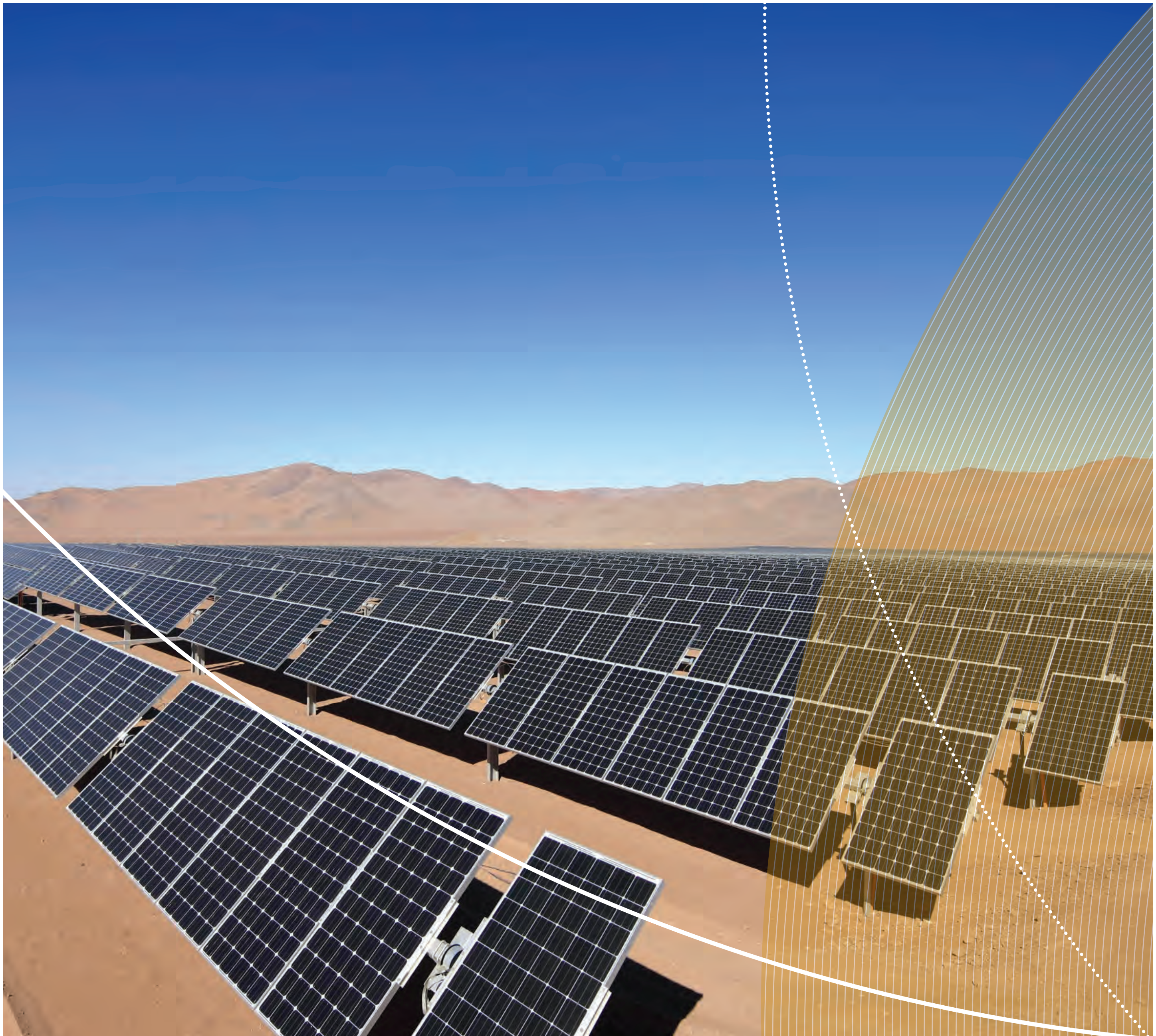

Utility-Scale Solar Photovoltaic Power Plants

A PROJECT DEVELOPER'S GUIDE

IN PARTNERSHIP WITH

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2121 Pennsylvania Avenue, N.W.
Washington, D.C. 20433
ifc.org

Cover Image: SunEdison Amanecer project in Chile, by Juan Payeras/IFC

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List of Abbreviations

°C	Degrees Centigrade
A	Amp
AC	Alternating Current
AEDP	Alternative Energy Development Plan
a-Si	Amorphous Silicon
BAPV	Building Applied Photovoltaic
BIPV	Building Integrated Photovoltaic
BOO	Build-Own-Operate
BoP	Balance of Plant
c-Si	Crystalline Silicon
CB	Circuit Breaker
CDM	Clean Development Mechanism
CdTe	Cadmium Telluride
CE	Conformance European (European Commission)
CER	Certified Emission Reduction
CERC	Central Electricity Regulatory Commission
CFADS	Cash Flow Available for Debt Service
CIGS/CIS	Copper Indium (Gallium) Di-Selenide
CIS	Copper Indium Selenide
CSC	Cost Settlement Center
CSP	Concentrated Solar Power
DC	Direct Current
DIN	Deutsches Institut für Normung
DNI	Direct Normal Irradiation
DSCR	Debt Service Coverage Ratio
DSRA	Debt Service Reserve Account
DSP	Digital Signal Processing
EHS	Environmental, Health and Safety
EIA	Environmental Impact Assessment
EN	European Norm
EMI	Electromagnetic Interference
EPC	Engineering, Procurement and Construction
EPIA	European Photovoltaic Industry Association
EPFI	Equator Principles Financial Institutions
ERU	Emission Reduction Units
EU	European Union
EUA	EU Allowance
FAC	Final Acceptance Certificate
FiT	Feed-in Tariff
GCR	Ground Cover Ratio
GHG	Greenhouse gas
GHI	Global Horizontal Irradiation
GSM	Global System for Mobile Communications
GTI	Global Tilted Irradiation
HV	High Voltage
IAC	Intermediate Acceptance Certificate
ICC	International Chamber of Commerce
ICSID	International Centre for Settlement of Investment Disputes
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEE	Initial Environmental Examination
IFC	International Finance Corporation
IGBT	Insulated Gate Bipolar Transistor
IP	International Protection Rating or Internet Protocol
IPs	Indigenous Peoples
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return

List of Abbreviations (*continued*)

I_{SC}	Short-Circuit Current
JI	Joint Implementation
JNNSM	Jawaharlal Nehru National Solar Mission
kWh	Kilowatt Hour
LCOE	Levelised Cost of Electricity
LD	Liquidated Damages
LLCR	Loan Life Coverage Ratio
LPS	Lightning Protection System
LTV	Loan to Value
LV	Low Voltage
MCB	Miniature Circuit Breakers
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
MRA	Maintenance Reserve Account
MTTF	Mean Time to Failure
MV	Medium Voltage
MVA	Mega-volt ampere
MW	Megawatt
MWp	Megawatt Peak
NAPCC	National Action Plan on Climate Change
NCRE	Non-Conventional Renewable Energy
NHSFO	Non Honoring of Sovereign Financial Obligations
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NVVN	National Thermal Power Corporation Vidyut Vyapar Nigam
OECD	Organisation for Economic Cooperation and Development
OEM	Original Equipment Manufacturer
O&M	Operations and Maintenance
PID	Potential Induced Degradation
PIR	Passive Infrared
PPA	Power Purchase Agreement
PR	Performance Ratio
PV	Photovoltaic
REC	Renewable Energy Certificate
REC	Renewable Energy Credit
REIPPP	Renewable Energy Independent Power Producer Procurement
ROI	Return on Investment
ROW	Right of way
RPO	Renewable Purchase Obligation
SCADA	Supervisory Control and Data Acquisition
SERC	State Electricity Regulatory Commission
SPV	Special Purpose Vehicle
STC	Standard Test Conditions
TCO	Total Cost of Ownership
TCP	Transmission Control Protocol
TGC	Tradable Green Certificate
THD	Total Harmonic Distortion
UL	Underwriters Laboratories, Inc.
UNFCCC	United Nations Framework Convention on Climate Change
UV	Ultraviolet
V_{OC}	Open Circuit Voltage
V	Volt
VAT	Value-Added Tax
VDE	Verband der Elektrotechnik, Elektronik und Informationstechnik
WACC	Weighted Average Cost of Capital
Wp	Watt Peak

Foreword

Although it currently represents a small percentage of global power generation, installations of solar photovoltaic (PV) power plants are growing rapidly for both utility-scale and distributed power generation applications. Reductions in costs driven by technological advances, economies of scale in manufacturing, and innovations in financing have brought solar power within reach of grid parity in an increasing number of markets. Continued advancements and further cost reductions will expand these opportunities, including in developing countries where favourable solar conditions exist. Policy environments for renewable energy in the developing world are being refined, drawing on the lessons learned from the successes and failures of policies adopted in first-mover markets. We now see several regulatory models being successfully deployed in the developing world with consequent increase in investment and installations. Solar is proving to be viable in more places and for more applications than many industry experts predicted even a few years ago.

At the same time, this rapid market growth has been accompanied by an observed uneven expertise and know-how demonstrated by new market entrants. Building capacity and knowledge on the practical aspects of solar power project development, particularly for smaller developers, will help ensure that new PV projects are well-designed, well-executed, and built to last.

Enhancing access to power is a key priority for the International Finance Corporation (IFC), and solar power is an area where we have significant expertise. IFC has invested in more than 55 solar power projects globally representing about 1,400 MW of capacity, with key recent transactions in Thailand, the Philippines, India, China, Jordan, Mexico, South Africa, Honduras, and Chile.

We trust that this publication will help build capacity amongst key stakeholders, as solar power continues to become a more and more important contributor to meeting the energy needs in emerging economies.

John Kellenberg

Manager, Energy & Efficiency Resource Advisory

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Executive Summary

1

The World Bank Group (including the International Bank for Reconstruction and Development, the International Development Association, IFC, and the Multilateral Investment Guarantee Agency) helps client countries secure the affordable, reliable, and sustainable energy supply needed to end extreme poverty and promote shared prosperity.

With an installed capacity greater than 137 GWs worldwide and annual additions of about 40 GWs in recent years,[1] solar photovoltaic (PV) technology has become an increasingly important energy supply option. A substantial decline in the cost of solar PV power plants (80% reduction since 2008)[2] has improved solar PV's competitiveness, reducing the needs for subsidies and enabling solar to compete with other power generation options in some markets. While the majority of operating solar projects is in developed economies, the drop in prices coupled with unreliable grid power and the high cost of diesel generators has driven fast-growing interest in solar PV technology in emerging economies as well.

Many emerging economies have an excellent solar resource, and have adopted policies to encourage the development of the solar industry to realize the benefits that expanded use of PV technology can have on their economies and on improving energy security, as well as on the local and global environmental. Also, solar installations can be built relatively quickly, often in 6–12 months, compared to hydro and fossil fuel projects that require more than 4–5 years to complete. This presents a major incentive in rapidly-growing, emerging markets with a high unmet demand and urgent need for power. Assuming that PV technology prices continue to fall relative to competing sources of electricity, the market penetration rate of utility-scale solar power projects can be expected to continue growing rapidly, including in emerging markets.

The World Bank Group (including the International Bank for Reconstruction and Development, the International Development Association, IFC, and the Multilateral Investment Guarantee Agency) helps client countries secure the affordable, reliable, and sustainable energy supply needed to end extreme poverty and promote shared prosperity. The approach mirrors the objectives

1 Source: IEA, "Trends 2014 in Photovoltaic Applications"

2 Source: IRENA, "Rethinking Energy 2014"

of the Sustainable Energy for All Initiative— achieving universal access, accelerating improvements in energy efficiency, and doubling the global share of renewable energy by 2030. The World Bank Group recognizes that each country determines its own path for achieving its energy aspirations, and that each country's transition to a sustainable energy sector involves a unique mix of resource opportunities and challenges, prompting a different emphasis on access, efficiency, and renewable energy.

Enhancing access to power is a key priority for IFC, which supports private sector investment in renewable energy solutions. As of May 2015, IFC has made over 350 investments in power in more than 65 countries. We are often at the forefront of markets opening to private participation. IFC has invested in more than 55 solar projects, representing about 1,400 MW of capacity, with key transactions in Thailand, the Philippines, India, China, Jordan, Mexico, South Africa, Honduras, and Chile.

The objective of this guidebook is to enhance the reader's understanding of how to successfully develop, finance, construct, and operate utility-scale solar PV power plants. It is aimed at project developers entering the market, and meant as a reference source for contractors, investors, government decision makers, and other stakeholders working on PV projects in emerging markets. This report is a substantially expanded version (second edition) of an earlier IFC publication, "*Utility-Scale Solar Power Plants,*" which was released in 2011. Substantial progress in the number of PV projects implemented globally and dramatic reduction in PV technology prices justified the need for an update in this fast moving market.

The guidebook focuses on aspects of project development that are specific to solar. From this perspective it covers all aspects of the overall project development process including site identification, plant design, energy yield, permits/licenses, contractual arrangements, and financing, giving sparser coverage to general project development basics that are not specific to solar.

Project development activities are interrelated and often are carried out in parallel. Technical aspects that determine the plant design and energy yield are accompanied by efforts to secure permits/licenses and financing. Assessments are repeated at increasing levels of detail and certainty as the project moves forward. For example, a preliminary design is initially developed (prefeasibility study) along with a high-level assessment of the regulatory environment and price of power, enabling a "back of the envelope" analysis to be carried out to determine whether the project meets investor requirements. If the project looks promising, the developer decides to proceed further. If the project does not appear to meet hurdle rates, changes to the design or financing adjustments may be considered, or the project development may be terminated. Similar analysis is repeated in the feasibility study at a more granular level of detail, ultimately leading to another "go/no-go" decision. Throughout the project development process, there are several key decision points when modifications are made, and the decision to proceed further is re-assessed. Changes are common until financial closure is achieved. After this, the focus shifts to procuring the equipment, construction, and commissioning the power plant within the projected schedule and budget.

This guide covers the key building blocks to developing a successful utility-scale solar power project (the threshold for "utility-scale" depends on the market, but generally at least 5 MW). Most lessons learned in this segment of the solar industry are drawn from experiences in developed markets. However, this guide makes an effort to anticipate and address the concerns of projects in emerging economies. In doing so, the guidebook covers the key three themes:

1. **Optimum power plant design:** A key project development challenge is to design a PV power plant that is optimally balanced in terms of cost and performance for a specific site.
2. **Project implementation**: Achieving project completion on time and within budget with a power plant that operates efficiently and reliably, and generates the expected energy and revenue, is another key

concern for developers. Key aspects of project implementation include: permits and licensing, selection and contracting of the Engineering, Procurement and Construction (EPC) company, power plant construction, and operations and maintenance (O&M).

3. **Commercial and financing aspects:** PV regulatory frameworks and specific types of incentives/support mechanisms for the development of PV projects, such as preferential tariffs and other direct and indirect financial supports, have an important impact on the financial viability of the project, as they affect the revenue stream. Power Purchase Agreements (PPAs) specify the terms under which the off-taker purchases the power produced by the PV plant; this is the most important document to obtain financing.

The **project development process** starts once interest has been established in a specific power market. Assessment of the market opportunity takes into account broad issues at the national level, such as the regulatory environment, prevailing power prices, structure of the power market, the credit-worthiness of potential off-takers, and any specific financial incentives for developing solar PV power plants. The first tangible steps in the process are development of a concept and identification of a site. The project will then proceed through several development stages, including the prefeasibility study, a more detailed feasibility study, permitting and financing, and finally engineering (detailed design), construction, and commercial operation of the power plant. As the project developer initiates preparatory activities including securing a land lease agreement and permits, preliminary financing schemes are assessed. Energy resource assessment and activities related to project financing run in parallel with the project design (e.g., engineering, construction, etc.). Detailed information on these overlapping work streams and guidance on coordination and successful execution of project activities is provided throughout all fifteen sections of this guidebook, beginning with an overview of the project development process in **Section 2**. A summary of key aspects of project development is provided in this section.

1.1 OPTIMUM POWER PLANT AND PROJECT DESIGN

PV plant design is developed initially as part of a prefeasibility study which is based on preliminary energy resource and yield estimates, as well as other site-specific requirements and constraints. The plant design is further improved during the feasibility study, which considers site measurements, site topography, and environmental and social considerations. Key design features include the type of PV module used, tilting angle, mounting and tracking systems, inverters, and module arrangement. Optimization of plant design involves considerations such as shading, performance degradation, and trade-offs between increased investment (e.g., for tracking) and energy yield. Usually, the feasibility study also develops design specifications on which the equipment to be procured is based. PV technology options are described in **Section 3,** and the PV plant design in **Section 7**.

Solar energy resource depends on solar irradiation of the geographic location as well as local issues like shading. Initially, solar resource assessment can be done based on satellite data or other sources, but as the project development moves forward, ground-based measurements are desirable to provide an increased level of confidence. Solar resource is covered in **Section 4**.

Energy yield is a critical parameter that determines (along with the capital costs and the tariff) the financial viability of the project. Probability-based energy yield (for example P50, P75, P90) are modelled over the operating life of the project. A thorough analysis of the solar resource and projected energy yield are critical inputs for the financial analysis. Details on the methodology, solar data sources and key issues to be considered when estimating the energy resource and project energy yield are provided in **Section 5**.

Site selection is based on many considerations, such as whether the PV plant is close to the grid, and whether the process for obtaining a grid connection agreement is transparent and predictable. Close cooperation with the grid company is essential in obtaining a grid connection agreement. The agreement, as well as applicable regulations should clearly state the conditions of the PV developer's access to the grid, and provide the guidelines for design, ownership, and operation of the grid connection. Access to land is also a basic requirement for project development. Project land must be purchased or leased for longer than the debt coverage period; a minimum of 15–20 years is desirable, although a 40–50 year lease is often signed. In addition to the project site, the developer needs to secure access to the land over which the grid connection will be laid out. Land use issues are reviewed along with the technical aspects of site selection in **Section 6**.

1.2 PROJECT IMPLEMENTATION

The objective of the project implementation process is to complete the project on schedule and within the allocated budget, with a PV power plant that operates efficiently and reliably, and generates the expected volumes of energy and revenue. In order to achieve this objective, a number of key activities need to be completed successfully.

Permits and licensing is often a very bureaucratic process involving multiple agencies in the central and local governments which may not coordinate their procedures and requirements. The list of permits/agreements needed is usually very long and differs from country to country. Typically, at least the following are needed: 1) Land lease agreement; 2) Site access permit; 3) Building permits; 4) Environmental permit; 5) Grid connection agreement; and 6) Operator/generation license. Understanding the requirements and the local context is essential. Consultations with the relevant authorities, the local community, and stakeholders are also important for a smoother approval process.

Environmental and social assessments should be performed early in the project planning process and actions should be taken to mitigate potential adverse impacts.

Grid connection agreement is critical to ensure that the PV plant can evacuate the power generated to the grid. **Section 8** of the report provides more information on permits, licensing and environmental considerations.

Engineering, procurement and construction can be broken into multiple contracts, but care must be taken to spell out responsibilities, so that all parties are clear on who is managing various risks and the overall process. In some cases, overall coordination is performed by the PV plant owner (if it has the in-house engineering expertise and experience in similar projects) or by an engineering company that is hired as a management contractor acting on behalf of the owner. However, the most common approach in building PV plants is turn-key responsibility through an EPC contract. An EPC contract involves one organization (the EPC Contractor) who has full responsibility to complete the project on time, under budget, and within the specified performance. The EPC contactor is paid a higher fee in return for managing and taking responsibility for all the risks of the project. **Section 9** provides more details on the development of a contracting strategy, and **Annex 2** contains Heads of Terms for an EPC contract. **Section 10** reviews the construction process.

Operation and Maintenance (O&M) of PV plants can be performed by the owner or contractors. Regular maintenance (including cleaning of the PV modules) is relatively easy and can be done by local staff trained by the equipment suppliers. Monitoring of plant performance can be achieved remotely by the original equipment manufacturer (OEM) or other asset manager. Spare parts, both for plant inventory and in response to equipment failures, need to be purchased from the OEM or an alternative supplier. **Section 11** provides more information on O&M contracting structures and best practices, while an overview of key terms for an O&M term sheet is found in **Annex 3**.

Annex 4 provides an overview of the rooftop solar market. This is an important development as distributed PV systems have grown and are expected to continue growing substantially. These PV systems are installed on rooftops of residential buildings (typically 10–50 kW) and commercial/industrial buildings (up to 1–2 MWs). From the design and construction point of view, key aspects are: optimal orientation and shading from adjacent (present and future) buildings and plants. Permits are easier to obtain, but they differ from large utility-scale PV plants, as different agencies are involved (mostly local authorities).

Depending on the regulatory framework affecting such installations, net metering or gross metering may be available; this is something that (along with the regulated tariff for electricity sold to the grid) will determine the payback period and overall attractiveness of the project. However, purchasing the PV system is not the only option for the owner of a building. There are companies offering lease agreements including leasing the PV plant or installing the PV plant and paying the owner of the building a rental. Under such agreements, electricity may be sold to the building owner at below-market prices.

1.3 COMMERCIAL AND FINANCING ASPECTS

Activities related to project financing run in parallel with the project design and permitting. As the project developer initiates preparatory activities including securing land lease agreement and permits, preliminary financing schemes are also assessed. Adequate funds should be allocated to complete the initial stages of project development, most importantly for the energy resource assessment, site selection, land lease agreement, and preliminary permits/licenses. Depending on the financing requirements of the project and how much of their own equity the developer can commit to the project, the developer may seek another sponsor. It is not unusual for the initial project developer to sell part or all of the rights to the project to another sponsor who will complete the project, often a sponsor with greater technical expertise and financial resources. As the project progresses, the developer/sponsor will reach out to potential debt financiers to get an idea of current lending rates, requirements and terms, and as the project develops, they will undergo due diligence. The experience and creditworthiness of the sponsor is critical for achieving financial closure and obtaining attractive financing.

Power projects are typically financed on a "back-to-back" basis, meaning that all contracts eventually rely on a bankable PPA. In other words, a PPA with a creditworthy off-taker covering adequately all the key risks of the project provides a sound basis for the project developer to sign EPC and O&M contracts, lease or purchase land, etc., so the project can be implemented.

As the project takes shape, the developer begins negotiations with the off-taker (often but not always a state-owned utility in most emerging economies) on the price, duration, and terms of the PPA. In many markets, PV projects have benefitted from regulatory support providing above-market price for power. For example, under a Feed-in Tariff (FiT) program, the price of electricity from renewable energy is specified for a set period of time, usually 10–25 years. In another example, terms of the PPA may be pre-determined through a tender process in which the developer is submitting a competitive bid (e.g., reverse auction). In a third example, utilities may have an obligation to source a portion of their total energy from renewable sources, and then negotiate with developers according to their own priorities and parameters. In the (relatively rare) instance of a merchant-solar power plant, power will be sold in the open market (i.e., "day-ahead," "hour-ahead" markets) at fluctuating rates rather than at a pre-determined tariff. However, in the future (if PV prices continue to decline) regulatory support may not be needed and merchant PV plants may become more common.

The grid connection and dispatching need to be clarified in the PPA. In most countries, the regulation requires the grid operator to take all the electricity produced by renewable facilities (*"obligation to take"*), but curtailment rules need to be included clearly in the PPA. **Section 12** provides more information on the regulatory support mechanisms used for PV projects. **Section 13** describes key elements of PPAs that are specific to solar, and explains several solar-specific risks that this key legal document is used to mitigate, such as indexing the power-purchase price (tariff) to a foreign currency to avoid devaluation risks.

Key risks associated with PV projects:

- **Completion risks affected by permitting/licensing and construction delays.**
- **Energy yield:** how much energy the facility will be producing depends on the energy resource and the design of the PV plant. An incorrect estimation of the energy resource, an unforeseen change in weather patterns and performance degradation of the PV plant could significantly affect the revenue of the project.
- **Regulatory environment:** Changes impacting the amount of power the off-taker is obligated to purchase and the price they pay can clearly impact the project, especially when applied retroactively. While this is not the norm, several countries (including developed markets generally seen as credible!) have implemented retroactive changes, raising the risk associated regulatory incentives. A comprehensive assessment of the power sector provides useful insight into the sustainability of such regulations. Developers are advised to consider the viability of their projects without subsidies or special treatment, particularly if such consideration makes the effective price of power well above the levelised cost of power in the existing power market.
- **Off-taker creditworthiness:** A thorough due diligence of the off-taker is an essential step before financing is finalized.

The appropriate financing arrangement depends on the specifics of each PV project, including investor risk appetite. The most common arrangement for such projects generally is to use a project finance type arrangement, typically with at least 30 percent equity and the remainder as debt. However, all equity financing may be chosen in certain situations. For example, if local commercial debt is difficult to access or is expensive, or the due diligence process for obtaining debt is expected to slow down a project and tariffs are sufficiently high, equity investors may be incentivized to back the entire project. While debt is cheaper than equity, all equity financing can allow for speedier project development, a priority in markets where a specified amount of construction must be achieved by a certain deadline in order to be eligible for incentives. This dynamic is not unique to solar, but as solar projects have historically been smaller, it has been more feasible for developers to finance them without debt financing, or at least to delay debt financing until the projects were operational, and presented a significantly lower risk profile to lenders. For solar projects that are among the first in their market, local banks may be reluctant to lend until they have evidence of successful projects; in such circumstances, seeking financing from development finance institutions like the IFC, which is willing to be a first-mover in new markets for renewables, may be a solution. **Sections 14 and 15** provide more specifics on financing, due diligence, and the typical financial analysis carried out.

Boxes

Boxes elaborate on a wide variety of topics. They provide case studies and "on the ground lessons learned" from a variety of countries.

Issues and lessons described in these boxes will inform the actions of developers, lenders and contractors thereby promoting good practice in the industry. This will help facilitate financing within the solar sector.

