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TECHNICAL BRIEF
SOLAR PV & ENERGY EFFICIENCY

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1. INTRODUCTION

The aim of this technical brief is to draw attention to technology choices and practical considerations for improving the total efficiency of solar PV systems.

The EEP portfolio contains a wide range of solar photovoltaic (PV) projects, from large solar arrays with gigawatt-order power outputs, to small pay-as-you-go (PAYG) solar home systems and solar lamps with single-wattage power outputs.

The size and complexity of these systems vary greatly. The solar photovoltaic (PV) industry is developing rapidly, with many technologies and products constantly entering the market.

The subsystem diagrams (Figures 1-5) offer a basic point of departure for discussing efficiency within the field of solar PV systems.

Regardless of the complexity, the final efficiency of a solar energy system (and therefore performance) is directly linked to the efficiencies of the subsystems and the matching of components within these systems.

The yield of a solar PV system depends on subsystem efficiencies, but is a function of the way in which solar radiation is utilized within an operational and environmental context.

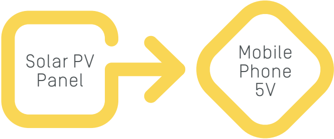


Figure 1: A solar panel which directly powers a DC load.

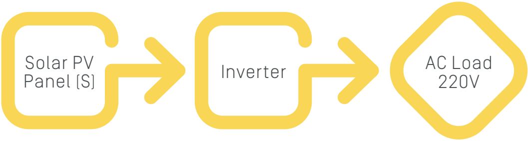


Figure 2: A solar panel which uses an inverter to power an AC load.

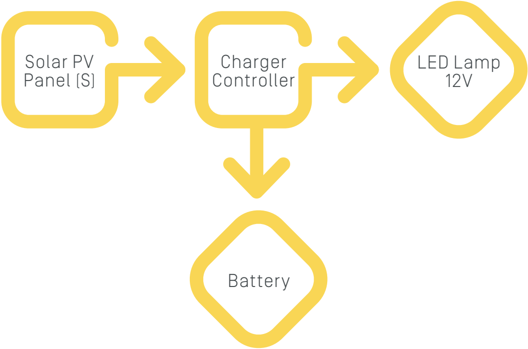


Figure 3: A solar panel which uses a charge controller to store energy in a battery and power a DC load.

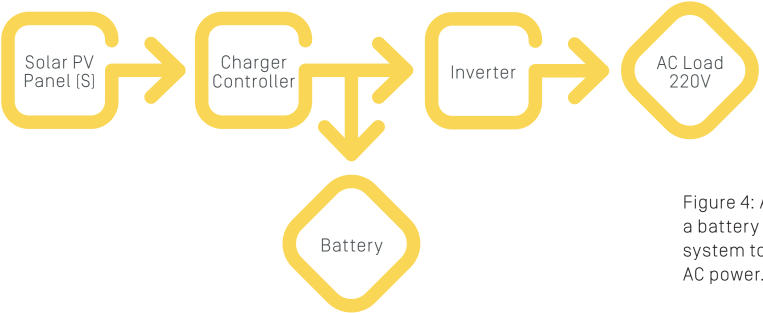
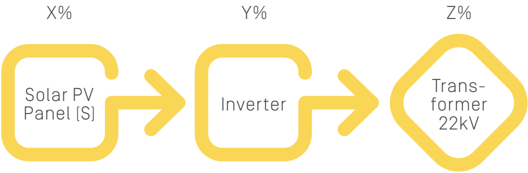


Figure 4: A solar panel which uses a battery system and an inverter system to store and provide AC power.



Total efficiency = X% * Y% * Z%
Where x, y, and z are the subsystem efficiencies

Figure 5: A solar system which only provides AC electricity and connects to the grid, with the compounded solar component efficiencies indicated.

2. EFFICIENCY IN SOLAR PV

The Solar PV sector is rapidly developing new technologies for improving efficiency. As a general trend, efficiency and technology costs are directly proportional. The total efficiency of solar PV systems is a multifaceted issue which can be divided into two main concepts:

1. Sub-system or component efficiencies: the energy transfer efficiency due to a subsystem's technical characteristics.

2. Overall design efficiency: environmental and operational impacts which affect the energy output of the respective systems and impact the overall performance of the system.

To achieve the best return on investment for Solar PV systems as a whole, the complex balance between cost, sub-system efficiencies and yield has to be considered.

2.1.
SUB-SYSTEM EFFICIENCIES

2.1.1.
SOLAR PANELS: MINIMISING REFLECTIONS

A cell's efficiency can be increased by minimizing the amount of pre-photovoltaic losses that are caused by incident light being reflected away from the cell's surface. With untreated surfaces, reflectivity increases as a function of the incident angle of the light that strikes the solar panel. This means that photons do not enter the semiconductor region of the solar panel, thereby constituting a pre-photovoltaic loss.[1]

Untreated silicon reflects more than 30% of incident light. Quarter-wavelength anti-reflective coatings and nano-textured surfaces help decrease reflection due to refracting more incident light into the solar panel.[2]

A high-efficiency cell will appear dark blue or black, with reflective losses in the order of only 5%.

