,788	1,828	10,691
B	1,940	407	2,369	8,812	1,828	10,804
C	1,636	407	2,380	7,425	1,828	10,880

Figure 25

Scenario 3 Results. Evolution of the components sizing from 2022 to 2050 to cover the demand for the Base Model with installations on the different geographic locations. The solar farm size includes the panels and small inverters.

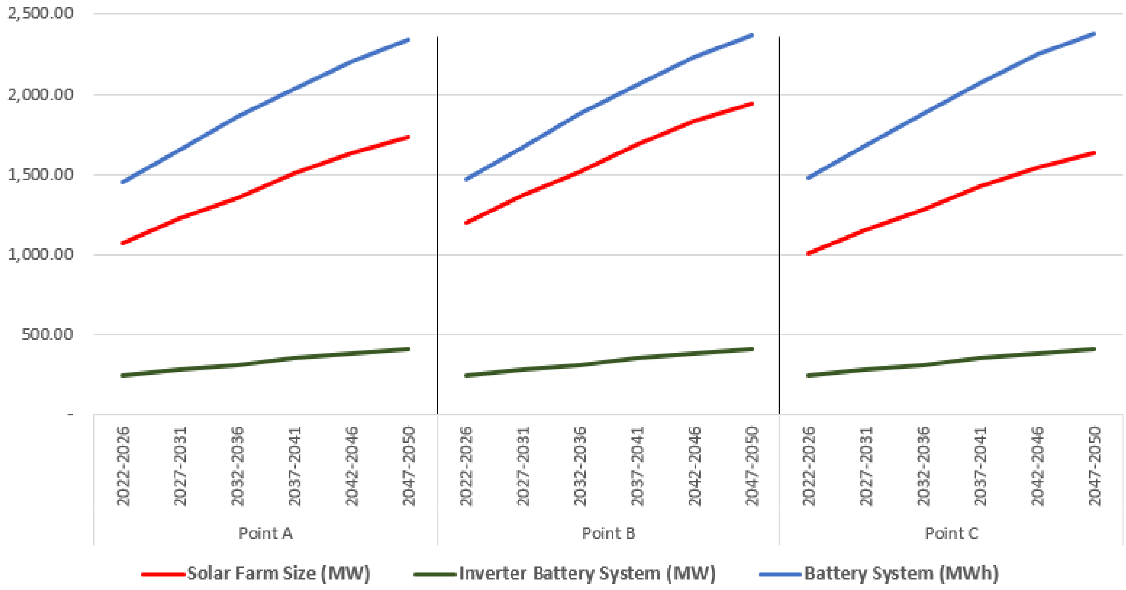
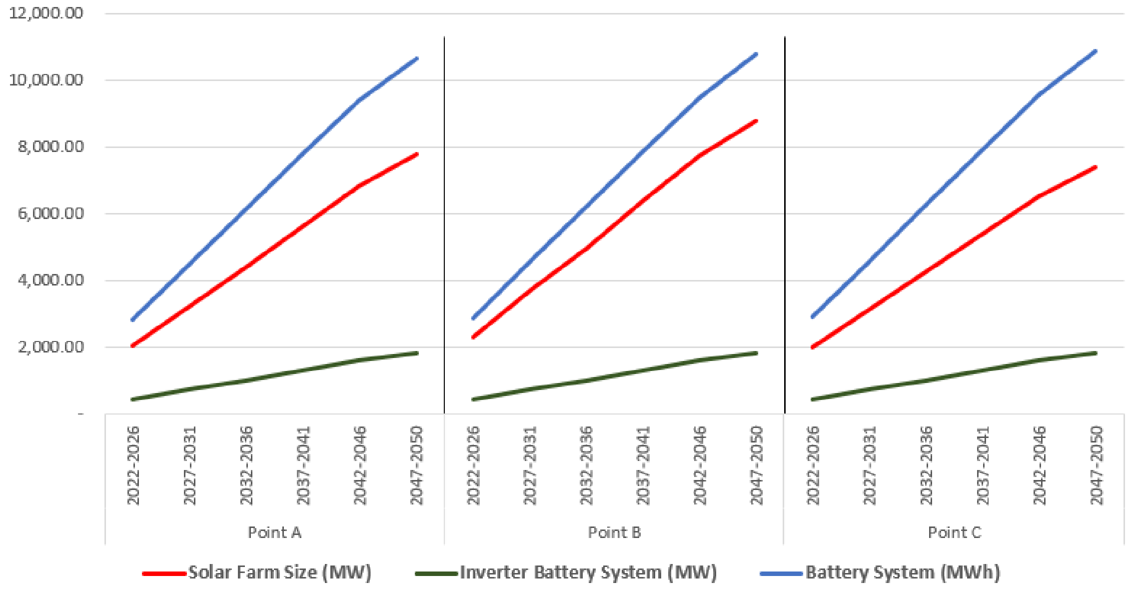


Figure 26

Scenario 3 Results. Evolution of the components sizing from 2022 to 2050 to cover the demand for the Total Coverage Model with installations on different geographic locations. The solar farm size includes the panels needed to supply power to the single axis tracking system.



4.4. Economic analysis

4.4.1 Electricity generation costs

The reports IRENA, (2021) and Vartiainen et al., (2019) were the starting point for the economic assessment. For the different components used in the scenarios analyzed, the price in 2020 was taken and then projected to 2047 with the respective LR, following the deployment strategy established in the methodology. The results are consolidated in Table 15, which were then used to calculate the LCOE.

a. Capital costs

The price for the PV panels and inverters in 2020 were taken from Chile, which is the only country in South America in the report IRENA, (2021). Same for the installation costs that include: racking and mounting, grid connection, cabling/wiring, safety and security, monitoring and control, mechanical installation, electrical installation and inspection. The information for the single axis tracking system was taken from the base model in A. Stein, (2018) an its projection up to 2050. For the battery system, the base costs projection done by Vartiainen et al., s(2019) was taken, as the authors used several sources for their calculations, and the values are close enough to the ones reported by Cole et al., (2020) and IRENA, (2017).

In relation to the LR for the different components, the value reported in IRENA, (2021) for utility-scale solar PV of 34%, was used for PV panels. For the inverters it was taken instead a lower value of 18.9% from Vartiainen et al., (2019) as it was also done in the research by Bernsen et al., (2020). While for the installation costs, the consolidation of a LR for all the elements reported in this segment is a complex task, as different factors affect the labor and the materials used in the infrastructure that supports and connects the solar farms, and there is no detailed-consolidated information available about them for Latin America. The value of 7.5% proposed by Vartiainen et al.,(2019) and also used by Bernsen et al., (2020) was taken for this research for the installation costs. In the case of the battery systems, a LR of 16±5% was found for utility scale system in Schmidt et al., (2019), although, as mentioned before, the projection from Vartiainen et al., (2019) was taken instead.

The cumulative capacity projection for the PV panels, inverters, and installation costs up to 2050 were taken from IRENA, (2019), to predict the future prices of the components with the previous LR, adjusted to South America with the prices for Chile.

b. Operation and maintenance (O&M) costs

The report IRENA, (2021) shows a value for the O&M costs in the United States between 10 USD/kW peryear and 18 USD/kW per year for the period 2018-2020. While for Europe, it was reported a range between 9 USD/kW per year and 10 USD/kW per year. With this, a value of 17.8 USD/kW per year was used as a “all-in” value for the O&M costs in countries members of the Organization of Economic Co-operation and Development-OECD, to estimate the LCOE for that report. For the non-OECD countries, the report used a value of 9 USD/kW.

In this research was used the projection done by Vartiainen et al., (2019), which was one of the sources for IRENA, (2021), with an initial value in 2020 for the PV panels and inverters of 10.39 USD_{2020}/kW and 4.6 USD_{2020}/kWh for the battery system. The sum of the two values gives 14.98USD/kW per year which is between the two values used by IRENA, and it is valid for Colombia, as the country just joined the OECD in April of 2020.

Table 15

Prices for capital costs, and operation and maintenance costs for the components used in the technical assessment.

Year	Cumulative Capacity (GW) for PV Panels, Inverters and Installation Costs	PV Panels (USD$_{2020}$/kW)	Inverters (USD$_{2020}$/kW)	Installation Costs (USD$_{2020}$/kW)	O&M PV Panels + Inverters (USD$_{2020}$/kW/year)	Single Axis Tracking System (USD$_{2020}$/kW)	Battery System (USD$_{2020}$/Wh)	Battery System O&M (USD$_{2020}$/kWh/year)
2020	778	305.00	60.00	390.00	10.39	2000.0	0.296	4.60
2022	1083	250.14	54.29	375.76	9.56	1800.0	0.247	4.25
2027	2080	169.15	44.57	349.16	8.15	1720.0	0.166	3.42
2032	3500	123.82	38.09	329.31	7.20	1680.0	0.125	3.07
2037	4950	100.59	34.30	316.72	6.38	1570.00	0.104	2.72
2042	6370	86.48	31.78	307.86	5.67	1480.00	0.090	2.60
2047	7840	76.36	29.85	300.76	5.19	1410.00	0.081	2.48