Many of the lessons learned reduce to the same fundamental point: **for a successful project it is essential to have suitable expertise within the project team.** This does not only apply to technical expertise but also to financial, legal and other relevant fields. Suitable expertise can be incorporated in a variety of ways: by hiring staff, using consultants or partnering with other organisations.

Photovoltaic (PV) Project Development 2

Even though each solar PV project may follow a different "road map," the key steps for developing a solar PV project are well established.

2.1 PROJECT DEVELOPMENT OVERVIEW

This section provides an overview of the project development process, from inception of the idea to the start of commercial operation. In broad terms, this process applies to the development of any privately-financed, utility-scale power plant. Aspects of the process that are unique to the use of solar PV technology, such as assessment of solar energy yield, site selection, and technology selection are emphasized more in the subsections below.

Developing a PV project is a process involving many stages and requires a multidisciplinary team of experts. The project developer starts by identifying a power market that offers adequate risk-reward opportunities, then identifies a promising site and secures the land-use rights for this site, carries out two separate rounds of technical-financial assessments (prefeasibility study and feasibility study), obtains all required permits and licenses, secures power purchase and interconnection agreements, arranges financing, and selects a team to design and construct the project (often an EPC contractor), supervises plant construction, and carries out testing and start-up. As the project moves from one stage to the next, the technical-financial assessments become more detailed until a final design is developed and construction starts.

It is important to emphasize the back-to-back nature of many project contracts and documents; a PPA is needed in order for financing to be completed. However, this must be preceded by a grid connection agreement, construction and site access permits, land lease agreement, etc. Throughout this process, technical, commercial, and legal/regulatory experts are involved, working in parallel on distinct yet interdependent activities. While clear responsibilities can be identified for each expert, most project activities are related and the work of one expert influences the work of other experts; hence close coordination is needed. It is crucial to emphasize this latter point. Although this guide lays out the process as a series of steps, some project development activities must happen in parallel. It is up to the individual developer or project manager to oversee the activities and ensure they are coordinated and synchronized appropriately.

The key steps for developing a solar PV project are well established, and yet there is no definitive detailed "road map" a developer can follow. The approach taken in each project depends on site-specific parameters and the developer's priorities, risk appetite, regulatory requirements, and the types of financing support mechanisms (i.e., above market rates/subsidies or tax credits) available in a given market. However, in all cases, certain activities need to be completed that can broadly be organized in the following five stages:

1. Concept development and site identification.
2. Prefeasibility study.
3. Feasibility study.
4. Permitting, financing and contracts.
5. Engineering, construction and commercial operation.

These stages are described in the following subsections and show in Figure 1. A checklist of key tasks corresponding with each stage is provided at the end of the respective sub-section.

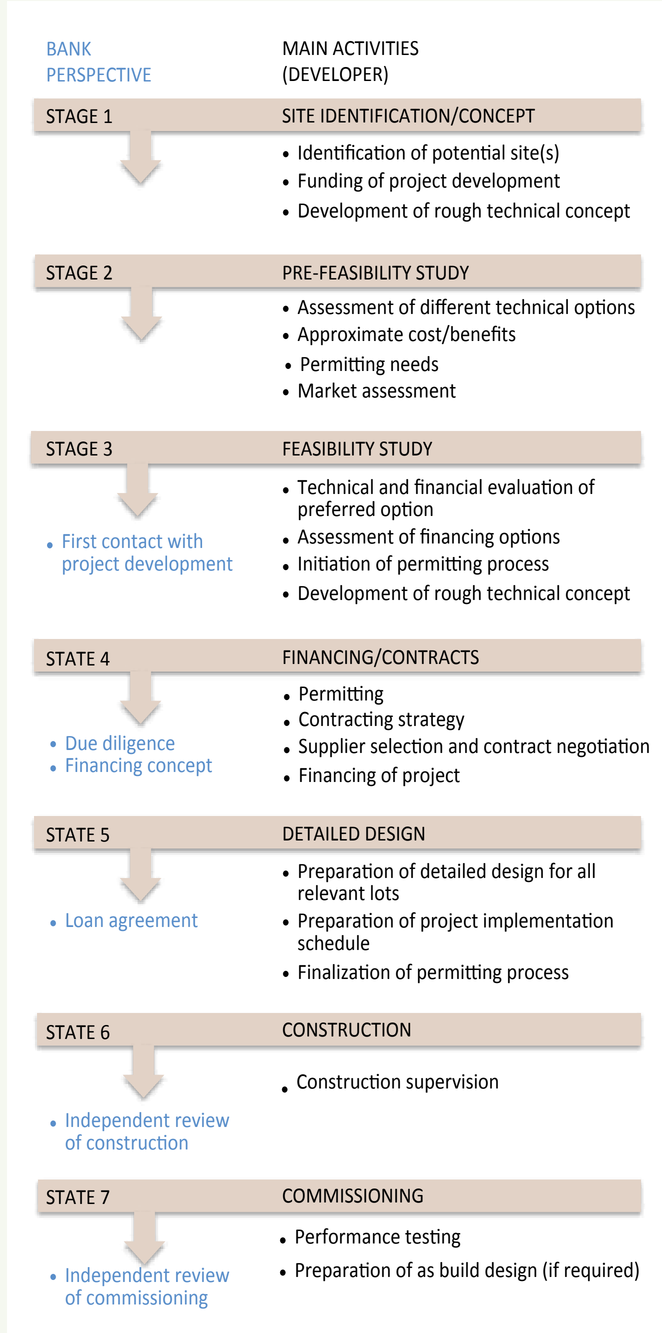
2.2 STAGE 1 – CONCEPT DEVELOPMENT AND SITE IDENTIFICATION

The concept development stage includes identification of the investment opportunity at a specific site and the formulation of a strategy for project development. It is assumed at this stage that a target market has been identified and the project developer understands any special prerequisites for investing in that specific country and power sector. These market-level decisions require a detailed assessment that carefully considers the risk–reward appetite of the project developer and potential investors.

2.2.1 SITE IDENTIFICATION

A desirable site has favourable local climate, good solar resource (irradiation), land available for purchasing or long-term leasing, an accessible grid connection or a binding regulatory commitment to connect the site to the transmission network, and no serious environmental or social concerns associated with the development of a PV project. Many countries require that the site be part of

Figure 1: Project Development Stages



a list pre-approved by the government; this needs to be confirmed at the outset of the site identification process. Section 6 provides more details on site selection.

2.2.2 THE PV PROJECT

At least a preliminary (conceptual) design should be developed that helps estimate installed capacity or megawatts (MW), expectations, approximate investment requirements, energy yield, expected tariff and associated revenue. This way, a preliminary assessment of costs and benefits can be made, including return on investment (ROI). A preliminary financial model is often developed at this stage.

2.2.3 OUTLINE OF PROJECT STRUCTURE

At the concept stage, a developer may not be ready to invest significant resources, and may leave the project structure undefined. However, it is important to think about structuring issues at an early stage. In emerging markets, the formation of a project company can be challenging, and may involve requirements to appoint country nationals to management positions. International developers/investors will need to carefully consider such requirements, as well as any potential concerns about taxes and repatriation of profits. If a developer is exploring a portfolio of opportunities in a new market, it may be worthwhile to establish or purchase a "placeholder" Special Purpose Vehicle (SPV) that can be utilized when a project moves towards development.

2.2.4 THE REGULATORY FRAMEWORK AND SUPPORT MECHANISMS

Often, support mechanisms (e.g., incentives) play a large role in the economics of PV projects, especially compared to traditional power generating technologies. Support mechanisms for solar and other types of renewables can take many forms, including direct subsidies, tax or investment credits, or favourable FiTs. Many countries set strict criteria for new renewable projects to qualify for financial support. Such criteria for solar PV will vary by country and may also differ based on project size (i.e., commercial rooftop solar versus projects over 1 or 5 MW). Also, actual financial support may vary for peak and off-peak hours. Developers need to understand the regulatory requirements for qualifying for financial support in order to secure the highest available tariff and, critically, must be acutely aware of cut-off dates for particular support mechanisms. Failure to understand support mechanism rules and regulatory dynamics could result in a significant loss of revenue and have a negative impact on project economics. Regulatory frameworks and support mechanisms (e.g., financial incentives) are discussed further in Section 12.

2.2.5 OFF-TAKER DUE DILIGENCE

Credit-worthiness of the off-taker is critical and should be a primary focus of the due diligence to determine the level of risk associated with a PPA. As a legal contract between the solar plant operator and the purchaser of the electricity produced, a PPA defines future project revenues. It is therefore critical to understand at the outset whether there are standardized terms in a given market for developing a PPA, or whether the agreement will be negotiated ad-hoc. If the agreement is not part of a structured program, such as a government tender, there may be other standardized terms required by the off-taker or broader regulatory framework. In many developing countries, there is only one company responsible for purchasing and distributing power. Even in countries that have begun privatization of power generation, this company is often partially or fully state owned. Understanding the off-taker's role compared to other regulatory authorities, as well as the off-taker's creditworthiness and the expected tenor and terms of the PPA, is paramount, as these will impact the terms of the debt financing and, therefore, the viability of the project.

2.2.6 FINANCING STRATEGY

At the concept stage, available funds are usually minimal, but the developer should still begin to sketch out an internal budget that will meet requirements as the project moves ahead. At this time, the developer should also consider whether a secondary equity investor will be needed. As the project progresses through the concept phase, the developer will begin to explore debt financing options; availability and terms vary widely across markets. It is important for developers to begin conversations with local financiers early, particularly in markets where there is less familiarity with solar technologies, as negotiations can take substantially longer in this context. This assumes use of a project finance structure, which for solar power projects is commonly a mixture of non-recourse debt and equity. Financing is discussed in greater detail in Section 14.

The concept stage is an iterative process that aims to develop an understanding of the risk, project-specific costs and revenues that enable an assessment of project economics. The developer's objective is to obtain sufficient information to make an informed decision about the probability that the project can be taken forward. If the project looks promising, the developer is likely to decide to proceed to the next stage.

Concept Stage Checklist

The checklist below covers key questions and factors the developer should consider when deciding whether to proceed to the next stage, which is to conduct a prefeasibility study.

- ☐ Project structure outlined.
- ☐ Does the country and power sector provide adequate risk-reward benefits to private investors?
- ☐ Regulatory support and tariffs, especially the duration and timeline for any incentives for solar power.
- ☐ Suitable site identified taking account of site constraints.
- ☐ Grid access (proximity, capacity, and policy provisions for access).
- ☐ Appropriate funds available to carry out the feasibility assessments.
- ☐ Identification of off-taker and available infrastructure to take the power generated.

2.3 STAGE 2 – PREFEASIBILITY STUDY

The aim of a prefeasibility study is to develop a preliminary plant design and investment requirements, which allow further assessment of the financial viability of a project. This assessment involves more detail than the previous stage and determines whether to proceed further with the project and commit additional financial resources. The prefeasibility study can be carried out as a desktop study even though a site visit is desirable. Given the uncertainty of data available at this stage, viability will be determined in reference to a minimum financial hurdle rate, and will take into account a wide margin of error (e.g., +/-30%) to compensate for the lack of site-specific assessment data.

A prefeasibility study should, at a minimum, include an assessment of:

- The project site and boundary area, ensuring access to the site is possible, both legally and technically.
- A conceptual design of the project giving different options of technology (if applicable) and the financial impacts, including estimation of installed capacity.
- The approximate costs for land, equipment, development, construction and operation of the project, as well as predicted revenue.
- Estimated energy yield of the project. While site-specific analysis should be performed at a later stage, for prefeasibility purposes, published, high-level solar resource data and estimates of plant losses, or an assumed performance ratio (based on nominal values seen in existing projects) can be used. Seasonal production estimates should be taken into account.
- The anticipated electricity tariff to be received based on market analysis in a deregulated market, a published FiT in a market with specific incentives for renewables, or the relevant components of the tariff in a market under consideration.
- A financial model to determine the commercial viability of the project for further investment purposes.
- Grid connection cost and likelihood of achieving a connection within the required timeline.
- Identification of key environmental and social considerations and other potential "deal-breakers."
- Permitting requirements, costs, and likelihood of achieving consent.

- Assessment of the current regulatory environment, stability assessment and possible risk of future changes (for example, likelihood of changes during upcoming regional/national elections).
- An initial concept of the project's legal/corporate structure; this should be formulated to take advantage of existing/future incentives. At the prefeasibility stage, the developer may begin making assumptions about the project company which, if the project moves ahead, would be set up to develop and own the specific project or portfolio.
- Solutions to specific challenges; as challenges to the project arise, possible solutions will begin to be identified. For example, if the power off-taker does not have a strong credit rating, the developer may want to explore the possibility of a sovereign guarantee, and/or support from an export credit agency or a multilateral institution – for example, a partial risk guarantee from the World Bank.
- Preliminary timeline for project activities; while the scheduled workflow will inevitably change significantly, it is important to begin to understand the spacing and timing of key required activities at an early stage.

2.4 STAGE 3 – FEASIBILITY STUDY

The feasibility phase will build on the work undertaken at the prefeasibility stage by repeating the assessment in more detail using site-specific data, such as solar resource measurements, and should consider any previously identified constraints in more detail. If multiple sites are being assessed, then the preferred site needs to be selected. The objective of the feasibility study is to provide more detailed information on the potential project design, the investment requirements, and to plan for financing and implementation. If the results of the study are favourable, the developer should be prepared to invest more to advance the project to the financing stage.

A typical scope for a feasibility study is outlined below in terms of key technical, regulatory, financial, and commercial aspects.

Prefeasibility Checklist

Below is a checklist of key considerations for the developer during the prefeasibility stage:

- ☐ Assessment of the site and boundary areas including access permissions and restrictions.
- ☐ Conceptual design completed including consideration of technology options and their financial impacts.
- ☐ Approximate costs for land, equipment, delivery, construction, and operation identified along with predicted revenue.
- ☐ Indicative energy yield completed.
- ☐ Identification of anticipated electricity tariff to be received, and review of expected terms/conditions of PPAs in the relevant market.
- ☐ High-level financial analysis completed.
- ☐ Cost and likelihood of achieving grid connection in the required timescales identified.
- ☐ Main environmental constraints identified along with other potential "deal breakers."
- ☐ Assessment of current and potential future regulatory environment completed.
- ☐ An initial concept of the project's legal/corporate structure.
- ☐ Solutions to project challenges.
- ☐ Permitting requirements/costs identified.
- ☐ Preliminary project timeline/workflow showing spacing of key activities drafted.

2.4.1 *TECHNICAL DESIGN OF SYSTEM*

- Outline system design. Essentially, this is a plan for the project's physical development, including the lay-out, identification of equipment, and costs, etc. The system design is often required to obtain permits/consents. To select an initial conceptual design, it is worthwhile to evaluate various design configurations and module sizes, so that a design can be selected that is optimised for the site.
- Assessment of shading and initial solar PV plant layout. This is discussed in Section 7. The process enables optimisation and typically takes into account:
  - Shading angles.
  - Operations and maintenance (O&M) requirements.

- Module cleaning strategy.
- Tilt angle, orientation, and tracking.
- Temperature and wind profiles of the site.
- Cable runs and electrical loss minimisation.

- Production of a detailed site plan, including site surveys, topographic contours, depiction of access routes, and other civil works requirements.
- Calculation of solar resource and environmental characteristics, especially those that will impact performance of technical requirements (temperature, wind speed, and geological hazards). These are discussed in Section 4. While the accuracy of satellite data is increasing and is acceptable in many cases, it is often desirable to implement site-specific measurements of irradiation[3] as early in the project planning process as possible; the feasibility study stage is a good time to bring such data into the planning process. Note that irradiation levels often vary across seasons, and this needs to be accounted for in the financing model.
- Electrical cabling design and single line diagrams (see Section 7.4).
- Electrical connections and monitoring equipment.
- Grid connection design, including transformers and metering, etc.
- Full energy yield analysis using screened solar data and the optimised layout (discussed in Section 5).
- Assessment of all technology options and cost/benefit analysis of potential suppliers given the project location, including:
    - Module selection. This is an optimized selection based on the feasibility phase output, current availability, and pricing in the market place. Note that in countries where the solar industry is still in its infancy, there may be challenges when importing solar modules and other critical components of plant infrastructure. Examples include delays at customs and difficult negotiations on the terms of sale with manufacturers lacking a local sales representative or distributor.
    - Inverter selection. Manufacturers are predominately based in Europe and North America, though others are emerging in China and Japan. As above, importation can result in delays to project schedules. See Section 3.5 for further information.
    - Mounting frame or tracking system selection, including consideration of site specific conditions.

2.4.2 PERMITTING AND ENVIRONMENTAL, HEALTH AND SAFETY (EHS) REQUIREMENTS

- Detailed review and inventory of all necessary permits and licences needed for constructing and operating the power plant. Examples are environmental permits, land use permits, and generator licences. For more information, see Section 8.
- Pre-application discussions with the relevant consenting authority about the schedule for permitting, to understand the financial implications.
- Detailed review of environmental and social considerations, such as wildlife conservation or other designations that may affect permissible activities at the project sites; this is usually performed with a desk-based assessment and if possible supplemented by an initial site survey.
- Initial consultation with key stakeholders, including local community stakeholders, as relevant.
- Grid connection issues. This should be a more detailed assessment of likelihood, cost, and timing of grid connection, as well as transmission line capacities and constraints. This may also include submission of an initial application into the grid interconnection queue or achieving a "feasibility stage tariff" approval from the regulator.

3 Irradiation is a measure of the energy incident on a unit area of a surface in a given time period. This is obtained by integrating the irradiance over defined time limits and is measured in energy per square meter (often kWh/m^2).

2.4.3 FINANCIAL FEASIBILITY OF PROJECT

- Financial modelling to determine commercial viability and attractiveness of the project is discussed further in Section 14. Such modelling includes all costs and revenues. It should also involve a sensitivity analysis to start assessing the project risks.
- Further assessment of the anticipated electricity tariff. This is especially pertinent in markets where the tariff is expected to fluctuate, either by:
  - Deliberate design, such as in a power market where the developer is an Independent Power Producer (IPP) selling power in a wholesale or spot exchange;
  - Market forces, such as use of Renewable Energy Credits (RECs) or another market-based instrument, which could contribute to the developer's revenue; or
  - Potential for revision of negotiated tariffs, such as if the government decides to revise the tariffs retroactively (uncommon but has occurred) or the off-taker asks for re-negotiation.

2.4.4 PROJECT DEVELOPMENT/COMMERCIAL ASPECTS

- Project implementation plan – Level 1 (minimum) including a Gantt chart laying out the project timeline, resource requirements, project development budget, procurement concept (e.g., full turnkey or multi-contracting approach), and O&M concept.
- Option agreements for land access for all privately held land or access roads, or a concession agreement with the relevant authority.
- Evaluation of the commercial structure of the project. This includes evaluating the project company or companies, which may involve a Special Purpose Vehicle (SPV), depending on company structures allowed under local law. This also includes evaluating any off-shore parent-company structures and incorporation location based on legal, financial and tax criteria corresponding to the project.
- Investment and funding requirements and the investment concept. This should include equity contribution amounts and sources, equity partner requirements and financing assumptions to be included in the financial model.
- A project structure and risk-mitigation strategy. In many emerging markets, to make a project "bankable" (i.e., able to attract reasonably-priced debt financing) it is typically necessary to secure credit enhancements, which can be either private (letters of credit, escrow accounts) or governmental (sovereign guarantees).
- Procurement of Owner's Engineer. As the intention to proceed with the project grows, so too the technical scope for the EPC or other technical tendering procurement contracts needs to be drafted and reviewed by the Owner's Engineer. The EPC's Owner's Engineer scope of work may also include support for the technical procurement (e.g., PV plant components) and technical design review. The same firm usually follows through as the Owner's Engineer during the construction phase.
- Tender and award of Owner's Counsel to support contracts development and negotiation as well as any relevant legal-structuring needs and company set-up during the development phase.

It should be noted that the feasibility study may overlap with activities related to permitting, financing, and contracts (see next phase) that are being carried out in parallel. Coordination of all technical, commercial, and regulatory activities is essential for the success of the project.

Feasibility Checklist

Below is a checklist for developers with the key considerations that must be addressed during the feasibility stage.

- ☐ Detailed site plan produced.
- ☐ Solar resource assessed including assessment of shading.
- ☐ Environmental characteristics that may affect performance identified.
- ☐ Detailed review of environmental and social considerations conducted.
- ☐ Detailed review of required permits and licences undertaken.
- ☐ Assessment of Capex for technology and supplier options; cost/benefit for options and project location completed.
- ☐ Pre-application discussions with relevant consenting authority undertaken.
- ☐ Initial consultations with key stakeholders including from the community completed.
- ☐ Grid connection assessment completed.
- ☐ Predicted energy yields established.
- ☐ Further assessment of anticipated electricity tariff undertaken.
- ☐ Financial analysis carried out. Preliminary financing planned.
- ☐ Project implementation plan developed.
- ☐ Options agreements for land access (where required) secured.
- ☐ Evaluation and concept of the commercial structure of the project and project company(s) carried out.

2.5 STAGE 4 – PERMITTING, CONTRACTS AND FINANCING

After the feasibility stage and assuming that the project still seems to be financially viable, the project moves to the next stage. This includes obtaining final permits, securing project finance and pre-implementation activities (commercial contracts). The timing and sequencing of this stage will vary significantly by project, but this phase usually includes the following activities:

- Engagement of relevant community or stakeholders.
- Preparation and submission of relevant permit and licence applications and associated documents for the proposed project.
- Environmental and social assessments (agreed in consultation with permitting authority and other statutory bodies), which may include a full Environmental and Social Impact Assessment (ESIA).
- Preparation and submission of a grid connection application.
- Review of the design and any permit/consent conditions; revision of design or consents as needed.
- Contractor prequalification, ranking, and short list selection.
- Decision on the financing approach (e.g., sources and proportions of equity and debt, including construction financing).
- Securing financing for the project as described in Section 14.
- Decision on contracting strategy (i.e., EPC contract or multi-contract).
- Preparation of solar PV module tender documentation. Supplier/contractor selection and contract negotiations.
- Preparation of construction or balance of plant tender documentation.
- Preparation of PPA documentation and final negotiations.
- Preparation of O&M concept and contracts, as relevant.
- Preparation of Owner's Engineer tender (if technical advisor is not continued into construction).
- Contracting and procurement of relevant insurances (i.e., construction, operation, etc.).
- Preparation of Lender's Engineers and Lender's Council tenders.
- Finalisation of grid interconnection agreement with grid operator or relevant authority.
- Preparation of detailed, bankable financial model covering the full lifecycle of the plant. Typically this will only be completed after negotiating the EPC or equipment and Balance of Plant (BoP) contracts, as

well as O&M contracts, so that the financial model can incorporate final costs of capital and O&M.

- Completion of a project risk analysis.
- Transportation analysis as necessary for difficult-to-reach project locations.
- Finalisation of all land, surface area, and access agreements—and trigger land agreement options to convert to long-term leases or easements, as necessary.
- Finalisation of the detailed project implementation plan.

The remainder of this section provides more information on the three key activities of this phase: permitting, financing, and contracts.

2.5.1 PERMITTING

An approved permit must be obtained before construction of a project commences. Permit requirements vary widely between different countries and regions and are discussed in detail in Section 8. In general, the type of permits may include, but are not limited to:

- Land lease agreement(s).
- Access agreements.
- Planning/land use consents.
- Building/construction permits.
- Environmental permits (forestry, endangered species, EIA, etc.).
- Social impacts (i.e., cultural heritage/archaeological sites, stakeholder consultations).
- Energy permit.
- Grid connection application.
- Operator/generation licences.

It is important to consider the permitting requirements at an early stage, as the application timeline for different permits will vary. The best approach is usually through early discussions with the relevant consenting authority. Such discussions should establish what supporting documents will be required when submitting permitting applications (i.e., environmental assessment, transport studies, etc.) as well as timescales for consent to be granted following submission. Supporting documentation requirements and response time will usually vary with the size of the PV plant, its location, and contextual sensitivities.

Obtaining permits sometimes requires amending the design of the PV plant, so that it conforms to the requirements of the local authority and addresses the concerns of other key agencies during the permitting process. Hence, it is difficult to overemphasize the importance of early discussions with relevant parties, so that their feedback can be incorporated into the design process at an early stage.

Once consents are obtained, it is important to consider any attached conditions that must be addressed prior to and/or during construction. Consent conditions will depend on site-specific characteristics and may present constraints to the development timeline. For example, a condition of consent may be that construction is not permitted during certain times of the year to avoid disturbing a particular species' breeding season. A review of all conditions should be carried out after consent is obtained to establish requirements and to open a dialogue to clarify any uncertainties with the relevant authority. It is likely that meeting certain conditions will require preparing additional documents for the consenting authority, whose written approval may be required before the development can proceed.

2.5.1.1 Environmental and social considerations

The likely environmental and social effects of a solar project should be considered and the impact of the project assessed. Part of this assessment could be done as a desk-top study, but a site visit is essential in order to assess the current situation of the site and surrounding environment. National legislation should be reviewed to determine any country-specific requirements related to developing solar projects. Similarly, referring to international best practices will ensure adverse project impacts are minimized and positive relationships developed with stakeholders.

Environmental and social considerations are covered in detail in Section 8.

Outcomes of environmental and social assessments, as well as stakeholder consultation, often provide feedback into the design process. Sometimes this includes design changes, or developing measures to mitigate any significant impacts. It is therefore important that these assessments are carried out in a timely manner that allows for any potentially necessary design amendments. Furthermore, leading lending institutions will require that the project adhere to rigorous environmental standards and principles, such as the Equator Principles (EPs)[4] and/or IFC Performance Standards (IFC PSs). Further details on environmental and social considerations and lending requirements are provided in Section 8.