2.1.2.
SOLAR PANELS: CONVERTING SUNLIGHT TO ELECTRICITY

Once the sunlight enters the solar panel, the photonic interaction with the semiconductor material results in the production of electricity from photons of light that match the bandgap energy of the specific semiconductor material's p-n junction. What this means, is that solar cells that contain only one type of semiconductor junction can only absorb a relatively narrow bandwidth of light. High-energy photos (high frequency light) and low-energy photos (low energy light) are often not 'caught' by the solar panel. The most efficient single-junction solar panels have efficiencies in the range of 22-23%, with a maximum theoretical efficiency of 34%.[3]

Advances in material sciences and improved fabrication technologies mean that multi-junction solar panels can be created. These solar cells use solar band-pass filters to direct certain wavelengths of light towards semiconductors with p-n junctions that are wavelength-matched to create current for those specific wavelengths. Multi-junction solar panels have efficiencies that are between 40-46%.[4]

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[1] pg1; Texturization of Silicon Wafers for Solar Cells by Anisotropic Etching with Sodium Silicate Solutions; CL Su et al; R & D Center for Membrane Technology and Department of Chemical Engineering; Chung Yuan Christian University; Taiwan; icrepq.com/icrepq'12/697-su.pdf

[2] Chapter 2; Single and Double-Layer Antireflection Coatings on Silicon; Department of Physics, Faculty of Science, Ege University, Turkey; 2001

[3] Milestone in solar cell efficiency achieved: New record for unfocused sunlight edges closer to theoretic limits. Wilson da Silva. Science Daily. May 17, 2016

[4] nrel.gov/ncpv/images/efficiency_chart.jpg; cleantechnica.com/2012/05/31/sharp-hits-concentrator-solar-cell-efficiency-record-43-5/

The fabrication of multi-junction technology is currently still expensive; these cells are only economically feasible in applications where weight and space is critical, such as space applications or concentrated solar technologies. However, tandem or two-layer cells offer an economically feasible and commercially available compromise, with efficiencies of approximately 30%.[5]

2.1.3.
CONCENTRATING SUNLIGHT

As discussed in the section above, the maximum theoretical efficiency for a single-bandgap material, such as conventional silicon cells, is about 34%. Commercially available solar cells are typically only 20-23% efficient.

Fresnel lenses or parabolic concentrators are typically used to improve the cost/efficiency ratio of a solar PV system by concentrating the light that reaches the solar panel. The intensity concentration ratio (also referred to as “suns”) is the average intensity of the focused light divided by an average solar constant of 1 kW/m². [6]

By concentrating sunlight onto a solar cell, more photons are transmitted into the semiconductor bandgap, which results in an increased emission of electrons (current). Concentrated sunlight is especially effective in combination with multi-junction solar panels.[7]

2.1.4.
BATTERIES

Solar PV is an example of a variable power generation technology that depends on climatic conditions. In the case of solar PV, energy can only be dispatched from the system when solar radiation is available; expected power output diminishes on overcast days or at night. Energy storage is necessitated for variable power generation technologies, in order to make this power available on demand.[8] Since solar panels produce direct current, electrical batteries are the most applicable form of energy storage.

Lead acid batteries are currently one of the most viable charge storage solutions for solar PV. All batteries have charging and discharging losses, which means that less power is discharged than the power used to charge the batteries.

Since lead acid batteries are usually charged at the float voltage of approximately 13.5 V and the discharge voltage is about 12 V, the voltage efficiency is about 88%. The efficiency of charge transfer is approximately 90%. This means that the power output from a battery has a net charge-discharge efficiency of approximately 80%.[9] Energy which is lost due to the internal resistance of the battery is released as heat; battery efficiency is thermally affected, which means that this heating effect can further reduce the performance of the battery.

It should be noted that batteries cannot store energy indefinitely and, depending on the type of battery used, there is a gradual loss of charge over time.

2.1.5.
CHARGING BATTERIES WITH SOLAR POWER

Charge controllers have a two-fold purpose:

1. Preventing battery overcharge.

2. Only permitting one-way current to prevent battery discharge via solar panels at night.

When the panel is connected to the battery through a simple charge regulator, its voltage will be pulled down to near that of the battery. This lead to lower power output from the panel. Thus, the panel will be able to produce its maximum power when the battery voltage is near its maximum (fully charged).

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[5] High-efficiency multi-junction solar cells, Current status and future potential; Natalya V. Yastrebova, Centre for Research in Photonics, University of Ottawa, April 2007

[6] pg 5; Current Status Of Concentrator Photovoltaic (CPV) Technology; Version 1.2; February 2016; Dr. SP. Philipps, Dr. Andreas; W. Bett; Fraunhofer Institute For Solar Energy Systems Isein Freiburg, Germany

[7] pg 30; Technology roadmap: Solar Photovoltaic Energy; International Energy Agency; 2014 edition; iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdf

[8] pg 11; Technology Roadmap, Smart Grids; 2011; International Energy Agency; iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf

[9] solar-facts.com/batteries/battery-charging.php

With simple charge controllers that use pulse width modulation (PWM), a system has to be designed in such a way that the batteries remain close to their full charge at most times. However, rainy or heavily clouded days might cause batteries to remain in the state of low charge, which pulls down the panel voltage and degrades the total output of the system.