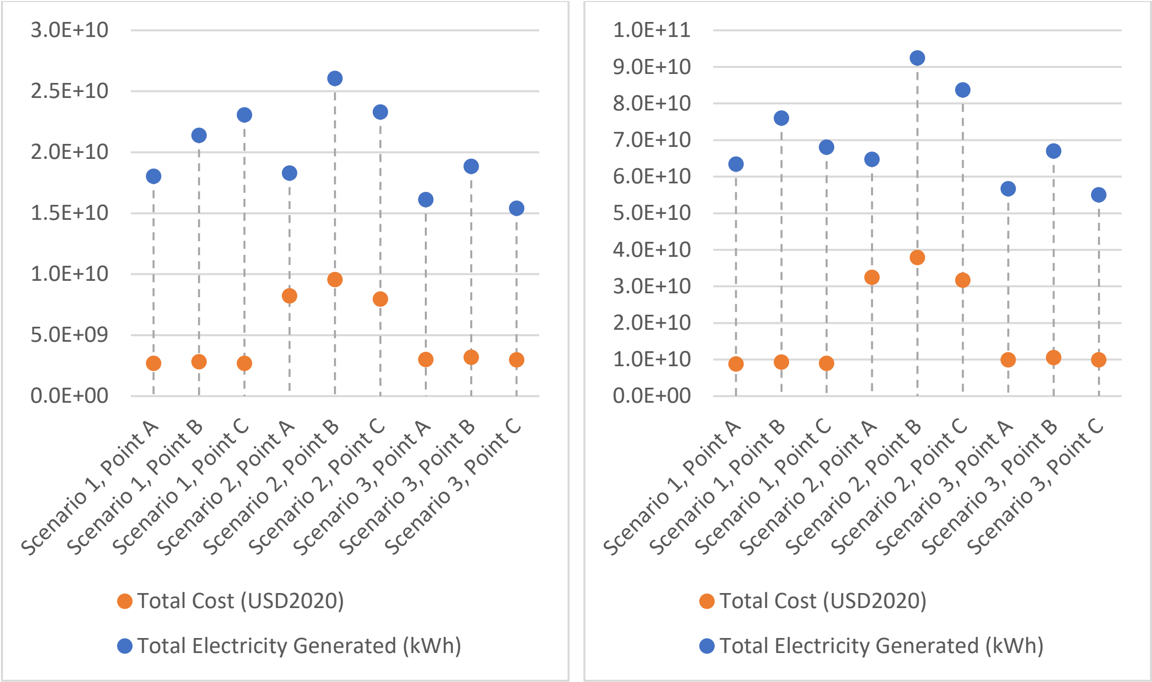
4.4.2 Levelized costs of electricity, LCOE

With the data consolidated in Table 15, and the data for the deployment of each scenario, the LCOE was calculated in each geographic location, for each type of architecture. In Appendix 3 can be found the tables for the calculations carried in Excel. Figure 27 show the consolidated costs and electricity generation per scenario, while Figure 28 shows the LCOE for each case.

In the LCOE calculations it was not included the land prices, as there is not available information about the region (only for minor data about the residential sector).

Figure 27

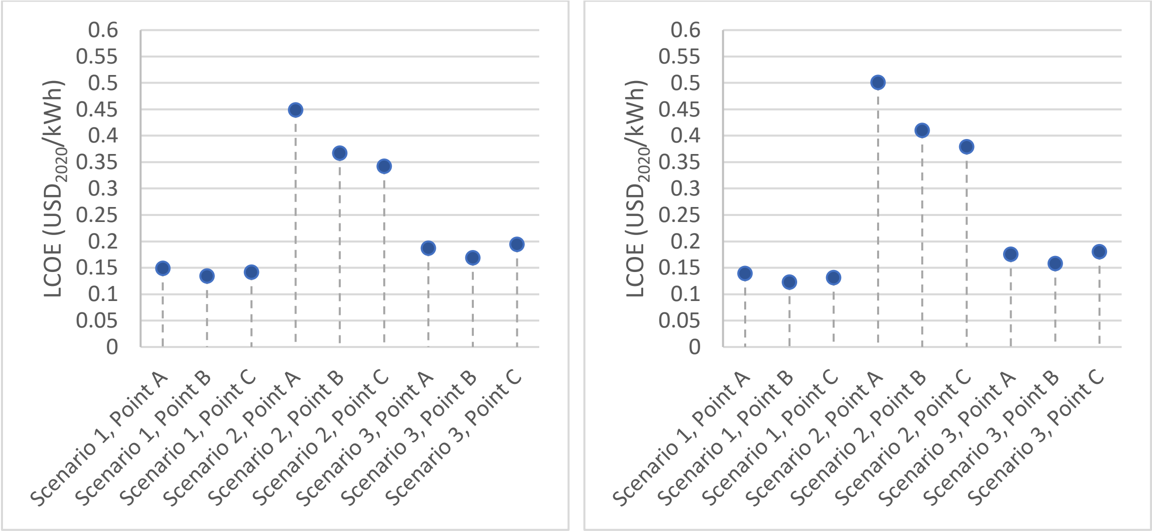
Total generation costs and electricity generated for the base model of demand (A) and total coverage of households' model (B)



A **B**

Figure 28

LCOE for all the scenarios analyzed in the research, with the base demand model (A) and total coverage of households' model (B).



A **B**

5. DISCUSSION

5.1. Key findings

La Guajira, despite its size in comparison to other regions of the country, has an average electricity consumption lower than the average per person and households reported for Colombia. This is related to the characterization of the sector in the region, where intermediate coverage and low reliability definitely play a role in the access of electricity, especially for the indigenous people that live in remote areas and that are a big part of the local demographic.

Beyond the characterization of the region, the lack of data with resolution higher than a month about the electricity consumption, makes it difficult to properly forecast the demand for a period as long as the one set for this research. The forecasted electricity demand for this research, provides a general perspective for the sector that is aligned with the historic behavior reported, with the lower social strata having the biggest demand. These values are sufficient for the type of analysis carried out, but they might come short when trying to implement machine learning techniques to optimize with advanced algorithms the combined operation of the PV panels, inverters and the battery systems, and their subsequent integration to the grid.

To cover the electricity demand of the region with PV systems, the geographic locations selected for the analysis, even though they have similar average year irradiance, the PV panels presented different performance in each one of them. The effects of the temperature over the PV panels were more evident on Point A that is in the middle of the desert in the Upper Guajira; while point C that is at the base of a mountain presented the best results of annual generation per panel for all the scenarios evaluated. This caused the variation reported in the sizing of the different components for all the scenarios.

To put the results obtained in perspective, the current five greatest solar farms worldwide according to NS Energy (https://www.nsenergybusiness.com/features/largest-solar-power-plants/) are Bhadla Solar Park, India – 2.25GW, Huanghe Hydropower Hainan Solar Park, China – 2.2GW, Shakti Sthala solar power project, India – 2GW, and Tengger Desert Solar Park, China – 1.55GW. The last one, covers an area of 43 km² and give electricity to a bit more than 600,000 homes. While in the case of battery system, according to the report of Environmental+Energy Leader (https://www.environmentalleader.com/2021/01/worlds-largest-utility-scale-battery-energy-storage-system-now-online/) The Moss Landing Energy Storage Facility is the largest utility-scale battery energy storage with a maximum capacity of 1,200 MWh and it is about to go up to 1,600 MWh in the near future.

The solar farm sizes by 2050 for the scenarios assessed in this research vary between 1.64 GW and 2.2 GW for the base model of demand; and the battery system between 2,274 MWh and 2,426 MWh. For the total coverage model, the values vary respectively, between 8.0 GW and 9.9 GW for the solar farm, and between 10,366 MWh and 10,944 MWh for the battery system. For 2050 there is a projection of 654,798 households for La Guajira, which would correspond to target of the total coverage model, while 60.7% of that would be the target for the base model. Contrasting this information with the previous paragraph, it is clear to see that despise the use of additional installed capacity of the solar farm to charge the battery systems, the values obtained for the total coverage model are higher than what it is currently manage in the market, while the base model is close enough. This is a clear reflection of the methodology set for high reliability of the system on the coverage of the electricity demand, and it was expected as established at the end of the deployment strategy.

When comparing the final figures for each scenario in the section 4.3 it can be seen that although there is no significant changes in the size of the battery system between locations per scenario, the solar farms do reduce in size for the point C, reflecting once more the effect of the temperature across the region over the performance of the PV panels.

Even though there are minor deviations between the technical performance of the different architectures, the same cannot be said for the economic assessment, as there are visible differences between the LCOE of the different scenarios. Same as before, to put the results obtained in the economic analysis in perspective, IRENA reported a LCOE for solar farms between 0.057 USD_{2020}/kWh and 0.25 USD_{2020}/kWh in the report IRENA, (2021), while the company Lazard reported values between 0.081 USD_{2020}/kWh and 0.140 USD_{2020}/kWh for PV + Storage applications (*Lazard.Com | Levelized Cost of Energy and of Storage*, n.d.).

Scenario 2 has values for LCOE almost four times of those handle by the market. In spite of the fact that this architecture generated the two highest values of electricity generation, it is not enough to overcome the impact of the investment costs for the single axis tracking system, to consider this scenario as a valid choice. In the case of Scenarios 1 and 3, their LCOE are close to one another, and their value decrease with the increase of the sizing from the base model to the total coverage model as it should be expected from utility-scale applications. Scenario 3 has slightly greater values of LCOE than Scenario 1, but this is not enough to disregard this choice. In Scenario 3, every kW produced by the PV panels is put directly into the grid, while for Scenario 1 the inverter of the system serves a curtailment of the electricity production. If there is a case where the solar farm is generating more than the inverter capacity, the additional electricity would be curtailed.

Finally, based on the deployment strategy set, it is important to note that the LCOE calculated was done with a second investment in PV panels that take place almost at the end of the period of the assessment. Those PV panels will have 21 years more to produce electricity after 2050.

5.2. Limitations

This research was carried out adhered to the next limitations:

- Standard PV panels were considered exclusively, special designs like Bi-Facial panels were left out of the scope.
- Only residential electricity consumption was taken into account, no industrial applications.
- Due to the current changes in the energy landscape of Colombia (UPME, 2019), no electricity price schemes were included, so there was no calculation of NPV or IRR, only LCOE.
- No DC-DC conversion was considered.
- Due the lack of information, land prices were not included in the economic analysis.
- It was assumed that there are no operation restrictions over the plant from the grid administrator.

5.3. Further research

This research serves as a general guideline to assess the performance of solar applications in combination with battery storage in La Guajira, and beyond that, shows the extensive potential of this type of applications in the region. There are several ways to extend the results obtained, the first one is to lift one or more of the limitations previously indicated, and add them accordingly to the analysis, updating the respective results.

In relation to the economic assessment, only the technical elements of the system were considered for this research, but the socio-economic situation of Colombia and even more of La Guajira discussed throughout this report, calls for the inclusion of additional factors. A good way to aboard this is with the elaboration of a risk assessment. This will help identify the main threads in case the solar farm is decided to be built and help create the respective mitigation and prevention plans.

Also, a revision over the electricity demand forecasting with more detailed data, if possible, will not only help improve the demand models built, but it would also open the door for the implementation of more advanced algorithms to balance de operation of PV panels and battery systems, allowing to reduce the sizing initially found.