2.5.2 *FINANCING*

Financing a solar PV project is similar in principle to financing other types of power projects, however, certain risks that are unique to solar PV must be accounted for in the financing plan. Risks associated specifically with solar PV projects are related to the energy resource (irradiation), project siting and permitting, solar technology (relatively new), potential degradation of PV modules, and reliability of long-term plant performance, as well as potential uncertainty of the tariff and revenue collection.

- PV project financing generally involves two key components:
    - Equity, from one or more investors, injected directly or via a special purpose vehicle (SPV or "project company").
    - Non- or limited-recourse debt from one or more lenders, secured against the assets owned by the SPV.

In order to obtain financing, the developer must prepare comprehensive documentation of the project, so that financiers may carry out their due diligence to assess the risks of the prospective investment. Detailed design and comprehensive documentation that enable reliable revenue projections are particularly critical, because the lender depends entirely on the cash flow of the project for repayment, as opposed to the balance sheet of the sponsor. Commercial banks in new markets may not be familiar with solar projects, so developers should be prepared for a rigorous due diligence process, and incorporate sufficient time in the project schedule to identify and address lender requirements.

Throughout the planning process, the developer constantly assesses and tries to manage risks, so there is favourable risk-reward balance. More information on some of the typical risks specific to solar PV projects is found in Section 10.

More details on PV project financing are provided in Section 13.

2.5.3 CONTRACTS

2.5.3.1 Contract Strategy

Contracts present developers with several important considerations. Perhaps foremost is establishing a project company or SPV (special purpose vehicle); if not already initiated, an SPV should be formally established. The developer typically creates and owns the project company, potentially with equity co-investment from another financial backer (sponsor), such as an infrastructure fund. All contracts, land agreements, financing and secured project permits and licenses need to be issued in the name of the SPV; transferring these later to the SPV can be very difficult and time consuming. Also, lenders often insist upon the rights of assignability (e.g., the right for project assets and liabilities to be assigned to them in the event of default). Considering assignability at early stages of incorporation can save significant time later in the development process.

With regard to procurement and construction of the PV plant, a strategy needs to be developed to address technology, construction, and performance risks, while still meeting investment requirements. There are two main contracting methods that a developer may consider:

4 A list of all EP financial institutions can be found at http://www.equator-principles.com/index.php/members-reporting

multiple contracts or a single EPC contract. In the former case, multiple contractors are engaged to deliver/construct different parts of the PV plant, but one company (typically the owner/developer or the Owner's Engineer or a third party) retains the responsibility of integrating all components and services provided under the various contracts. In the case of an EPC contract, one company is assigned full responsibility for completing the entire project. The next sub-section discusses key contract-related activities. In addition, contractual aspects are covered in more detail in Section 9, and a template EPC Contract Heads of Terms is provided in Annex 2.

A multi-contract approach requires significantly more management effort on the part of the developer, and also exposes the developer to significantly more risk. However, a multi-contract approach is generally cheaper than an EPC. While the EPC option is higher cost, it transfers a substantial amount of risk from the developer to the EPC contractor.

If an EPC is chosen, it is critical that the developer ensures that the EPC contract clearly defines expectations, requirements, and responsibilities. The developer should be certain that the contract is satisfactory in this regard before signing, as it will be much easier and more economical to make changes to the contract before it is signed. If the developer has little or no experience, or is unsure of any aspect of the project, he should seek advice from a consultant experienced in the respective topic. It is highly recommended that an Owner's Engineer is engaged during the development and construction phase, in order to ensure the quality of all contractor work, as well as the meeting of timelines and maintenance of budgets. The Owner's Engineer can also ensure consistency between the OEM (Original Equipment Manufacturer) of the solar modules and warranty requirements across other contracts and their respective works.

There is no single preferred contracting approach. The approach taken will depend on the experience, capabilities and cost-sensitivity of the developer. However, turnkey EPC contracts are most commonly used in the solar industry.

Checklist for Permitting, Financing, and Contracts

Below is a checklist of critical issues that a developer needs to consider during the stage of project development that involves securing permitting, contracts, and financing.

- ☐ Preparation and submission of relevant permit and license applications.
- ☐ Environmental and social assessments (as required) completed.
- ☐ Grid connection application prepared and submitted. Grid connection agreement signed.
- ☐ Review of design and permit/consent conditions completed.
- ☐ Contracting strategy approach determined.
- ☐ Financing structure decided. Financing secured for the project.
- ☐ Community or stakeholder engagement completed.
- ☐ Solar PV tender documentation prepared.
- ☐ Supplier selection and ranking undertaken.
- ☐ PPA documentation prepared.
- ☐ O&M concept and contracts prepared.
- ☐ Owner's Engineer tender prepared.
- ☐ Relevant insurance procured and contracted.
- ☐ Lender's Engineer and Lender's Council tenders prepared.
- ☐ Tendering and evaluation of bidders for all contracts carried out.
- ☐ Contract negotiations completed.
- ☐ Bank-grade energy yield completed.
- ☐ Detailed bankable financial model completed.
- ☐ Transportation analysis (if required) carried out.
- ☐ All land and access agreements finalised.
- ☐ Project risk analysis completed.
- ☐ PPA finalised with off-taker.
- ☐ Detailed project implementation plan finalised.
- ☐ Technical and legal due diligence completed (if required).

2.5.3.2 *Coordination of Contract Signing*

It is critical that the developer or project sponsor closely coordinates the structure, terms and timelines for execution of key strategic documents. Without close coordination, there are likely to be conflicts or contradictions between documents, or worse, the developer can create financial obligations that cannot be met. Critical path analysis is essential to identify interdependencies and key activities that require close monitoring to avoid project delays.

Project timelines and corresponding contractual signing should be coordinated to avoid sub-optimal bargaining positions in reaching financial close. Examples of poor coordination include:

- The signing of a PPA without knowing the requirements of the grid interconnection agency and/or without having a grid connection agreement.
- Signing of an EPC contract without the necessary financial commitment from investors. If the financing is not yet in place, a developer should commit only to an EPC agreement that is not binding until financial close is reached.
- Signing of an EPC contract before all permits and licenses are obtained.

The EPC contract and PPA should be negotiated in parallel to the financing, as some financial institutions may need to request changes to the contract terms.

2.6 STAGE 5 – ENGINEERING, PROCUREMENT, CONSTRUCTION AND COMMERCIAL OPERATION

A single EPC contract is most commonly used for developing PV plants. In this case, one contractor is responsible for the complete project. The EPC contractor is required to confirm the solar energy resource, develop the detailed design of the PV plant, estimate its energy yield, procure the equipment according to specifications agreed upon with the developer, construct the PV plant, carry out the acceptance tests, and transfer the plant for commercial operation to its owner/operator.

2.6.1 ENGINEERING AND PROCUREMENT

The key aspects of EPC activities are discussed below. Section 9 provides more information on EPC contracts, as well as the alternative approach that involves the developer managing multiple contracts.

2.6.1.1 *Development of Detailed PV Design*

The EPC contractor will prepare the necessary detail documentation for the solar PV plant to be tendered and constructed. The following documentation will be prepared:

- Detailed layout design.
- Detailed civil design (buildings, foundations, drainage, access roads).
- Detailed electrical design.
- Revised energy yield.
- Construction plans.
- Project schedule.
- Interface matrix.
- Commissioning plans.

Key electrical systems must be designed in rigorous detail. This will include equipment required for protection, earthing and interconnection to the grid. The following designs and specifications should be prepared:

- Overall single line diagrams.
- Medium voltage (MV) and low voltage (LV) switch gear line diagrams.
- Protection systems.
- Interconnection systems and design.
- Auxiliary power requirements.
- Control systems.

Civil engineering items should be developed to a level suitable for construction. These will include designs of array foundations and buildings, as well as roads and infrastructure required for implementation and operation. The design basis criteria should be determined in accordance with national standards and site specific constraints such as geotechnical conditions. For example, wind loadings should be calculated to ensure that the design will be suitable for the project location.

2.6.1.2 *Energy Yield*

A bank-grade energy yield will be required to secure financing. Most often investors will require a P90 energy yield, or an estimate of the annual energy production which is reached with a probability of 90 percent. It is advised that this energy yield is either carried out or reviewed by an independent specialist. This will ensure that confidence can be placed in the results and will help attract investment.

The energy yield should include:

- An assessment of the inter-annual variation and yield confidence levels.
- Consideration of site-specific factors, including soiling or snow, and the cleaning regime specified in the O&M contract.
- Full shading review of the PV generator including near and far shading.
- Detailed losses and performance degradation over time.
- A review of the proposed design to ensure that parameters are within design tolerances.

2.6.1.3 *Detailed Project Documentation*

The EPC contractor will develop a detailed project report, which along with all project documentation (drawings, etc.) is housed in a "data room" that provides easy access to all parties involved in the project. This information will be used to secure financing from banks or investors. Documentation should be presented in a clearly organized way. Examples of the information that should be included are detailed below:

- Site layout showing the location of modules, inverters, and buildings.
- Indicative plans showing:
  - Mounting frame and module layout.
  - Inverter locations and foundations/housings.
  - Security measures.
- Initial electrical layouts:
  - Schematics of module connections through to the inverter.
  - Single line diagrams showing anticipated cable routes.
  - Grid connection and potential substation requirements.
- Bill of materials for major equipment.
- Energy yield analysis.
  - Losses assumed with regard to the energy yield forecast.
- Financial model inputs including:
  - Long term O&M costs and contingencies (up to the end of the design life and/or debt term).
  - Availability assumptions.
  - Degradation of module performance assumptions.
  - Spare parts inventory cost.
  - Connection cost for electricity and services.
  - Cash flow model including maintenance of a specified debt service coverage ratio (DSCR)[5] if applicable, and contingency reserve to be used for inverter replacement, weather damage, and other unexpected costs associated with plant operation.
- Copies of all contracts negotiated:
  - PPA.
  - EPC Contract.
  - Equity subscription agreement and incorporation documents for project SPV.

5 DSCR is the ratio of cash available for debt servicing to interest, principal and lease payments.

    - Copies of applicable insurance and other risk-mitigation.
    - Other documents, such as currency hedging agreements, etc., as applicable.
- Details of the permitting and planning status.
- Environmental impact, restrictions, and mitigation plans.

2.6.2 CONSTRUCTION AND COMMERCIAL OPERATION

After the contract(s) have been awarded (whether multiple or a single EPC), the role of the developer is to oversee the implementation of the project. This can be done using the developer's own staff, if they have the expertise and experience, or by hiring an Owner's Engineer. Each contractor designs, procures, and installs the components of the PV plant under the terms of its contract. If multiple contracts are awarded, coordination of schedule and interfaces is critical.

Critical tasks that need to be carried out independently for each type of contract include:

- Planning and sequencing of tasks.
- Cost management.
- Risk management.
- Coordination among all organizations involved in the project.

More information on construction is provided in Section 10.

Commercial operation commences after commissioning, which includes performance and reliability tests specified in the contract. Such tests may be conducted for individual components and then for the overall system. Component-by-component testing is always needed, but especially so in the case of multiple contracts in order to assess whether each contractor has fulfilled its obligations. Successful tests are usually a trigger to release payments to the contractor(s). Unsuccessful tests may result in design modifications, and even legal action if the PV plant cannot meet performance and reliability guarantees.

Upon completion of acceptance tests, the contractor(s) should provide the plant owner with "hand-over documentation," which should include design data, drawings, O&M procedures, information about spare parts, and any other information pertinent to complete handover of the plant and its successful future operation and maintenance.

Solar PV Technology

3

Modules are either mounted on fixed angle frames or on sun-tracking frames. Fixed frames are simpler to install, cheaper, and require less maintenance. However, tracking systems can increase yield by up to 45 percent. Tracking, particularly for areas with a high direct/diffuse irradiation ratio, also enables a smoother power output.

3.1 SOLAR PV TECHNOLOGY OVERVIEW

This section discusses module technologies, mounting systems, inverters and methods of quantifying plant performance. It provides an overview of current commercially available technologies used in utility-scale solar PV projects. The purpose is to provide a framework of understanding for developers and investors before they commit to a specific technology.

PV cell technologies are broadly categorised as either crystalline or thin-film. Crystalline silicon (c-Si) cells provide high efficiency modules. They are sub-divided into mono-crystalline silicon (mono-c-Si) or multi-crystalline silicon (multi-c-Si). Mono-c-Si cells are generally the most efficient, but are also more costly than multi-c-Si. Thin-film cells provide a cheaper alternative, but are less efficient.[6] There are three main types of thin-film cells: Cadmium Telluride (CdTe), Copper Indium (Gallium) Di-Selenide (CIGS/CIS), and Amorphous Silicon (a-Si).

The performance of a PV module will decrease over time due to a process known as degradation. The degradation rate depends on the environmental conditions and the technology of the module.

Modules are either mounted on fixed-angle frames or on sun-tracking frames. Fixed frames are simpler to install, cheaper and require less maintenance. However, tracking systems can increase yield by up to 45 percent. Tracking, particularly for areas with a high direct/diffuse irradiation ratio also enables a smoother power output.

Inverters convert direct current (DC) electricity generated by the PV modules into AC electricity, ideally conforming to the local grid requirements. They are arranged either in string or central configurations. Central configuration inverters are considered to be more suitable for multi-MW plants. String inverters enable

6 Less efficient modules mean that more area is required to produce the same power.

individual string Maximum Power Point Tracking (MPPT)[7] and require less specialised maintenance skills. String configurations offer more design flexibility.

PV modules and inverters are all subject to certification, predominantly by the International Electrotechnical Commission (IEC). New standards are currently under development for evaluating PV module components and materials.

The performance ratio (PR) of a well-designed PV power plant will typically be in the region of 77 percent to 86 percent (with an annual average PR of 82 percent), degrading over the lifetime of the plant. In general, good quality PV modules may be expected to have a useful life of 25 to 30 years.

3.2 OVERVIEW OF GROUND MOUNTED PV POWER PLANT

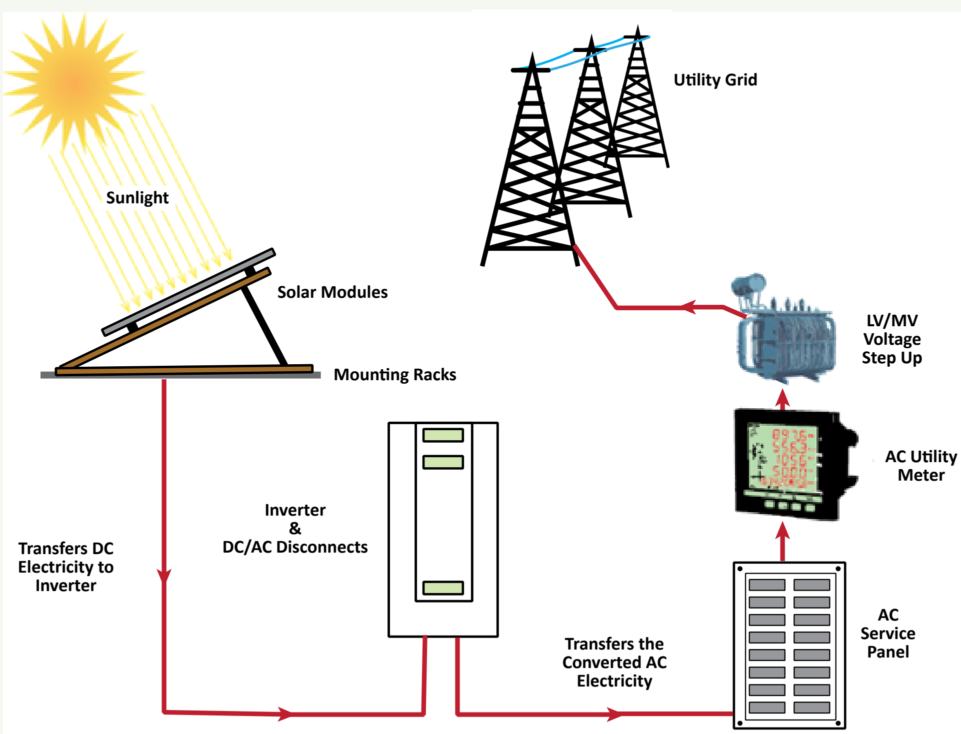
Figure 2 gives an overview of a megawatt-scale grid-connected solar PV power plant. The main components include:

- **Solar PV modules:** These convert solar radiation directly into electricity through the photovoltaic effect in a silent and clean process that requires no moving parts. The PV effect is a semiconductor effect whereby solar radiation falling onto the semiconductor PV cells generates electron movement. The output from a solar PV cell is DC electricity. A PV power plant contains many cells connected together in modules and many modules connected together in strings[8] to produce the required DC power output.

7 The purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions.

8 Modules may be connected together in a series to produce a string of modules. When connected in a series the voltage increases. Strings of modules connected in parallel increase the current output.

Figure 2: Overview of Solar PV Power Plant



- **Inverters:** These are required to convert the DC electricity to alternating current (AC) for connection to the utility grid. Many modules in series strings and parallel strings are connected to the inverters.
- **Module mounting (or tracking) systems:** These allow PV modules to be securely attached to the ground at a fixed tilt angle, or on sun-tracking frames.
- **Step-up transformers:** The output from the inverters generally requires a further step-up in voltage to reach the AC grid voltage level. The step-up transformer takes the output from the inverters to the required grid voltage (for example 25kV, 33kV, 38kV, or 110kV, depending on the grid connection point and country standards).
- **The grid connection interface:** This is where the electricity is exported into the grid network. The substation will also have the required grid interface switchgear such as circuit breakers (CBs) and disconnects for protection and isolation of the PV power plant, as well as metering equipment. The substation and metering point are often external to the PV power plant boundary and are typically located on the network operator's property.[9]

3.3 SOLAR PV MODULES

This section describes commercially available technology options for solar PV modules, discusses module certification and describes how solar PV module performance can degrade over time.

3.3.1 BACKGROUND ON PV MATERIALS

Unusual semiconducting properties required for PV cells limit the raw materials from which they may be manufactured. Silicon is the most common material, but cells using CdTe and CIGS/CIS are also viable. Emerging PV technologies such as organic cells are made from polymers. However, they are not commercially available yet.

Each material has unique characteristics that impact the cell performance, manufacturing method and cost.

PV cells may be based on either silicon wafers (manufactured by cutting wafers from a solid ingot block of silicon) or "thin-film" technologies for which a thin layer of a semiconductor material is deposited on low-cost substrates.

PV cells can further be characterised according to the long-range structure of the semiconductor material, "mono-crystalline," "multi-crystalline" (also known as "poly-crystalline") or less-ordered "amorphous" material.

Figure 3 shows the most commonly used PV technologies:

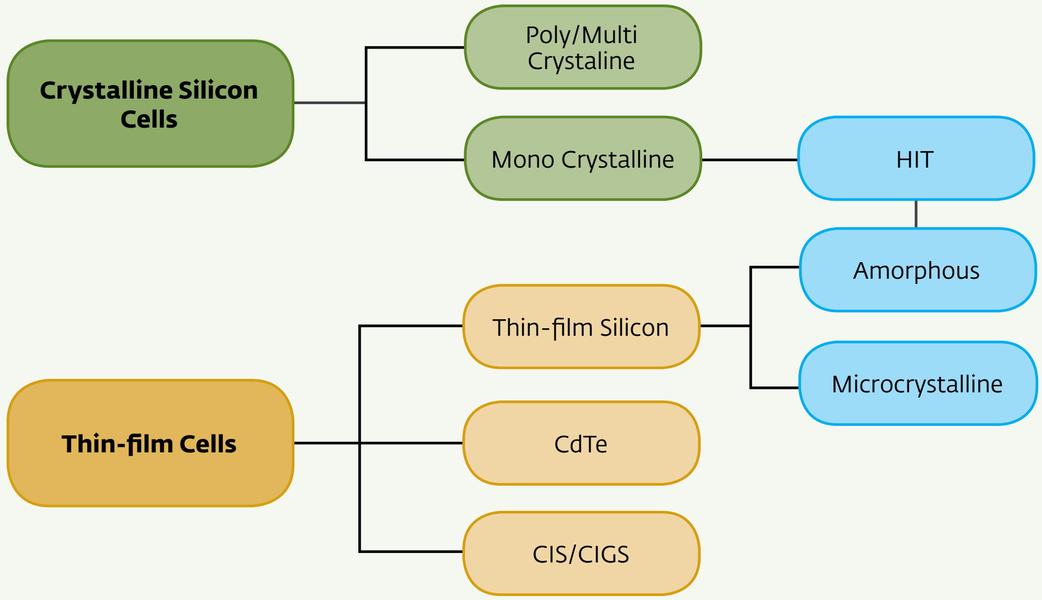
- **Crystalline Silicon (c-Si):** Modules are made from cells of either mono-crystalline or multi-crystalline silicon. Mono-c-Si cells are generally the most efficient, but are also more costly than multi-c-Si.
- **Thin-film:** Modules are made with a thin-film deposition of a semiconductor onto a substrate. This class includes semiconductors made from:
  - Amorphous Silicon (a-Si).
  - Cadmium Telluride (CdTe).
  - Copper Indium Selenide (CIS).
  - Copper Indium (Gallium) Di-Selenide (CIGS/CIS).
- **Heterojunction with intrinsic thin-film layer (HIT):** Modules are composed of a mono-thin c-Si wafer surrounded by ultra-thin a-Si layers.

Due to reduced manufacturing costs and maturity of the technology, wafer-based crystalline modules are expected to maintain a market share of up to 80 percent until at least 2017.[10] Thin-film (17 percent) and high efficiency (3 percent) modules are expected to make up the remaining 20 percent.

9 Responsibility for this is defined in the grid connection contract. Normally, the onus is on the grid operator to maintain the equipment in the grid operator's boundary—and there will be a cost to be paid by the PV plant owner.

10 European Photovoltaic Industry Association, 'Global Market Outlook for Photovoltaics 2013-2017', http://www.epia.org/fileadmin/user_upload/Publications/GMO_2013_-_Final_PDF.pdf, 2013 (accessed July 2014).

Figure 3: PV Technology Classes



3.3.2 CRYSTALLINE SILICON (c-Si) PV MODULES

C-Si modules consist of PV cells connected together and encapsulated between a transparent front (usually glass) and a backing material (usually plastic or glass).

Mono-c-Si wafers are sliced from a large single crystal ingot in a relatively expensive process.

Cheaper, multi-c-Si wafers may be made by a variety of techniques. One of the technologies involves the carefully controlled casting of molten multi-silicon, which is then sliced into wafers. These can be much larger than mono-crystalline wafers. Multi-crystalline cells produced in this way are currently cheaper, but the end product is generally not as efficient as mono-crystalline technology.

Both mono-crystalline and multi-crystalline module prices have decreased considerably in the last two years.

3.3.3 THIN-FILM PV MODULES

Crystalline wafers provide high-efficiency solar cells, but are relatively costly to manufacture. In comparison, thin-film cells are typically cheaper due to both the materials used and the simpler manufacturing process. However, thin-film cells are less efficient.

A well-developed thin-film technology uses silicon in its less-ordered, non-crystalline (amorphous) form. Other technologies use CdTe and CIGS/CIS with active layers less than a few microns thick. Some thin-film technologies have a less established track record than many crystalline technologies. The main characteristics of thin-film technologies are described in the following sections.

3.3.3.1 Amorphous Silicon (a-Si)

In a-Si technologies, the long-range order of c-Si is not present and the atoms form a continuous random network. Since a-Si absorbs light more effectively than c-Si, the cells can be much thinner.

A-Si can be deposited on a wide range of both rigid and flexible low-cost substrates. The low cost of a-Si makes it suitable for many applications where low cost is more important than high efficiency.

3.3.3.2 *Cadmium Telluride (CdTe)*

CdTe is a compound of cadmium and tellurium. The cell consists of a semiconductor film stack deposited on transparent conducting oxide-coated glass. A continuous manufacturing process using large area substrates can be used. Modules based on CdTe produce a high energy output across a wide range of climatic conditions with good low light response and temperature response coefficients. CdTe modules are well established in the industry and have a good track record.

3.3.3.3 *Copper Indium (Gallium) Di-Selenide (CIGS/CIS)*

CIGS/CIS is a semiconductor consisting of a compound of copper, indium, gallium and selenium.

CIGS absorbs light more efficiently than c-Si, but modules based on this semiconductor require somewhat thicker films than a-Si PV modules. Indium is a relatively expensive semiconductor material, but the quantities required are extremely small compared to wafer-based technologies.

Commercial production of CIGS/CIS modules is in the early stages of development. However, it has the potential to offer the highest conversion efficiency of all the thin-film PV module technologies.

3.3.4 *HETEROJUNCTION WITH INTRINSIC THIN-FILM LAYER (HIT)*

The HIT solar cell is composed of a mono-thin-crystalline silicon wafer surrounded by ultra-thin amorphous silicon layers. HIT modules are more efficient than typical crystalline modules, but they are more expensive.

3.3.5 *MODULE DEGRADATION*

The performance of a PV module decreases over time. Degradation has different causes, which may include effects of humidity, temperature, solar irradiation and voltage bias effects; this is referred to as potential induced degradation (PID).[11] Other factors affecting the degree of degradation include the quality of materials used in manufacture, the manufacturing process, and the quality of assembly and packaging of the cells into the module. Maintenance has little effect on the degradation rate of modules, which is predominantly dependent on the specific characteristics of the module being used and the local climatic conditions. It is, therefore, important that reputable module manufacturers are chosen and power warranties and degradation rates are carefully reviewed by an independent technical advisor.