Maximum Power Point Tracking (MPPT) charge controllers use more complex technology to keep panels closer to their maximum power outputs, and simultaneously produces the voltage required by the battery. Where a basic charge controller simply prevents damage of batteries by preventing over-charging, a MPPT controller performs an extra function to improve solar PV system efficiency by using more of the panel's available power.[10]

Consider a typical 100W 12V solar panel with 18Vmp and 5A Imp. The table below shows the comparative efficiencies whilst a battery is being charged by a PWM and MPPT system respectively. Due to the fact that the PWM system cannot adjust the charging current, the solar panel's energy is wasted.

Battery status	PWM	MPPT [increases the current]
Low battery [V = 11V]	11V x 5A = 55W	11V x [(18Vmp/11V) x 5A] = 11V x 8,18A = 90W
High battery [V = 14V]	14V x 5A = 70W	14V x [(18Vmp/14V) x 5A] = 14V x 6,43A = 90W

2.1.6.
INVERTERS

When the solar PV system is used to power AC loads, an inverter is needed to switch DC power to AC power. Typical solar inverters are between 80% to 90% efficient.[11] The topology in which inverters are installed in a solar PV system has further effects on the total efficiency of the system:

1. String inverters: Multiple solar panels can be wired in a string, with multiple strings being connected to independent MPPT channels. If a panel in a string is shaded, it will affect the string that it is on.

2. String inverters with DC optimisers: These devices individually manage separate panels, which means that shaded panels are affected and not the entire string.

3. Micro-inverters: These devices are installed at every solar panel and invert the DC power at the panel level. This means that AC power is reticulated from the panel, which reduces transmission losses as explained in the section below.

2.1.7.
RETICULATION

All electrical transmission lines have resistance. The physical dimensions of the conductors affect the resistance as follows:

1. Diameter: Increased diameter reduces resistance.

2. Length: Increased length increases resistance.

3. Material resistivity: the properties of the conductor affect the transmission of electrons.

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[10] physics.ucsd.edu/do-the-math/2012/09/blow-by-blow-pv-system-efficiency
[11] solar-facts.com/inverters/inverter-efficiency.php

Ohmic losses in an electrical transmission line are also directly proportional to the electrical current flowing through the line. This is why AC power is 'stepped up' to higher voltages, which significantly reduces the transmission losses. Consequently, micro-inverters mentioned in the section above serve to reduce the transmission losses in a solar PV plant.[12]

2.1.8.
TRANSFORMERS

Transformers convert alternating current from one voltage and current to a different alternating voltage and current with the power on each side of the two coils (primary and secondary) relatively equal. In reality there are actual losses. These losses are brought about by eddy currents that generate heat in the metal/ composite core of the transformer. The size of the core of the transformer and material of construction therefore plays a major role in its efficiency. The two main types of transformers are Dry type and Wet type transformers. The differences are highlighted below:

- Dry type transformers are considered safer and suitable for placement in buildings as there is no flammable oil directly in contact with the coils or core of the transformer. Since the core is cooled by air the unit needs to be larger and this reduces its efficiency.

- Wet type transformers are so called as they are cooled with oil. The oil is in contact with the core directly and facilitates heat transfer therefore requiring smaller surface area. This makes it more efficient with efficiencies up to >99% (Figure 6). Modern oils have been developed that address the safety and flammability concerns.

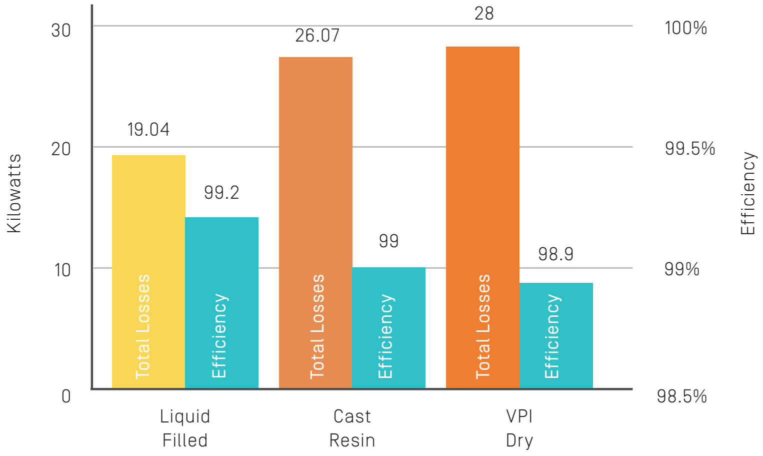

Figure 6: Comparing transformer efficiencies. (A cast resin transformer is a type of dry transformer) [13]

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[12] pg 35; energy.gov/sites/prod/files/oeprod/DocumentsandMedia/primer.pdf

[13] Determination Analysis of Energy Conservation Standards for Distribution Transformers; Barnes 1996; Barnes, P.R., J.W. Van Dyke, B.W. McConnell, and S. Das.; Oak Ridge National Laboratory ORNL-6847; July 1996; Developed for US Department of Energy

2.2.
DESIGN EFFICIENCY

2.2.1.
DIRECTION AND ANGLE

As one moves away from the equator, the seasonal variation of the sun's inclination varies with latitude. The duration, intensity and incident angle of sunlight onto the Earth's surface varies at different times of the year.

The orientation of a solar panel has to be carefully considered for fixed solar systems, so that the maximum amount of sunlight can be exploited throughout the year.

Systems that track the sun are significantly more efficient, but expend a certain amount of energy to actuate the tracking mechanism. Moreover, the cost of tracking mechanisms has to be offset against the cost of potential energy savings.