6. Conclusions

With the current plan of Colombia to improve its energy infrastructure, La Guajira has an important opportunity to improve their electric system with the increase of the use of renewable sources like solar energy.

La Guajira has had an annual electricity demand between 300 GWh and 400 GWh for the last six years. This demand can growth up to 1,200 GWh by 2050, if the current electricity coverage of 60.7% of the region is kept. If the electric system improve, and there is an increment in the coverage of the service, this demand will be higher.

To cover the demand of the region up to 2050 with PV Panels and battery storage, two main configurations are recommended to be used. The first one consists in several arrays of PV Panels connected to an inverter big enough to support the maximum power demanded for the region, and a battery system also connected to the inverter. The second choice is similar, but it also adds a microinverter to each PV panel while keeping the big inverter connected to the battery system. Whichever the configuration selected, the system should growth over time starting in 2022 with a solar farm of around 1 GW and a battery system of 1.5 GWh; and it should reach around 1.8 GW for the solar farm and 2.4 GWh for the battery system by 2050.

The investment and operation costs for solar applications and battery storage will change up to 2050 based on the technological advances in the manufacturing process of the equipment, and their market growth. Based on current projections it would be possible to cover the electricity demand of La Guajira from 2022 to 2050 with just PV panels and battery storage with a LCOE of around 0.15 USD_{2020}/kWh, without including land prices. If the demand increases as a consequence of the improvement in the coverage of the electric system in the region, the generation capacity can be increased keeping the LCOE close the value indicated. As a rule of thumb, the greater the whole system, the lower the LCOE will be.

Beyond answering the main research question (and taking the 43 km^2 of area of the Tengger Desert Solar Park as a reference) this research also allows to establish that with the use of only one square of the highest irradiance of 59 km^2 showed in Figure 14 (B) a Solar PV Farm with Battery Storage can covered all the demand for the region.

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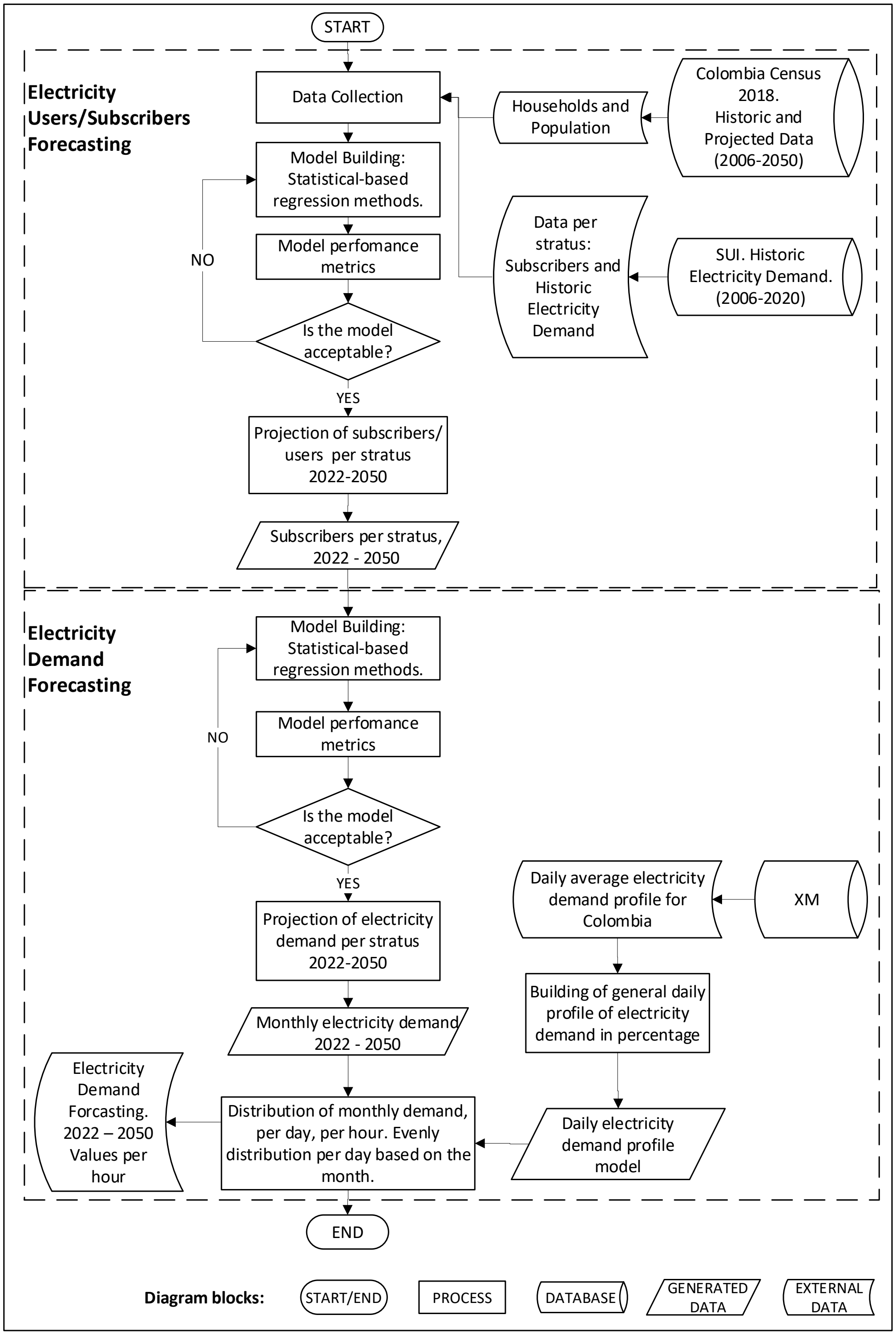
8. APPENDICES

8.1. Appendix 1. Electrical Demand Forecasting

Electricity forecasting models flow diagram for Python programming

Figure A1. 1

Method to create the Electricity Demand Forecasting of La Guajira from 2022 to 2050.



Population growth information

In December 2020, the National Administrative Department of Statistic of Colombia (DANE in Spanish) published the consolidated and updated results of the population and housing census carried out in 2018 (Departamento Administrativo Nacional de Estadística, 2021). For La Guajira, the statistics in Table A1.1 consolidates the parameters that are aligned with the scope of this research and play a role as electricity demand determinants, and their projections up to 2050.

Table A1.1

Colombian Census 2018. Main Population Indicators for the Department of La Guajira, projections up to 2050. (Departamento Administrativo Nacional de Estadística, 2021).

Year	***Parameter***					
	Population			***Households***		
	Total	Urban Areas	Rural Areas	Total	Urban Areas	Rural Areas
2018	825,364	391,901	433,463	227,367	114,060	113,307
2019	927,506	445,158	482,348	246,878	119,712	127,166
2020	965,718	473,082	492,636	263,124	130,358	132,766
2021	987,781	488,775	499,006	275,760	138,195	137,565
2022	1,002,394	498,687	503,707	286,706	144,647	142,059
2023	1,015,909	507,830	508,079	297,699	151,027	146,672
2024	1,028,951	516,373	512,578	307,773	157,585	150,188
2025	1,041,773	524,492	517,281	319,146	164,106	155,040
2026	1,054,530	532,290	522,240	330,819	170,679	160,140
2027	1,067,267	539,793	527,474	342,819	177,301	165,518
2028	1,080,009	547,010	532,999	355,111	183,972	171,139
2029	1,092,773	553,942	538,831	367,747	190,687	177,060
2030	1,105,667	560,644	545,023	380,687	197,395	183,292
2031	1,118,510	567,136	551,374	393,852	204,096	189,756
2032	1,131,012	573,379	557,633	407,017	210,748	196,269
2033	1,143,153	579,365	563,788	420,171	217,343	202,828
2034	1,154,917	585,085	569,832	433,283	223,871	209,412
2035	1,166,347	590,570	575,777	446,376	230,351	216,025
2036	1,177,490	595,853	581,637	459,534	236,824	222,710
2037	1,188,328	600,925	587,403	472,823	243,326	229,497
2038	1,198,846	605,781	593,065	486,271	249,878	236,393

2039	1,209,031	610,416	598,615	499,898	256,478	243,420
2040	1,218,918	614,852	604,066	513,677	263,136	250,541
2041	1,228,542	619,116	609,426	527,589	269,833	257,756
2042	1,237,896	623,206	614,690	541,629	276,571	265,058
2043	1,246,971	627,117	619,854	555,742	283,320	272,422
2044	1,255,758	630,844	624,914	569,914	290,072	279,842
2045	1,264,279	634,402	629,877	584,148	296,845	287,303
2046	1,272,526	637,788	634,738	598,399	303,601	294,798
2047	1,280,462	640,982	639,480	612,629	310,350	302,279
2048	1,288,079	643,983	644,096	626,746	317,077	309,669
2049	1,295,364	646,781	648,583	640,830	323,769	317,061
2050	1,302,329	649,384	652,945	654,798	330,376	324,422

Note: Urban Areas correspond to the geographic delimitation “Municipal Areas” in the census, which are the main town of the department with an established city hall. Rural areas covered the geographic locations “Populated Centers” and “Dispersed rural” with the households near and far of the stablished towns.

Demand models equations

Final equations of electricity demand generated with multi linear variable method, using in addition to the number of households and population, all the users of the electric system of La Guajira. For Stratus 5 the model generated was discarded as the electricity demand for the stratus showed little variation across the data set from SUI. Instead, the values of demand for Stratus 5 were kept up to 2050, repeating the information from 2006 to 2019 cyclically.