The extent and nature of degradation varies among module technologies. For crystalline modules, the degradation rate is typically higher in the first year upon initial exposure to light and then stabilises. The initial irreversible light-induced degradation (LID) occurs due to defects that are activated on initial exposure to light. It can be caused by the presence of boron, oxygen or other chemicals left behind by the screen printing or etching process of cell production. Depending on the wafer and cell quality, the LID can vary from 0.5 percent-2.0 percent.[12]

Amorphous silicon (a-Si) cells degrade through a process called the Staebler-Wronski Effect.[13] This degradation can cause reductions of 10–30 percent in the power output of the module in the first six months of exposure to light. Thereafter, the degradation stabilises and continues at a much slower rate.

A-Si modules are generally marketed at their stabilised performance levels. Interestingly, degradation in a-Si modules is partially reversible with temperature. In other words, the performance of the modules may tend to recover during the summer months, and drop again in the colder winter months.

11 PID is dependent on temperature, humidity, and system voltage and ground polarity. It can be detected with a relatively short test. The degradation is reversible by applying a suitable external voltage.

12 Pingel et al., *Initial degradation of industrial silicon solar cells in solar panels*, Solon SE, 2011. B.Sopori et al., "Understanding Light-induced degradation of c-Si solar cells," 2012 IEEE Photovoltaic Specialists Conference, Austin, Texas, June 3-8 2012, Conference Paper NREL/CP-5200-54200, June 2012. Accessed from http://www.nrel.gov/docs/fy12osti/54200.pdf (accessed July 2014).

13 An effect in which the electronic properties of the semiconductor material degrade with light exposure.

Additional degradation for both amorphous and crystalline technologies occurs at the module level and may be caused by:

- Effect of the environment on the surface of the module (for example, pollution).
- Discolouration or haze of the encapsulant or glass.
- Lamination defects.
- Mechanical stress and humidity on the contacts.
- Cell contact breakdown.
- Wiring degradation.

PV modules may have a long-term power output degradation rate of between 0.3 percent and 1.0 percent per annum. For crystalline modules, a generic degradation rate of 0.4 percent per annum is often considered applicable. Some module manufacturers have carried out specific independent tests showing that lower degradation rates can be safely assumed. For a-Si and CIGS modules, a generic degradation rate of 0.7–1.0 percent is often considered reasonable, however a degradation rate of more than 1.5 percent has sometimes been observed. For CdTe a value of 0.4–0.6 percent is often applicable.

In general, good quality PV modules can be expected to have a useful life of 25 to 30 years. The risk of increased rates of degradation becomes higher thereafter.

3.3.6 *MODULE EFFICIENCY*

Table 1 shows the commercial efficiency of some PV technology categories. As may be expected, while higher efficiency technologies are more costly to manufacture, less efficient modules require a larger area to produce the same nominal power. As a result, the cost advantages gained at the module level may be offset by the cost incurred in providing additional power system infrastructure (cables and mounting frames) and the cost of land for a larger module area. Therefore, using the lowest cost module does not necessarily lead to the lowest cost per watt peak (Wp)[14] for the complete plant. The relationship between the plant layout and module efficiency is discussed in Section 7.2.

At the time of writing, c-Si technology comprises almost 80 percent of globally installed solar capacity and is likely to remain dominant until at least 2017. As of 2014, CdTe accounted for the large majority of installed thin-film capacity. CIGS is thought to have promising cost reduction potential, however the market share is still low. A-Si seems to have poor prospects for penetrating the utility-scale ground-mount market, mainly due to the reduced cost of the more efficient crystalline technologies.

3.3.7 *CERTIFICATION*

The International Electrotechnical Commission (IEC) issues internationally accepted standards for PV modules. Technical Committee 82, "*Solar photovoltaic energy systems,*" is responsible for writing all IEC standards pertaining to photovoltaics. PV modules will typically

14 Watt Peak value specifies the output power achieved by a solar module under full solar radiation (under set Standard Test Conditions

Table 1: Characteristics of some PV Technology Classes

Technology	Crystalline Silicon	Heterojunction with intrinsic Thin-film Layer	Amorphous Silicon	Cadmium Telluride	Copper Indium Gallium Di-Selenide
Category	c-Si	HIT	a-Si	CdTe	CIGS or CIS
Current commercial efficiency (Approx.)	13%-21%	18%-20%	6%-9%	8%-16%	8%-14%
Temperature co-efficient for power[a] (Typical)	-0.45%/°C	0.29%/°C	-0.21%/°C	-0.25%/°C	-0.35%/°C

a The temperature co-efficient for power describes the dependence on power output with increasing temperature. Module power generally decreases as the module temperature increases..

be tested for durability and reliability according to these standards. Standards IEC 61215 (for c-Si modules) and IEC 61646 (for thin-film modules) include tests for thermal cycling, humidity and freezing, mechanical stress and twist, hail resistance and performance under standard test conditions (STC).[15] These are an accepted minimum quality mark and indicate that the modules can withstand extended use. However, they say very little about the performance of the module under field conditions.

An IEC standard for power and energy rating of PV modules at different irradiance[16] and temperature conditions became available in 2011. IEC 61853-1 "Photovoltaic Module Performance Testing and Energy Rating" provides the methodology for ascertaining detailed module performance. An accurate protocol for comparing the performance of different module models is thus now available.

IEC standards 61853-2-3-4 are currently under development. IEC 61853-2 will describe procedures for measuring the effect of angle of incidence on module performance. IEC 61853-3 will describe the methodology for calculating module energy ratings (watt-hours). IEC 61853-4 will define the standard time periods and weather conditions that can be used for calculating energy ratings.

An IEC standard relating to potential induced degradation (PID) is expected to be issued at the end of 2014.

Table 2 summarises major PV quality standards. Standards in development for evaluating PV module components (e.g., junction boxes) and materials (e.g., encapsulants and edge seals) will give further direction to the industry.

3.3.8 *MODULE MANUFACTURERS*

Manufacturers of PV modules are based predominantly in Asia (China, Japan, Taiwan, India and Korea). European and North American manufacturers have lost a significant portion of their market share in recent years. A 2014 survey by *Photon International* (Feb. 2014) indicated that there are 89 suppliers of PV modules and over 3,250 products currently available. The same survey indicated 129 suppliers in 2013. This is illustrative of the consolidation that has been occurring in the module manufacturing industry.

Financial institutions often keep lists of module manufacturers they consider bankable. However, these lists can quickly become dated as manufacturers introduce new products and quality procedures.

While there is no definitive and accepted list of modules that are considered "bankable," Bloomberg New Energy Finance[17] runs an annual survey of EPC contractors, debt lenders and independent technical consultants, and summarises which manufacturers are considered "bankable" by the respondents. Market research organisation NPD Solarbuzz[18] also issues annual updates of the top ten module manufacturers.

When assessing the quality of a module for any specific project, it is recommended that an independent technical advisor is approached to review the PV module technical specifications, quality assurance standards, track record and experience, as well as compliance with relevant international and national technical and safety standards. The expected degradation of the modules should be ascertained and the module warranties should be reviewed and compared to industry norms.

3.3.9 *MODULE TECHNOLOGY DEVELOPMENTS*

Solar PV module technology is developing rapidly. While a wide variety of different technical approaches are being explored, the effects of these approaches are focused on either improving module efficiency or reducing manufacturing costs.

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15 Standard Test Conditions are defined as follows—irradiation: 1000 W/m², temperature: 25°C, AM: 1,5 (AM stands for Air Mass, the thickness of the atmosphere; at the equator, air mass = 1, in Europe approx. 1,5).

16 Irradiance is the power of the sunlight incident on a surface per unit area and is measured in power per square meter (W/m2).

17 Bloomberg New Energy Finance, "Sustainable Energy in America 2015," http://about.bnef.com

18 Solar Buzz, "Top Ten PV Module Suppliers in 2013," http://www.solarbuzz.com

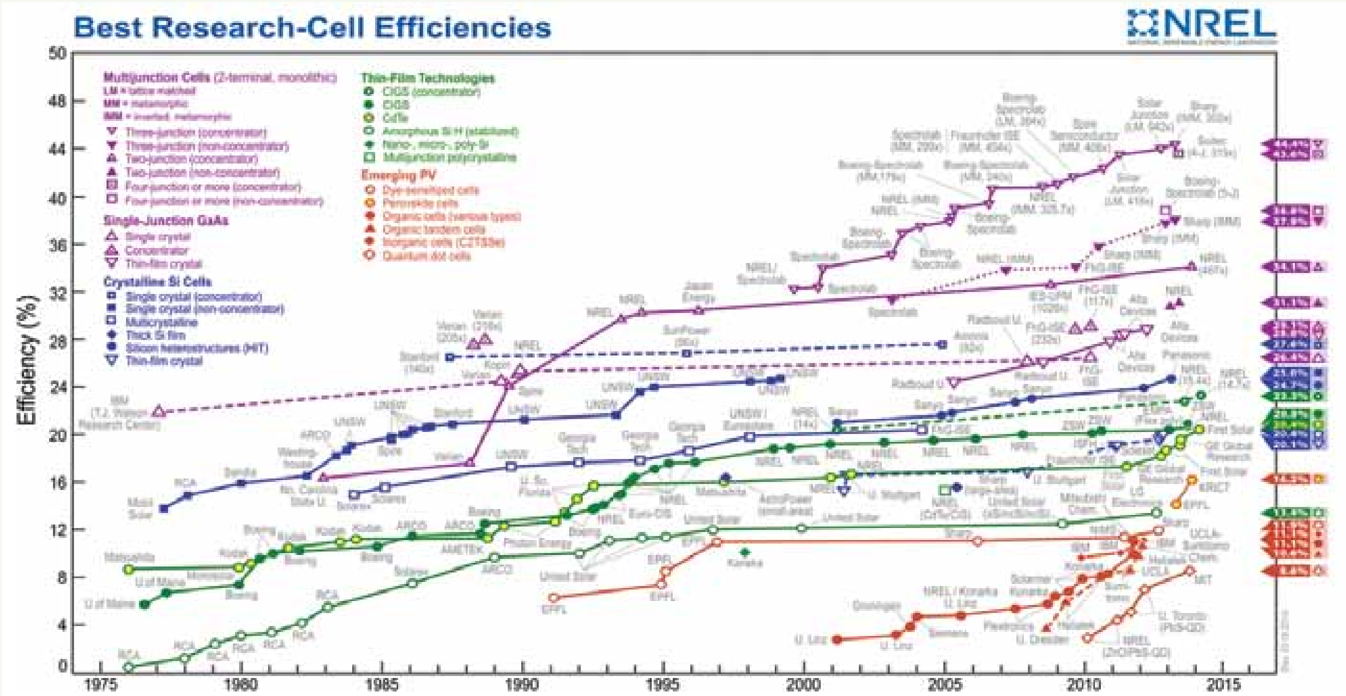
Table 2: PV Module Standards		
Test	**Description**	**Comment**
IEC 61215	Crystalline silicon (c-Si) terrestrial PV modules - Design qualification and type approval	Includes tests for thermal cycling, humidity and freezing, mechanical stress and twist and hail resistance. The standard certification uses a 2,400Pa pressure. Modules in heavy snow locations may be tested under more stringent 5,400Pa conditions.
IEC 61646	Thin-film terrestrial PV modules - Design qualification and type approval	Very similar to the IEC 61215 certification, but an additional test specifically considers the additional degradation of thin-film modules.
EN/IEC 61730	PV module safety qualification	Part 2 of the certification defines three different Application Classes: 1) Safety Class O - Restricted access applications. 2) Safety Class II - General applications. 3) Safety Class III - Low voltage (LV) applications.
IEC 60364-4-41	Protection against electric shock	Module safety assessed based on: 1) Durability. 2) High dielectric strength. 3) Mechanical stability. 4) Insulation thickness and distances.
IEC 61701	Resistance to salt mist and corrosion	Required for modules being installed near the coast or for maritime applications.
IEC 61853-1	Photovoltaic Module Performance Testing and Energy Rating	Describes the requirements for evaluating PV module performance in terms of power rating over a range of irradiances and temperatures.
IEC 62804 (pending issue)	System voltage durability test for c-Si modules	Describes the test procedure and conditions for conducting a PID test. The PV module will be deemed to be PID resistant if power loss is less than 5% following testing.
Conformité Européenne (EC)	The certified product conforms to the European Union (EU) health, safety and environmental requirements.	Mandatory in the European Economic Area.
UL 1703	Comply with the National Electric Code, Occupational Safety and Health Administration and the National Fire Prevention Association. The modules perform to at least 90% of the manufacturer's nominal power.	Underwriters Laboratories Inc. (UL) is an independent U.S. based product safety testing certification company which is a Nationally Recognised Testing Laboratory (NRTL). Certification by an NRTL is mandatory in the U.S.

Incremental improvements are being made to conventional c-Si cells. One of these improvements is the embedding of the front contacts in laser-cut microscopic grooves in order to reduce the surface area of the contacts and so increase the area of the cell that is exposed to solar radiation. Similarly, another approach involves running the front contacts along the back of the cell and then directly through the cell to the front surface at certain points.

Different types of solar cells inherently perform better at different parts of the solar spectrum. As such, one area of interest is the stacking of cells of different types. If the right combination of solar cells is stacked (and the modules are sufficiently transparent) then a stacked or "multi-junction" cell can be produced that performs better across a wider range of the solar spectrum. This approach is taken to the extreme in III-V cells (named after the respective groups of elements in the Periodic Table) in which the optimum materials are used for each part of the solar spectrum. III-V cells are very expensive, but have achieved efficiencies in excess of 40 percent. Less expensive approaches based on the same basic concept include hybrid cells (consisting of stacked c-Si and thin-film cells) and multi-junction a-Si cells.

Other emerging technologies, which are not yet market-ready, but could be of commercial interest in the future,

Figure 4: Development of Research Cell Efficiencies



Source: Data from United States National Renewable Energy Laboratory http://www.nrel.gov/ncpvl, accessed April 2014.

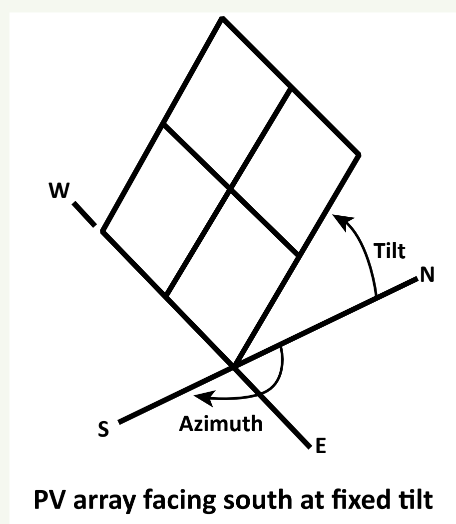
include spherical cells, sliver cells and dye-sensitized or organic cells. Dye-sensitized solar cells have gained attention recently because of their low production costs and ease of fabrication. However, their low efficiency and their instability over time is still a significant disadvantage.

Figure 4 illustrates the development of the efficiencies of research cells from 1975 to the present day. It should be noted that commercially available cells lag signifcantly behind research cells in terms of efficiency. See Box 1 for a discussion of module risk on project economics.

3.4 MOUNTING AND TRACKING SYSTEMS

PV modules must be mounted on a structure to keep them oriented in the correct direction and to provide them with structural support and protection. Mounting structures may be fixed or tracking. Fixed tilt arrays are typically tilted away from the horizontal plane in order to maximise the annual irradiation they receive. The optimum tilt angle is dependent on the latitude of the site location. The direction the system is facing is referred to as its orientation or azimuth, as shown in Figure 5. The ideal azimuth for a system in the northern hemisphere is

Figure 5: PV Array Tilt and Azimuth



Box 1: Module Risk

PV modules typically comprise approximately 50% of the system cost of a solar PV power plant. They are expected to have a functional life for the duration of the project, typically in excess of 25 years. Module failure or abnormal degradation can therefore significantly impact project economics. Careful selection of the PV modules is required. Although modules are an up-front capital cost, developers should think of long-term revenues.

The "bankability" of a module may be understood in different ways by developers, financiers and module manufacturers. The "bankability" usually includes an overall assessment of:

- Module technical characteristics.
- Quality of the manufacturing facility.
- Certification and testing procedures.
- Track record of the company and module.
- Warranty conditions.
- Company financial position.

To fully understand module risk, a full assessment of these criteria should be undertaken.

Current certification standards do not fully assess the technical adequacy of PV modules over the project life. A bath-tub failure curve is typical for PV modules, with increased risk of failure during the early years (infant-failures), low risk for the mid-term of the project (midlife-failures) and increased risk at the end of the project lifetime as modules deteriorate (wear-out-failures). From the lenders perspective, revenues from projects are most important during the first 15 years to coincide with typical debt terms. A lender is therefore well protected if the risk of infant-failure can be passed on to the EPC contractor or module manufacturer.

Most EPC contractors are willing to provide plant (PR) guarantees during the EPC warranty period (typically two years). Accompanied by a linear power warranty provided by the module manufacturer, a degree of infant failure module risk is covered.

The interests of the owner can be protected still further with additional testing of the modules during the EPC warranty period accompanied by appropriate termination scenarios whereby the owner has the right to reject the plant if it fails performance tests. Examples of module testing include external or on-site flash testing of a sample of modules upon delivery and prior to the end of the EPC warranty period, electro-luminescence testing and thermographic testing. These tests help to identify defects that may not affect the plant power within the EPC warranty period, but may do so in the future.

Many module manufacturers now typically offer a 25-year linear power output warranty. However, during historical periods of PV module over-supply, a large number of module manufacturers have entered insolvency, and many more have had poor financial positions. This means that not all module manufacturers can be assumed to be in a position to honour long-term warranty claims. Some module manufacturers, therefore, provide additional risk protection by offering third-party warranty insurance so that power output warranties can still be honoured in the case of manufacturer bankruptcy.

Developers, owners and financiers are advised to consider incorporating such additional risk reduction strategies into project contracts in order to match the project risk with their own risk profile requirements.

geographic south, and in the southern hemisphere it is geographic north.

3.4.1 FIXED MOUNTING SYSTEMS

Fixed mounting systems keep the rows of modules at a fixed tilt angle[19] while facing a fixed angle of orientation.[20]

Mounting structures will typically be fabricated from steel or aluminium, although there are also examples of systems based on wooden beams. A good quality mounting structure may be expected to:

- Have undergone extensive testing to ensure the designs meet or exceed the load conditions experienced at the site. This would include the design of the corrosion protection system to resist below-ground and atmospheric corrosion.
- Have been designed specifically for the site location with structural design calculations provided for

19The tilt angle or "inclination angle" is the angle of the PV modules from the horizontal plane.

20 The orientation angle or "azimuth" is the angle of the PV modules relative to south. Definitions may vary but 0° represents true south, -90° represents east, 180° represents north, and 90° represents west.

verification of the site-specific design, and a structural warranty document provided.

- Allow the desired tilt angle to be achieved within a few degrees.
- Allow field adjustments that may reduce installation time and compensate for inaccuracies in placement of foundations.
- Minimise tools and expertise required for installation.
- Adhere to the conditions described in the module manufacturer's installation manual.
- Allow for thermal expansion, using expansion joints where necessary in long sections, so that modules do not become unduly stressed.

Purchasing quality structures from reputable manufacturers is generally a low-cost, low-risk option. Some manufacturers provide soil testing and qualification in order to certify designs for a specific project location.

Alternatively, custom-designed structures may be used to solve specific engineering challenges or to reduce costs. If this route is chosen, it is important to consider the additional liabilities and cost for validating structural integrity. This apart, systems should be designed to ease installation. In general, installation efficiencies can be achieved by using commercially available products.

The topographic conditions of the site and information gathered during the geotechnical survey will influence the choice of foundation type. This, in turn, will affect the choice of support system design as some designs are more suited to a particular foundation type.

Foundation options for ground-mounted PV systems include:

- **Concrete piers cast in-situ:** These are most suited to small systems and have high tolerance to uneven and sloping terrain. They do not have large economies of scale.
- **Pre-cast concrete ballasts:** This is a common choice for manufacturers with large economies of scale. It is suitable even at places where the ground is difficult to penetrate due to rocky outcrops or subsurface obstacles. This option has low tolerance to uneven or sloping terrain, but requires no specialist skills for installation. Consideration must be given to the risk of soil movement or erosion.
- **Driven piles:** If a geotechnical survey proves suitable, a structural steel profile driven into the ground can result in low-cost, large-scale installations that can be quickly implemented. Specialist skills and pile driving machinery are required, but may not always be available.
- **Earth screws:** Helical earth screws typically made of steel have good economics for large-scale installations and are tolerant to uneven or sloping terrain. These require specialist skills and machinery to install.
- **Bolted steel baseplates:** In situations where the solar plant is located over suitable existing concrete ground slabs, such as disused airfield runway strips, a steel baseplate solution bolted directly to the existing ground slabs may be appropriate.

Fixed tilt mounting systems are simpler, cheaper and have lower maintenance requirements than tracking systems. They are the preferred option for countries with a nascent solar market and limited indigenous manufacturing of tracking technology.

3.4.2 TRACKING SYSTEMS

In locations with a high proportion of direct irradiation, single- or dual-axis tracking systems can be used to increase the average total annual irradiation. Tracking systems follow the sun as it moves across the sky. These are generally the only moving parts employed in a solar PV power plant.

Single-axis trackers alter either the orientation or tilt-angle only, while dual-axis tracking systems alter both orientation and tilt angle. Dual-axis tracking systems are able to face the sun more precisely than single-axis systems.

Depending on the site and precise characteristics of the solar irradiation, trackers may increase the annual energy yield by up to 27 percent for single-axis and 45 percent for dual-axis trackers. Tracking also produces a smoother power output plateau, as shown in Figure 6. This helps meet peak demand in afternoons, which is common in hot climates due to the use of air conditioning units.

Almost all tracking system plants use crystalline silicon (c-Si) modules. This is because their higher efficiency reduces additional capital and operating costs required for the tracking system (per kWp installed). However, relatively inexpensive single-axis tracking systems are used with some thin-film modules.

There are many manufacturers and products of solar PV tracking systems. Most fall into one of six basic design classes (classic dual-axis, dual-axis mounted on a frame, dual-axis on a rotating assembly, single-axis tracking on a tilted axis, tracking on a horizontal axis and single-axis tracking on a vertical axis). In general, the simpler the construction, the lower the extra yield compared to a fixed system, and the lower the maintenance requirement.

Figure 6: Benefit of Dual Axis Tracking System

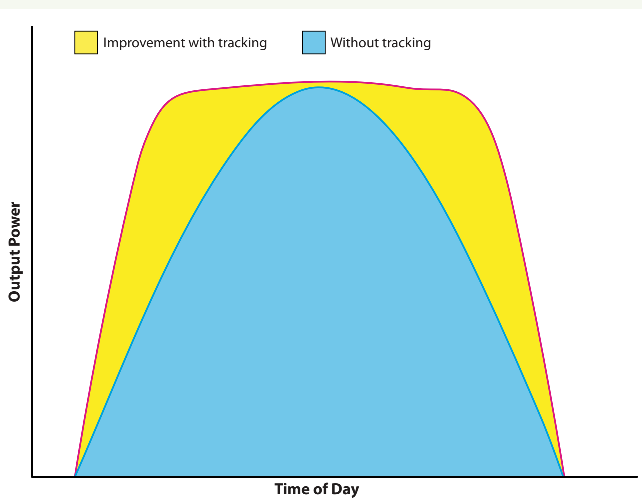


Image courtesy of Future Mechatronic Systems

Aspects to take into account when considering the use of tracking systems include:

- **Financial:**
  - Additional capital costs for the procurement and installation of the tracking systems.
  - Additional land area required to avoid shading compared to a free field fixed tilt system of the same nominal capacity.
  - Increased installation costs due to the need for large tracking systems that may require cranes to install. Higher maintenance cost for tracking systems due to the moving parts and actuation systems.
- **Operational:**
  - Tracking angles: all trackers have angular limits, which vary among different product types. Depending on the angular limits, performance may be reduced.
  - High wind capability and storm mode: dual-axis tracking systems in particular need to go into a storm mode when the wind speed is over 16-20m/s. This may reduce the energy yield and hence revenues at high wind speed sites.
  - Direct/diffuse irradiation ratio: tracking systems will give greater benefits in locations that have a higher direct irradiation component.

The higher financial and operational costs of tracker installations, combined with the reduced costs of the silicon-based modules has reduced the interest being shown in tracking projects in recent years.

3.4.3 CERTIFICATION

Support structures should adhere to country-specific standards and regulations, and manufacturers should conform to ISO 9001:2000. This specifies requirements for a quality management system where an organisation needs to:

- Demonstrate its ability to consistently provide products that meet customer and applicable regulatory requirements.
- Aim to enhance customer satisfaction through the effective application of the system. These include processes for continual improvement, as well as the assurance of conformity to customer and applicable regulatory requirements.

3.5 INVERTERS

Inverters are solid state electronic devices. They convert DC electricity generated by the PV modules into AC electricity, ideally conforming to the local grid requirements. Inverters can also perform a variety of functions to maximise the output of the plant. These range from optimising the voltage across the strings and monitoring string performance to logging data and providing protection and isolation in case of irregularities in the grid or with the PV modules.

3.5.1 INVERTER CONNECTION CONCEPTS

There are two broad classes of inverters: central inverters and string inverters. The central inverter configuration shown in Figure 7 remains the first choice for many medium- and large-scale solar PV plants. A large number of modules are connected in a series to form a high voltage (HV) string. Strings are then connected in parallel to the inverter.

