

CHAPTER II. LITERATURE REVIEW

2.1 General overview

Indonesia has the annual Global Horizontal Irradiation (GHI) ranging from 4.3 to 6 kWh/m² (Silalahi et al., 2021). This means that Indonesia is blessed with abundant and constant solar irradiation the whole year. Utilizing solar energy as an alternative source of electricity in Indonesia has a significant potential, especially as the world are moving towards net-zero emission.

This work extends the work of my senior, Karel Christoferro, with his thesis title of: “Study on Integrated Solar PV and Air Conditioning Solutions for Low-Carbon Cooling Infrastructure Growth in Indonesia”. His thesis focuses on the utilization of PV panels to power portable power air conditioner to help people in rural areas to cope with the tropical Indonesian heat. He utilized 1100Wp solar panels, without batteries, directly connected to an inverter. He stated on his thesis that with his setup, he could only get 164.5W peak with a maximum sustained load of 120W (Christoferro 2024, p.106). He stated that this is due to mismatch of the inverter specification, as he observed significant voltage drop when loading the inverter with the AC unit.

In contrast to his thesis, I took up on the idea to add batteries and focusing more on typical household applications, such as lighting and small household appliances such as a rice cooker. I also have taken into account to make sure the components have correct specifications and can work together with other components with this common voltage in mind.

Indonesia has the world’s 4th largest population of 284 Million people (Worldometer, 2025). The population is projected to reach 335 million in 2050. As of 2023, the electrification ratio of households in Indonesia has reached 99.79% (Kementrian ESDM 2023, p.7). This means that as the country pushes electrification, people will be more reliant on electricity for cooking, air conditioning, lighting, transportation, entertainment, etc. Currently, Indonesia is powered by 54.58% coal and 25.46% from gas. Solar Power Plants only account for 0.66% (Kementrian ESDM 2023, p.21). This is a meager number compared to fossil fuels. This indicates that as an equatorial country, more installations of PV power plants should be installed, supporting the net-zero emission target and the electricity demand.

By 2050, it is assumed that the population will grow to 335 Million people, per capita annual consumption electricity and energy consumption will grow to match Singapore (9MWh), and complete solar electrification will cause complete displacement of all fossil fuels including transport, air conditioning, and industry. This would triple electricity consumption (Silalahi et al., 2021) (Lu et al., 2020). It is assumed that the annual electricity demand in 2050 is 355 Mio people * 9 MWh per person * 3, which equals 9000 TWh per year. Assuming an average capacity factor of 15.4%, this corresponds to 6.7 Terawatts (TW) of solar power. It equates to 35000 km² (100m² per person). This number is 30 times larger than the current 300 TWh electricity consumption (Silalahi et al., 2021).

The applications of portable solar panels in the EU are diverse and far-reaching. Campers and outdoor enthusiasts can power their devices and appliances during remote adventures. Recreational vehicle (RV) owners can enjoy off-grid living without compromising modern amenities. Boaters can harness the sun's energy to fuel their journeys, reducing reliance on traditional fuel sources. Moreover, portable solar panels have proven valuable in remote areas with limited access to electricity (Jackery EU, 2023). Such devices are made only to tackle small loads such as lighting, phone & laptop charging, and small appliances, not for whole household use.

In Indonesia, although recently the electrification ratio has reached a number higher than 99% nationally, there are still some areas that have quite low electrification. These are locations in remote areas, usually in small islands. This forces the community to rely on diesel generators either as a backup or as a primary source of electricity (Utama, 2021). This means that the communities need a constant supply of diesel fuel, which in case of small islands, need to be transported on a scheduled basis.

2.2 Solar irradiance in the world

With the help of modern science technology, global horizontal irradiation data has been collected, and this helps to assess the estimated energy yield from potential PV plant. The GHI map indicates the total solar radiation power available per unit area on a horizontal surface and is

measured in kilowatt-hours per square meter (kWh/m^2). For a better overview of the solar irradiance in the world during 2024, see Figure 2.1.

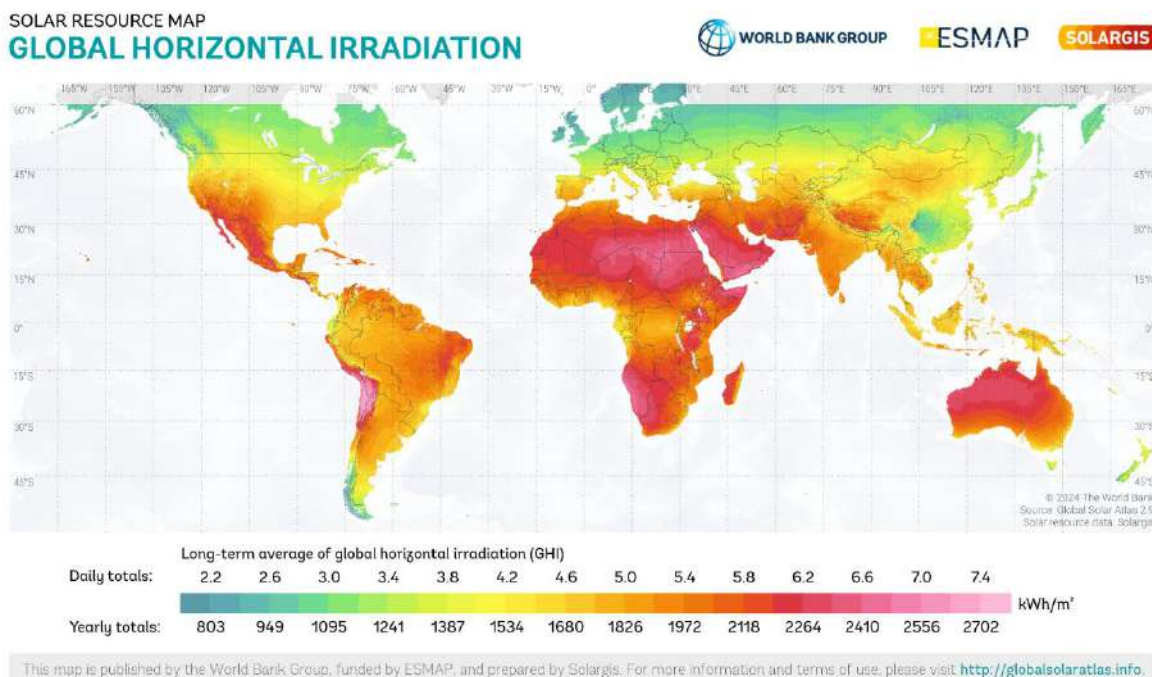


Figure 2.1: Global Horizontal Irradiation Map (Solargis, 2024)