Table A1. 2

Equations for the multi linear variable models generated for the demand

Stratus	Model Generated $y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_6 + a_7x_7 + a_8x_8$ y = electricity demand (kWh) x_1 = time(month) x_2 = households x_3 = population x_4 = Subscribers Stratus 1 x_5 = Subscribers Stratus 2 x_6 = Subscribers Stratus 3 x_7 = Subscribers Stratus 4 x_8 = Subscribers Stratus 5
Stratus 1	a_0= -34295832.215 a_1= 21607.6 a_2= 25.1823 a_3= 29.1383 a_4= 73.5368 a_5= -118.241 a_6= 1842.88 a_7=-36403.1 a_8=118953
Stratus 2	a_0= -29367578.011 a_1= 18079.4 a_2= -82.5253 a_3= 39.7261 a_4= 14.8569 a_5= 93.8408 a_6= 1471.77 a_7=-23791.7 a_8=87292.3
Stratus 3	a_0= -1348484.381 a_1= 8867.43 a_2= -22.5637 a_3= 4.3961 a_4= 8.28652 a_5= -15.3078 a_6= 642.817 a_7=-7539.43 a_8=8854.83
Stratus 4	a_0= 135058.643 a_1= 886.288 a_2= -1.03319 a_3= -0.147794 a_4= 0.770871 a_5= -1.89886 a_6= 19.3946 a_7=-60.8268 a_8=741.255

Daily electricity demand profile

Based on the average daily electricity demand profile of Colombia shown in Figure A1. 2, Table A1. 3 was made to replica the same profile in percentage, based on knowing the total demand of a day.

Figure A1. 2

Average daily electricity demand profile for Colombia (*Histórico de Demanda*, n.d.)

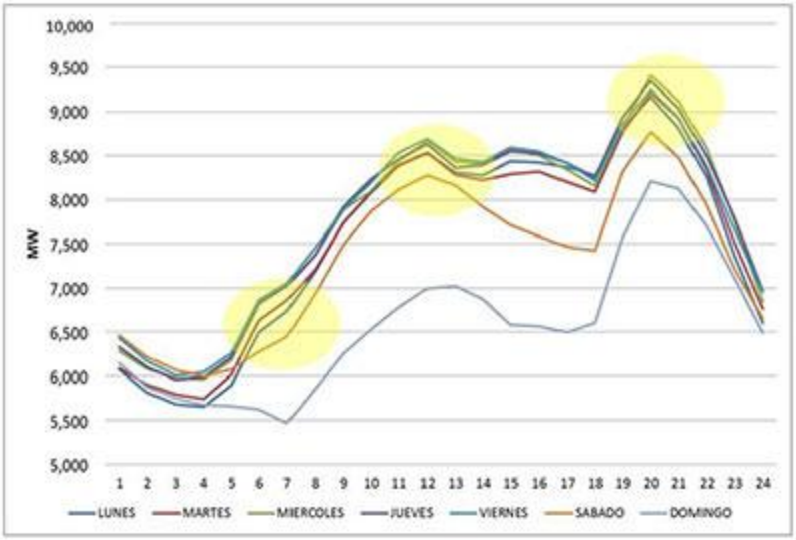


Table A1. 3

Distribution of consumption of the Total Daily Demand per day to replicate the average profile of daily demand for Colombia.

Hour	*Percentage of Total Daily Demand*
0:00	0.37%
1:00	0.37%
2:00	0.22%
3:00	0.22%
4:00	0.22%
5:00	0.74%
6:00	2.23%
7:00	3.71%
8:00	4.46%
9:00	5.57%
10:00	6.13%
11:00	6.31%
12:00	6.68%
13:00	6.31%
14:00	5.94%
15:00	5.94%

16:00	5.94%
17:00	5.20%
18:00	4.46%
19:00	7.43%
20:00	8.91%
21:00	6.68%
22:00	5.20%
23:00	0.74%
TOTAL	100%

8.2. Appendix 2. Solar PV systems technical assessment

Scenario 1. Consolidated results

Point A								
Period	Base Model of Demand				Total Coverage of Households			
	PV Panels (Amount)	Solar Farm Size (MW)	Inverter (MW)	Battery System (MWh)	PV Panels (Amount)	Solar Farm Size (MW)	Inverter (MW)	Battery System (MWh)
2022-2026	3,206,729	1,155.49	251.82	1,406.75	6,155,797	2,218.13	468.09	2,753.20
2027-2031	3,656,608	1,317.59	287.16	1,602.64	9,690,633	3,491.85	749.49	4,367.81
2032-2036	4,038,651	1,455.26	314.89	1,801.54	13,236,481	4,769.53	1,003.75	5,974.89
2037-2041	4,501,802	1,622.15	353.76	1,974.49	16,841,929	6,068.69	1,320.44	7,552.65
2042-2046	4,889,394	1,761.81	384.10	2,143.73	20,438,181	7,364.54	1,602.96	9,120.45
2047-2050	5,185,095	1,868.36	407.45	2,274.21	23,300,812	8,396.04	1,828.07	10,366.21

Point B								
Period	Base Model of Demand				Total Coverage of Households			
	PV Panels (Amount)	Solar Farm Size (MW)	Inverter (MW)	Battery System (MWh)	PV Panels (Amount)	Solar Farm Size (MW)	Inverter (kW)	Battery System (MWh)
2022-2026	3,731,660	1,289.22	251.82	1,440.85	7,193,903	2,485.36	468.09	2,840.91
2027-2031	4,255,067	1,470.04	287.16	1,642.11	11,438,060	3,951.63	749.49	4,475.38
2032-2036	4,716,894	1,629.60	314.89	1,840.61	15,433,514	5,331.98	1,003.75	6,127.43
2037-2041	5,234,584	1,808.45	353.76	2,018.90	19,859,076	6,860.93	1,320.44	7,718.60
2042-2046	5,684,922	1,964.03	384.10	2,193.38	24,030,165	8,301.96	1,602.96	9,326.30
2047-2050	6,027,127	2,082.26	407.45	2,324.17	27,348,970	9,448.55	1,828.07	10,603.66

Point C								
Period	**Base Model of Demand**				**Total Coverage of Households**			
	PV Panels (Amount)	Solar Farm Size (MW)	Inverter (MW)	Battery System (MWh)	PV Panels (Amount)	Solar Farm Size (MW)	Inverter (kW)	Battery System (MWh)
2022-2026	3,078,893	1,097.26	251.82	1,455.52	6,059,799	2,159.61	468.09	2,881.69
2027-2031	3,509,610	1,250.76	287.16	1,658.38	9,534,046	3,397.77	749.49	4,533.84
2032-2036	3,904,068	1,391.34	314.89	1,856.55	12,994,361	4,630.96	1,003.75	6,179.37
2037-2041	4,321,368	1,540.06	353.76	2,040.83	16,433,508	5,856.62	1,320.44	7,814.83
2042-2046	4,691,322	1,671.91	384.10	2,215.19	19,847,691	7,073.37	1,602.96	9,438.42
2047-2050	4,973,828	1,772.59	407.45	2,347.12	22,563,519	8,041.25	1,828.07	10,729.91

Scenario 2. Consolidated results

Point A

Period	Base Model of Demand						Total Coverage of Households					
	PV Panels (Amount)	Solar Farm Size (MW)	Inverter (kW)	Battery System (MWh)	Tracking System Additional PV	Tracking System Additional Sizing	PV Panels (Amount)	Solar Farm Size (MW)	Inverter (kW)	Battery System (MWh)	Tracking System Additional PV	Tracking System Additional Sizing (MW)
2022-2026	3,048,735	1,123.86	251.82	1,427.20	10,830	3.99	5,862,851	2,161.23	468.09	2,790.43	20,827	7.68
2027-2031	3,473,356	1,280.39	287.16	1,624.24	12,339	4.55	9,279,555	3,420.73	749.49	4,416.61	32,965	12.15
2032-2036	3,859,296	1,422.66	314.89	1,823.45	13,710	5.05	12,688,205	4,677.27	1,003.75	6,038.96	45,074	16.62
2037-2041	4,276,574	1,576.48	353.76	1,998.67	15,192	5.60	16,139,048	5,949.36	1,320.44	7,635.20	57,332	21.13
2042-2046	4,645,005	1,712.29	384.10	2,171.72	16,501	6.08	19,550,454	7,206.91	1,602.96	9,227.43	69,451	25.60
2047-2050	4,925,393	1,815.65	407.45	2,301.72	17,497	6.45	22,265,223	8,207.66	1,828.07	10,492.78	79,095	29.16

Point B

Period	Base Model of Demand						Total Coverage of Households					
	PV Panels (Amount)	Solar Farm Size (MW)	Inverter (kW)	Battery System (MWh)	Tracking System Additional PV	Tracking System Additional Sizing	PV Panels (Amount)	Solar Farm Size (MW)	Inverter (kW)	Battery System (MWh)	Tracking System Additional PV	Tracking System Additional Sizing (MW)
2022-2026	3,799,774	1,344.09	251.82	1,502.41	14,067	4.98	7,287,023	2,577.63	468.09	2,872.34	26,977	9.54
2027-2031	4,331,636	1,532.22	287.16	1,712.47	16,036	5.67	11,600,646	4,103.48	749.49	4,528.82	42,946	15.19
2032-2036	4,843,208	1,713.18	314.89	1,915.24	17,930	6.34	15,900,951	5,624.62	1,003.75	6,232.04	58,866	20.82
2037-2041	5,326,386	1,884.09	353.76	2,106.46	19,719	6.98	20,172,861	7,135.71	1,320.44	7,923.73	74,681	26.42
2042-2046	5,787,188	2,047.09	384.10	2,288.98	21,424	7.58	24,422,396	8,638.89	1,602.96	9,606.70	90,413	31.98
2047-2050	6,133,681	2,177.69	407.45	2,426.17	22,707	8.03	27,799,874	9,833.60	1,828.07	10,944.26	102,916	36.40

Point C												
Period	Base Model of Demand						Total Coverage of Households					
	PV Panels (Amount)	Solar Farm Size (MW)	Inverter (kW)	Battery System (MWh)	Tracking System Additional PV	Tracking System Additional Sizing	PV Panels (Amount)	Solar Farm Size (MW)	Inverter (kW)	Battery System (MWh)	Tracking System Additional PV	Tracking System Additional Sizing (MW)
2022-2026	3,097,576	1,082.31	251.82	1,421.75	11,609	4.06	6,129,922	2,141.84	468.09	2,812.04	22,974	8.03
2027-2031	3,529,744	1,233.32	287.16	1,620.00	13,229	4.62	9,644,372	3,369.81	749.49	4,424.26	36,145	12.63
2032-2036	3,947,458	1,379.27	314.89	1,811.81	14,794	5.17	13,144,731	4,592.86	1,003.75	6,030.01	49,264	17.21
2037-2041	4,344,144	1,517.87	353.76	1,993.77	16,281	5.69	16,622,160	5,807.89	1,320.44	7,626.05	62,297	21.77
2042-2046	4,715,121	1,647.49	384.10	2,164.18	17,671	6.17	20,073,824	7,013.93	1,602.96	9,210.55	75,233	26.29
2047-2050	4,996,311	1,745.74	407.45	2,293.30	18,725	6.54	22,819,563	7,973.31	1,828.07	10,470.94	85,523	29.88