Figure 7 describes the main angles that need to be taken into account when placing solar panels on a site. The Azimuth is the angle of a line perpendicular to the solar panel and either due south or due north, depending on whether you are in the northern or southern hemisphere respectively.

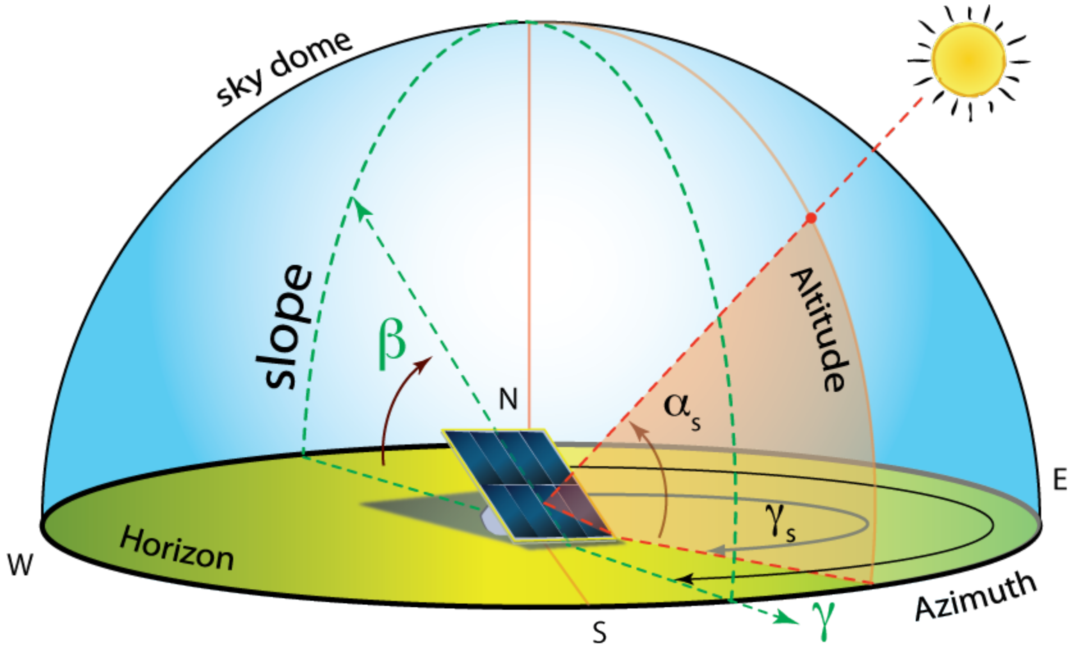

Figure 7: A diagram depicting the solar angles that are applicable in good design.[14] Credit: Jeffrey Brownson

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[14] e-education.psu.edu/eme810/node/576

2.2.2.
SHADING

There are two different types of shading, which have different effects on the performance of solar panels: [15]

1. 'Soft shading' is typically caused by cloud cover, and evenly attenuates the intensity of light that reaches the entire surface of a solar panel. This leads to reduced current output in a solar panel.

2. 'Hard shading' occurs when part of all of a solar panel are shaded without any light reaching the shaded area. Hard shading on even a small area of can have a significant effect on a solar panel's power output. This is especially the case where cells within a solar panel are connected in series. As soon as one solar cell is shaded, the current flow through this cell is restricted. Solar panel manufacturers circumvent this problem by wiring bypass diodes in parallel with solar cells, which allows the current in a solar panel to flow non-conducting cells.

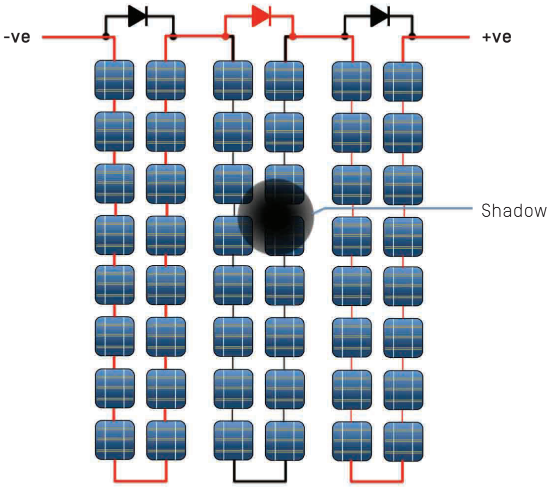

Figure 8: In this example, 48 solar PV cells are connected in series to create a solar panel. If a specific part of the panel is shaded, it creates a high resistance path which creates a hot spot on the panel and impedes the flow of current. The current still flows through the unshaded strings due to the bypass path created by the diodes (shown in red). Even though a string of 16 cells no longer produce current, the remaining strings allow for flow of current. If the bypass diodes were not installed, the power output of the solar panel would be significantly reduced.

In solar arrays, the effects of shading can be even greater: If separate solar panels are connected in series to form strings, the current must be the same throughout all the respective panels. That means that without the bypass diodes, any shade on any cell in the string would cause the entire string to stop producing power entirely. Such a devastating loss of power has to be avoided, so typically three diodes are placed in along the solar cells. The diodes are placed in such a way they will allow current to flow through them only if the solar cells they bypass are shaded and opened. Since the diodes have a negligible voltage drop, there are very little losses induced by the diodes, so the only real loss from a shaded group of cells is whatever voltage they were providing. [16]

Bypass diodes may be integrated into the design of a solar PV panel, or supplied as a separate part. The specification of a product must be consulted to confirm whether bypass diodes are integrated into the product. Most low-cost panels do not include bypass diodes, since these semiconductor devices add additional component and fabrication costs. High-end panels mostly include bypass diodes.