In the context of solar energy, kWh/kWp refers to the amount of energy (kWh) produced by a solar system for every kilowatt peak of its rated capacity over a period. Combined, the two values stand for the PV yield that can be expected. The higher the kWh/kWp value is, the more effective a solar PV panels can produce electricity.

Global Horizontal Irradiance (GHI) and Photovoltaic (PV) Power Potential are related concepts in solar energy, but they represent different stages in understanding how much electricity can be generated from sunlight at a particular location.

Global Horizontal Irradiance (GHI) is the total amount of solar radiation received on a horizontal surface at the Earth's surface. It comprises two main components:

- Direct Normal Irradiance (DNI): The sunlight that travels in a straight line from the sun to the surface.
- Diffuse Horizontal Irradiance (DHI): The sunlight that has been scattered by the atmosphere (clouds, particles, etc.) and reaches the surface from all directions.

GHI is typically measured in kilowatt-hours per square meter (kWh/m²) over a specific period (e.g., daily, monthly, annually) or in Watts per square meter (W/m²) for instantaneous power. Instruments called pyranometers are used to measure GHI. It is a fundamental metric for assessing the solar resource available at a location. It represents the raw solar energy input before considering any specific solar technology. Locations with higher GHI generally have a greater potential for solar energy generation. (Vizzuality, no date)

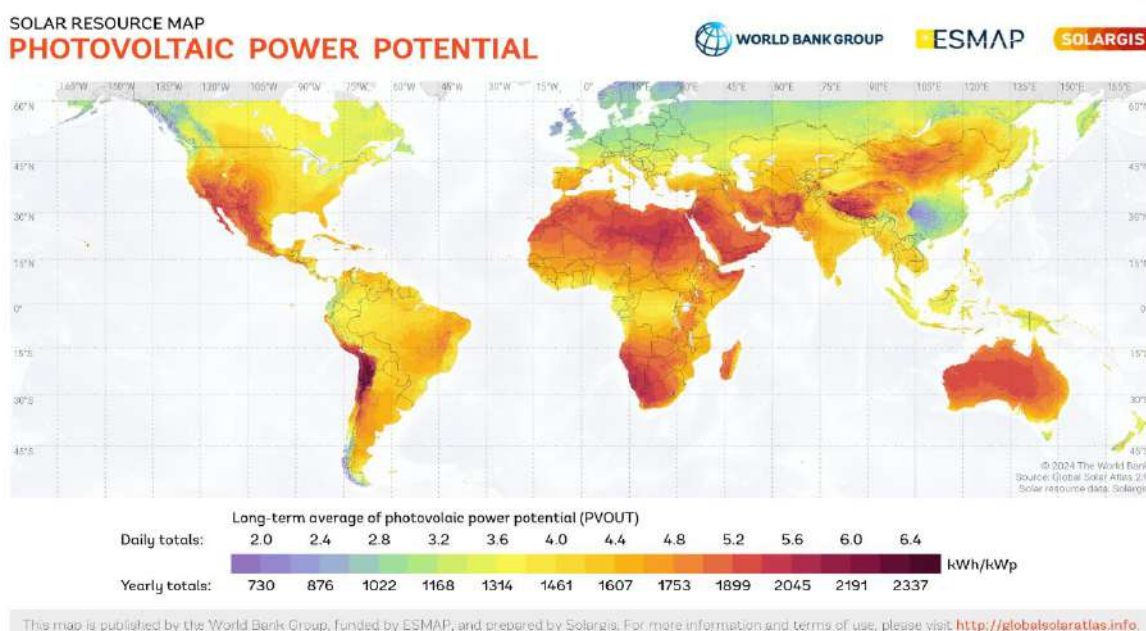


Figure 2.2: Photovoltaic Power Potential Map (Solargis, 2024)

Photovoltaic (PV) Power Potential on the other hand, is an estimate of the amount of electricity that can be generated by a photovoltaic system installed at a specific location over a period (typically annually), considering the local solar resource and the characteristics of the PV system. It is derived from the solar resource data (often GHI, but sometimes also considering Direct Normal Irradiance for tracking systems) and takes into account several factors, including:

- PV system efficiency: The efficiency of the solar panels in converting sunlight into electricity.
- System configuration: The tilt angle and orientation of the solar panels. For example, tracking systems that follow the sun's movement can utilize DNI more effectively.
- Performance ratio: A factor that accounts for various system losses, such as inverter efficiency, temperature effects, shading, soiling, and wiring losses.

PV power potential is often expressed in kilowatt-hours per kilowatt peak (kWh/kWp). kWp (kilowatt peak) refers to the maximum power output of the PV system under Standard Test Conditions (STC).