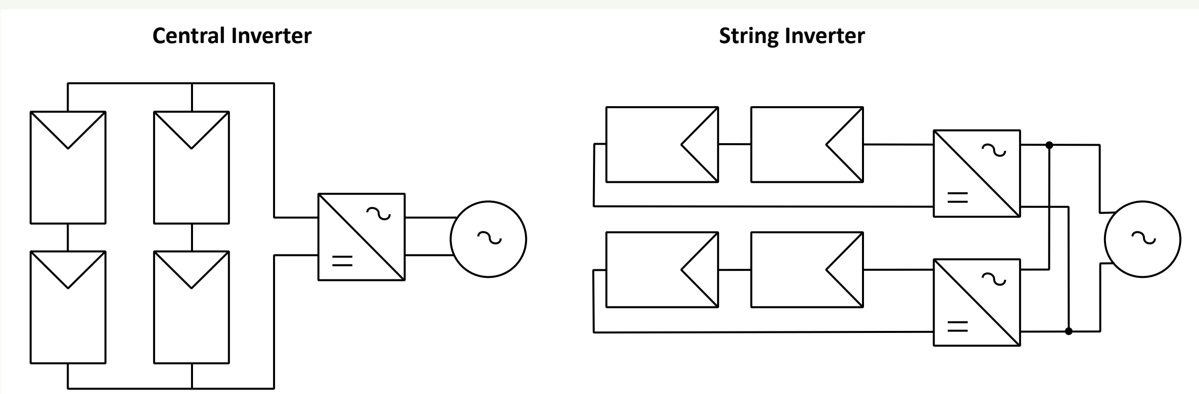
Central inverters offer high reliability and simplicity of installation. However, they have disadvantages: increased mismatch losses[21] and absence of maximum power point tracking (MPPT)[22] for each string. This may cause problems for arrays that have multiple tilt and orientation angles, or suffer from shading, or use different module types.

Central inverters are usually three-phase and can include grid frequency transformers. These transformers increase the weight and volume of the inverters, although they provide galvanic isolation from the grid. In other words, there is no electrical connection between the input and output voltages—a condition that is sometimes required by national electrical safety regulations.

21 Mismatch refers to losses due to PV modules with varying current/voltage profiles being used in the same array.

22 Maximum Power Point Tracking is the capability of the inverter to adjust its impedance so that the string is at an operating voltage that maximises the power output.

Figure 7: PV System Configurations



Central inverters are sometimes used in a “master-slave” configuration. This means that some inverters shut down when the irradiance is low, allowing the other inverters to run more closely to optimal loading. When the irradiance is high, the load is shared by all inverters. In effect, only the required number of inverters is in operation at any one time. As the operating time is distributed uniformly among the inverters, design life can be extended.

In contrast, the string inverter concept uses multiple inverters for multiple strings of modules. String inverters provide MPPT on a string level with all strings being independent of each other. This is useful in cases where modules cannot be installed with the same orientation or where modules of different specifications are being used or when there are shading issues.

String inverters, which are usually in single phase, also have other advantages. First of all, they can be serviced and replaced by non-specialist personnel. Secondly, it is practical to keep spare string inverters on site. This makes it easy to handle unforeseen circumstances, as in the case of an inverter failure. In comparison, the failure of a large central inverter, with a long lead time for repair, can lead to significant yield loss before it can be replaced.

Inverters may be transformerless or include a transformer to step up the voltage. Transformerless inverters generally have a higher efficiency, as they do not have transformer losses.

In the case of transformerless string inverters (see Figure 8), the PV generator voltage must either be significantly higher than the voltage on the AC side, or DC-DC step-up converters must be used. The absence of a transformer leads to higher efficiency, reduced weight, reduced size (50-75 percent lighter than transformer-based models[23]) and lower cost due to the smaller number of components. On the downside, additional protective equipment must be used, such as DC sensitive earth-leakage circuit breakers (CB), and live parts must be protected. IEC Protection Class II[24] must be implemented across the installation. Transformerless inverters also cause increased electromagnetic interference (EMI).[25]

Inverters with transformers provide galvanic isolation. Central inverters are generally equipped with transformers. Safe voltages (<120V) on the DC side are possible with this design. The presence of a transformer also leads to a reduction of leakage currents, which in turn reduces EMI. But this design has its disadvantages in the form of losses (load and no-load[26]) and increased weight and size of the inverter.

3.5.2 *INVERTER ELECTRICAL ARRANGEMENT*

Inverters operate by use of power switching devices such as thyristor or Insulated Gate Bipolar Transistor (IGBT)[27] to chop the DC current into a form of pulses that provide a reproduction of an AC sinusoidal waveform. The nature of the generated AC wave means that it may spread interference across the network. Therefore, filters must be applied to limit Electromagnetic Compatibility (EMC) interference emitted into the grid. Circuit protection functions should be included within a good inverter design.

Inverters should be provided with controllers to measure the grid output and control the switching process. In addition, the controller can provide the MPPT functionality.

23 Navigant Consulting Inc., “A Review of PV Inverter Technology Cost and Performance Projections,” National Renewable Energy Laboratory, U.S. Department of Energy, Jan 2006, http://www.nrel.gov/docs/fy06osti/38771.pdf (accessed July 2014).

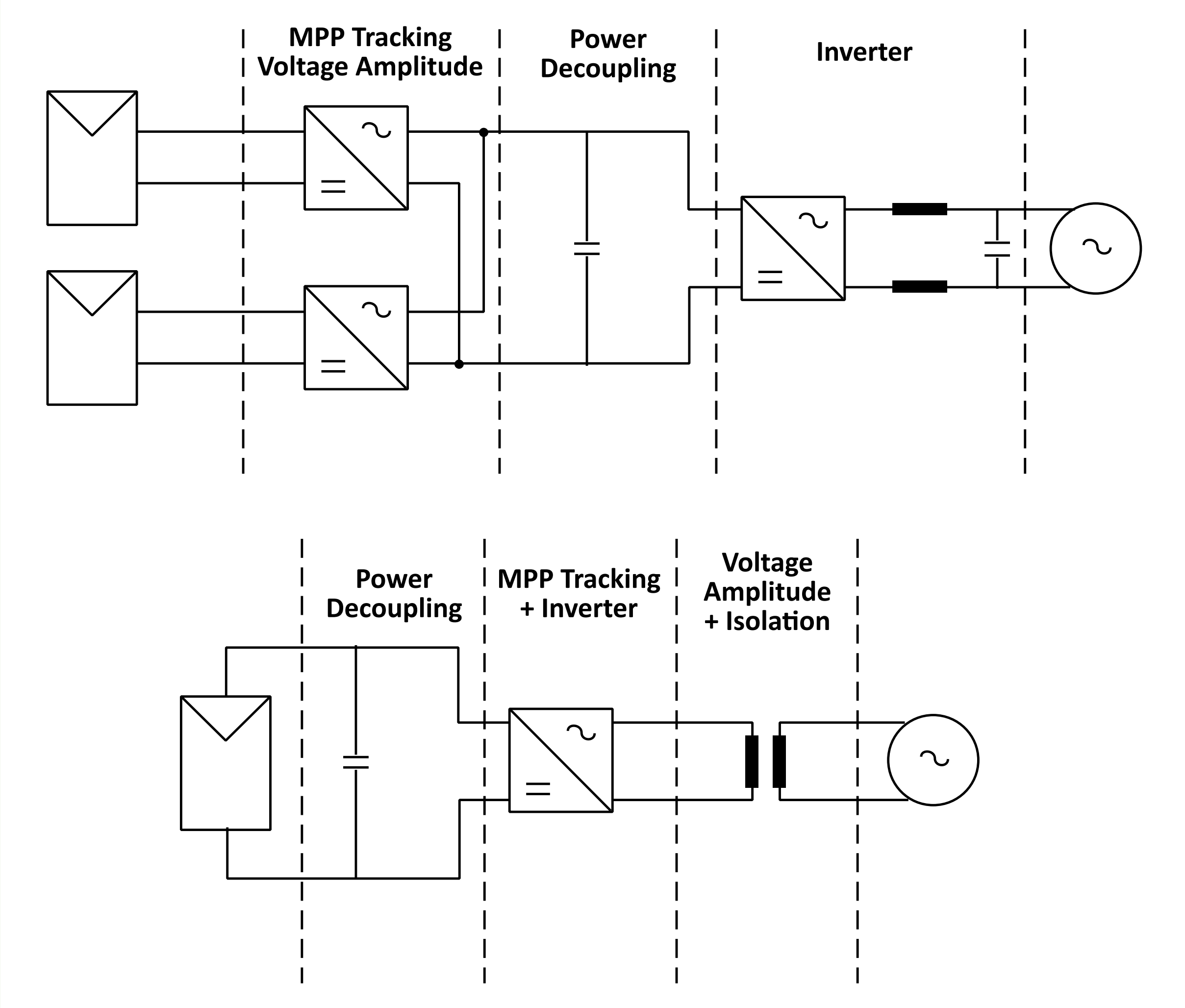
24 IEC Protection Class II refers to a device that is double insulated and therefore does not require earthing.

25 Electromagnetic disturbance affects an electrical circuit due to either electromagnetic induction or electromagnetic radiation emitted from an external source. The disturbance may interrupt, obstruct, or otherwise degrade or limit the effective performance of the circuit.

26 The load-dependent copper losses associated with the transformer coils are called load losses. The load-independent iron losses produced by the transformer core magnetising current are called no-load losses.

27 Insulated Gate Bipolar Transistor is a three-terminal power semiconductor device primarily used as an electronic switch and in newer devices is noted for combining high efficiency and fast switching.

Figure 8: Transformer and Transformerless Inverter Schematic



3.5.3 EFFICIENCY

A number of different types of efficiencies have been defined for inverters. These describe and quantify the efficiency of different aspects of an inverter's operation. The search for an objective way of quantifying inverter performance is still ongoing. New ways of measuring efficiency are frequently suggested in the literature. The most commonly used methods are discussed below.

The conversion efficiency is a measure of the losses experienced during the conversion from DC to AC. These losses are due to multiple factors: the presence of a transformer and the associated magnetic and copper losses, inverter self-consumption, and losses in the power electronics. Conversion efficiency is defined as the ratio of the fundamental component of the AC power output from the inverter, divided by the DC power input:

$$n_{Con} = \frac{P_{AC}}{P_{DC}} = \frac{\textit{Fundamental component of AC power output}}{\textit{DC power input}}$$

The conversion efficiency is not constant, but depends on the DC power input, the operating voltage, and the weather conditions, including ambient temperature and irradiance. The variance in irradiance during a day causes fluctuations in the power output and maximum power point (MPP) of a PV array. As a result, the inverter is continuously subjected to different loads, leading to varying efficiency. The voltage at which inverters reach their maximum efficiency is an important design variable, as it allows system planners to optimise system wiring.

Due to the dynamic nature of inverter efficiency, diagrams are also more suited to depiction than uniform numeric values. An example depicting the dependency of the inverter efficiency on the inverter load is given in Figure 9.

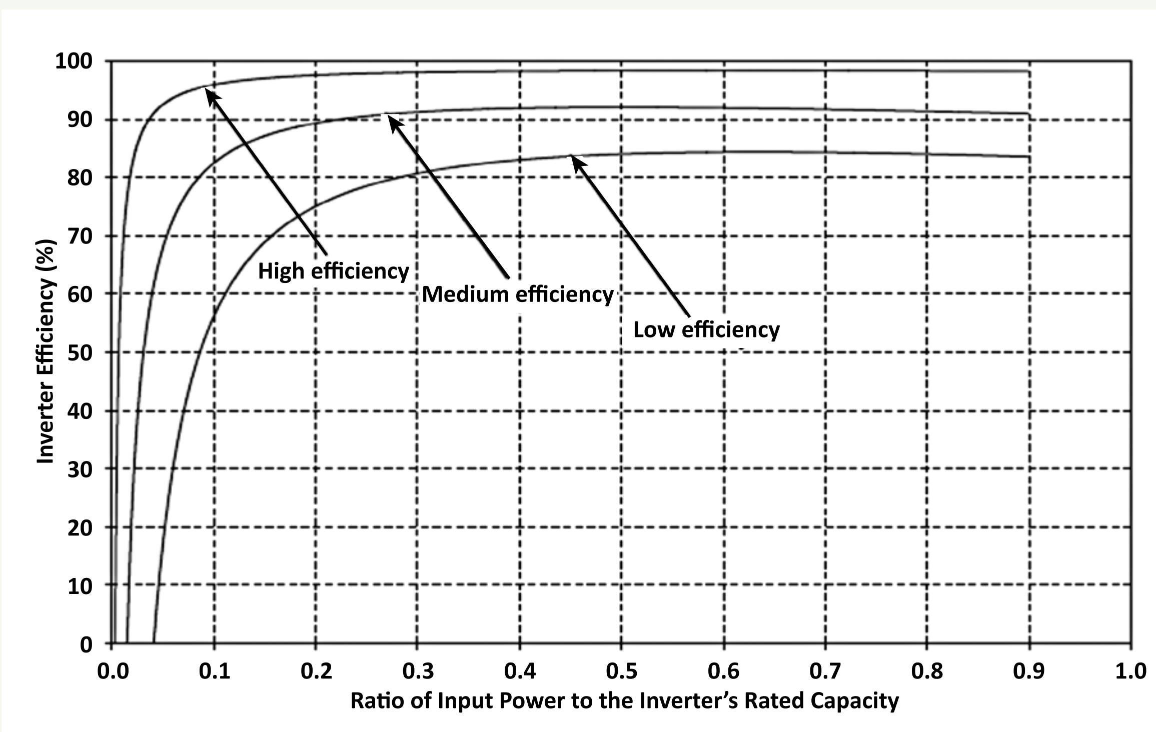
The European Efficiency is an accepted method of measuring inverter efficiency. It is a calculated efficiency averaged over a power distribution corresponding to the operating climatic conditions of a central European location. As a useful means of comparing inverter efficiencies,[28] the efficiency standard also attempts to capture the fact that in central Europe, most energy is generated near the middle of a PV module's power range.

Another method of comparing efficiencies is using the Californian Efficiency. While the standard is based on the same reasoning as the European Efficiency, it is calibrated for locations with higher average irradiance.

Inverters can have a typical European Efficiency of 95 percent and peak efficiencies of up to 98 percent. Most inverters employ MPPT algorithms to adjust the load

28 If $h_{50\%}$ denotes the efficiency at a load equal to 50% of the nominal power, the European Efficiency is defined as:
$n_{Euro} = 0.03 \times n_{5\%} + 0.06 \times n_{10\%} + 0.13 \times n_{20\%} + 0.1 \times n_{30\%} + 0.48 \times n_{50\%} + 0.2 n_{100\%}$

Figure 9: Efficiency Curves of Low, Medium and High Efficiency Inverters as Functions of the Input Power to Inverter Rated Capacity Ratios



Source: J.D. Mondol, Y. G. Yohanis, B. Norton, "Optimal sizing of array and inverter for grid-connected photovoltaic systems," *Solar Energy*, Vol.80, Issue 12, 2006, p.1517-1539, (accessed July 2014).

impedance and maximise the power from the PV array. The highest efficiencies are reached by transformerless inverters.

3.5.4 CERTIFICATION

In order to ensure a high level of quality and performance, and to minimise risk, inverters must be compliant with a number of standards. The requirements, in terms of compliance with standards, depend on the location of the project and the type of inverter.

Important standards bodies for inverters are Deutsches Institut für Normung (DIN), Verband der Elektrotechnik, Elektronik und Informationstechnik (VDE), IEC, and European Norm (EN). Inverters must be Conformance European (CE)-compliant in order to be installed in Europe. Table 3 is a non-exhaustive list of standards to which inverters should conform according to European practice.

3.5.5 INVERTER MANUFACTURERS

Manufacturers of solar inverters are predominantly based in Europe and North America, however big players from China and Japan have entered the inverter market. Some of the leading suppliers, such as SMA, ABB (which acquired Power One) and Kaco, have lost portions of their market share mainly due to reduced sales volumes in the Asia market.

A 2014 survey by *Photon International* (Apr. 2014) indicated that there were over 60 inverter suppliers and over 1,757 products, 1,445 of which are in the 10kW to 500kW category.

Market research organisations such as IHS, Solarbuzz and Bloomberg New Energy Finance[29] give annual lists of the top ten inverter suppliers.

It is recommended that an independent technical advisor should review the technology and type of inverter with regards to technical specification, quality recognition, track record, and experience of the supplier, as well as compliance with relevant international and national technical and safety standards. Warranties should also be reviewed and assessed for compliance with industry norms.

3.6 QUANTIFYING PLANT PERFORMANCE

The performance of a PV power plant is expected to fall during its lifetime, especially in the second and third decade of its life as modules continue to degrade and plant components age. In addition to the quality of the

29 IHS Technology, https://technology.ihs.com; Solar Buzz, http://www.solarbuzz.com; Bloomberg New Energy Finance, http://www.nef.com.

Table 3: Indicative List of Inverter-related Standards

EN 61000-6-1: 2007	Electromagnetic compatibility (EMC). Generic standards. Immunity for residential, commercial and light-industrial environments.
EN 61000-6-2: 2005	EMC. Generic standards. Immunity for industrial environments.
EN 61000-6-3: 2007	EMC. Generic standards. Emission standard for residential, commercial and light-industrial environments.
EN 61000-6-4: 2007	EMC. Generic standards. Emission standard for industrial environments.
EN 55022: 2006	Information technology equipment. Radio disturbance characteristics. Limits and methods of measurement.
EN 50178: 1997	Electronic equipment for use in power installations.
IEC 61683: 1999	Photovoltaic systems—Power conditioners—Procedure for measuring efficiency.
IEC 61721: 2004	Characteristics of the utility interface.
IEC 62109-1&2: 2011-2012	Safety of power converters for use in photovoltaic power systems.
IEC 62116 : 2008	Islanding prevention measures for utility-interconnected photovoltaic inverters.

initial installation, a high degree of responsibility for the performance of a PV plant lies with the O&M contractor. This section discusses how the operational performance of a PV plant may be quantified.

3.6.1 PERFORMANCE RATIO

The Performance Ratio (PR) is a parameter commonly used to quantify PV plant performance. Usually expressed as a percentage, the PR provides a benchmark to compare plants over a given time independent of plant capacity or solar resource. A plant with a high PR is more efficient at converting solar irradiation into useful energy.

The PR is defined as the ratio between the exported AC yield and the theoretical yield that would be generated by the plant if the modules converted the irradiation received into useful energy according to their rated capacity. The full definition of PR is given in IEC 61724 "Photovoltaic system performance monitoring—Guidelines for measurement data exchange and analysis." It may be expressed as:

$$PR = \frac{\text{AC Yield (kWh)} \times 1 \left(\text{kW}/\text{m}^2\right)}{\text{DC Installed Capacity (kWp)} \times \text{Plane of Array Irradiation(kWh/m}^2\text{)}} \times 100\%$$

The PR quantifies the overall effect of system losses on the rated capacity, including losses caused by modules, temperature, low light efficiency reduction, inverters, cabling, shading and soiling.

The PR of a plant may be predicted using simulations, or alternatively may be calculated for an operational plant by measuring irradiation and the AC yield.

As PV plant losses vary according to environmental conditions through the year, the plant PR also varies. For example, the more significant negative temperature coefficient of power for crystalline modules may lead to increased losses at high ambient temperatures. A PR varying from approximately 77 percent in summer up to 86 percent in winter (with an annual average PR of 82 percent) would not be unusual for a well-designed solar PV power plant that is not operating in high ambient temperature conditions.

Some plants using a-Si modules show the opposite effect: in summer months, the PR increases, dropping again in the colder winter months. This is due to the fact that Staebler-Wronski degradation is partially reversible at high temperatures. It is common to observe seasonal oscillations in the PR of a-Si plants due to this thermal annealing process.

Averaged across the year, a PR in the upper seventies or lower eighties is typical for a well-designed plant. This may be expected to reduce as the plant ages, depending on the module degradation rates.

3.6.2 SPECIFIC YIELD

The "specific yield" (kWh/kWp) is the total annual energy generated per kWp installed. It is often used to help determine the financial value of a plant and compare operating results from different technologies and systems. The specific yield of a plant depends on:

- The total annual irradiation falling on the collector plane. This can be increased by optimally tilting the modules or employing tracking technology.
- The performance of the module, including sensitivity to high temperatures and low light levels.
- System losses including inverter downtime.

Some module manufacturers claim much higher kWh/kWp energy yields for their products than those of their competitors. However the divergence between actual peak power and nominal power and correction for other technical distortions should also be taken into account.

3.6.3 CAPACITY FACTOR

The capacity factor of a PV power plant (usually expressed as a percentage) is the ratio of the actual output over a period of a year and its output if it had operated at nominal power the entire year, as described by the formula:

$$CF = \frac{\text{Energy generated per annum (kWh)}}{8760 \text{ (hours/annum)} \times \text{Installed Capacity (kWp)}}$$

The use of the term "capacity factor" is less common in the solar industry than "specific yield." Capacity factor and specific yield are simply related by the factor 8760. The capacity factor of a fixed tilt PV plant can vary from 12 percent to 24 percent depending on the solar resource and the performance ratio of the plant. In Germany, a capacity factor of 12 percent may be typical. Higher capacity factors in the region of 16 percent may be experienced in southern Spain, which has a higher solar resource. For Thailand and Chile, capacity factors may be in the region of 18 percent and 22 percent, respectively. A 5MWp plant in Chile will generate the equivalent energy of a continuously operating 1.1MW plant.

4 The Solar Resource

4.1 SOLAR RESOURCE OVERVIEW

The solar resource expected over the lifetime of a solar PV plant is most accurately estimated by analysing historical solar resource data for the site. Obtaining a first approximation of the power output of a PV plant depends on the plane of array irradiance. The accuracy of any solar energy yield prediction is therefore heavily dependent on the accuracy of the historical solar resource dataset. Obtaining reliable historical resource data is a crucial step in the development process and essential for project financing.

There are two main sources of solar resource data: satellite-derived data and land-based measurement. Since both sources have particular merits, the choice will depend on the specific site. Land-based site measurement can be used to calibrate resource data from satellites in order to improve accuracy and certainty.

As solar resource is inherently intermittent, an understanding of inter-annual variability is important. Often ten years or more of data are desirable to calculate the variation with a reasonable degree of confidence, although many projects have been completed with less detailed levels of historical data (see the checklist at the end of Chapter 4).

The following sections describe how the solar resource may be quantified and summarises the steps in the solar resource assessment process.

4.2 QUANTIFYING SOLAR RESOURCE

The solar resource of a location is usually defined by the direct normal irradiation,[30] the diffuse horizontal irradiation and the

As solar resource is inherently intermittent, an understanding of inter-annual variability is important. At least ten years of data are usually required to calculate the variation with a reasonable degree of confidence.

30 DNI is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky.

global horizontal irradiation.[31] These parameters are described below:

- **Direct Normal Irradiation (DNI):** The beam energy component received on a unit area of surface *directly facing the sun at all times*. The DNI is of particular interest for solar installations that track the sun and for concentrating solar technologies (concentrating technologies can only make use of the direct beam component of irradiation).
- **Diffuse Horizontal Irradiation (DHI):** The energy received on a unit area of horizontal surface from radiation that is scattered off the atmosphere or surrounding area is known as DHI.
- **Global Horizontal Irradiation (GHI):** The total solar energy received on a unit area of a horizontal surface is the GHI. It includes energy from the sun that is received in a direct beam (the horizontal component of the DNI) and the DHI. The yearly sum of the GHI is of particular relevance for PV power plants, which are able to make use of both the diffuse and beam components of solar irradiation.

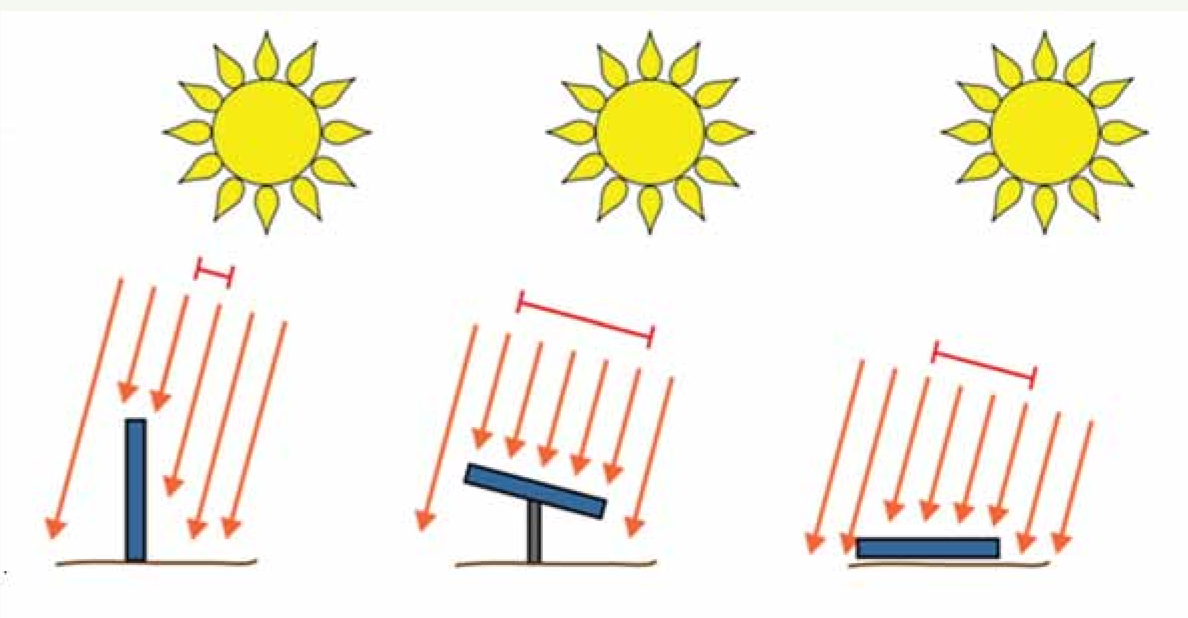
In the northern hemisphere, a surface tilted at an angle towards the south receives a higher total annual global irradiation compared to a horizontal surface. This is because a surface tilted towards the south more directly faces the sun for a longer period of time. In the southern hemisphere a surface tilted towards the north receives a higher total annual global irradiation. Figure 10 illustrates why the tilt angle is important for maximising the energy incident on the collector plane.