2.2.3.
SOILING (DUST AND DIRT ACCUMULATION)

In the section above, the concept of 'soft shading' was introduced for cases where the light that reaches a solar panel is attenuated. Whether this happens due to cloud cover or dirt accumulation, the effects are the same. Dust and dirt accumulation on a solar panel have similar effects to soft shading, whilst grime such as bird droppings has the same effect as hard shading.[17]

The dusting allowance of a solar array is the decrease in efficiency that that may be tolerated due to soiling. Since dirt accumulation is a constant issue, care must be taken to clean and maintain the surface of solar panels on a regular basis.

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[15] sargosis.com/how-shade-affects-a-solar-array

[16] Section 4; Shading Effects on Output Power of Grid Connected Photovoltaic Generator Systems; R. E. Hanitsch, Detlef Schulz and Udo Siegfried; Technical University Berlin · Institute of Electrical Power and Automation Technology; Germany

[17] pg 2; Effects of Dust on the Performance of PV Panels; SA. Sulaiman et al; waset.org/publications/10305/effects-of-dust-on-the-performance-of-pv-panels

2.2.4.
TEMPERATURE

The bandgap of a semiconductor device is affected by temperature. Solar cells generally work best at low temperatures. For this reason, the efficiency of solar panels is tested at 25° Celsius. Higher temperatures cause the solar cell's semiconductor properties to shift, resulting in a slight increase in current, but a much larger decrease in voltage. A solar panel's temperature coefficient indicates the unit's susceptibility to thermal losses for temperatures above 25° Celsius. In general, efficiency decreases with 0.5% per degree Celsius increase above 25° Celsius.

Proper thermal management improves both efficiency and lifetime of solar panels.[18] In sub-Saharan Africa, the following considerations contribute towards improving temperature-related effects on solar PV arrays:

1. Solar panels with improved temperature coefficients should be selected; this consideration is a cost-performance trade-off.

2. Stand-off mounting: The panel should be mounted in such a way that airflow below (or behind) the panel can remove heat by convective airflow.

3. Mounting surface: The surface should ideally be treated with a white/reflective paint, to prevent unnecessary radioactive absorption.

4. Frames: Solar panel frames should be as narrow as possible to avoid radioactive absorption.

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[18] Pg 3; Photovoltaic Efficiency: Lesson 2, The Temperature Effect - Fundamentals Article; researchgate.net

2.3.
SUMMARY

The issues discussed in the previous section have significant ramifications on the overall performance of a solar PV system. Figure 9 offers a breakdown of all design- and integration-specific efficiencies for a typical solar panel array.

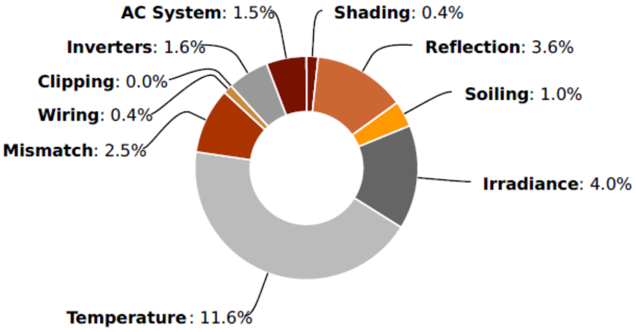

Figure 9: A complete breakdown of the losses from an example solar PV plant. [Modelled on Helioscope ™]

As indicated in the breakdown, a solar array's total yield is also affected by the following factors:

- Location: Despite the abundance of solar resource in Africa, it is critical to consider localized weather conditions within a region. Furthermore, location shading and dusting are also affected by location.
- Direction and angle: Stationary fixed-tilt panels should be facing towards the equator to optimize on solar yield. As a general guideline, Southern Hemisphere installations should face north; the Azimuth angle should be of zero degrees and a tilt angle should be equal to the latitude. This optimizes the annual yield of the panel.
- Shading: Solar panels produce most of their output power from directly incident light. Shading reduces this considerably. Shading may not always be apparent at first glance, but as seasons change, structures get built in the vicinity, and foliage grows, shading can become a major impacting factor on the performance of a solar system.
- Reflection (previously addressed as this impacts the PV panel subsystem).
- Soiling: Soiling on solar panels prevents photons from reaching the semiconductors that convert them to electricity. This can be mitigated by ensuring that the plant is designed to facilitate easy cleaning and that the surrounding location does not have activities that generate excessive dust.
- Irradiance (previously addressed as this impacts the PV panel subsystem).
- Temperature: As discussed before, the semiconductors in solar panels are sensitive to temperature. Each panel comes with a temperature coefficient, typically 0.4% per degree Celsius. This is the value by which the efficiency decreases as the temperature increases over the Standard Test Condition values.
- Mismatch is caused by slight variation in the tolerances of identical devices, or by effects of shading and dusting. The panel with the lowest current will limit the maximum current of an entire string of solar panels.

- As discussed, wiring losses have an impact on the overall system performance.

- Clipping losses are incurred when the voltage output from the solar array exceeds that of the inverter's specified voltage input.