Scenario 3. Consolidated results

Point A								
Period	Base Model of Demand				Total Coverage of Households			
	PV Panels + Inverters (Amount)	Solar Farm Size (MW)	Inverter for the Battery System (kW)	Battery System (MWh)	PV Panels + Inverters (Amount)	Solar Farm Size (MW)	Inverter for the Battery System (kW)	Battery System (MWh)
2022-2026	2,975,309	1,072.10	251.82	1,451.28	5,707,092	2,056.45	468.09	2,839.55
2027-2031	3,392,827	1,222.55	287.16	1,651.08	8,980,436	3,235.94	749.49	4,504.48
2032-2036	3,743,648	1,348.96	314.89	1,858.31	12,261,374	4,418.17	1,003.75	6,162.54
2037-2041	4,177,350	1,505.23	353.76	2,031.73	15,620,183	5,628.46	1,320.44	7,787.76
2042-2046	4,536,834	1,634.77	384.10	2,207.71	18,957,267	6,830.92	1,602.96	9,405.43
2047-2050	4,811,409	1,733.71	407.45	2,339.74	21,613,920	7,788.20	1,828.07	10,690.83

Point B								
Period	Base Model of Demand				Total Coverage of Households			
	PV Panels + Inverters (Amount)	Solar Farm Size (MW)	Inverter for the Battery System (kW)	Battery System (MWh)	PV Panels + Inverters (Amount)	Solar Farm Size (MW)	Inverter for the Battery System (kW)	Battery System (MWh)
2022-2026	3,477,727	1,201.49	251.82	1,468.45	6,728,055	2,324.41	468.09	2,891.53
2027-2031	3,965,491	1,370.00	287.16	1,673.57	10,682,272	3,690.52	749.49	4,557.51
2032-2036	4,399,358	1,519.89	314.89	1,875.12	14,425,026	4,983.57	1,003.75	6,237.02
2037-2041	4,877,855	1,685.21	353.76	2,057.66	18,527,539	6,400.91	1,320.44	7,863.29
2042-2046	5,297,599	1,830.22	384.10	2,235.47	22,413,735	7,743.52	1,602.96	9,501.95
2047-2050	5,616,251	1,940.31	407.45	2,368.82	25,505,549	8,811.68	1,828.07	10,803.97

Point C								
Period	**Base Model of Demand**				**Total Coverage of Households**			
	PV Panels + Inverters (Amount)	Solar Farm Size (MW)	Inverter for the Battery System (kW)	Battery System (MWh)	PV Panels + Inverters (Amount)	Solar Farm Size (MW)	Inverter for the Battery System (kW)	Battery System (MWh)
2022-2026	2,841,846	1,012.78	251.82	1,476.08	5,595,400	1,994.10	468.09	2,921.98
2027-2031	3,239,292	1,154.43	287.16	1,681.83	8,803,393	3,137.38	749.49	4,597.23
2032-2036	3,604,875	1,284.71	314.89	1,882.50	11,998,524	4,276.07	1,003.75	6,265.76
2037-2041	3,988,364	1,421.38	353.76	2,069.72	15,174,108	5,407.79	1,320.44	7,924.08
2042-2046	4,329,755	1,543.05	384.10	2,246.56	18,326,641	6,531.30	1,602.96	9,570.37
2047-2050	4,590,275	1,635.89	407.45	2,380.39	20,834,338	7,425.00	1,828.07	10,879.92

8.3. Appendix 3 LCOE calculations

Scenario 1. LCOE calculations. Base model of demand.

Point A

Base Model

Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter (MW)	Inverter Deployment (MW)	Cost(USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	1,155.49	1,155.49	289,037,364	251.82	251.82	13,671,733	450,641	55,248,946	1,406.75	1,406.75	416,651,215	5,978,913
2027-2031	1,317.59	162.10	27,419,678	287.16	35.35	1,575,445	60,910	53,666,363	1,602.64	1,602.64	395,244,063	5,487,036
2032-2036	1,455.26	137.67	17,046,585	314.89	314.89	11,993,089	48,069	52,401,439	1,801.54	1,801.54	299,739,726	5,529,926
2037-2041	1,622.15	166.89	16,787,541	353.76	38.87	1,333,009	54,959	51,707,978	1,974.49	1,974.49	246,969,459	5,361,496
2042-2046	1,761.81	139.66	12,077,226	384.10	384.10	12,207,068	44,233	49,919,829	2,143.73	2,143.73	222,605,235	5,567,961
2047-2050	1,868.36	1,868.36	142,658,694	407.45	23.36	697,132	575,199	48,527,288	2,274.21	2,274.21	203,951,063	5,638,355
	Total Cost Solar Farm (USD)		**505,027,089**	Total Cost Inverter (USD)		**41,477,477**	**1,234,012**	**311,471,842**	Total Cost Battery System (USD)		**1,785,160,762**	**33,563,687**
	Total Cost (USD)										**2,677,934,869**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	3,206,729	2,268,953,171
2027-2031	3,656,608	2,587,269,556
2032-2036	4,038,651	2,857,587,902
2037-2041	4,501,802	3,185,295,023
2042-2046	4,889,394	3,459,539,619
2047-2050	5,185,095	3,668,765,818
	Total Electricity (kWh)	18,027,411,089

LCOE (USD_{2020}/kWh) 0.14854794

Point B

Base Model

Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter (MW)	Inverter Deployment (MW)	Cost(USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	1,289.22	1,289.22	322,488,214	251.82	251.82	13,671,733	502,795	61,643,012	1,440.85	1,440.85	426,751,249	6,123,847
2027-2031	1,470.04	180.83	30,587,420	287.16	35.35	1,575,445	67,947	59,875,928	1,642.11	1,642.11	404,976,428	5,622,147
2032-2036	1,629.60	159.55	19,756,108	314.89	314.89	11,993,089	55,710	58,679,002	1,840.61	1,840.61	306,241,191	5,649,872
2037-2041	1,808.45	178.85	17,990,802	353.76	38.87	1,333,009	58,898	57,646,468	2,018.90	2,018.90	252,523,512	5,482,070
2042-2046	1,964.03	155.58	13,454,195	384.10	384.10	12,207,068	49,276	55,649,660	2,193.38	2,193.38	227,760,787	5,696,915
2047-2050	2,082.26	2,082.26	158,990,806	407.45	23.36	697,132	641,049	54,082,877	2,324.17	2,324.17	208,431,476	5,762,219
	Total Cost Solar Farm (USD)		**563,267,546**	Total Cost Inverter (USD)		**41,477,477**	**1,375,676**	**347,576,947**	Total Cost Battery System (USD)		**1,826,684,643**	**34,337,071**
	Total Cost (USD)										**2,814,719,360**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	3,731,660	2,692,616,590
2027-2031	4,255,067	3,070,286,145
2032-2036	4,716,894	3,403,522,035
2037-2041	5,234,584	3,777,066,431
2042-2046	5,684,922	4,102,012,318
2047-2050	6,027,127	4,348,933,758
	Total Electricity (kWh)	21,394,437,276

LCOE (USD_{2020}/kWh) 0.13156314

Point C

Base Model

Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter (MW)	Inverter Deployment (MW)	Cost(USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	1,097.26	1,097.26	274,472,567	251.82	251.82	13,671,733	427,933	52,464,912	1,455.52	1,455.52	431,095,914	6,186,193
2027-2031	1,250.76	153.50	25,964,975	287.16	35.35	1,575,445	57,679	50,944,498	1,658.38	1,658.38	408,989,182	5,677,855
2032-2036	1,391.34	140.58	17,406,658	314.89	314.89	11,993,089	49,085	50,099,864	1,856.55	1,856.55	308,892,623	5,698,789
2037-2041	1,540.06	148.72	14,959,659	353.76	38.87	1,333,009	48,975	49,091,279	2,040.83	2,040.83	255,267,517	5,541,640
2042-2046	1,671.91	131.85	11,401,433	384.10	384.10	12,207,068	41,758	47,372,447	2,215.19	2,215.19	230,025,330	5,753,557
2047-2050	1,772.59	1,772.59	135,345,867	407.45	23.36	697,132	545,713	46,039,731	2,347.12	2,347.12	210,489,363	5,819,111
	Total Cost Solar Farm (USD)		**479,551,159**	Total Cost Inverter (USD)		**41,477,477**	**1,171,143**	**296,012,729**	Total Cost Battery System (USD)		**1,844,759,928**	**34,677,144**
	Total Cost (USD)										**2,697,649,581**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	3,078,893	2,395,748,221
2027-2031	3,509,610	2,730,897,733
2032-2036	3,904,068	3,037,833,392
2037-2041	4,321,368	3,362,542,868
2042-2046	4,691,322	3,650,411,475
2047-2050	4,973,828	3,870,235,043
	Total Electricity (kWh)	19,047,668,733

LCOE (USD_{2020}/kWh) 0.14162623

Scenario 1. LCOE calculations. Total coverage model.