PV power potential provides a more practical estimate of the actual electricity generation achievable with a PV system. It helps in determining the appropriate size and configuration of a PV system to meet energy needs, Estimating the energy yield for calculating the return on investment, as well as in comparing different locations or technologies, which includes assessing the suitability of a site for PV deployment and comparing the performance of different PV systems. (Overen, O.K. and Meyer, E.L., 2022)

2.2.1 Solar PV potential in Indonesia

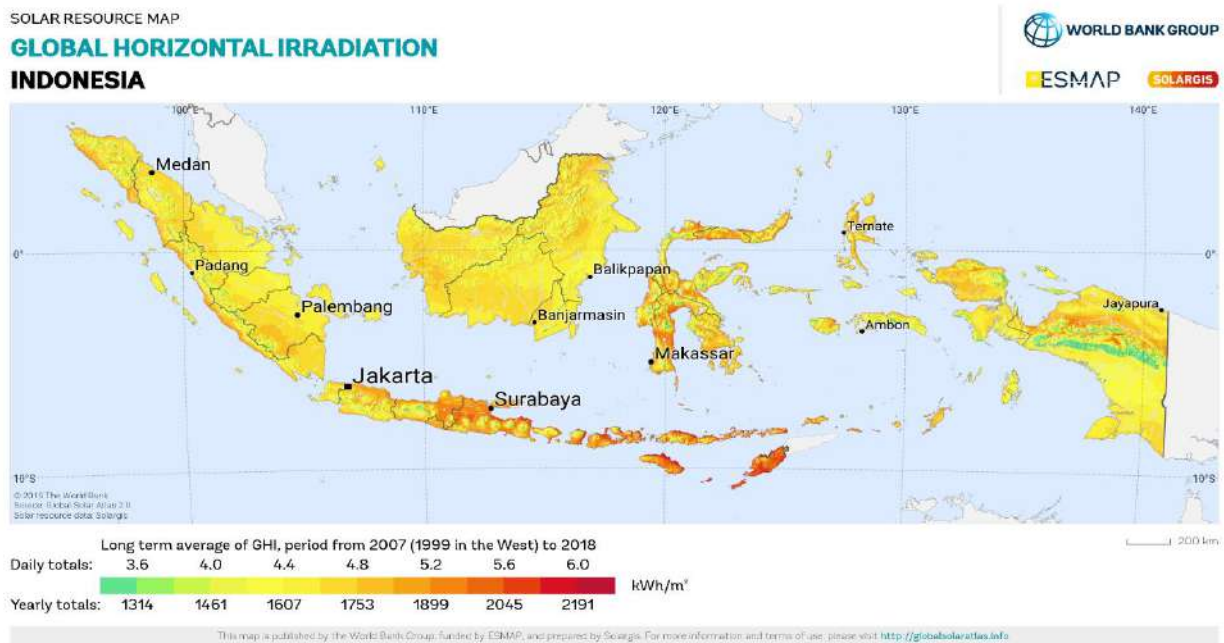


Figure 2.3: Global Horizontal Irradiation in Indonesia (Solargis, 2019)

Indonesia's strategic equatorial location ensures high average daily Global Horizontal Irradiance (GHI). According to Business Indonesia (2024), the average daily GHI is 4.8 kWh/m², which surpasses that of several countries with significant solar capacity, including Germany, Japan, China, and Singapore.

The Institute for Essential Services Reform (IESR) has conducted geospatial assessments revealing an enormous technical potential for solar PV in Indonesia. Their analysis indicates a potential

capacity ranging from 3,396 GWp up to 19,835 GWp, with a generation potential of 4,705 – 26,791 TWh/year (IESR, n.d.). This is significantly larger than the current national estimates.

The Indonesian government recognizes this potential and has set ambitious targets for solar PV deployment in its national energy plans (Presidential Regulation No. 22/2017). While current installed capacity is still relatively low compared to the vast potential, there is a strong drive to increase it through various initiatives, including rooftop solar, floating solar PV systems, and utility-scale solar farms (Business Indonesia, 2024).

2.2.2 Area of high potential in Indonesia

Developing photovoltaic (PV) farms in Indonesia, particularly in East Nusa Tenggara (Nusa Tenggara Timur - NTT), is highly feasible due to the region's significant solar power potential.

Reasons for Feasibility:

1. **High Solar Irradiance:** East Nusa Tenggara is known to have some of the highest levels of solar irradiance in Indonesia. Studies indicate a daily Global Horizontal Irradiance (GHI) ranging from 4.8 to 6.0 kWh/m²/day, and even higher in some coastal areas (7.03 to 8.01 kWh/m²/day in Kupang according to one study) (IESR, n.d.; EUDL, 2023). This high solar resource translates to greater electricity generation potential per unit area of PV installation.
2. **Vast Technical Potential:** Geospatial assessments by the Institute for Essential Services Reform (IESR) highlight Indonesia's enormous overall solar PV technical potential, ranging from 3,396 GWp up to 19,835 GWp (IESR, n.d.). While this is a national figure, East Nusa Tenggara would contribute significantly due to its high irradiance and available land, especially when considering less densely populated areas.
3. **Government Support and Targets:** The Indonesian government has set ambitious targets for renewable energy, including solar PV, in its national energy plans (Presidential Regulation No. 22/2017). There is a push to increase solar capacity through various projects, including utility-scale solar farms (Business Indonesia, 2024).
4. **Existing Projects and Studies:** There are existing solar PV projects in East Nusa Tenggara, such as a 5 MW Solar PV Power Plant in Kupang, which has demonstrated good performance ratios (ResearchGate, 2021). Feasibility studies have also been conducted for

floating PV (FPV) systems around the coastal areas of NTT, indicating economic viability (EUDL, 2023).

5. **Lower Electrification Rates:** East Nusa Tenggara has historically had lower electrification rates compared to other parts of Indonesia (UI Scholars Hub, n.d.). Developing solar PV farms can be a crucial solution to improve energy access in the region, especially in remote and rural areas, reducing reliance on more expensive and polluting diesel generators (IJE-PYC, 2020).
6. **Land Availability:** Compared to more densely populated islands like Java, East Nusa Tenggara may have more available land suitable for large-scale solar PV farms.