- Inverter losses are incurred, as discussed in Section 2.1.3.

- AC system (previously addressed as this impacts the AC wiring as a subsystem).

Software programmes such as Helioscope™ and PVSYST™ employ engineering models to predict the power output of solar plants. These programmes have been refined to include all of the above-mentioned criteria, as well as the local weather conditions. Figure 10 illustrates the predicted power output for a Solar PV plant which is modelled in PVSYST™.

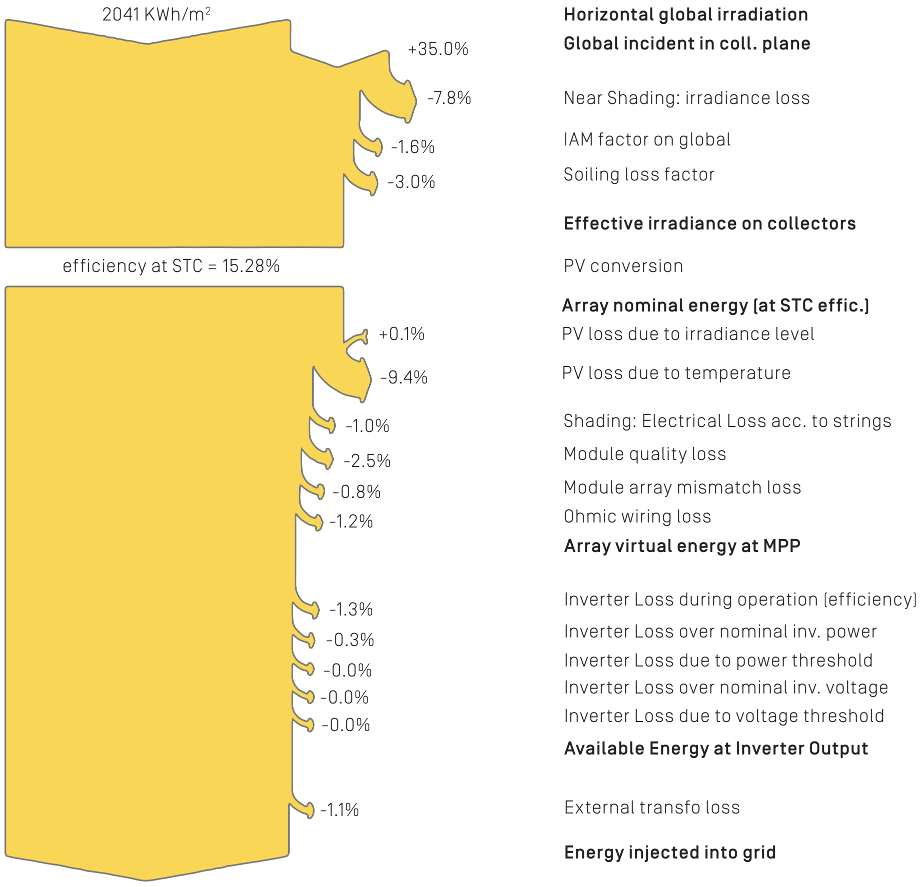

Figure 10: Example from PVSYST™ V6.41 modelling

3. IMPORTANCE OF EFFICIENCY IN SOLAR PV PROJECTS

In solar systems, improved efficiency often comes at greater cost. Since cost is one of the main drivers of solar projects, these two variables have to be balanced in such a way that the return generated by power sales and the efficiencies that mitigate potential losses ensure the repayment of the initial capital investment.

A good example of capital expenditure for improving system efficiency that may not necessarily improve project viability is the use of complex two axis tracing to increase yield of a solar plant. Due to the high cost of maintenance and operating the tracker in rural areas, the additional yield of solar power from the asset might not validated. This can be modelled in an investor's discounted project cash flow, backed by a technical model. In some instances this result may actually prove to be beneficial, based on the real cost of the overall tracking design and the income figures that are dependent mainly on the operations and maintenance cost, the power generated and the cost per unit of energy.

Depending on the project, procurements of specific subsystems with higher efficiencies (such as high-efficiency solar panels) could improve a project's financial viability. Certain thin film solar panel technologies have a better yield per day but lower overall peak efficiency. They are also comparatively priced per watt output power. This allows for higher yields and sales with the same expenditure, which make specific project viable.

Efficiency of solar also changes over time. This is due to transient changes in the environment, soiling, shading from trees, weather patterns, and also specific subsystem changes. Changes in solar panel efficiency are predictable for Tier 1 suppliers; guaranteed efficiency degradation over 25–30 years is illustrated in Figure 11.

Even through certain products or technologies may seem equivalent in terms of initial cost and upfront performance, the lifecycle efficiency should be considered for costing a project.