Point A

Total Coverage of Households

Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter (MW)	Inverter Deployment (MW)	Cost(USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	2,218.13	2,218.13	554,849,861	468.09	468.09	25,413,599	865,072	106,058,502	2,753.20	2,753.20	815,443,368	11,701,549
2027-2031	3,491.85	1,273.72	215,452,730	749.49	281.40	12,543,077	478,608	142,225,482	4,367.81	4,367.81	1,077,189,795	14,954,253
2032-2036	4,769.53	1,277.68	158,205,507	1,003.75	1,003.75	38,229,303	446,120	171,742,806	5,974.89	5,974.89	994,102,697	18,340,293
2037-2041	6,068.69	1,299.16	130,683,093	1,320.44	316.69	10,862,115	427,830	193,446,898	7,552.65	7,552.65	944,685,712	20,508,320
2042-2046	7,364.54	1,295.85	112,059,496	1,602.96	1,602.96	50,944,137	410,422	208,669,827	9,120.45	9,120.45	947,067,632	23,688,730
2047-2050	8,396.04	8,396.04	641,079,863	1,828.07	225.10	6,718,837	2,584,828	218,072,002	10,366.21	10,366.21	929,641,623	25,700,527
	Total Cost Solar Farm (USD)		**1,812,330,550**	Total Cost Inverter (USD)		**144,711,068**	**5,212,881**	**1,040,215,518**	Total Cost Battery System (USD)		**5,708,130,828**	**114,893,672**
	Total Cost (USD)										**8,825,494,516**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	6,155,797	4,355,595,725
2027-2031	9,690,633	6,856,704,285
2032-2036	13,236,481	9,365,604,496
2037-2041	16,841,929	11,916,675,283
2042-2046	20,438,181	14,461,239,348
2047-2050	23,300,812	16,486,722,539
	Total Electricity (kWh)	63,442,541,677

LCOE (USD_{2020}/kWh) 0.13911004

Point B

Total Coverage of Households

Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter (MW)	Inverter Deployment (MW)	Cost(USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	2,485.36	2,485.36	621,693,544	468.09	468.09	25,413,599	969,289	118,835,545	2,840.91	2,840.91	841,419,539	12,074,305
2027-2031	3,951.63	1,466.27	248,024,602	749.49	281.40	12,543,077	550,964	160,952,686	4,475.38	4,475.38	1,103,717,476	15,322,527
2032-2036	5,331.98	1,380.35	170,918,159	1,003.75	1,003.75	38,229,303	481,968	191,995,665	6,127.43	6,127.43	1,019,482,136	18,808,520
2037-2041	6,860.93	1,528.95	153,797,468	1,320.44	316.69	10,862,115	503,502	218,700,393	7,718.60	7,718.60	965,441,988	20,958,921
2042-2046	8,301.96	1,441.03	124,614,504	1,602.96	1,602.96	50,944,137	456,405	235,231,110	9,326.30	9,326.30	968,442,680	24,223,378
2047-2050	9,448.55	9,448.55	721,444,028	1,828.07	225.10	6,718,837	2,908,856	245,408,962	10,603.66	10,603.66	950,935,870	26,289,220
	Total Cost Solar Farm (USD)		**2,040,492,305**	Total Cost Inverter (USD)		**144,711,068**	**5,870,984**	**1,171,124,360**	Total Cost Battery System (USD)		**5,849,439,689**	**117,676,872**
	Total Cost (USD)										**9,329,315,278**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	7,193,903	5,190,832,649
2027-2031	11,438,060	8,253,246,574
2032-2036	15,433,514	11,136,206,362
2037-2041	19,859,076	14,329,514,879
2042-2046	24,030,165	17,339,205,857
2047-2050	27,348,970	19,733,922,793
	Total Electricity (kWh)	75,982,929,113

LCOE (USD_{2020}/kWh) 0.12278173

Point C

Total Coverage of Households

Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter (MW)	Inverter Deployment (MW)	Cost(USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	2,159.61	2,159.61	540,209,934	468.09	468.09	25,413,599	842,247	103,260,107	2,881.69	2,881.69	853,499,240	12,247,648
2027-2031	3,397.77	1,238.16	209,438,529	749.49	281.40	12,543,077	465,249	138,393,492	4,533.84	4,533.84	1,118,136,114	15,522,696
2032-2036	4,630.96	1,233.20	152,696,919	1,003.75	1,003.75	38,229,303	430,587	166,753,169	6,179.37	6,179.37	1,028,123,414	18,967,944
2037-2041	5,856.62	1,225.65	123,288,924	1,320.44	316.69	10,862,115	403,623	186,686,698	7,814.83	7,814.83	977,478,811	21,220,230
2042-2046	7,073.37	1,216.76	105,220,049	1,602.96	1,602.96	50,944,137	385,372	200,419,771	9,438.42	9,438.42	980,085,221	24,514,589
2047-2050	8,041.25	8,041.25	613,989,675	1,828.07	225.10	6,718,837	2,475,601	208,856,908	10,729.91	10,729.91	962,258,149	26,602,232
	Total Cost Solar Farm (USD)		**1,744,844,031**	Total Cost Inverter (USD)		**144,711,068**	**5,002,678**	**1,004,370,146**	Total Cost Battery System (USD)		**5,919,580,951**	**119,075,339**
	Total Cost (USD)										**8,937,584,213**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	6,059,799	4,715,250,798
2027-2031	9,534,046	7,418,631,874
2032-2036	12,994,361	10,111,172,181
2037-2041	16,433,508	12,787,241,245
2042-2046	19,847,691	15,443,885,321
2047-2050	22,563,519	17,557,125,404
	Total Electricity (kWh)	68,033,306,823

LCOE (USD_{2020}/kWh) 0.13137072

Scenario 2. LCOE calculations. Base model of demand.

Point A												
Base Model												
Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter (MW)	Inverter Deployment (MW)	Cost(USD)	Tracking System (USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	1,123.86	1,123.86	281,125,126	251.82	251.82	13,671,733	2,022,946,378	438,305	53,736,536	1,427.20	1,427.20	422,707,207	6,065,816
2027-2031	1,280.39	156.53	26,477,257	287.16	35.35	1,575,445	269,229,166	58,817	52,151,087	1,624.24	1,624.24	400,570,562	5,560,982
2032-2036	1,422.66	142.27	17,616,112	314.89	314.89	11,993,089	239,012,857	49,675	51,227,469	1,823.45	1,823.45	303,385,278	5,597,183
2037-2041	1,576.48	153.82	15,472,997	353.76	38.87	1,333,009	241,500,108	50,655	50,252,159	1,998.67	1,998.67	249,993,519	5,427,146
2042-2046	1,712.29	135.82	11,744,743	384.10	384.10	12,207,068	201,006,485	43,016	48,516,828	2,171.72	2,171.72	225,511,301	5,640,649
2047-2050	1,815.65	1,815.65	138,634,322	407.45	23.36	697,132	2,560,072,067	558,972	47,158,343	2,301.72	2,301.72	206,418,429	5,706,567
	Total Cost Solar Farm (USD)		**491,070,557**	Total Cost Inverter (USD)		**41,477,477**	**5,533,767,062**	**1,199,440**	**303,042,421**	Total Cost Battery System (USD)		**1,808,586,296**	**33,998,343**
	Total Cost (USD)											**8,213,141,598**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	3,048,735	2,301,977,849
2027-2031	3,473,356	2,622,592,181
2032-2036	3,859,296	2,914,000,038
2037-2041	4,276,574	3,229,069,964
2042-2046	4,645,005	3,507,257,475
2047-2050	4,925,393	3,718,967,239
	Total Electricity (kWh)	18,293,864,747

LCOE (USD_{2020}/kWh) 0.44895607

Point B													
Base Model													
Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter (MW)	Inverter Deployment (MW)	Cost(USD)	Tracking System (USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	1,344.09	1,344.09	336,213,600	251.82	251.82	13,671,733	2,419,357,156	524,194	64,266,594	1,502.41	1,502.41	444,982,313	6,385,462
2027-2031	1,532.22	188.13	31,823,505	287.16	35.35	1,575,445	323,591,513	70,693	62,408,471	1,712.47	1,712.47	422,328,365	5,863,038
2032-2036	1,713.18	180.96	22,406,528	314.89	314.89	11,993,089	304,008,524	63,184	61,688,677	1,915.24	1,915.24	318,656,966	5,878,932
2037-2041	1,884.09	170.91	17,192,286	353.76	38.87	1,333,009	268,334,502	56,284	60,057,727	2,106.46	2,106.46	263,475,892	5,719,837
2042-2046	2,047.09	163.00	14,095,459	384.10	384.10	12,207,068	241,238,036	51,625	58,003,116	2,288.98	2,288.98	237,687,268	5,945,203
2047-2050	2,177.69	2,177.69	166,277,467	407.45	23.36	697,132	3,070,540,486	670,429	56,561,533	2,426.17	2,426.17	217,578,567	6,015,096
	Total Cost Solar Farm (USD)		**588,008,846**	Total Cost Inverter (USD)		**41,477,477**	**6,627,070,218**	**1,436,409**	**362,986,118**	Total Cost Battery System (USD)		**1,904,709,370**	**35,807,568**
	Total Cost (USD)											**9,561,496,006**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	3,799,774	3,276,127,145
2027-2031	4,331,636	3,734,693,243
2032-2036	4,843,208	4,175,765,506
2037-2041	5,326,386	4,592,356,745
2042-2046	5,787,188	4,989,655,622
2047-2050	6,133,681	5,288,398,421
	Total Electricity (kWh)	26,056,996,682

LCOE (USD_{2020}/kWh) 0.36694544

Point C													
Base Model													
Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter (MW)	Inverter Deployment (MW)	Cost(USD)	Tracking System (USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	1,082.31	1,082.31	270,732,780	251.82	251.82	13,671,733	1,948,164,167	422,102	51,750,059	1,421.75	1,421.75	421,092,434	6,042,644
2027-2031	1,233.32	151.00	25,542,477	287.16	35.35	1,575,445	259,724,027	56,740	50,233,815	1,620.00	1,620.00	399,523,167	5,546,442
2032-2036	1,379.27	145.95	18,072,082	314.89	314.89	11,993,089	245,199,392	50,961	49,665,088	1,811.81	1,811.81	301,448,781	5,561,456
2037-2041	1,517.87	138.60	13,942,310	353.76	38.87	1,333,009	217,609,375	45,644	48,384,007	1,993.77	1,993.77	249,380,627	5,413,840
2042-2046	1,647.49	129.62	11,209,164	384.10	384.10	12,207,068	191,840,269	41,054	46,680,762	2,164.18	2,164.18	224,728,347	5,621,065
2047-2050	1,745.74	1,745.74	133,296,339	407.45	23.36	697,132	2,461,498,931	537,450	45,342,556	2,293.30	2,293.30	205,662,965	5,685,682
	Total Cost Solar Farm (USD)		**472,795,152**	Total Cost Inverter (USD)		**41,477,477**	**5,324,036,161**	**1,153,951**	**292,056,287**	Total Cost Battery System (USD)		**1,801,836,321**	**33,871,130**
	Total Cost (USD)											**7,967,226,479**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	3,097,576	2,930,802,508
2027-2031	3,529,744	3,339,702,583
2032-2036	3,947,458	3,734,926,861
2037-2041	4,344,144	4,110,255,287
2042-2046	4,715,121	4,461,258,885
2047-2050	4,996,311	4,727,309,616
	Total Electricity (kWh)	23,304,255,741

LCOE (USD_{2020}/kWh) 0.34187861

Scenario 2. LCOE calculations. Total coverage model.