The amount of irradiation received can be quantified for any tilt angle by the global tilted irradiation (GTI).[32] The optimal tilt angle varies primarily with latitude and may also depend on local weather patterns and plant layout configurations. Simulation software may be used to calculate the irradiation on a tilted plane. Part of this calculation will take into account the irradiance reflected from the ground towards the modules. This is dependent

31 GHI is the total amount of shortwave radiation received from above by a surface horizontal to the ground.

32 GTI is the total irradiation that falls on a tilted surface.

Figure 10: Effect of Tilt on Solar Energy Capture



on the ground reflectance, or albedo. These terms are defined below:

- **Global Tilted Irradiation (GTI):** The total solar energy received on a unit area of a tilted surface. It includes direct beam and diffuse components. A high value of long-term annual GTI average is the most important resource parameter for project developers.
- **Albedo:** The ground reflectance or albedo is highly site-dependent. A higher albedo translates into greater reflection. Fresh grass has an albedo factor of 0.26, reducing down to a minimum of approximately 0.15 when dry. Asphalt has a value between 0.09 and 0.15, or 0.18 if wet. Fresh snow has an albedo of approximately 0.8, meaning that 80 percent of the irradiation is reflected.

4.3 SOLAR RESOURCE ASSESSMENT

Long-term annual average values of GHI and DNI can be obtained for a site by interpolating measurements taken from nearby ground-based measurement stations or by solar models that utilise satellite, atmospheric and meteorological data. Ideally, historical time series of hourly GHI and DHI values are used for PV project development. Data representing a period of at least ten continuous years are desirable to account for climate variability. However, such extensive historical data is not always available, particularly from ground-based measurement stations. Satellite data sources are therefore often acceptable.

Data in hourly or sub-hourly time steps are preferred. Statistical techniques can be used to convert average monthly values into simulated hourly values if these are not immediately available.

Ground-based solar resource measurement stations are very unevenly distributed throughout the world. Countries have different standards of calibration, maintenance procedures and historical measurement periods. In addition, as the distance from a solar measuring station increases, the uncertainty of interpolated irradiation values increases. On the other hand, the development of solar models using satellite data has advanced as the accuracy of such data increases. The precise distance at which satellite data become preferable over data interpolated from ground sensors depends on the individual case. The relative merits of ground-based measurements and satellite-derived data are discussed below.

4.3.1 GROUND BASED MEASUREMENTS

The traditional approach to solar resource measurement is to use ground-based solar sensors. A variety of sensors for measurements of global and diffuse radiation is available from a number of manufacturers with different accuracy and cost implications. The two main technology classes are:

- **Thermal Pyranometers:** These typically consist of a black metal plate absorber surface below two hemispherical glass domes in a white metal housing. Solar irradiance warms up the black metal plate in proportion to its intensity. The degree of warming, compared to the metal housing, can be measured with a thermocouple. High precision measurements of global irradiance ion can be achieved with regular cleaning and recalibration. Also, diffuse irradiance can be measured if a sun-tracking shading disc is used to block out beam irradiance travelling directly from the sun. An example of a pyranometer is shown in Figure 11. The theoretical uncertainty of daily aggregated values measured by pyranometers (depending on the

Figure 11: Pyranometer Measuring GHI Image

Image courtesy of NREL

accuracy class) is in the range of ± 2 percent to ± 8 percent. Thermal pyranometers have a relatively slow response time and may not be able to capture rapidly varying irradiance levels due to clouds.

- **Silicon Sensors:** Typically, these are cheaper than pyranometers and consist of a PV cell, often using crystalline silicon (c-Si). The current delivered is proportional to the irradiance. Temperature compensation can be used to increase accuracy, but its scope is limited by the spectral sensitivity of the cell. Some wavelengths (i.e., long wavelength infrared) may not be accurately measured, resulting in a higher measurement uncertainty of daily aggregated values of approximately ± 5 percent compared to thermal pyranometers.

Each sensor type is subject to ageing, and accuracy reduces with time. Therefore, it is important to re-calibrate at least every two years. It can be expected that annual GHI solar irradiation from well-maintained ground-based sensors can be measured with a relative accuracy of ± 3 percent to ± 5 percent, depending on the category of the sensor, position of the site, calibration and maintenance. Maintenance is very important since soiled or ill-calibrated sensors can easily yield unreliable data.

Section 7.7.2 gives quality benchmarks for the irradiation monitoring of mega-watt scale PV power plants to enable developers to use equipment that will be acceptable for investors and financial institutions.

4.3.2 SATELLITE-DERIVED DATA

Satellite-derived data offer a wide geographical coverage and can be obtained retrospectively for historical periods during which no ground-based measurements were taken. This is especially useful for assessing hourly or sub-hourly time series or aggregated long-term averages. A combination of analytical, numerical and empirical methods can offer 15-minute or 30-minute data with a nominal spatial resolution down to 90m x 90m, depending on the region and satellite.

One advantage of a satellite resource assessment is that data are not susceptible to maintenance and calibration discontinuities. Radiometric and geometric variations in the satellite sensors can be controlled and corrected. The same sensor is used to assess locations over a wide area for many years. This can be particularly useful in comparing and ranking sites because bias errors are consistent. Monthly GHI, DHI (or DNI) solar radiation maps at a spatial resolution of approximately 4km are today a standard for the generation of long-term historical time series and spatially continuous solar atlases, such as those shown in Figure 12 and Figure 13.

Efforts are underway to improve the accuracy of satellite-derived data. One way is to use more advanced techniques for better mapping clouds, especially in high mountains, coastal zones, and high reflectivity surfaces, such as salt plains and snow-covered regions. Substantial improvements can also be seen in improved atmospheric models and input data, such as aerosols and water vapour. Higher spatial and temporal resolution of the input atmospheric databases helps to improve mapping of locally generated dust, smoke from biomass burning and anthropogenic pollution. Effects of terrain features (elevation and shading effects) are also better considered by new approaches.

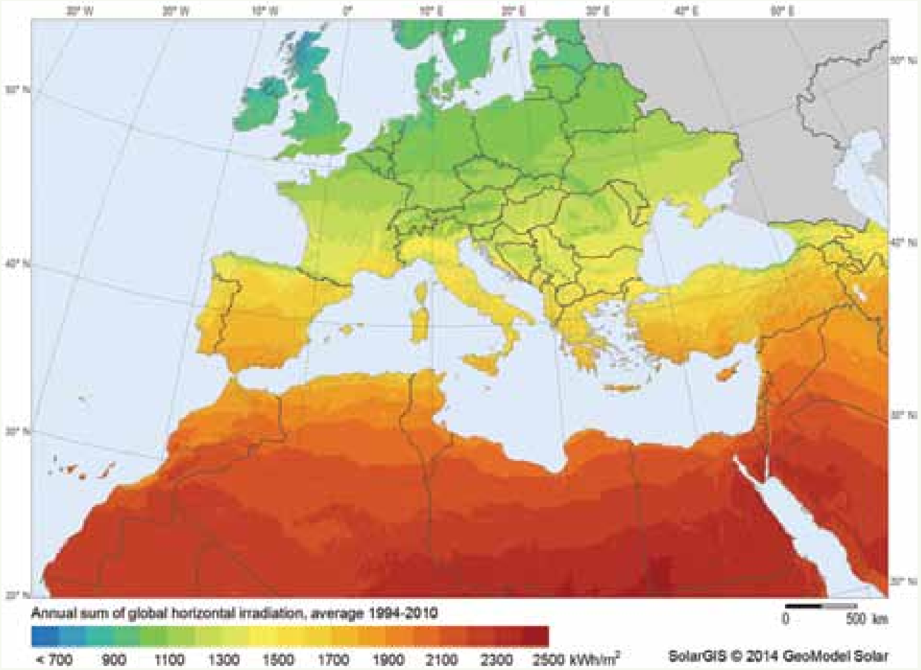
4.3.3 SITE ADAPTION OF SATELLITE DERIVED RESOURCE DATA

For locations that have a low density of meteorological stations, and rely on satellite data, site-solar resource monitoring may be considered during the feasibility stage of the project. Short-term site resource measurements may be used to adapt (calibrate) long-term satellite-derived time series. This site adaption of the satellite data reduces bias (systematic deviation) and random deviation of hourly or sub-hourly values. In general, measurement data for a minimum of nine months can be used to reduce existing bias, and improve the estimation of the long-term mean. The best results however are obtained by monitoring for a minimum of 12 months to better capture seasonal variations.

4.3.4 VARIABILITY IN SOLAR IRRADIATION

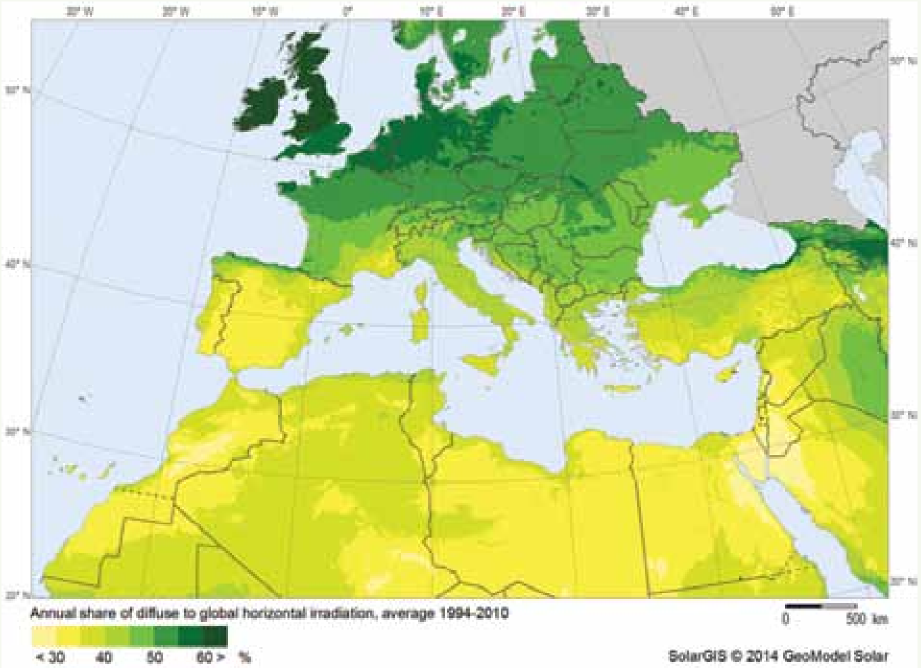
Solar resource is inherently intermittent: in any given year, the total annual global irradiation on a horizontal plane varies from the long-term average due to weather

Figure 12: Annual Sum of GHI, average 1994-2010



Source: Image courtesy of Geomodel Solar http://geomodelsolar.eu/

Figure 13: Annual Share of DHI to GHI, average 1994-2010



Source: Image courtesy of Geomodel Solar http://geomodelsolar.eu/

fluctuations. Even though the owner of a PV power plant may not know what energy yield to expect in any given year, one can have a good idea of the expected yield averaged over the long term.

To help lenders understand the risks and perform a sensitivity analysis, it is important to quantify the limits of such year-by-year variability, or "inter-annual variation." Usually, 10 years of ground measurements or satellite data are desirable, although an assessment of the inter-annual variation can sometimes be obtained with reasonable confidence using a data set covering a shorter historical period. Research papers[33] show that for southern Europe (including Spain), the coefficient of variation (standard deviation divided by the mean[34]) is below 4 percent. In Central Europe it can be above 12 percent.

33 M. Suri, T. Huld, E.D. Dunlop, M. Albuisson, M. Lefevre & L. Wald, "Uncertainties in photovoltaic electricity yield prediction from fluctuation of solar radiation," Proceedings of the 22nd European Photovoltaic Solar Energy Conference, Milan, Italy, 3-7 September 2007 (accessed July 2014).

Table 4: Inter-annual Variation in Global Horizontal Irradiation as Calculated from SolarGIS Database

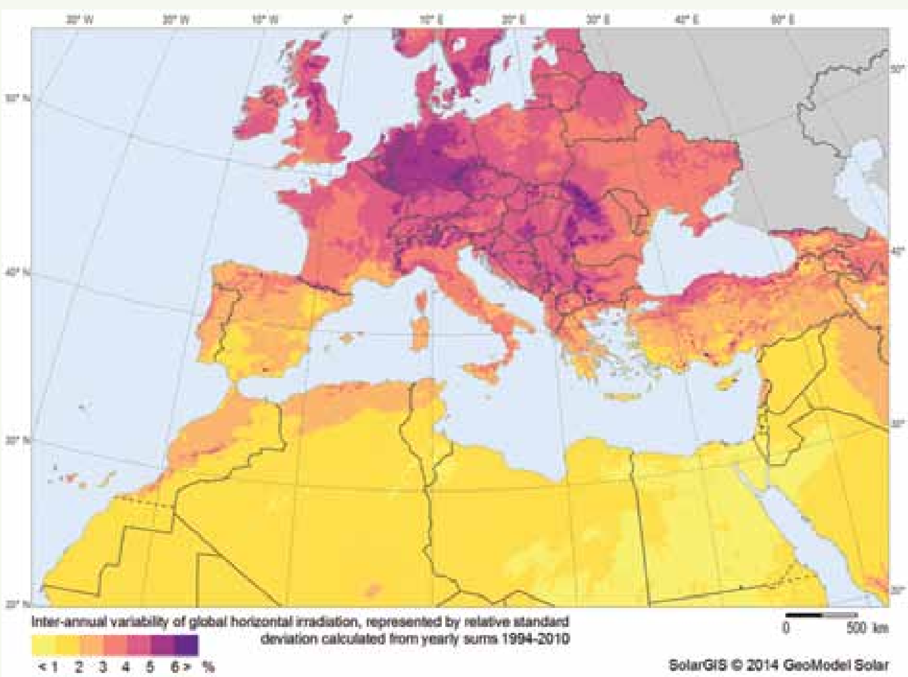
Location	Number of Years of Data	Coefficient of Variation
New Delhi	15	3.4%
Mumbai	15	2.5%
Chennai	15	2.2%

Table 4 shows the coefficient of variation for three locations in India as derived from data provided by SolarGIS.

Figure 14 shows how the inter-annual variability varies depending on the site location for Europe, North Africa and the Middle East.

34 The coefficient of variation is a dimensionless, normalised measure of the dispersion of a probability distribution. It enables the comparison of different data streams with varying mean values.

Figure 14: Inter-annual Variability in GHI (relative standard deviation) 1994-2010



Source: Image courtesy of Geomodel Solar http://geomodelsolar.eu/

4.3.5 SOURCES OF SOLAR RESOURCE DATA

There are a variety of different solar resource datasets that are available with varying accuracy, resolution, historical time period and geographical coverage. The datasets either make use of ground-based measurements at well-controlled meteorological stations or use processed satellite data. Table 5 summarizes some of the more globally applicable datasets. Further information on which dataset is available for a specific country or region may be obtained online.[35]

35 United Nations Environment Programme, "Solar Dataset," http://www.unep.org/climatechange/mitigation/RenewableEnergy/SolarDataset/tabid/52005/Default.aspx (accessed July 2014).

In financing solar power projects, financial institutions are becoming more sophisticated in their analysis of the solar resource. Their requirements are moving towards the analysis of multiple datasets, cross referencing with values obtained from high resolution satellite data and a robust uncertainty analysis.

In a competitive market, financial institutions will tend to give better terms of financing to those projects that have the lowest risk to the financial return. An important component of the risk assessment is the confidence that can be placed in the solar resource at the site location. Developers can reduce the perceived long-term solar resource risk by:

Table 5: Solar Resource Datasets

Data Source	Type	Description
SolarGIS [1]	Commercial satellite derived	Solar resource data are available for latitudes between 60° North and 50° South at a spatial resolution of 250m. The solar resource parameters are calculated from satellite data, atmospheric data and digital terrain models. Solar resource data are available from years 1994, 1999, or 2006 (depending on the region) up to the present time and have time resolution of up to 15 minutes. The database has been extensively validated at more than 180 locations globally.
3Tier [2]	Commercial satellite derived	The dataset has global coverage between 48° S to 60° N with spatial maps and hourly time series of irradiance at a spatial resolution of approximately 3km (2 arc minutes). Depending on the location, data is available beginning in 1997, 1998, or 1999 up to the present day. The satellite algorithm error is based on validation against 120 reference stations across the globe with a standard error for global horizontal irradiance of 5 percent.
HelioClim v4.0 [3]	Commercial satellite derived	Has a spatial resolution of approximately 4km. The region covered extends from -66° to 66° both in latitude and longitude (mainly Europe, Africa and the Middle East). The data are available from February 2004 and are updated daily.
Meteonorm v7.0 [4]	Commercial	Interpolated global solar resource database. It enables the production of typical meteorological years for any place on earth. It includes a database for radiation for the period 1991-2010. Where a site is over 10km from the nearest measurement station, a combination of ground and satellite measurements are used. Additionally, uncertainty and P10/90 estimates are given.
NASA Surface Meteorology and Solar Energy data set [5]	Free	Satellite-derived monthly data for a grid of 1°x1° (equal to 100km x 100km at the equator) covering the globe for a 22 year period (1983-2005). The data may be considered reasonable for preliminary feasibility studies of solar energy projects in some regions however these data have a low spatial resolution.
PVGIS – Classic [6]	Free	The original PVGIS database for Europe is based on an interpolation of ground station measurements for the period 1981-1990 (10 years).
PVGIS – ClimSAF [7]	Free	Data for a total of 14 years that is satellite-derived. From the first generation of Meteosat satellites, there are data from 1998 to 2005, and from the second generation, there are data from June 2006 to December 2011. The spatial resolution is 1.5 arc-minutes or approximately 2.5km directly below the satellite at 0° N.
PVGIS – HelioClim [8]	Free	Data are monthly values for any location in Africa and parts of the Middle East. Data are derived from satellite-based calculations. The spatial resolution of the original calculation is 15 arc-minutes, or about 28km directly below the satellite (at the equator, 0° W). The data cover the period 1985-2004.

- Comparing different data sources, assessing their uncertainty and judiciously selecting the most appropriate data for the site location.
- Assessing the inter-annual variation in the solar resource in order to quantify the uncertainty in the revenue in any given year.

This analysis requires a considerable degree of experience and technical understanding of the statistical properties of each dataset. Technical advisors are available to perform this task.

Box 2: Case Study of Solar Resource for a Location in India

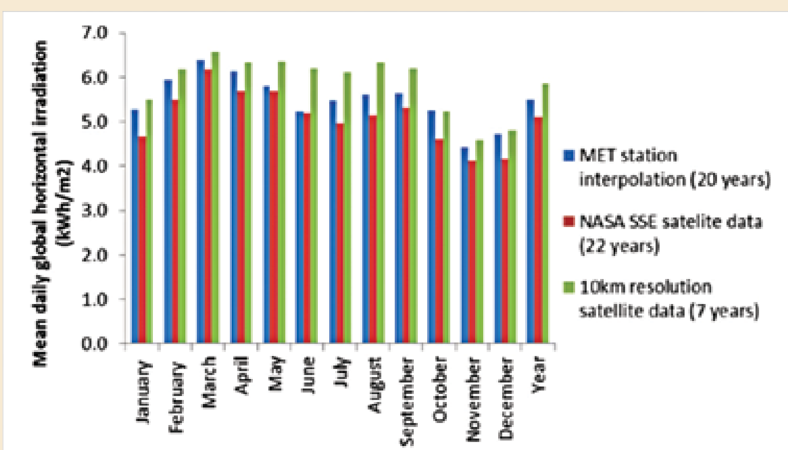
There are a variety of possible solar irradiation data sources that may be accessed for the purpose of estimating the irradiation at potential solar PV sites in India. The data sources for solar radiation in India are of varying quality. Comparison and judicious selection of data sources by specialists in solar resource assessment is recommended when developing a project. Some of the more accessible data sources include:

- India Meteorological Department data from 23 field stations of the radiation network, measured from 1986 to 2000.
- SolMap project, data measured at approximately 115 Solar Measuring Stations over India.[a]
- NASA's Surface Meteorology and Solar Energy data set. Due to large deviation from other databases, and course spatial resolution, it is not advised to apply this database for solar energy projects in India. The data can provide some indication about the inter-annual variability.
- The METEONORM global climatological database and synthetic weather generator. This database has limitations in regions with sparse availability of historical ground Solar Measuring Stations, such as India.
- Satellite-derived geospatial solar data products from the United States-based National Renewable Energy Laboratory (NREL). Annual average DNI and GHI, latitude tilt, and diffuse data are available at 40km resolution for South and East Asia and at 10km resolution for India.
- Commercial databases. SolarGIS has historical coverage of 15+ years at 3km spatial resolution and 30 minute time resolution. The database is updated daily and has been validated over India.[b]

In order to support financing, the developer of the 5 MW plant in Tamil Nadu had a basic solar resource assessment carried out. However, only one data source was used and there was no assessment made of the inter-annual variability of the resource. Nor was any analysis provided of the historical period on which the data were based. The location of the 5 MW plant in Tamil Nadu was more than 200km from the nearest meteorological station. Data interpolated from these distant meteorological stations had a high degree of uncertainty.

The image below compares the data obtained for the site location from three data sources. There is a significant discrepancy between them. A robust solar resource assessment would compare the data sources, discuss their uncertainty and select the data most likely to represent the long-term resource at the site location. An improved resource assessment could be carried out by purchasing commercially available satellite-derived data for the site location.

Where there is significant uncertainty in the data sources (or in the case of large-capacity plants), a short-term data monitoring campaign may be considered. Short-term monitoring (ideally up to one year in duration) may be used to calibrate long-term satellite-derived data and increase the confidence in the long-term energy yield prediction.



a Responsible organisation being the Centre for Wind Energy Technology (CWET), Chennai, Tamil Nadu, India.

b SolarGIS is available for many countries globally and in some independent studies has been ranked as the most accurate database.

Solar Resource Assessment Checklist

The checklist below provides the basic requirements for any solar resource assessment. It is intended to assist solar PV plant developers during the development phase of a PV project, and to ensure that suitable analysis has been completed to facilitate financing.

- [ ] A variety of solar resource datasets consulted with at least ten years of data.
- [ ] Satellite-derived data or data interpolated from ground-based measurements has been appropriately used.
- [ ] Site adaption (calibration) of satellite data has been used, where appropriate, to reduce the uncertainty in locations remote from a meteorological station.
- [ ] Algorithms have been used to convert global horizontal irradiation to irradiation on the tilted plane of the modules.
- [ ] A robust uncertainty analysis has been completed.

Energy Yield Prediction

5

To accurately estimate the energy produced from a PV power plant, information is needed on the solar resource and temperature conditions of the site in addition to the layout and technical specifications of the plant components.

5.1 ENERGY YIELD PREDICTION OVERVIEW

An important step in assessing project feasibility and attracting financing is to calculate the electrical energy expected from the PV power plant. The energy yield prediction provides the basis for calculating project revenue. The aim is to predict the average annual energy output for the lifetime of the proposed power plant, typically 25 to 30 years.

The accuracy needed for the energy yield prediction depends on the stage of project development. For example, a preliminary indication of the energy yield can be carried out using solar resource data and an assumed performance ratio (PR) from nominal values seen in existing projects. For a more accurate energy yield prediction, software should be used with detailed plant specifications as input, three-dimensional modelling of the layout and detailed calculation of shading losses with time-step simulation.

To accurately estimate the energy produced from a PV power plant, information is needed on the solar resource and temperature conditions of the site in addition to the layout and technical specifications of the plant components. Sophisticated software is often used to model the complex interplay of temperature, irradiance, shading and wind-induced cooling on the modules. While a number of software packages can predict the energy yield of a PV power plant at a basic level, financiers generally require an energy yield prediction carried out by a suitable technical expert.

Typically, the procedure for predicting the energy yield of a PV plant using time-step (hourly or sub-hourly) simulation software will consist of the following steps:

1. Sourcing modelled or measured environmental data, such as irradiance, wind speed and temperature from ground based meteorological stations or satellite sources (or a combination of both). This results in a time series of “typical” irradiation

on a horizontal plane at the site location along with typical environmental conditions.

2. Calculating the irradiation incident on the tilted collector plane for a given time step.
3. Modelling the performance of the plant with respect to varying irradiance and temperature to calculate the energy yield prediction in each time step.
4. Applying losses using detailed knowledge of the inverters, PV modules and transformers characteristics, the site layout and module configuration, DC and AC wiring, downtime, auxiliary equipment and soiling characteristics.
5. Applying statistical analysis of resource data and assessing the uncertainty in input values to derive appropriate levels of uncertainty in the final energy yield prediction.

A checklist covering the basic requirements of energy yield assessments has been included at the end of this chapter.

The following sections summarise the main steps required for calculating the electrical energy expected from a solar PV plant.

5.2 IRRADIATION ON MODULE PLANE

In order to predict the solar resource over the lifetime of a project, it is necessary to analyse historical data for the site. These data are typically given for a horizontal plane. The assumption is that the future solar resource will follow the same patterns as the historical values. Historical data may be obtained from land-based measurements or from data obtained from satellites as described in Section 4.3. Data in hourly or sub-hourly time steps are preferred. Statistical techniques can be used to convert average monthly values into simulated hourly values if these are not immediately available.

5.3 PERFORMANCE MODELLING

Sophisticated simulation software is used to predict the performance of a PV power plant in time steps for a set of conditions encountered in a typical year. This allows a detailed simulation of the efficiency with which the plant converts solar irradiance into AC power and the losses associated with the conversion. While some of these losses may be calculated within the simulation software, others are based on extrapolations of data from similar PV plants and analysis of the site conditions.