Challenges and Considerations:

- **Intermittency of Solar Power:** Solar power generation is dependent on sunlight availability, requiring energy storage solutions (like batteries) or grid integration strategies to ensure a stable power supply.
- **Initial Investment Costs:** Building large-scale PV farms requires significant upfront capital investment.
- **Infrastructure Development:** Adequate grid infrastructure may be needed to transmit the generated electricity to demand centers.
- **Land Acquisition and Environmental Impact:** Careful planning is necessary to minimize any potential environmental or social impacts associated with land use for solar farms.

The high solar irradiance, vast technical potential, government support, and the need for increased electrification make the development of PV farms in Indonesia, particularly in East Nusa Tenggara, highly feasible and strategically important. While challenges exist, the long-term benefits of clean energy access and reduced reliance on fossil fuels make solar PV a promising solution for the region's energy future. (Business Indonesia, 2024) (EUDL, 2023)

2.2.3. Feasibility of PV Rooftop use in big cities in Indonesia

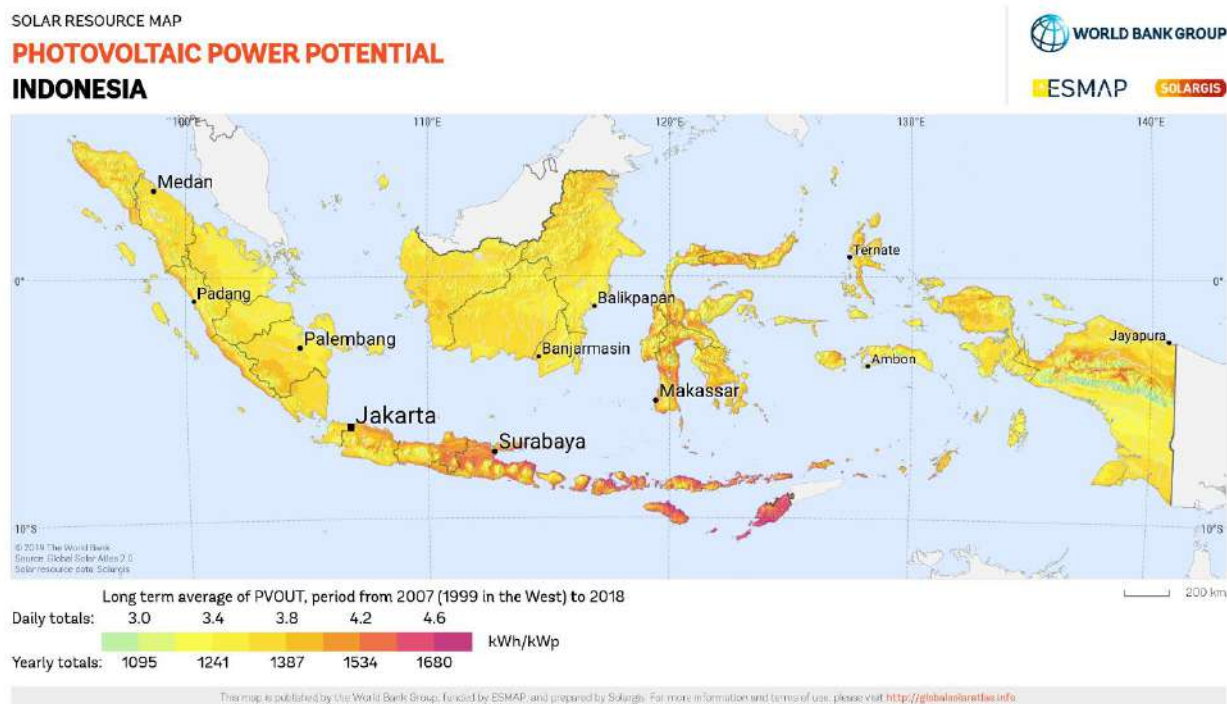


Figure 2.4: Photovoltaic Power Potential in Indonesia (Solargis, 2019)

As it can be seen from Figure 2.4, many big cities in Indonesia especially in Java island have high potential for photovoltaic energy, and this rises the opportunity to install them on rooftops of dense population settlements. Here are the compelling reasons:

1. **High Solar Irradiance:** Despite being urban areas, big cities in Indonesia still receive significant solar irradiation due to the country's equatorial location. Average Global Horizontal Irradiance (GHI) across Indonesia is around 4.8 kWh/m²/day (IESR, n.d.), which is sufficient for effective rooftop solar generation. Some studies even show higher potential in specific urban areas (E3S Web of Conferences, 2020). It is not as high as in East Nusa Tenggara, but the demand in these bigger cities with dense population is also higher.
2. **High Electricity Demand and Cost:** Big cities have high electricity consumption, often leading to significant electricity bills for residents, commercial buildings, and industries. Rooftop solar offers a way to offset these costs and reduce reliance on the grid.
3. **Government Support and Regulations:** The Indonesian government has been promoting rooftop solar installations through various regulations and initiatives, although the specific policies have evolved over time. While there have been changes in net metering

policies, the overall direction is towards encouraging solar adoption (Ashurst, 2024; SSEK Law Firm, 2024).

4. **Untapped Potential:** Studies by the Institute for Essential Services Reform (IESR) indicate a substantial technical potential for residential and commercial rooftop solar in major metropolitan areas like Greater Jakarta and Surabaya (IESR, n.d.). This signifies a large, underutilized resource.
5. **Economic Viability:** While the initial investment can be a factor, the long-term economic benefits of reduced electricity bills and potential for energy independence make rooftop solar increasingly viable, especially as solar technology costs continue to decline (E3S Web of Conferences, 2020; Jakarta Investment Center, n.d.).
6. **Environmental Benefits:** Deploying rooftop solar in cities contributes to reducing greenhouse gas emissions and air pollution, aligning with the growing global emphasis on sustainable energy and the Indonesian government's emission reduction targets (Jakarta Investment Center, n.d.).
7. **Grid Stability and Resilience:** Distributed generation from rooftop solar can help reduce the strain on the central grid, especially during peak demand, and enhance the resilience of the urban power supply.