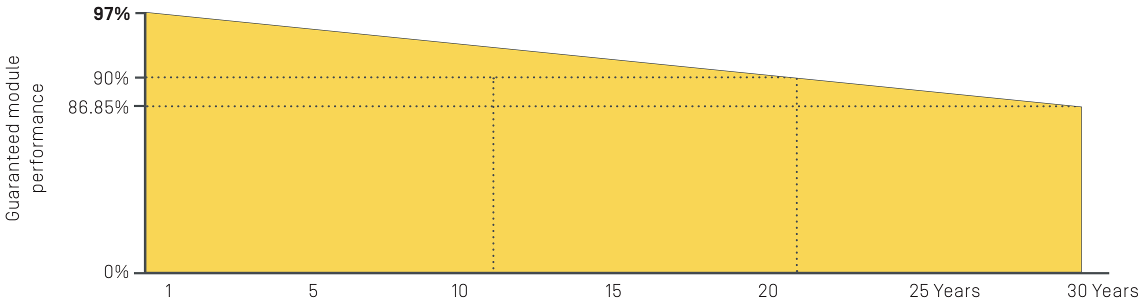

Figure 11: The degradation curve that is guaranteed by a solar panel supplier – industry standard for Tier 1 panels.[19]

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[19] solarworld-usa.com/products-and-services/sunmodule-solar-panels

4. SOLAR PV IN THE EEP PORTFOLIO

Solar PV technology makes a significant contribution to the EEP portfolio in southern and east Africa. Figure 12 illustrates the funding that has been allocated solar projects across the 13 different EEP S&EA countries.

The types of technologies that have been funded in the EEP S&EA portfolio include the following technologies:

- Grid connected Solar PV plants
- Offgrid solar minigrids
- Solar/Diesel hybrids
- Solar Home Systems
- Solar lights and lanterns

Energy efficiency and yield considerations have a significant impact on the feasibility of a solar PV plant.

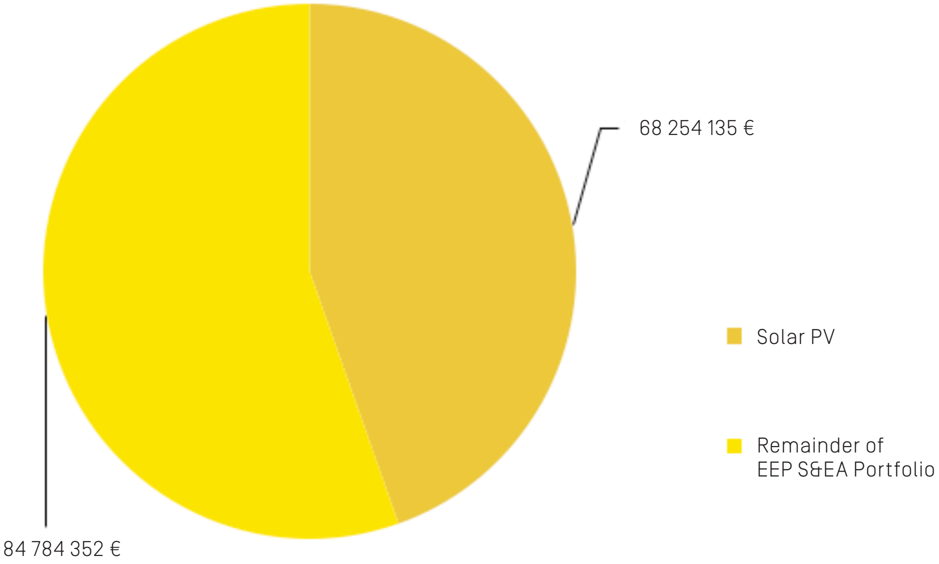

Figure 9: A complete breakdown of the losses from an example solar PV plant. (Modelled on Helioscope ™)

5. CONCLUSION

5.1.
TECHNOLOGY

Due to the diversity of solar PV technologies and topologies that are implemented in the EEP S&EA portfolio, the following information is required for effective project assessments:

1. A system diagram must indicate the topology of all functional elements.
2. Product specifications must be supplied for all functional elements of the system.
3. Peripheral systems for improving system efficiency (such as panel or battery cooling or tracking systems) must be listed.

5.2.
POWER OUTPUT

The power produced depends on the following:

1. Wattage rating of the solar PV panel or solar PV array.
2. Sub-system capacity and efficiencies as explained in Section 2.1.
3. Design and yield considerations as explained in Section 2.2.

Solar home systems are strongly supported by the EEP and are becoming widely adopted in sub-Saharan Africa. Since the power from solar home systems is used mostly at night, the M&E should consider the both rated power output of the solar panel as well as the energy transfer to the system's battery. If the solar panel is oversized, the storage capacity of the battery and the efficiency of the battery will determine the power output of the system. If the battery is oversized, the output power from the solar panel and the yield considerations due to installation will determine the amount of useable power.

5.3.
INSTALLATION

System installation directly affects the energy yield of a solar PV system. Table 3 provides a checklist for installation considerations. The impact of installation standards becomes more pronounced for distributed systems (such as solar home systems), where multiple contractors of varying technical ability are often used to deploy the systems. M&E on distributed systems must be performed on a statistically significant sample to verify consistent installation standards. Furthermore, the evaluation should include installations from all installation contractors on a roll-out, in order to ensure consistency.

5.4.
OPERATION AND MAINTENANCE

The annual power output of a solar PV installation is significantly affected by maintenance. Without proper maintenance (such as cleaning), efficiency rapidly declines. Similarly, effective usage and consistent operational conditions affect the annual energy output of a solar system. The checklist in Table 4 allows for effective project evaluation and M&E within the context of system operation and maintenance.