There are several solar PV modelling software packages available on the market, which are useful analytical tools for different phases of a project's life. These packages include PVSyst, PV*SOL, RETScreen, HOMER, INSEL, Archelios and Polysun, among others. For bank-grade energy yield assessments, PVSyst has become one of the most widely used in Europe and other parts of the world due to its flexibility and ability to accurately model utility-scale PV plants.

Depending on specific site characteristics and plant design, energy yield losses may be caused by any of the factors described in Table 6. Energy yield prediction reports should consider and (ideally) quantify each of these losses.

5.4 ENERGY YIELD PREDICTION RESULTS

The predicted annual energy yield may be expressed within a given confidence interval. A P90 value is the annual energy yield prediction that will be exceeded with 90 percent probability; P75 is the yield prediction that will be exceeded with 75 percent probability; and P50 is the yield prediction that will be exceeded with 50 percent probability. Good quality "bank grade" energy yield reports will give the P50 and P90 energy yield prediction values as a minimum.

Projects typically have a financing structure that requires them to service debt once or twice a year. The year-on-year uncertainty in the resource is therefore taken into account by expressing a "one year P90." A "ten year P90" includes the uncertainty in the resource as it varies over a ten-year period. The exact requirement will depend on the financial structure of the specific plant and the requirements of the financing institution.

Table 6: Losses in a PV Power Plant	
Loss	**Description**
Air pollution	The solar resource can be reduced significantly in some locations due to air pollution from industry and agriculture. Air pollution reduces solar irradiance incident on the module and thereby reduces power output. This is more significant in urban and peri-urban locations, particularly in more recently industrialised nations.
Soiling	Losses due to soiling (dust and bird droppings) depend on the environmental conditions, rainfall frequency, and cleaning strategy as defined in the O&M contract. This loss can be relatively large compared to other loss factors. It has the potential to reach up to 15 percent[a] annually and potentially higher in deserts, but is usually less than 4 percent unless there is unusually high soiling or problems from snow settling on the modules for long periods of time. The soiling loss may be expected to be lower for modules at a high tilt angle as inclined modules will benefit more from the natural cleaning effect of rainwater. Tracking systems typically record similar soiling losses as fixed systems. As this loss can have an important impact on the PR, it is recommended that an expert is consulted to quantify the soiling loss.
Shading	Shading losses occur due to mountains or buildings on the far horizon, mutual shading between rows of modules and near shading due to trees, buildings, pylons or overhead cabling. To model near-shading losses accurately, it is recommended that a 3D representation of the plant and shading obstacles are generated within the modelling software. This loss can potentially be quite large, thus it is important that the plant is modelled accurately.
Electrical shading	The effect of partial shadings on electrical production of the PV plant is non-linear and is modelled through partitioning of the strings of modules. Modules installed in landscape configuration for an orientation towards the equator will typically experience less electrical shading losses than modules installed in portrait configuration due to the connection of diodes. Similarly, some types of thin-film technology are less impacted than crystalline PV modules. Electrical shading effects can typically be set within the modelling software. This will be quantified differently depending on module configuration, chosen technology and the system type (i.e., tracking or fixed).
Incident angle	The incidence angle loss accounts for radiation reflected from the front glass when the light striking it is not perpendicular. For tilted PV modules, these losses may be expected to be larger than the losses experienced with dual axis tracking systems, for example.
Low irradiance	The conversion efficiency of a PV module generally reduces at low light intensities. This causes a loss in the output of a module compared with the Standard Test Conditions (STC) (1,000W/m2). This "low irradiance loss" depends on the characteristics of the module and the intensity of the incident radiation. Most module manufacturers will be able to provide information on their module low irradiance losses. However, where possible, it is preferable to obtain such data from independent testing institutes.
Module temperature	The characteristics of a PV module are determined at standard temperature conditions of 25°C. For every degree rise in Celsius temperature above this standard, crystalline silicon modules reduce in efficiency, generally by around 0.5 percent. In high ambient temperatures under strong irradiance, module temperatures can rise appreciably. Wind can provide some cooling effect, which can also be modelled.
Module quality	Most PV modules do not exactly match the manufacturer's nominal specifications. Modules are sold with a nominal peak power and a guarantee of actual power within a given tolerance range. The module quality loss quantifies the impact on the energy yield due to divergences in actual module characteristics from the specifications. Typically, the module output power at STC is greater than the nominal power specified in the datasheets. As such, a positive quality factor can be applied to the energy yield.
Module mismatch	Losses due to "mismatch" are related to the fact that the real modules in a string do not all rigorously present the same current/voltage profiles; there is a statistical variation between them which gives rise to a power loss. This loss is directly related to the modules' power tolerance.
Degradation	The performance of a PV module decreases with time (see Section 3.3.5). If no independent testing has been conducted on the modules being used, then a generic degradation rate depending on the module technology may be assumed. Alternatively, a maximum degradation rate that conforms to the module performance warranty may be considered as a conservative estimate.
Inverter performance	Inverters convert current from DC into AC with an efficiency that varies with inverter load. Manufacturers are usually able to provide an inverter's efficiency profile for low, medium and high voltages; entering these into the modelling software will provide more accurate inverter losses.
MPP tracking	The inverters are constantly seeking the maximum power point (MPP) of the array by shifting inverter voltage to the MPP voltage. Different inverters do this with varying efficiency.

(Continued)

a S. Canada, "Impacts of Soiling on Utility-Scale PV System Performance," Issue 6.3, Apr/May 2013, http://solarprofessional.com/articles/operations-maintenance/impacts-of-soiling-on-utility-scale-pv-system-performance (accessed April 2014).

Table 6: Losses in a PV Power Plant *(Continued)*	
Loss	**Description**
Curtailment of tracking	Yield losses can occur due to high winds enforcing the stow mode of tracking systems so that the PV modules are not optimally orientated.
Transformer performance	Transformer losses are usually quantified in terms of iron and resistive/inductive losses, which can be calculated based on the transformer's no-load and full-load losses.
DC cable losses	Electrical resistance in the cable between the modules and the input terminals of the inverter give rise to ohmic losses (I^2R).[b] These losses increase with temperature. If the cable is correctly sized, this loss should be less than 3 percent annually.
AC cable losses	AC cable losses are the ohmic losses in the AC cabling. This includes all cables post inverter up to the metering point. These losses are typically smaller than DC cable losses and are usually smaller for systems that use central inverters.
Auxiliary power	Power may be required for electrical equipment within the plant. This may include security systems, tracking motors, monitoring equipment and lighting. Plants with string inverter configurations will typically experience smaller auxiliary losses than central inverter configurations. It is usually recommended to meter this auxiliary power requirement separately. Furthermore, care should be taken as to how to quantify both daytime and nighttime auxiliary losses.
Downtime	Downtime is a period when the plant does not generate due to failure. The downtime periods will depend on the quality of the plant components, design, environmental conditions, diagnostic response time, and repair response time.
Grid availability and disruption	The ability of a PV power plant to export power is dependent on the availability of the distribution or transmission network. The owner of the PV plant relies on the distribution network operator to maintain service at high levels of availability. Unless detailed information is available, this loss is typically based on an assumption that the local grid will not be operational for a given number of hours/days in any one year, and that it will occur during periods of average production.
Grid compliance loss	Excessive loading of local transmission or distribution network equipment such as overhead lines or power transformers may lead to grid instability. In this case, the voltage and frequency of the grid may fall outside the operational limits of the inverters and plant downtime may result. In less developed regional networks, the risk of downtime caused by grid instability can have serious impacts on project economics.

b Ohmic Loss is the voltage drop across the cell during passage of current due to the internal resistance of the cell.

5.5 UNCERTAINTY IN THE ENERGY YIELD PREDICTION

The uncertainty of energy yield simulation software depends on each modelling stage and on the uncertainty in the input variables. Modelling software itself can introduce uncertainty of 2 percent to 3 percent.

The uncertainty in the daily aggregated values of irradiation measured by ground based pyranometers (depending on the accuracy class) is in the range of ± 2 percent to ± 8 percent. This represents the upper limit in accuracy of resource data obtained through meteorological stations. However, in many cases, the presence of a ground-based pyranometer at the project location during preceding years is unlikely. If this is the case, solar resource data will likely have been obtained using satellites or by interpolation as described in Section 4.3. This will increase the uncertainty in the resource data, depending on the quality of the data used. In general, resource data uncertainty in the region of 5 percent to 8 percent or higher may be expected, depending on the region.

Uncertainty in other modelling inputs include estimates in downtime, estimates in soiling, uncertainty in the inter-annual variation in solar resource and errors due to module specifications not accurately defining the actual module characteristics.

The energy yield depends linearly, to a first approximation, on plane of array irradiance. Therefore, uncertainty in the resource data has a strong bearing on the uncertainty in the yield prediction. Total uncertainty figures in the region of 8 percent to 10 percent may be expected, depending on the region. A good energy yield report will quantify the uncertainty for the specific site location.

Figure 15: Uncertainty in Energy Yield Prediction

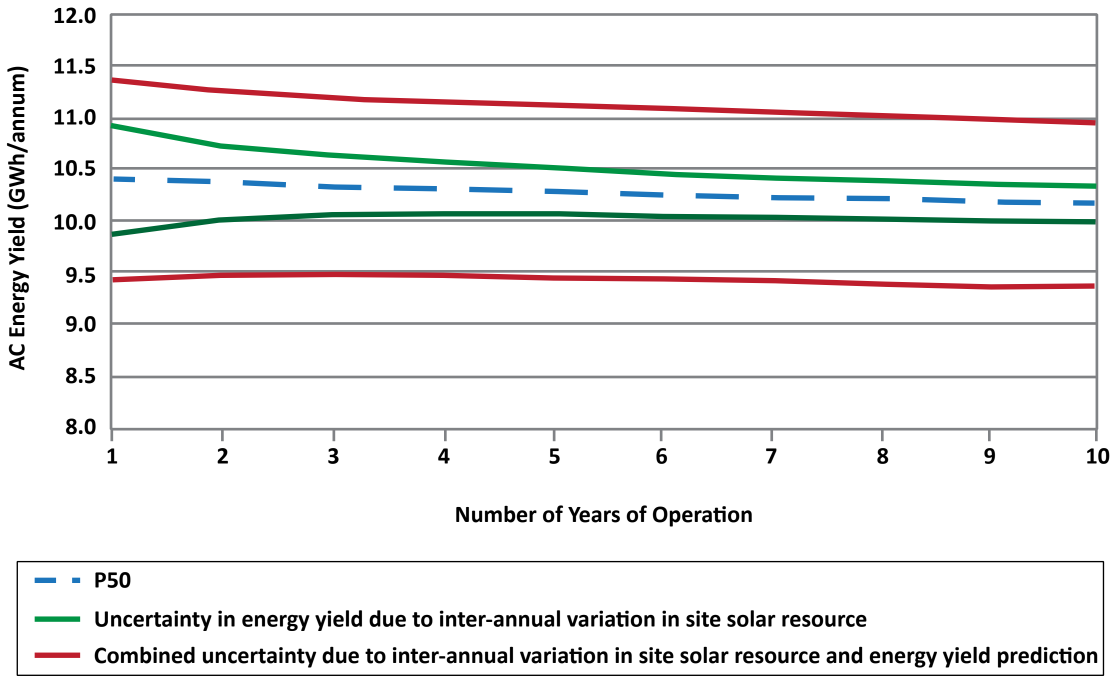


Figure 15 represents the typical combined uncertainties in the yield prediction for a PV power plant. The dashed blue line shows the predicted P50 yield. The green lines represent uncertainty in energy yield due to inter-annual variability in solar resource. The solid red lines represent the total uncertainty in energy yield when inter-annual variability is combined with the uncertainty in the yield prediction. The total uncertainty decreases over the lifetime of the PV plant. The lower limit on the graph corresponds to the P90 and the upper limit corresponds to the P10.

Box 3: Energy Yield Prediction Case Study in India

The developer of a 5MW plant in Tamil Nadu, India, required a solar energy yield prediction to confirm project feasibility and assess likely revenues. In this instance, the developer was either not aware of or did not consider a number of additional losses and did not calculate a long-term yield prediction over the life of the project with uncertainty analysis. Both of these would have been essential for potential project financiers.

The developer sourced global horizontal irradiation data for the site location. Commercially available software was used to simulate the complex interactions of temperature and irradiance impacting the energy yield. This software took the plant specifications as input and modelled the output in hourly time steps for a typical year. Losses and gains were calculated within the software. These included:

- Gain due to tilting the module at 10°.
- AC losses. Reflection losses (3.3 percent).
- Losses due to a lower module efficiency at low irradiance levels (4.2 percent).
- Losses due to temperatures above 25°C (6 percent).
- Soiling losses (1.1 percent).
- Losses due to modules deviating from their nominal power (3.3 percent).
- Mismatch losses (2.2 percent).
- DC Ohmic losses (1.8 percent).
- Inverter losses (3.6 percent).

The software gave an annual sum of electrical energy expected at the inverter output in the first year of operation. Although this is a useful indicative figure, an improved energy yield prediction would also consider:

- Inter-row shading losses (by setting up a 3D model).
- Horizon shading, if any.
- Near shading from nearby obstructions, including poles, control rooms and switch yard equipment.
- Downtime and grid availability.
- Degradation of the modules and plant components over the lifetime of the plant.

This analysis modelled energy yield for one year, however lifetime analysis is typically required. In order to clearly show the expected output during the design life of the plant and assess the confidence in the energy yield predictions, it is necessary to analyse the level of certainty in the data and processes used for this analysis, including:

- Level of accuracy of solar resource data used.
- Reliability/accuracy of modelling process.
- Inter-annual variation of the solar resource.

The energy yield prediction for the 5MW plant was provided as a first-year P50 value (the yield that will be exceeded with 50 percent probability in the first year), excluding degradation. An investor will usually look for a higher level of confidence in the energy yield prediction, typically expressed as the P90 value, or the annual energy yield prediction that will be exceeded with 90 percent probability.

Energy Yield Assessment Checklist

The following checklist covers the basic requirements and procedures for energy yield assessments. It is intended to assist solar PV power plant developers during the development phase of a PV project.

- ☐ A variety of judiciously-selected solar resource datasets consulted.
- ☐ Hourly generation profile obtained or synthetically generated.
- ☐ Plant design basic information detailed (plant capacity, tilt and shading angles, orientation, number of modules per string, total number of modules and inverters).
- ☐ Module, inverter and transformer datasheets available.
- ☐ 3D shading model generated using modelling software.
- ☐ Horizon and near-shading obstacles detailed and implemented in 3D model.
- ☐ DC and AC cable losses calculated.
- ☐ Soiling losses assessed based on precipitation profile, environmental conditions and cleaning schedule.
- ☐ Auxiliary losses broken down and assessed.
- ☐ Availability losses based on grid and plant availability assessed.
- ☐ Essential module characteristics available (degradation, low light performance, tolerance, temperature coefficient).
- ☐ Essential inverter characteristics available (including Maximum Power Point Tracking capability, efficiency profile for three voltages).
- ☐ Overall energy yield loss calculated.
- ☐ P50 calculated monthly and for project duration.
- ☐ PR calculated monthly and for project duration.
- ☐ Specific yield calculated for year 1 of operation.
- ☐ Inter-annual variation obtained.
- ☐ Solar resource measurement uncertainty obtained.
- ☐ Overall uncertainty assessed.
- ☐ P90 calculated for years 1, 10 and 20.

6 Site Selection

6.1 SITE SELECTION OVERVIEW

In general, the process of site selection must consider the constraints of each site and the impact it will have on the cost of the electricity generated. "Showstoppers" for developing a utility-scale PV power plant in a specific location may include constraints due to a low solar resource, low grid capacity or insufficient area to install modules. However, a low solar resource could be offset by high local financial incentives that make a project viable. A similar balancing act applies to the other constraints. A Geographical Information System (GIS) mapping tool can be used to assist the site selection process by assessing multiple constraints and determining the total area of suitable land available for solar PV project development.

The checklist at the end of the chapter lists the basic requirements and procedures necessary to assist developers with the site selection process.

Selecting a suitable site is a crucial component of developing a viable solar PV project.

6.2 SITE SELECTION CRITERIA

Selecting a suitable site is a crucial component of developing a viable solar PV project. There are no clear-cut rules for site selection. Viable projects have been developed in locations that may initially seem unlikely, such as steep mountain slopes, within wind farms and on waste disposal sites. In general, the process of site selection must consider the constraints and the impact the site will have on the cost of the electricity generated. The main constraints that need to be assessed include:

- Solar resource.
- Available area.
- Local climate.
- Topography.
- Land use.
- Local regulations/land use policy or zoning.

- Environmental designations.
- Geotechnical conditions.
- Geopolitical risks.
- Accessibility.
- Grid connection.
- Module soiling.
- Water availability.
- Financial incentives.

It can be useful to use GIS mapping tools to aid in the process of site selection to visually display constraints, enable consideration of multiple constraints to a particular site, and determine the total land area available for development.

As mentioned before, "showstoppers" for developing a utility-scale PV power plant in a specific location may include constraints due to a low solar resource, low grid capacity or insufficient area to install modules. However, constraints can sometimes be offset; for example, high local financial incentives can offset a low solar resource and make a project viable. Similar considerations apply to other constraints, which are discussed in further detail below.

6.3 SITE SELECTION CONSTRAINTS

6.3.1 *SOLAR RESOURCE*

A high average annual GTI is the most basic consideration for developing a solar PV project. The higher the resource, the greater the energy yield per kWp installed. When assessing the GTI at a site, care must be taken to minimise any shading that will reduce the irradiation received. Shading could be due to mountains or buildings on the far horizon, mutual shading between rows of modules, or shading near the location due to trees, buildings or overhead cabling. Particular care should be taken to consider any shading that could occur due to future construction projects or by growth of vegetation.

Avoiding shading is critical, as even small areas of shade may significantly impair the output of a module or string of modules. The loss in output could be more than predicted by simply assessing the proportion of the modules that are shaded.

When assessing shading, it must be remembered that the path the sun takes through the sky changes with the seasons. An obstacle that provides significant shading at mid-day in December may not provide any shading at all at mid-day in June. The shading should be assessed using the full sun path diagram for the location.

6.3.2 *AREA*

The area required per kWp of installed capacity varies with the technology chosen. The distance between rows of modules (the pitch) required to avoid significant inter-row shading varies with the site latitude. Sites should be chosen with sufficient area to allow the required capacity to be installed without having to reduce the pitch to levels that cause unacceptable yield loss.

For example, depending on the site location (latitude) and the type of PV module selected (efficiency), a well-designed PV power plant with a capacity of 1MWp developed in India is estimated to require between one and two hectares (10,000 to 20,000 m^2) of land. A plant using lower efficiency CdTe thin-film modules may require approximately 40 percent to 50 percent more space than a plant using multi-crystalline modules. Table 7 lists the approximate area required for plants in five different countries.

6.3.3 *CLIMATE*

In addition to a good solar resource, the climate should not suffer from extremes of weather that will increase the risk of damage or downtime. Weather events that may need consideration include:

- **Flooding:** May cause damage to electrical equipment mounted on or close to ground level. Also increased risk of erosion of the support structure and foundations, depending on geotechnical conditions.

Table 7: Area Required for Megawatt-scale Solar Power Plant		
Country	Technology	Approximate Area (ha/MWp)[a]
South Africa	c-Si	0.9 – 1.4
	CdTe	1.5 – 2.0
Chile	c-Si	1.0 – 1.5
	CdTe	1.7 – 2.2
Thailand	c-Si	0.8 – 1.2
	CdTe	1.3 – 1.8
India	c-Si	1.0 – 1.5
	CdTe	1.6 – 2.0
Indonesia	c-Si	0.8 – 1.2
	CdTe	1.3 – 1.8

a Exact area will vary according to the tilt angles and pitch.

- **High wind speeds:** The risk of a high wind event exceeding the plant specifications should be assessed. Locations with a high risk of damaging wind speeds should be avoided. Fixed systems do not shut down at high wind speeds, but tracking systems must shut down when high wind speeds are experienced.
- **Snow:** Snow settling on modules can significantly reduce annual energy yield if mitigating measures are not incorporated. If the site is prone to snow, then one has to consider factors such as the extra burden on the mounting structures, the loss in energy production, and the additional cost of higher specification modules or support structures. The cost of removing the snow needs to be weighed against the loss in production and the likelihood of further snowfall. The effects of snow can be mitigated by a design with a high tilt angle and frameless modules. The design should also ensure that the bottom edge of the module is fixed higher than the average snow level for the area. Most importantly, a site that that has regular coverings of snow for a long period of time may not be suitable for developing a solar PV power plant.
- **Temperature:** The efficiency of a PV power plant reduces with increasing temperature. If a high temperature site is being considered, mitigating measures should be included in the design and technology selection. For instance, it would be better to choose modules with a low temperature coefficient for power.
- **Air pollutants:** The location of the site in relation to local air pollution sources must be considered. Local industrial atmospheric pollution may reduce the irradiation received or contain significant levels of airborne sulphur or other potentially corrosive substances. Similarly, the distance to the sea (coastline) should be considered as this may lead to elevated levels of salts in the atmosphere. All these conditions could lead to accelerated corrosion of unprotected components. PV modules to be used in highly corrosive atmospheres such as coastal areas must be certified for salt mist corrosion as per standard IEC 61701. Further information on the impact of air pollution can be found in Section 5.3.

6.3.4 TOPOGRAPHY

Ideally, the site should be flat or on a slight south-facing slope in the northern hemisphere or north-facing slope in the southern hemisphere. Such topography makes installation simpler and reduces the cost of technical modifications required to adjust for undulations in the ground. With additional cost and complexity of installation, mounting structures can be designed for most locations. In general, the cost of land must be weighed against the cost of designing a mounting structure and installation time.

6.3.5 LAND USE

Solar PV power plants will ideally be built on low value land. If the land is not already owned by the developer, then the cost of purchase or lease needs to be considered. The developer must purchase the land or use rights for the duration of the project. Section 8 (Permits and Licensing) provides further details. Besides access to the site, provision of water, electricity supplies and the rights to upgrade access roads must be considered along with relevant land taxes.

Since government permission will be required to build a solar power plant, it is necessary to assess the site in line with the local conditions imposed by the relevant regulatory bodies. See Section 12 for further information on regulations.

If the land is currently used for agricultural purposes, then it may need to be re-classified for "industrial use," with cost and time implications. The best locations for solar plants are usually previously developed lands or brownfield sites because they often have existing energy use nearby. Use of high-quality agricultural land should be avoided if possible. In some instances, due to the spacing between modules and their elevation, some agricultural activity such as sheep grazing can remain.

The future land use of the area must also be taken into account. It is likely that the plant will be in operation for at least 25 years. Furthermore, external factors also need to be considered to assess the likelihood of their impact on energy yield. For example, the dust associated with building projects or vehicular traffic could have significant soiling effect and associated impact on the energy yield of the plant. Any trees on the project site and surrounding land may need to be removed, with cost implications.

Clearances from the military may be required if the site is in or near a military-sensitive area. Glare from solar modules can affect some military activities.

6.3.6 LOCAL REGULATIONS / LAND USE POLICY

Any planning restrictions for the area of the development should be taken into consideration. These will differ from country to country, but may include land use zoning regulations or constraints to a particular type of development. These issues are discussed further in Section 8 (Permits and Licensing).

It is advisable to contact the relevant government department in the first instance to ascertain any specific restrictions on the area in question.

6.3.7 ENVIRONMENTAL & SOCIAL CONSIDERATIONS

Most regulatory regimes require some sort of Environmental Impact Assessment (EIA) or Environmental and Social Impact Assessment (ESIA), or an environmental scoping document which screens for any significant issues so that a decision can be made by the relevant authorities as to whether a full-blown assessment is required. However, there may be some countries where no such regulatory requirements exist. In either case, the siting process should consider the following key environmental and social criteria:

- **Biodiversity:** Avoiding sensitive or critical habitats and species is crucial. Construction and operation of solar PV power plant sites and ancillary infrastructure (access roads, transmission lines) leads to clearing of existing habitats and disturbance to fauna and flora. Facilities, including ancillary infrastructure, should be sited away from ecologically sensitive areas, e.g., protected areas and those with high biodiversity value such as wetlands, undisturbed natural forests and important wildlife corridors. Ideally, solar PV power plants should be built on sites that are either open or barren (e.g., desert or semi-desert locations) or that have previously been disturbed, e.g., farmland, industrial land, abandoned land or existing transportation and transmission corridors. Impacts on designated conservation or biodiversity protection sites should be avoided wherever possible, in particular those with national or international significance.
- **Land acquisition:** Avoiding or minimizing involuntary resettlement is a key concern. Installation of solar PV plants results in long-term land acquisition and conversion. If involuntary resettlement (i.e., physical or economic displacement of households) is necessary, this may complicate and slow project development and give rise to possible project delays later in the development cycle, particularly where land tenure and ownership laws are tenuous and/or customary land tenure exists. Sites that would require physical displacement (relocation of residences) should be avoided wherever

possible; site selection should furthermore aim to avoid or minimize economic displacement (e.g. loss of croplands, businesses or other livelihood sources).

- **Other social impacts:** Avoiding cultural heritage, visual impacts and indigenous peoples (IPs) is another critical concern. Besides involuntary resettlement, solar PV projects and their ancillary infrastructure may adversely impact cultural heritage or IPs, may result in visual impacts to nearby communities and may require establishment of worker accommodation camps involving an influx of outsiders into a local community, with attendant social risks. Sites should be selected in such as manner as to avoid close proximity to settled areas, to avoid cultural heritage (e.g., graves, sacred sites) and to avoid or minimize adverse impacts on IPs' lands or properties.

6.3.8 GEOTECHNICAL

A geotechnical survey of the site is recommended prior to final selection. Its purpose is to assess the ground conditions in order to inform the foundation design approach and right of way (ROW) to ensure that the mounting structures will have adequately designed foundations. The level of detail required in the geotechnical survey will depend on the proposed foundation design.