Challenges and Considerations:

- **Space Constraints:** While rooftops offer available space, optimizing panel placement in densely built urban environments can be challenging due to shading from tall buildings.
- **Initial Investment:** The upfront cost of purchasing and installing solar panels remains a barrier for some.
- **Regulatory Landscape:** Evolving regulations and administrative processes can sometimes create uncertainty for potential adopters (Ashurst, 2024; SSEK Law Firm, 2024).
- **Grid Connection and Net Metering Policies:** The economic benefits are closely tied to the regulations regarding feeding excess electricity back to the grid. Recent changes in net metering policies need careful consideration (ABNR, 2024).

2.2.4 Types of solar irradiance

There are three primary types of solar irradiance that are important in the context of solar energy and photovoltaic systems: (Fluke, 2024)

1. **Direct Normal Irradiance (DNI)** This is the amount of solar radiation received directly from the sun on a surface perpendicular (normal) to the sun's rays. It represents the undiffused sunlight that has passed through the atmosphere without being scattered. DNI is most relevant for concentrating solar power (CSP) systems and for photovoltaic systems equipped with solar trackers that follow the sun's movement.
2. **Diffuse Horizontal Irradiance (DHI)** This is the amount of solar radiation received on a horizontal surface that has been scattered by the atmosphere (by clouds, aerosols, air molecules, etc.). It comes from all directions in the sky. DHI is an important component of the total solar radiation received by fixed, non-tracking solar panels, especially on cloudy days.
3. **Global Horizontal Irradiance (GHI)** This is the total amount of solar radiation received on a horizontal surface at the Earth's surface. It is the sum of the direct horizontal component (the projection of DNI onto a horizontal surface) and the diffuse horizontal irradiance (DHI). GHI is the most commonly used metric for estimating the energy yield of fixed-tilt solar photovoltaic (PV) systems. Mathematically, GHI is calculated using the formula: $GHI = DHI + DNI \times \cos(z)$ where z is the solar zenith angle (the angle between the sun and the vertical).

2.3 Solar Panel

A photovoltaic (PV) panel, also known as a solar panel or PV module, is an assembly of interconnected photovoltaic cells designed to convert sunlight directly into electricity through the photovoltaic effect. These panels are the fundamental building blocks of solar power systems.

A PV panel typically consists of:

- **Photovoltaic Cells:** The core component, usually made of semiconductor materials like silicon, which generate electricity when exposed to sunlight.
- **Encapsulant:** A transparent material (e.g., ethylene-vinyl acetate or EVA) that seals and protects the PV cells from environmental factors like moisture and physical damage.

- **Front Cover:** A protective transparent layer, usually made of tempered glass, that allows sunlight to pass through while shielding the cells.
- **Backsheet:** A durable material on the rear of the panel that provides electrical insulation and further environmental protection.
- **Frame:** Typically made of aluminum, the frame provides structural support and facilitates mounting.
- **Wiring and Junction Box:** Components that collect the electricity generated by the cells and provide connection points for external wiring.

PV panels are manufactured in various sizes and power ratings, depending on the number and efficiency of the PV cells they contain. Their efficiency, which is the ratio of electricity produced to the sunlight energy incident on the panel, is a crucial factor in determining their performance. (U.S. Energy Information Administration. 2024.)

2.3.1. Solar Cell

A solar cell also known as a photovoltaic (PV) cell, is a semiconductor device that directly converts sunlight (or any light source) into electrical energy through a physical and chemical phenomenon called the photovoltaic effect. It is the fundamental building block of solar panels. (Australian Government, 2025) (U.S. Energy Information Administration, 2024)

Here is the simplified working principle of the solar cell:

1. **Light Absorption:** When light strikes the solar cell material (typically silicon), the energy from the light is absorbed by electrons in the semiconductor atoms.
2. **Electron Excitation:** This absorbed energy excites the electrons, allowing them to break free from their atomic bonds.
3. **Charge Separation:** The solar cell is engineered with an internal electric field (usually created by doping different layers of the semiconductor material). This electric field forces the freed electrons to move in one direction, creating an electrical potential difference (voltage) across the cell.
4. **Current Flow:** If an external circuit is connected to the solar cell, the directed movement of these electrons constitutes an electric current.

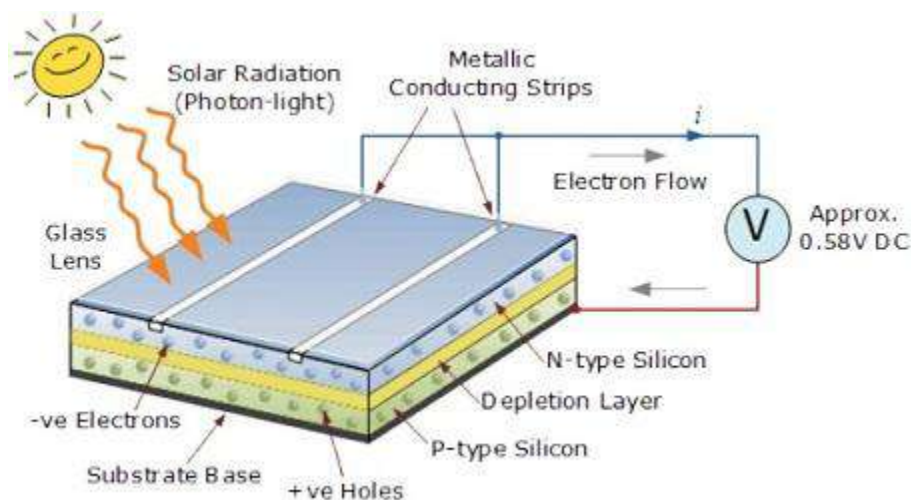


Figure 2.5: Solar Cell Working Principle (Chaudhry, 2022)

In essence, the solar cell harnesses the energy of photons (light particles) to create a flow of electrons, thus generating electricity. The generated electric current is direct current (DC)

2.3.2 PV Panels array configuration

A photovoltaic (PV) array consists of multiple PV panels (modules) connected together to achieve the desired voltage and current for a solar power system. These panels can be wired in two primary configurations: series and parallel, each with its own advantages and disadvantages (Renogy, 2024).