6. EVALUATION CRITERIA

The evaluation criteria below can be used during project selection as well as M&E. *Before the system is evaluated for efficiency, a line diagram which indicates the interaction between all functional elements must be submitted.*

Battery status	Product type	Model number	Rated efficiency [%]	Additional info
Solar panel				1. Wattage: 2. Open circuit voltage: 3. Close circuit current: 4. Thermal coefficient: 5. Lifespan:
Voltage regulator [small systems]				
Charge controller [battery systems]				
Battery				1. Charge cycles:
Inverter				
Transformer				
Bypass diodes between cells inside panels			n/a	
Bypass diodes between series panels in array			n/a	
Voltage controllers between series panels				

Table 1: Equipment listing – complete where relevant and list product specification sources.

Device/system	Projected yield / efficiency improvement
Is a tracking system installed on the solar array?	
Is a cooling system installed on the solar array?	
Is the battery bank ventilated?	
Is the battery bank cooled?	

Table 2: Large system checks

Consideration	Value
Azimuth angle (as close to zero as possible)	
Inclination angle (as close to the latitude as possible)	
Is there a risk of shading from buildings or plants?	
How is the panel mounted on the surface – is it secure against gusts?	
Is there an air gap under the panel, or is it mounted directly onto the surface?	
What is the composition of the mounting surface?	
What is the colour of the mounting surface?	

Table 3: Installation checks.

Consideration	Value / Response
PAYG systems: What is the contractual allowance for usage downtime?	
Grid-tied systems: How often is the grid off during the day, where solar capacity cannot be added to the grid?	
Mini-grids and grid-tied systems: When is the power consumed, and for what types of loads?	
Home systems: When is the power consumed, and for what applications/appliances?	
Large grids: Frequency of washing/cleaning	

Table 4: Operation and maintenance of Solar PV.

7. REFERENCE GRAPH: SOLAR PV EFFICIENCY

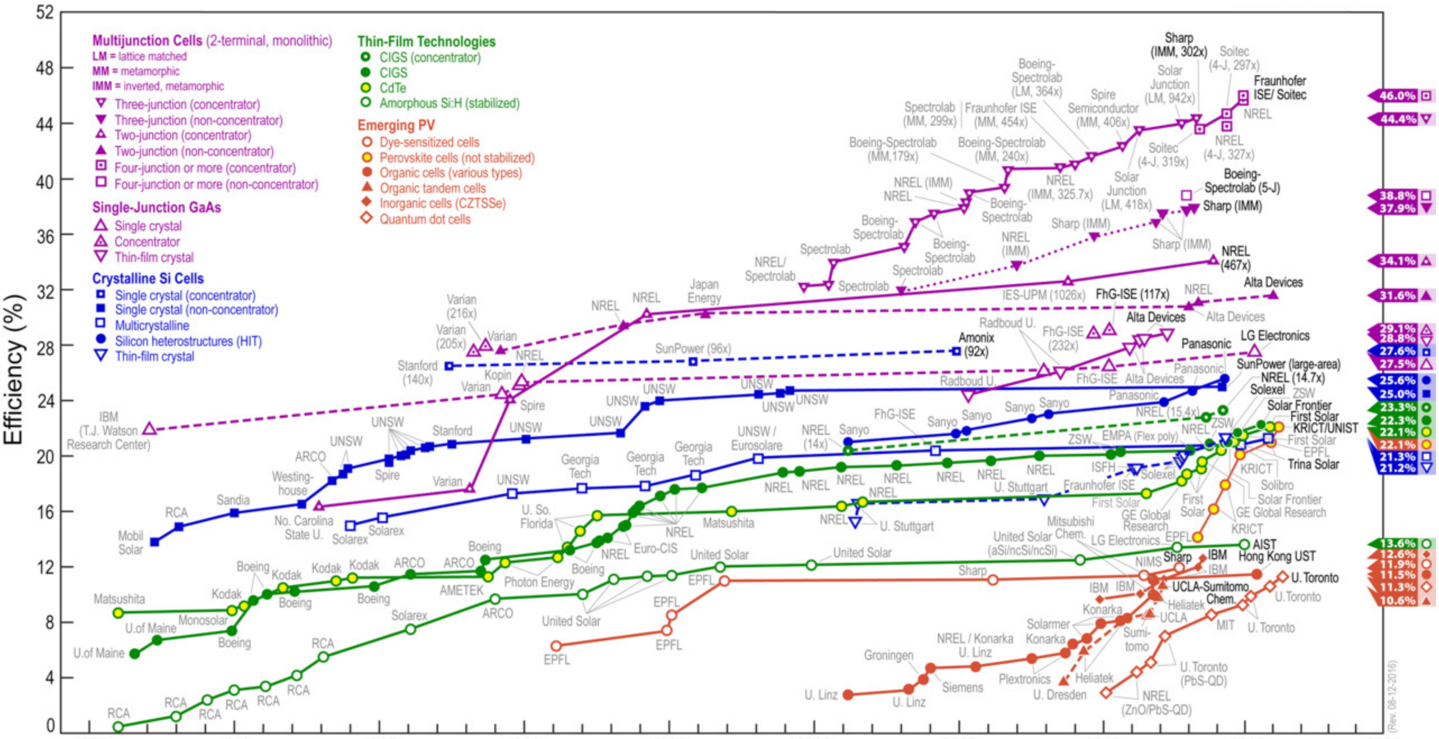

Figure 16: The historic improvement of EE in solar panel technologies.[20]

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[20] Best research – Cell Efficiencies; National Renewable Energy Laboratory (NREL); United States Department of Energy; 2016

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