Point A													
Total Coverage of Households													
Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter (MW)	Inverter Deployment (MW)	Cost(USD)	Tracking System (USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	2,161.23	2,161.23	540,615,936	468.09	468.09	25,413,599	3,890,214,531	842,880	103,337,714	2,790.43	2,790.43	826,469,261	11,859,770
2027-2031	3,420.73	1,259.50	213,048,697	749.49	281.40	12,543,077	2,166,346,853	473,268	139,328,902	4,416.61	4,416.61	1,089,224,851	15,121,331
2032-2036	4,677.27	1,256.54	155,586,778	1,003.75	1,003.75	38,229,303	2,110,978,847	438,736	168,420,516	6,038.96	6,038.96	1,004,762,664	18,536,959
2037-2041	5,949.36	1,272.09	127,959,980	1,320.44	316.69	10,862,115	1,997,179,240	418,915	189,642,925	7,635.20	7,635.20	955,011,316	20,732,480
2042-2046	7,206.91	1,257.55	108,747,868	1,602.96	1,602.96	50,944,137	1,861,175,444	398,293	204,203,442	9,227.43	9,227.43	958,176,643	23,966,596
2047-2050	8,207.66	8,207.66	626,696,000	1,828.07	225.10	6,718,837	11,572,797,433	2,526,832	213,179,136	10,492.78	10,492.78	940,992,331	26,014,325
	Total Cost Solar Farm (USD)		**1,772,655,259**	Total Cost Inverter (USD)		**144,711,068**	**23,598,692,347**	**5,098,924**	**1,018,112,635**	Total Cost Battery System (USD)		**5,774,637,067**	**116,231,461**
	Total Cost (USD)											**32,430,138,762**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	5,862,851	4,426,804,276
2027-2031	9,279,555	7,006,620,798
2032-2036	12,688,205	9,580,356,067
2037-2041	16,139,048	12,185,949,583
2042-2046	19,550,454	14,761,765,797
2047-2050	22,265,223	16,811,579,278
	Total Electricity (kWh)	64,773,075,800

LCOE (USD$_{2020}$/kWh) 0.50067313

Point B													
Total Coverage of Households													
Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter (MW)	Inverter Deployment (MW)	Cost(USD)	Tracking System (USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	2,577.63	2,577.63	644,774,199	468.09	468.09	25,413,599	4,639,726,267	1,005,274	123,247,369	2,872.34	2,872.34	850,728,773	12,207,892
2027-2031	4,103.48	1,525.85	258,101,921	749.49	281.40	12,543,077	2,624,462,349	573,350	167,137,446	4,528.82	4,528.82	1,116,896,849	15,505,492
2032-2036	5,624.62	1,521.14	188,350,622	1,003.75	1,003.75	38,229,303	2,555,513,941	531,126	202,532,830	6,232.04	6,232.04	1,036,887,481	19,129,633
2037-2041	7,135.71	1,511.10	152,001,747	1,320.44	316.69	10,862,115	2,372,419,366	497,623	227,459,328	7,923.73	7,923.73	991,099,523	21,515,924
2042-2046	8,638.89	1,503.18	129,988,903	1,602.96	1,602.96	50,944,137	2,224,707,093	476,089	244,777,786	9,606.70	9,606.70	997,559,728	24,951,674
2047-2050	9,833.60	9,833.60	750,844,883	1,828.07	225.10	6,718,837	13,865,376,081	3,027,400	255,410,061	10,944.26	10,944.26	981,480,788	27,133,654
	Total Cost Solar Farm (USD)		**2,124,062,275**	Total Cost Inverter (USD)		**144,711,068**	**28,282,205,097**	**6,110,861**	**1,220,564,821**	Total Cost Battery System (USD)		**5,974,653,141**	**120,444,269**
	Total Cost (USD)											**37,872,751,533**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	7,287,023	6,282,798,360
2027-2031	11,600,646	10,001,960,975
2032-2036	15,900,951	13,709,640,943
2037-2041	20,172,861	17,392,839,026
2042-2046	24,422,396	21,056,745,607
2047-2050	27,799,874	23,968,773,364
	Total Electricity (kWh)	92,412,758,275

LCOE (USD$_{2020}$/kWh) 0.40982168

Point C													
Total Coverage of Households													
Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter (MW)	Inverter Deployment (MW)	Cost(USD)	Tracking System (USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	2,141.84	2,141.84	535,764,360	468.09	468.09	25,413,599	3,855,303,110	835,316	102,410,344	2,812.04	2,812.04	832,869,711	11,951,616
2027-2031	3,369.81	1,227.97	207,714,963	749.49	281.40	12,543,077	2,112,111,743	461,420	137,254,598	4,424.26	4,424.26	1,091,110,261	15,147,506
2032-2036	4,592.86	1,223.05	151,440,401	1,003.75	1,003.75	38,229,303	2,054,721,405	427,044	165,380,917	6,030.01	6,030.01	1,003,273,064	18,509,477
2037-2041	5,807.89	1,215.04	122,221,081	1,320.44	316.69	10,862,115	1,907,607,403	400,127	185,133,528	7,626.05	7,626.05	953,866,709	20,707,632
2042-2046	7,013.93	1,206.03	104,292,900	1,602.96	1,602.96	50,944,137	1,784,930,471	381,976	198,735,388	9,210.55	9,210.55	956,423,512	23,922,746
2047-2050	7,973.31	7,973.31	608,802,017	1,828.07	225.10	6,718,837	11,242,360,599	2,454,684	207,092,256	10,470.94	10,470.94	939,033,720	25,960,178
	Total Cost Solar Farm (USD)		**1,730,235,721**	Total Cost Inverter (USD)		**144,711,068**	**22,957,034,731**	**4,960,567**	**996,007,031**	Total Cost Battery System (USD)		**5,776,576,977**	**116,199,154**
	Total Cost (USD)											**31,725,725,249**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	6,129,922	5,799,887,000
2027-2031	9,644,372	9,125,119,012
2032-2036	13,144,731	12,437,018,683
2037-2041	16,622,160	15,727,222,906
2042-2046	20,073,824	18,993,049,316
2047-2050	22,819,563	21,590,957,728
	Total Electricity (kWh)	83,673,254,644

LCOE (USD$_{2020}$/kWh) 0.37916208

Scenario 3. LCOE calculations. Base model of demand.

Point A

Base Model

Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter Battery System (MW)	Inverter Deployment (MW)	Cost(USD)	Inverters PV Panels (kW)	Cost Inverters PV Panels (USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	1,072.10	1,072.10	268,178,074	251.82	251.82	13,671,733	1,130,617	61,383,617	418,119	51,261,732	1,451.28	1,451.28	429,840,999	6,168,185
2027-2031	1,222.55	150.45	25,448,251	287.16	35.35	1,575,445	1,289,274	57,467,284	56,531	49,795,143	1,651.08	1,651.08	407,189,843	5,652,875
2032-2036	1,348.96	126.41	15,652,621	314.89	314.89	11,993,089	1,422,586	54,181,301	44,138	48,573,681	1,858.31	1,858.31	309,185,119	5,704,185
2037-2041	1,505.23	156.28	15,719,966	353.76	38.87	1,333,009	1,587,393	54,445,127	51,464	47,981,167	2,031.73	2,031.73	254,128,788	5,516,919
2042-2046	1,634.77	129.53	11,201,550	384.10	384.10	12,207,068	1,723,997	54,790,710	41,026	46,320,187	2,207.71	2,207.71	229,248,087	5,734,116
2047-2050	1,733.71	1,733.71	132,377,250	407.45	23.36	697,132	1,828,335	54,572,340	533,744	45,029,915	2,339.74	2,339.74	209,828,152	5,800,831
	Total Cost Solar Farm (USD)		**468,577,711**	Total Cost Inverter (USD)		**41,477,477**		**336,840,379**	**1,145,023**	**288,961,825**	Total Cost Battery System (USD)		**1,839,420,988**	**34,577,112**
	Total Cost (USD)												**3,011,000,516**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	2,975,309	2,027,375,553
2027-2031	3,392,827	2,311,872,318
2032-2036	3,743,648	2,550,921,747
2037-2041	4,177,350	2,846,446,290
2042-2046	4,536,834	3,091,398,688
2047-2050	4,811,409	3,278,494,093
	Total Electricity (kWh)	16,106,508,688

LCOE (USD$_{2020}$/kWh) 0.18694309

Point B

Base Model

Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter Battery System (MW)	Inverter Deployment (MW)	Cost(USD)	Inverters PV Panels (kW)	Cost Inverters PV Panels (USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	1,201.49	1,201.49	300,543,450	251.82	251.82	13,671,733	1,321,536	71,749,006	468,580	57,448,312	1,468.45	1,468.45	434,924,040	6,241,126
2027-2031	1,370.00	168.51	28,504,476	287.16	35.35	1,575,445	1,506,887	67,166,997	63,320	55,801,108	1,673.57	1,673.57	412,736,820	5,729,882
2032-2036	1,519.89	149.89	18,560,031	314.89	314.89	11,993,089	1,671,756	63,671,301	52,337	54,728,798	1,875.12	1,875.12	311,982,299	5,755,790
2037-2041	1,685.21	165.31	16,628,764	353.76	38.87	1,333,009	1,853,585	63,575,098	54,439	53,717,948	2,057.66	2,057.66	257,372,238	5,587,332
2042-2046	1,830.22	145.01	12,540,176	384.10	384.10	12,207,068	2,013,088	63,978,362	45,929	51,858,158	2,235.47	2,235.47	232,131,309	5,806,234
2047-2050	1,940.31	1,940.31	148,152,225	407.45	23.36	697,132	2,134,175	63,701,082	597,348	50,395,987	2,368.82	2,368.82	212,435,509	5,872,913
	Total Cost Solar Farm (USD)		**524,929,121**	Total Cost Inverter (USD)		**41,477,477**		**393,841,845**	**1,281,954**	**323,950,310**	Total Cost Battery System (USD)		**1,861,582,214**	**34,993,277**
	Total Cost (USD)												**3,182,056,200**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	3,477,727	2,369,723,178
2027-2031	3,965,491	2,702,085,567
2032-2036	4,399,358	2,997,722,541
2037-2041	4,877,855	3,323,770,397
2042-2046	5,297,599	3,609,783,959
2047-2050	5,616,251	3,826,913,431
	Total Electricity (kWh)	18,829,999,073