1. Series Connection:

- **Wiring:** In a series connection, the positive terminal of one PV panel is connected to the negative terminal of the next, and so on, forming a single path for the current.
- **Voltage:** The voltages of the individual panels are added together, while the current remains the same as that of a single panel.
- **Advantages:**
 - **Higher System Voltage:** Allows for more efficient power transmission over longer distances with thinner wires, reducing energy loss.
 - **Better Performance with MPPT Charge Controllers:** Maximum Power Point Tracking (MPPT) charge controllers often operate more efficiently with higher input voltages.
 - **Simpler Wiring:** Requires fewer cables compared to parallel connections for the same number of panels.

- Disadvantages:
 - Shade Sensitivity: If one panel in the series string is shaded, the current flow through the entire string is reduced to the level of the least performing panel, significantly decreasing the overall power output.
 - Single Point of Failure: If one panel fails completely, the entire string may stop producing power.
 - Voltage Limitations: The total voltage of the series string must be within the operating limits of the inverter or charge controller.

2. Parallel Connection:

- Wiring: In a parallel connection, all the positive terminals of the PV panels are connected together, and all the negative terminals are connected together, creating multiple paths for the current.
- Voltage: The voltage of the array remains the same as the voltage of a single panel, while the currents of the individual panels are added together.
- Advantages:
 - Shade Tolerance: If one panel is shaded, the other panels in the parallel array can continue to operate with minimal impact on their output.
 - Redundancy: If one panel fails, the other panels will continue to produce power.
 - Lower Voltage Systems: Suitable for lower voltage systems, such as those using PWM charge controllers or charging 12V/24V battery banks directly.
- Disadvantages:
 - Higher Current: Requires thicker wires and higher-rated components to handle the increased current, which can increase installation costs.
 - Voltage Drop: Voltage drop can be more significant over long distances due to the higher current.
 - Potential for Circulating Currents: If panels with slightly different voltage characteristics are connected in parallel, circulating currents can occur, leading to energy loss and potential heating.

In practice, larger solar PV systems often utilize a combination of series and parallel connections (series-parallel) to optimize both voltage and current levels to match the requirements of the inverter and charge controller while also considering shading conditions and system reliability.

2.4 Batteries

The very first steps into designing an off-grid PV system is to determine the battery voltage, array and type to be used. This is due to the fact that the system has to be referenced by the battery voltage. (Solar-Electric.com, n.d) The considerations for the battery system are as follows:

a) Battery type

The battery type is one of the most important decision that has to be made before building the system. Different inverters/controllers only support some types of battery, and in many cases might be incompatible with a specific types of battery. The type of supported battery by the inverter must first be ensured and then to choose the battery type based on compatible battery types. Common battery technologies which are commonly used in a PV systems (Renogy, 2024b) (Lane, 2020) (Wigness, 2025):

- Lead-acid battery (Flooded)

This type of battery uses anode and cathode plates which are submerged in an acidic electrolyte solution. It is commonly used in cars, trucks and motorcycles, as it is quite inexpensive, easily repairable, and offers very high current, which are beneficial to turn starter motor in internal combustion engine vehicles. However this battery type generally isn't recommended for PV system as it is not designed to be charged and discharged deeply.

- Sealed Lead Acid (SLA) / Valve Regulated Lead Acid (VRLA) / AGM

This battery type works in a similar principal with the regular lead acid battery, except its electrolyte is sealed and not user serviceable. This makes it lighter and safer for indoor use as it won't leak electrolytes and doesn't emit acidic fumes. VRLA is a subtype of SLA, where its electrolyte are controlled with a valve to give the battery some slightly more capacity and higher tolerances of overcharging, etc. AGM (Absorbed Glass Mat) is a variant of VRLA battery with a more advanced design. Its construction allows the electrolyte to be suspended within the fiberglass matting surrounding the plates, enhancing longevity and cycle efficiencies. These battery types are commonly used in small ev bikes, power sports, toy vehicles as well as solar system applications.

- GEL

GEL batteries work in a similar fashion with SLA batteries in general, however it is designed to not gas during charging, and similar to AGM it can be used upside down or on

its side. It uses gel consistency electrolyte, and because of this, it has a lower recharge voltage to prevent the gel electrolyte from liquefying. Its strengths lie in its ability to discharge better and tolerate higher heat environment compared to flooded and other SLA battery types. It is used in a very deep cycle applications that uses energy slowly over longer periods of time, due to its ability to discharge slowly and efficiently. Commonly used in RVs, backup energy storage, and also solar PV applications.

- Lithium cells battery (LFP/NMC)

Nowadays, many PV systems, especially the higher capacity ones work using lithium cells. This type includes both Lithium Ferro Phosphate and Nickle Manganese Cobalt batteries, which both are a technology of lithium-ion batteries. LFP batteries excels in safety and longevity while NMC offers higher density and power. Both batteries are used widely for electric vehicles and also PV system applications. LFP are generally recommended for PV system as it offers better longevity, while NMC usually used in EVs due to is amazing density and performance.

b) Battery voltage

Controllers and inverters only work within specific range of voltage, and this voltage needs to be referenced based on the battery array voltage. Important voltage parameters, which are dependent of battery type, need to be determined are stated as follows:

- Maximum Charging Voltage & Float Voltage

This refers to the maximum tolerable charging voltage for the battery. Higher voltage will cause damages to the battery. Float Voltage refers to the specific stage in the charging process designed to maintain a fully charged battery. This charging stage occurs after the battery has reached a near-full or full state of charge, which is a lower voltage that the controller applies to the battery to compensate for self-discharge, essentially keeps the battery topped off without overcharging it. This stage is crucial for maintaining the battery's long term health and ensuring it's ready to deliver power when needed, and reducing battery stress of repeated deep discharges.

- Low Voltage Disconnect (LVD)

Also known as cutoff voltage, it refers to the voltage the controller allows the battery discharge to, and cuts off the load when the battery voltage is lower. Discharging a battery

below its safe lowest discharge voltage will cause permanent damage to the battery, thus disconnecting the load from the battery before it reaches this voltage is crucial.

- Discharge Reconnect Voltage

Refers to the voltage after which the load is reconnected to the battery after discharging the battery below this voltage. After the battery is discharged, the controller needs to charge the battery until a specific voltage before allowing the load to be reconnected, ensuring the battery will be ready to handle the load and not dropping its voltage too quickly.

2.5 Solar Charge Controller

Solar Charge Controller (SCC) is a device that controls the charge voltage and current to the battery and the load. SCC plays a very important role in a PV system, whether it is on-grid or off-grid.

SCC can be either a standalone or integrated with other components, such as a hybrid inverter. Solar panels by its nature will produce varying voltages and it needs a reference voltage (battery) so that it knows the safe charging voltages and current for the battery based on its type. Modern controllers employ sophisticated algorithms to optimize the charging process, ensuring batteries are charged efficiently and effectively.

By itself, there are two types of Solar Charge Controllers:

- PWM (Pulse Width Modulation)

These controllers are simpler and less expensive. They work gradually by reducing the amount of charge going into the battery as it nears full charge. It works by using a series of pulses using mainly MOSFETs to gradually reduce the amount of current going into the battery, which means the panel's voltage will be pulled down to match the battery's voltage, resulting in inefficiencies.

- MPPT (Maximum Power Point Tracking)

MPPT controllers use sophisticated electronics to constantly track the solar panel's maximum power point. It will convert excess voltage from the solar panel into extra amperage, resulting in more efficient charging, maximizing the solar panel's power output by operating it at its optimal voltage. MPPT controllers can extract more power out of varying weather conditions, while being more expensive but also more efficient.

By its rail type, there are two types of railing in solar charge controllers, which are positive or negative common rail. This common rail is a bus that connects either all of the positive or all of

the negative terminals together, and controls the other rails. This refers to the internal wiring configuration and the grounding scheme of the controller. This dictates how the positive and negative terminals of the solar panels, battery, and load are internally connected and how the system might be grounded (earthed). There are key differences between the two:

- Negative Common Rail Solar Charge Controller:
 - Internal Connection: In a negative common rail controller, the negative terminals of the solar panel input, battery output, and load output are internally connected or share a common negative rail within the controller.
 - Switching: The switching and regulation of the charging and load circuits primarily occur on the positive side. The controller interrupts or modulates the positive current flow to control charging and prevent over-discharge.
 - Grounding: In a system using a negative common rail controller, the negative terminal of the battery is typically connected to the system's ground (chassis in a vehicle, earth ground in a fixed installation). The negative sides of the solar panels and loads are also effectively at this ground potential through the controller.
 - Common Usage: Negative ground systems are more common, especially in automotive, RV, and marine applications, as these vehicles typically have a negative ground chassis. Most standard off-grid solar systems also utilize negative grounding for safety and compatibility.

- Positive Common Rail Solar Charge Controller:
 - Internal Connection: In a positive common rail controller, the positive terminals of the solar panel input, battery output, and load output are internally connected or share a common positive rail within the controller.
 - Switching: The switching and regulation of the charging and load circuits primarily occur on the negative side. The controller interrupts or modulates the negative current flow.
 - Grounding: In a system using a positive common rail controller, the positive terminal of the battery is connected to the system's ground. The positive sides of the solar panels and loads are at this ground potential through the controller.

- Common Usage: Positive ground systems are less common in modern installations. They were sometimes found in older systems or specific applications. Some manufacturers might still produce positive common rail controllers for compatibility with existing positive ground setups.

2.6 Inverter

Inverter by itself is a device, with the sole purpose of inverting DC (Direct Current) to AC (Alternating Current) power. AC voltage is used by most home appliances, while DC is mainly produced by batteries. The enables the usage of the energy stored in the battery and produced from the panels to be used by our home appliances and devices. The whole system's power is to be determined by the capacity of the inverter, thus choosing the suitable inverter for each specific use case is crucial to avoid inefficiencies, wasted capacity and/or budget overruns.

There are two types of inverters based on its output waveform:

- Modified Sine Wave Inverter

Instead of a smooth oscillation between positive and negative voltage, a modified sinewave inverter typically switched the DC voltage from positive to negative and back again rapidly. It also often includes a brief pause at zero voltage between the positive and negative cycles, and creates a resulting waveform that looks like a series of flattened square wave with a short dip to zero in between.

Modified Sine Wave Inverters usually only supports resistive loads, and can cause damages to devices that uses inductive loads, or devices that needs the pure sine waveform, such as most modern electronic appliances. It can also produce interference with radio communication equipment around its vicinity. Because of its simplicity in design, this type of inverter usually considerably cheaper than its pure sine wave counterparts, while also being smaller and compact in size.

- Pure Sine Wave Inverter

In contrast to modified sine wave inverters, pure sine wave inverters produces an AC waveform that is virtually identical to the smooth continuous sine wave provided by the utility grid. These kind of inverters are also known as low frequency inverters, and uses a transformer, whether it's a conventional one or a toroidal transformer. The device first oscillates the DC voltage to create a fundamental AC signal, then this waveform is then

boosted with the transformer, allowing its output to match the utility grid, whether it's 110V or 220V.

Pure sine wave inverters are more expensive than the modified sine wave counterparts, while being compatible to every AC loads that normally uses the grid voltage. It is safe for sensitive electronics, provides optimal performance for motors, no buzzing or electromagnetic interference, provides better power output efficiency and reduced risk of overheating. It is however generally bigger in size. Inverters with toroidal transformers provides better performance, capacity and efficiency than conventional transformers, while also being generally bigger and more expensive.