LCOE (USD$_{2020}$/kWh) 0.16898865

Point C

Base Model

Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter Battery System (MW)	Inverter Deployment (MW)	Cost(USD)	Inverters PV Panels (kW)	Cost Inverters PV Panels (USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	1,012.78	1,012.78	253,340,654	251.82	251.82	13,671,733	1,079,901	58,630,141	394,986	48,425,587	1,476.08	1,476.08	437,186,559	6,273,593
2027-2031	1,154.43	141.64	23,959,294	287.16	35.35	1,575,445	1,230,931	54,866,728	53,223	47,020,639	1,681.83	1,681.83	414,772,421	5,758,142
2032-2036	1,284.71	130.29	16,132,461	314.89	314.89	11,993,089	1,369,853	52,172,858	45,492	46,260,400	1,882.50	1,882.50	313,211,016	5,778,459
2037-2041	1,421.38	136.67	13,747,579	353.76	38.87	1,333,009	1,515,578	51,981,994	45,007	45,308,312	2,069.72	2,069.72	258,880,953	5,620,084
2042-2046	1,543.05	121.67	10,521,164	384.10	384.10	12,207,068	1,645,307	52,289,846	38,534	43,721,383	2,246.56	2,246.56	233,282,375	5,835,025
2047-2050	1,635.89	1,635.89	124,908,772	407.45	23.36	697,132	1,744,305	52,064,177	503,631	42,489,411	2,380.39	2,380.39	213,473,375	5,901,606
	Total Cost Solar Farm (USD)		**442,609,925**	Total Cost Inverter (USD)		**41,477,477**		**322,005,744**	**1,080,873**	**273,225,732**	Total Cost Battery System (USD)		**1,870,806,699**	**35,166,909**
	Total Cost (USD)												**2,986,373,358**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	2,841,846	1,936,433,864
2027-2031	3,239,292	2,207,253,569
2032-2036	3,604,875	2,456,361,825
2037-2041	3,988,364	2,717,671,230
2042-2046	4,329,755	2,950,295,057
2047-2050	4,590,275	3,127,813,385
	Total Electricity (kWh)	15,395,828,930

LCOE (USD$_{2020}$/kWh) 0.19397289

Scenario 3. LCOE calculations. Total coverage model.

Point A

Total Coverage Model

Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter Battery System (MW)	Inverter Deployment (MW)	Cost(USD)	Inverters PV Panels (kW)	Cost Inverters PV Panels (USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	2,056.45	2,056.45	514,406,047	468.09	468.09	25,413,599	2,168,695	117,743,048	802,016	98,327,743	2,839.55	2,839.55	841,017,919	12,068,542
2027-2031	3,235.94	1,179.49	199,514,462	749.49	281.40	12,543,077	3,412,566	152,109,515	443,203	131,802,210	4,504.48	4,504.48	1,110,894,858	15,422,168
2032-2036	4,418.17	1,182.23	146,385,987	1,003.75	1,003.75	38,229,303	4,659,322	177,457,173	412,791	159,090,832	6,162.54	6,162.54	1,025,323,239	18,916,283
2037-2041	5,628.46	1,210.29	121,743,414	1,320.44	316.69	10,862,115	5,935,670	203,584,293	398,563	179,413,887	7,787.76	7,787.76	974,093,271	21,146,733
2042-2046	6,830.92	1,202.46	103,983,801	1,602.96	1,602.96	50,944,137	7,203,761	228,944,263	380,844	193,549,985	9,405.43	9,405.43	976,660,267	24,428,922
2047-2050	7,788.20	7,788.20	594,668,069	1,828.07	225.10	6,718,837	8,213,290	245,151,096	2,397,696	202,284,401	10,690.83	10,690.83	958,753,545	26,505,345
	Total Cost Solar Farm (USD)		**1,680,701,779**	Total Cost Inverter (USD)		**144,711,068**		**1,124,989,388**	**4,835,113**	**964,469,059**	Total Cost Battery System (USD)		**5,886,743,098**	**118,487,993**
						Total Cost (USD)							**9,924,937,498**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	5,707,092	3,888,812,489
2027-2031	8,980,436	6,119,269,090
2032-2036	12,261,374	8,354,900,244
2037-2041	15,620,183	10,643,592,696
2042-2046	18,957,267	12,917,481,734
2047-2050	21,613,920	14,727,725,088
	Total Electricity (kWh)	56,651,781,341

LCOE (USD$_{2020}$/kWh) 0.17519198

Point B

Total Coverage Model

Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter Battery System (MW)	Inverter Deployment (MW)	Cost(USD)	Inverters PV Panels (kW)	Cost Inverters PV Panels (USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	2,324.41	2,324.41	581,435,190	468.09	468.09	25,413,599	2,556,661	138,806,542	906,522	111,140,237	2,891.53	2,891.53	856,412,763	12,289,457
2027-2031	3,690.52	1,366.11	231,080,777	749.49	281.40	12,543,077	4,059,263	180,935,003	513,325	150,317,481	4,557.51	4,557.51	1,123,972,130	15,603,716
2032-2036	4,983.57	1,293.05	160,108,118	1,003.75	1,003.75	38,229,303	5,481,510	208,771,410	451,485	179,449,894	6,237.02	6,237.02	1,037,715,554	19,144,910
2037-2041	6,400.91	1,417.34	142,570,844	1,320.44	316.69	10,862,115	7,040,465	241,477,064	466,748	204,036,687	7,863.29	7,863.29	983,540,188	21,351,818
2042-2046	7,743.52	1,342.61	116,103,106	1,602.96	1,602.96	50,944,137	8,517,219	270,687,543	425,232	219,407,888	9,501.95	9,501.95	986,682,384	24,679,602
2047-2050	8,811.68	8,811.68	672,816,051	1,828.07	225.10	6,718,837	9,692,109	289,291,035	2,712,788	228,867,497	10,803.97	10,803.97	968,900,299	26,785,858
	Total Cost Solar Farm (USD)		**1,904,114,088**	Total Cost Inverter (USD)		**144,711,068**		**1,329,968,597**	**5,476,100**	**1,093,219,684**	Total Cost Battery System (USD)		**5,957,223,318**	**119,855,360**
						Total Cost (USD)							**10,554,568,215**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	6,728,055	4,584,496,677
2027-2031	10,682,272	7,278,900,141
2032-2036	14,425,026	9,829,212,716
2037-2041	18,527,539	12,624,665,075
2042-2046	22,413,735	15,272,719,029
2047-2050	25,505,549	17,379,481,089
	Total Electricity (kWh)	66,969,474,726

LCOE (USD$_{2020}$/kWh) 0.15760267

Point C

Total Coverage Model

Period	Solar Farm Size (MW)	Solar Farm Deployment (MW)	CAPEX(USD)	Inverter Battery System (MW)	Inverter Deployment (MW)	Cost(USD)	Inverters PV Panels (kW)	Cost Inverters PV Panels (USD)	Installation CAPEX PV Panles + Inverter (USD)	O&M PV Panels + Inverter	Battery System (MWh)	Battery System Deployment (MWh)	Cost(USD)	O&M Battery System
2022-2026	1,994.10	1,994.10	498,810,384	468.09	468.09	25,413,599	2,126,252	115,438,730	777,700	95,346,662	2,921.98	2,921.98	865,431,444	12,418,874
2027-2031	3,137.38	1,143.27	193,387,901	749.49	281.40	12,543,077	3,345,289	149,110,783	429,594	127,787,542	4,597.23	4,597.23	1,133,768,123	15,739,710
2032-2036	4,276.07	1,138.69	140,994,868	1,003.75	1,003.75	38,229,303	4,559,439	173,652,982	397,588	153,973,859	6,265.76	6,265.76	1,042,496,982	19,233,123
2037-2041	5,407.79	1,131.72	113,840,535	1,320.44	316.69	10,862,115	5,766,161	197,770,414	372,691	172,379,757	7,924.08	7,924.08	991,144,302	21,516,896
2042-2046	6,531.30	1,123.51	97,156,385	1,602.96	1,602.96	50,944,137	6,964,124	221,328,281	355,839	185,060,378	9,570.37	9,570.37	993,787,117	24,857,311
2047-2050	7,425.00	7,425.00	566,935,877	1,828.07	225.10	6,718,837	7,917,048	236,308,860	2,285,880	192,850,921	10,879.92	10,879.92	975,710,867	26,974,141
	Total Cost Solar Farm (USD)		**1,611,125,951**	Total Cost Inverter (USD)		**144,711,068**		**1,093,610,048**	**4,619,292**	**927,399,117**	Total Cost Battery System (USD)		**6,002,338,835**	**120,740,055**
						Total Cost (USD)							**9,904,544,366**	

Electricity generation

Period	Amount of Panels	Electricity Generated
2022-2026	5,595,400	3,812,705,560
2027-2031	8,803,393	5,998,631,990
2032-2036	11,998,524	8,175,794,254
2037-2041	15,174,108	10,339,637,191
2042-2046	18,326,641	12,487,773,177
2047-2050	20,834,338	14,196,517,913
	Total Electricity (kWh)	55,011,060,086

LCOE (USD$_{2020}$/kWh) 0.18004642