2.7 Safety components

PV systems work with electricity, and many times it involves high current and high voltages. This means that proper protections are needed to avoid unwanted events. These protection devices include, but are not limited to:

- **Miniature Circuit Breaker**

A miniature circuit breaker (MCB) is a safety electrical component that functions like a switch and will automatically turn off the power if there is a problem, mainly over current, or a sudden dangerous short circuit on the loop. It helps prevent fires and electric shocks that can happen on the wiring system, as well as protecting sensitive electronic devices. It is resettable easily. There are MCBs for both DC and AC circuits.

- **Fuses**

A fuse is a small electrical component that functions similarly to a MCB. It uses tiny wires encapsuled in a small, usually cylindrical insulator container. However, fuses are single use and once it blows, it needs to be replaced. Unlike MCBs, fuses do not include arc chamber, but it is also smaller in size and can be used on electronic circuit boards.

2.8 Cabling

Rated Voltage : 450/750 V

Standard Specification : SNI 04-6629.3 : 2006 (IEC 02)

Cable Size (No. of core x Conductor Area)	Conductor Make-up (No. of wire x Diameter)	DC Resistance at		Current Carrying Capacity in air 30°C	Short Circuit Current 1 Sec.	Insulation/ Thickness	Overall Diameter	Cable Weight	Standard Packing Length *
nom. (mm ²)	nom. (mm)	max. (ohm/km)	min. (Mohm.km)	max. (A)	max. (A)	nom. (mm)	approx. (mm)	approx. (kg/km)	(meter/ packing)
1.5	30 x 0.25	13.3	0.010	24	173	0.7	3.2	22	100/c
2.5	50 x 0.25	7.98	0.009	32	288	0.8	3.9	35	100/c
4	56 x 0.30	4.95	0.007	41	460	0.8	4.4	52	100/c
6	84 x 0.30	3.30	0.006	53	690	0.8	5.0	73	100/c
10	80 x 0.40	1.91	0.0056	72	1,150	1.0	6.4	122	100/c
16	126 x 0.40	1.21	0.0046	97	1,840	1.0	7.4	180	100/c
25	196 x 0.40	0.78	0.0044	128	2,875	1.2	9.3	275	1,000/d
35	276 x 0.40	0.554	0.0038	156	4,025	1.2	10.5	347	1,000/d
50	396 x 0.40	0.386	0.0037	195	5,750	1.4	12.4	531	1,000/d
70	360 x 0.50	0.272	0.0032	243	8,050	1.4	14.2	735	1,000/d
95	475 x 0.50	0.206	0.0032	287	10,925	1.6	16.5	969	1,000/d
120	608 x 0.50	0.161	0.0029	342	13,801	1.6	18.5	1,279	1,000/d
150	756 x 0.50	0.129	0.0029	386	17,251	1.8	20.3	1,559	1,000/d
185	925 x 0.50	0.106	0.0029	441	21,276	2.0	22.6	1,899	500/d
240	1221 x 0.50	0.0801	0.0028	520	27,601	2.2	25.7	2,479	500/d

Test Voltage : 2,500 VAC/5 minutes

Figure 2.5: Cable Current Capacity Table (PT KMI Wire and Cable Tbk, 2015)

Cabling refers to all the wires and connectors that link the different parts of the solar power system together. It connects the PV, Controllers, Inverters and other important devices together. The cable type and thickness is very important, as it determines the maximum electric current carrying capacity, and exceeding this capacity can lead to overheating, or even cause fire.

Proper connections also need to be ensured to ensure maximum power deliverability. Loose connections can cause sparks and fire. One of the most important connectors are the battery terminal connectors and the ring connectors.



Figure 2.6: F1 (left) and F2 (right) Battery Terminal (BatteryStuff.com, 2018)



Figure 2.7: M5 Ring Terminal (RS-Online, (2025))

Different batteries require different connectors as they have different terminal types and sizes. The same goes with other components, such as inverters, controllers, etc. Appropriate connector sizes ensures safe and secure electrical connection, preventing bad connections and fire hazards.

2.9 Power Interruptions in Indonesia



Figure 2.8: Power Interruptions in Indonesia (Kementrian ESDM 2023, p.56)

As can be seen in Figure 2.8, in 2023 Indonesia experiences 5.64 hours of total power interruptions per year on average. Each electricity subscriber also experiences on average 4.27 interruptions per year. This means that the average power interruption lasts roughly 1.32 hours on average. This data however, is based on the national averages, and each area, with different connected gridlines, experiences different number of outages. Some areas may experience more interruptions than other areas in Indonesia.

This makes it difficult to estimate how much energy people typically needs during a power outage in Indonesia, as the data is averaged for the whole nation.

TAHUN YEAR	JUMLAH PENDUDUK/ NUMBER OF POPULATION	KONSUMSI TENAGA LISTRIK/ ENERGY CONSUMPTION GWH
2019	266.911.900	289.340,82
2020	269.603.400	293.465,27
2021	272.248.500	305.627,28
2022	274.859.100	322.336,67
2023	277.433.400	370.997,44

Figure 2.9: Indonesian Population and Energy Consumption (Kementrian ESDM 2023, p.48)

Based on the data from Figure 2.9, the average energy consumption in GWh can be divided by the total number of population in Indonesia, which resulted in 0.001193 GWh/person/year. Dividing this number with 365 days/year then by 24 hours/day, then multiplying the number by one million to convert GWh to kWh, resulted in a number of 0.1362kWh/person/hour. This way it is predicted very roughly that on average, one person will consume 0.1362 kWh or 136.2Wh per hour in Indonesia.

With the average blackout lasting 1.32 hours and the average electricity consumption of 0.1362 kWh, multiplying these numbers together gives the output of 0.179784 kWh or $\cong 180$ Wh of average electricity demand per person during an average duration power interruption in Indonesia.