Best practice dictates that either boreholes or trial pits are made at regular intervals, along with soil sampling and in-situ testing, at a depth appropriate for the foundation design. This is usually around 2.5m to 3m below ground level. The boreholes or trial pits would typically assess:

- The groundwater level.
- The resistivity of the soil.
- The load-bearing properties of the soil.
- The presence of rocks or other obstructions.
- Suitability of chosen foundation types and drivability of piled foundations.
- The soil pH and chemical constituents in order to assess the degree of corrosion protection required and the adequate specification of cement properties to be used in foundation concrete.
- The degree of any ground contaminants present which may require special consideration during detailed design or special measures to be undertaken during construction.

Depending on the actual site location, the geotechnical study may also be expected to include an assessment of the risk of seismic activity, land slip, ground subsidence, historical mining or mineral extraction activity and the susceptibility of the soil to frost or clay heave, erosion and flooding.

6.3.9 GRID CONNECTION

A grid connection of sufficient capacity is required to enable the export of power. The viability of the grid connection will depend on factors such as capacity, proximity, ROW, grid stability and grid availability. These factors should be considered at an early stage of the project development process. If the grid connection study is neglected, unforeseen grid connection costs could seriously impact the viability of the project.

- **Proximity:** A major influence on the cost of connecting to the grid will be the distance from the site to the grid connection point. In order to ensure the grid connection does not adversely affect project economics, it is necessary to carry out a feasibility study to assess power evacuation and transmission line routes at the planning stage of the project.
- **Availability:** The grid availability is the percentage of time that the network is able to accept power from the solar PV plant. The annual energy yield from a plant may be significantly reduced if the grid has significant downtime. This may have adverse effects on the economics of the project. In developed areas, the availability of the grid is usually very high. In less developed and rural areas, networks may suffer from

much more significant downtime. Availability statistics should be requested from the network operator to establish the expected downtime of the network.

- **Capacity:** The capacity of the grid to accept exported power from a solar plant will depend on the existing network infrastructure and current loading of the system. The substation and export line capacity needs to be appropriate for the capacity of the plant being developed. Where the grid network does not have sufficient existing capacity to allow connection, there are a number of solutions available:
  - Curtail the maximum power exported to within allowable limits of the network.
  - Upgrade the network to allow an increased export capacity.
  - Reduce the capacity of the proposed plant.

Initial investigation into the network connection point capacity can often be carried out by reviewing published data. However, discussions with the network operator will be required to fully establish the scope of work associated with any capacity upgrades. The network operator will provide details of the work required, along with cost implications. Certain aspects of a grid network upgrade can be carried out by third party contractors. Others must be conducted by the network operator alone. An early grid feasibility study is the starting point for assessing the suitability of the power evacuation arrangement. Power system studies can also be conducted to model the likely grid capacity.

6.3.10 ACCESS AND RIGHT OF WAY (ROW)

The site should allow access for trucks to deliver plant and construction materials. This may require the upgrading of existing roads or construction of new roads. The closer the site is to a main access road, the lower the cost of adding this infrastructure. At a minimum, access roads should be constructed with a closed-surface gravel chip finish or similar. The site entrance may also need to be constructed, widened or upgraded. Safe packaging of the modules and their susceptibility to damage in transport must also be carefully considered.

ROW is the agreement that allows the project developer's transmission lines to cross property owned by another individual or entity. In order to avoid ROW risks, which may impact on the project schedule, all land permits and agreements need to be planned well in advance (see Box 4 in Chapter 7, "Grid Connection Experience in India").

6.3.11 MODULE SOILING

The efficiency of the solar plant could be significantly reduced if the modules are soiled (covered) by particulates/dust. It is important to take account of local weather, environmental, human and wildlife factors while determining the suitability of a site for a solar PV plant. The criteria should include:

- Dust particles from traffic, building activity, agricultural activity or dust storms.
- Module soiling from bird excreta. Areas close to nature reserves, bird breeding areas and lakes should be particularly carefully assessed.

Soiling of modules will require an appropriate maintenance and cleaning plan and potentially keeping equipment at or close to the site.

6.3.12 WATER AVAILABILITY

Clean, low mineral content water is preferred for cleaning modules. A main water supply, ground water, stored water or access to a mobile water tank may be required; the cost of the various options will have an impact on the project economics. The degree to which water availability is an issue will depend upon the expected level of module soiling, the extent of natural cleaning due to rainfall and the cleaning frequency. The quantity of water required varies according to available cleaning technologies and the local climate, however approximately 1.6 litres per m^2 of PV modules may be required. In arid environments with adjacent communities, attention needs to be paid to existing groundwater reliance by local populations and the impact (if any) of proposed groundwater extraction on local water sources. This is especially important where there are multiple solar developments in close proximity, i.e., where there may be cumulative impacts on water availability that could adversely impact local populations.

6.3.13 FINANCIAL INCENTIVES

Financial incentives such as FiTs or tax breaks, which vary by country and sometime regions within countries, have a strong bearing on the financial viability of a project (see also Section 14 on Financing Solar PV Projects). Such incentives could outweigh the costs associated with one or more of the site selection constraints.

In countries where there are significant incentives (i.e., high FiTs) that override otherwise very unfavourable economic conditions, developers should be cautious and consider the sustainability of those incentives. The potential impacts on the project should be considered should these incentives be withdrawn at any stage. It should be noted that incentives are not site-specific, but are typically dependant on the country or state in which the project is located.

Site Selection Checklist

The checklist below details the basic requirements and procedures to assist developers with the site selection process.

- ☐ Suitable land area identified for the scale of development proposed.
- ☐ Ownership of land determined.
- ☐ Current land use identified (e.g., industrial/agricultural/brownfield).
- ☐ Advice sought from regulatory authorities on land use restrictions.
- ☐ Solar resource assessed.
- ☐ Topographic characteristics obtained.
- ☐ Proximity to international, national and local environmental designations determined.
- ☐ Potential access routes to site assessed.
- ☐ Geotechnical survey completed.
- ☐ Grid connection assessed (capacity, proximity, right-of-way, stability and availability).
- ☐ Soiling risks assessed.
- ☐ Availability of water supply/ground water determined.
- ☐ GIS assessment of constraints (optional).
- ☐ Financial incentives identified.

7 Plant Design

7.1 PLANT DESIGN OVERVIEW

Designing a megawatt-scale solar PV power plant is an involved process that requires considerable technical knowledge and experience. There are many compromises that need to be made in order to achieve the optimum balance between performance and cost. This section highlights some of the key issues that need to be considered when designing a solar PV power plant.

For most large solar PV plants, reducing the levelised cost of electricity (LCOE) is the most important design criteria. Every aspect of the electrical system (and of the project as a whole) should be scrutinised and optimised. The potential economic gains from such an analysis are much larger than the cost of carrying it out.

It is important to strike a balance between cost savings and quality. Engineering decisions should be "careful" and "informed" decisions. Otherwise, design made with a view to reduce costs in the present could lead to increased future costs and lost revenue due to high maintenance requirements and low performance.

The performance of a solar PV power plant can be optimised by reducing the system losses. Reducing the total loss increases the annual energy yield and hence the revenue, though in some cases it may increase the cost of the plant. In addition, efforts to reduce one type of loss may conflict with efforts to reduce losses of a different type. It is the skill of the plant designer to make compromises that result in a plant with a high performance at a reasonable cost.

For plant design, there are some general rules of thumb. But specifics of project locations—such as irradiation conditions, temperature, sun angles and shading—should be taken into account in order to achieve the optimum balance between annual energy yield and cost.

Checklists of basic requirements and procedures for plant design considerations to assist solar PV plant developers during

For plant design, there are some general rules of thumb. But specifics of project locations—such as irradiation conditions, temperature, sun angles and shading—should be taken into account in order to achieve the optimum balance between annual energy yield and cost.

the development phase of a PV project are at the end of Chapter 7.

It may be beneficial to use simulation software to compare the impact of different module or inverter technologies and different plant layouts on the predicted energy yield and plant revenue.

The solar PV modules are typically the most valuable and portable components of a PV power plant. Safety precautions may include anti-theft bolts, anti-theft synthetic resins, CCTV cameras with alarms, and security fencing.

The risk of technical performance issues may be mitigated by carrying out a thorough technical due diligence exercise in which the final design documentation from the EPC contractor is scrutinised by an independent technical advisor.

7.2 LAYOUT AND SHADING

The general layout of the plant and the distance chosen between rows of mounting structures will be selected according to the specific site conditions. The area available to develop the plant may be constrained by space and may have unfavourable geological or topographical features. The aim of the layout design is to minimise cost while achieving the maximum possible revenue from the plant. In general this will mean:

- Designing row spacing to reduce inter-row shading and associated shading losses.
- Designing the layout to minimise cable runs and associated electrical losses.
- Creating access routes and sufficient space between rows to allow movement for maintenance purposes.
- Choosing a tilt angle and module configuration that optimises the annual energy yield according to the latitude of the site and the annual distribution of solar resource.
- Orientating the modules to face a direction that yields the maximum annual revenue from power production. In the northern hemisphere, this will be true south.[36] In the southern hemisphere, it is true north.

Computer simulation software may be used to help design the plant layout. Such software includes algorithms which describe the celestial motion of the sun throughout the year for any location on earth, plotting its altitude[37] and azimuth[38] angle on a sun path diagram. This, along with information on the module row spacing, may be used to calculate the degree of shading and simulate the annual energy losses associated with various configurations of tilt angle, orientation, and row spacing.

7.2.1 GENERAL LAYOUT

Minimising cable runs and associated electrical losses may suggest positioning a low voltage (LV) or medium voltage (MV) station centrally within the plant. If this option is chosen, then adequate space should be allocated to avoid the risk of the station shading modules behind it.

The layout should allow adequate distance from the perimeter fence to prevent shading. It should also incorporate access routes for maintenance staff and vehicles at appropriate intervals.

7.2.2 TILT ANGLE

Every location will have an optimal tilt angle that maximises the total annual irradiation (averaged over the whole year) on the plane of the collector. For fixed tilt grid connected power plants, the theoretical optimum tilt angle may be calculated from the latitude of the site. However, adjustments may need to be made to account for:

- **Soiling:** Higher tilt angles have lower soiling losses. The natural flow of rainwater cleans modules more effectively and snow slides off more easily at higher tilt angles.

36 True south differs from magnetic south, and an adjustment should be made from compass readings.

37 The elevation of the sun above the horizon (the plane tangent to the Earth's surface at the point of measurement) is known as the angle of altitude.

38 The azimuth is the location of the sun in terms of north, south, east and west. Definitions may vary but 0° represents true south, -90° represents east, 180° represents north, and 90° represents west.

- **Shading:** More highly tilted modules provide more shading on modules behind them. As shading impacts energy yield much more than may be expected simply by calculating the proportion of the module shaded, a good option (other than spacing the rows more widely apart) is to reduce the tilt angle. It is usually better to use a lower tilt angle as a trade-off for loss in energy yield due to inter-row shading.
- **Seasonal irradiation distribution:** If a particular season dominates the annual distribution of solar resource (monsoon rains, for example), it may be beneficial to adjust the tilt angle to compensate for the loss. Simulation software is able to assess the benefit of this option.

7.2.3 PV MODULE CONFIGURATION

The effect of partial shading of the PV modules on electrical production of the PV plant is non-linear due to the way that diodes are interconnected within a PV module and how modules are connected together in a string. Different types of technology will react differently to the electrical shading effect caused by near-shading obstacles and inter-row shading. For example, some thin-film modules are less affected by partial shading than crystalline technologies.

The modules' configuration (i.e., landscape or portrait) and the ways strings are connected together will also impact how the system experiences electrical shading effects. Modules installed in a landscape configuration will typically have smaller electrical shading losses than a system using a portrait configuration, due to the fact that diodes are usually connected along a module's length. However, a portrait configuration may be considered if east and west horizon shading is particularly prevalent.

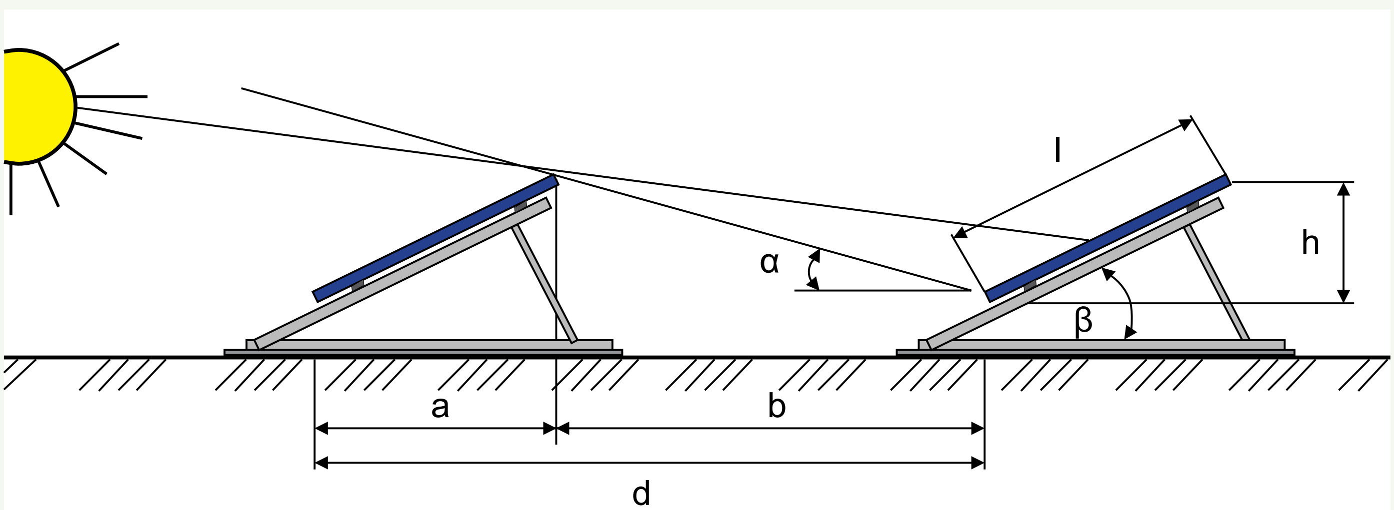
7.2.4 INTER-ROW SPACING

The choice of row spacing is made by compromising between reducing inter-row shading, keeping the area of the PV plant within reasonable limits, reducing cable runs and keeping ohmic losses within acceptable limits. Inter-row shading can never be reduced to zero: at the beginning and end of the day, the shadow lengths are extremely long. Figure 16 illustrates the angles that must be considered in the design process.

The shading limit angle[39] *a* is the solar elevation angle beyond which there is no inter-row shading on the modules. If the elevation of the sun is lower than *a*, then a

39 Also known as "critical shading angle."

Figure 16: Shading Angle Diagram



proportion of the module will be shaded, and there will be an associated loss in energy yield.

The shading limit angle may be reduced either by reducing the tilt angle *ß* or increasing the row pitch *d*. Reducing the tilt angle below the optimal is sometimes chosen because this may give only a minimal reduction in annual yield. The ground cover ratio (GCR), given by *l/d* is a measure of the PV module area compared to the area of land required.

For many locations, a design rule of thumb is to space the modules in such a way that there is no shading at solar noon on the winter solstice (December 21st in the northern hemisphere and June 21st in the southern hemisphere). In general, if there is less than a 1 percent annual loss due to shading, then the row spacing may be deemed acceptable.

Detailed energy yield simulations can be carried out to assess losses due to shading, and to obtain an economic optimisation that also takes into account the cost of land, if required.

7.2.5 ORIENTATION

In the northern hemisphere, the orientation that optimises the total annual energy yield is true south. In the tropics, the effect of deviating from true south may not be especially significant.

Some tariff structures encourage the production of energy during hours of peak demand. In such "time of day" rate structures, there may be financial (rather than energy yield) benefits of orientating an array that deviates significantly from true south. For example, an array facing in a westerly direction will be optimised to generate power in the afternoon. The effect of tilt angle and orientation on energy yield production can be effectively modelled using simulation software.

7.3 TECHNOLOGY SELECTION

7.3.1 MODULES

Certification of a module to IEC/CE/UL standards as described in Section 3.3.7 is essential. However, modules may perform differently under the varying conditions of irradiance, temperature, shading and voltage that are actually experienced in the field. This makes selecting modules a more complex process than it may first appear. Many developers employ the services of an independent technical advisor familiar with the bill of materials from which the modules are made, and the specific factory manufacturing conditions. Table 8 gives some of the selection criteria that should be considered.

7.3.1.1 Quality Benchmarks

- **Product guarantee:** A material and workmanship product guarantee of ten years has become common. Some manufacturers guarantee up to 12 years.
- **Power guarantee:** In addition to the product guarantee, manufacturers grant nominal power guarantees. These vary between manufacturers. A two-step power warranty (e.g., 90 percent until year 10 and 80 percent until year 25) has been the historical industry standard. However, good module manufacturers are now differentiating themselves by providing a power output warranty that is fixed for the first year and then reduces linearly each year by a proportion of the nominal output power. This linear warranty provides additional protection to the plant owner compared to the two-step warranty which would provide no recourse if, for example, the module degrades to 91 percent of its nominal power in the first year.

  It is rare for module manufacturers to offer a power output guarantee beyond 25 years. The conditions of both the power guarantee and product guarantee vary between manufacturers and should be carefully checked.
- **Lifetime:** Good quality modules with the appropriate IEC certification have a design life in excess of 25 years. Beyond 30 years, increased levels of degradation may be expected. The lifetime of crystalline modules has been proven in the field. Thin-film technology lifetimes are currently unproven and rely on accelerated lifetime laboratory tests, but are expected to be in the order of 25–30 years also.

Table 8: PV Module Selection Criteria	
Criterion	Description
Levelised cost of electricity (LCOE)[a]	The aim is to keep the levelised cost of electricity (LCOE) at a minimum. When choosing between high-efficiency/high-cost modules and low-efficiency/low-cost modules, the cost and availability of land and plant components will have an impact. High-efficiency modules require significantly less land, cabling and support structures per MWp installed than low-efficiency modules.
Quality	When choosing between module technologies such as mono-crystalline silicon (mono-c-Si), multi-crystalline silicon (multi-c-Si), and thin-film amorphous silicon (a-Si), it should be realised that each technology has examples of high quality and low quality products from different manufacturers.
PV module performance	Modules tested under a specific set of conditions of irradiance, temperature and voltage, with a specific inverter, may perform very differently under alternative conditions with a different inverter. Independent laboratories such as PV Evolution Labs[b] (PVEL) and TÜV Rheinland[c] can test PV modules according to a matrix of operational conditions under a wide range of environmental conditions in line with IEC 61853-1.
Power tolerance	The nominal power of a module is provided with a tolerance. Most crystalline modules are rated with a positive tolerance (typically 0/+3 percent to 0/±5 percent), while some crystalline, CdTe and CIGS modules may be given with a ±5 percent tolerance. Some manufacturers routinely provide modules at the lower end of the tolerance, while others provide modules that achieve their nominal power or above (positive tolerance). For a large plant, the impact of the module power tolerance on the overall energy yield can have a significant effect.
Flash tests	When ordering a large number of modules, it may be recommended to have a sample of modules independently flash tested from an accredited laboratory (such as Fraunhofer institute[d] or PI Berlin[e]) to confirm the tolerance. Additional acceptance tests such as electroluminescence tests may also be performed.
Temperature coefficient for power	The value of the power change with temperature will be an important consideration for modules installed in hot climates. Cooling by wind can positively affect plant performance in this respect.
Degradation	The degradation properties and long-term stability of modules should be ascertained. PV module manufacturers, independent testing institutes and technical consultants are sources of good information with regards to the potential induced degradation (PID), long-term degradation and, for crystalline modules, light-induced degradation (LID).
Bypass diodes	The position and number of the bypass diodes affect how the module performs under partial shading. The orientation of the PV modules on the support structure (portrait or landscape) can affect the inter-row shading losses (see also Section 5.3).
Warranty terms	The manufacturers' warranty period is useful for distinguishing between modules, but care should be taken with the power warranty. It is recommended that a detailed technical and legal review of warranty terms be conducted.
Suitability for unusual site conditions	Frameless modules may be more suitable for locations that experience snow, as snow tends to slide off these modules more easily. Modules located close to the coast should be certified for salt mist corrosion as described in Section 6.3.3.
Spectral response of the semiconductor	Different technologies have a differing spectral response and so will be better suited for use in certain locations, depending on the local light conditions. Some technologies show an improved response in low light levels compared to other modules.
Maximum system voltage	When sizing strings with modules with a high Open Circuit Voltage (V_{oc}), it should be verified that for extreme ambient temperature conditions (up to 60° and down to -10°), the maximum system voltage (1,000V) will not be exceeded.
Other	Other parameters important for selection of modules include cost ($/Wp) and the expected operational life.

a The cost per kWh of electricity generated that takes into account the time value of money.

b PV Evolution Labs, http://www.pvel.com

c TUV Rheinland, http://www.tuv.com/en/corporate/home.jsp

d Fraunhofer Institute, http://www.fraunhofer.de/en.html

e PI Berlin, http://www.pi-berlin.com

The module datasheet format and the information that should be included has been standardised and is covered by EN 50380: "Datasheet and nameplate information for photovoltaic modules." An example of the information expected in a datasheet is provided in Table 9.

7.3.2 INVERTERS

No single inverter is best for all situations. In practice, the local conditions and the system components have to be taken into account to tailor the system for the specific application. Different solar PV module technologies and layouts may suit different inverter types. Care needs to be taken in the integration of modules and inverters to ensure optimum performance and lifetime.

The most cost-effective inverter option requires an analysis of both technical and financial factors. Many of the inverter selection criteria listed in Table 10 feed into this analysis. The DC-AC conversion efficiency directly affects the annual revenue of the solar PV plant and varies according to a number of variables, including the DC input voltage and load. Several other factors should inform inverter selection, including site temperature, product reliability, maintainability, serviceability and total cost. Inverters also de-rate with altitude, which may be a consideration in mountainous locations.

Table 9: Comparison of Module Technical Specifications at STC

Manufacturer	Xxxx
Module Model	Xxxx
Type	Multi-crystalline
Nominal power (P_{MPP})	245Wp
Power tolerance	0/+3%
Voltage at P_{MAX} (V_{MPP})	30.2V
Current at P_{MAX} (I_{MPP})	8.13A
Open circuit voltage (V_{OP})	37.5V
Short circuit current (I_{SC})	8.68A
Maximum system voltage	$1000V_{DC}$
Module efficiency	15.00%
Operating temperature	-40°C to +85°C
Temperature coefficient of P_{MPP}	-0.43%/°C
Dimensions	1650×992×40mm
Module area	1.64m²
Weight	19.5kg
Maximum load	5400Pa
Product warranty	10 years
Performance guarantee	92%: after 10 years; 80%: after 25 years

7.3.2.1 *Containerised Inverter Solutions*

Where commercial scale PV systems export power to the grid at medium voltage, it is common that a containerised solution for inverter, transformer and switchgear is provided. This solution enables offsite manufacturing, thus reducing installation time on site.

Containers are generally shipping-type and manufactured from corrugated steel. However they can also be manufactured in glass-reinforced plastic or concrete. The architecture of containers should ensure there is sufficient space for equipment, including access for maintenance. Cabling between equipment should be neatly installed, and often is provided in a compartment below the floor of the container. Having separate compartments for HV/LV equipment and for transformers is good practice. Provision of suitable heating, ventilation or air conditioning is necessary to maintain stable environmental conditions.

7.3.2.2 *Quality Benchmarks*

The warranty offered for inverters varies among manufacturers. A minimum warranty of five years is typical, with optional extensions of up to twenty years or more available from many manufacturers. Some string inverters offer a 7- or 10-year warranty as standard.

Many manufacturers quote inverter lifetimes in excess of 20 years based on replacing and servicing certain components according to specific maintenance regimes. However, real world experience points to an expected lifetime of a central inverter of between 10 and 20 years. This implies that the inverters may need to be replaced or refurbished once or twice during a 25-year plant operational life.

Table 10: Inverter Selection Criteria	
Criterion	**Description**
Project capacity	The plant capacity influences the inverter connection concept. Central inverters are commonly used in megawatt-scale solar PV plants. Inverters are discussed more fully in Section 3.5.
Performance	High efficiency inverters should be sought. The additional yield often more than compensates for the higher initial cost. Consideration must also be given to the fact that efficiency changes according to design parameters, including DC input voltage and load.
Maximum Power Point (MPP) voltage range	A wide inverter MPP range facilitates design flexibility.
3-phase or single phase output	The choice will be subject to project size. Large capacity projects will require 3-phase inverters. National electrical regulations may set limits on the maximum power difference between the phases.
Incentive scheme	Banding of financial incentive mechanisms may have an influence on the choice of inverter. For example, FiT schemes might be tiered for different plant sizes, which may, in turn, influence the optimum inverter capacity.
Module technology	The compatibility of thin-film modules with transformerless inverters should be confirmed with manufacturers.
National and international regulations	A transformer inverter must be used if galvanic isolation is required between the DC and AC sides of the inverter.
Power quality/grid code compliance	Power quality and grid code requirements are country-dependent. It is not possible to provide universally applicable guidelines. The national regulations and standards should be consulted when selecting an inverter and designing a solar PV power plant. National grid codes may specify requirements for: • Frequency limitation. • Voltage limitation. • Reactive power control capability—over-sizing inverters slightly may be required. • Harmonic distortion limitation—to reduce the harmonic content of the inverter's AC power output. • Fault ride through capability.
Product reliability	High inverter reliability ensures low downtime and maintenance and repair costs. If available, inverter mean time between failures, figures and track record should be assessed.
Mismatch	If modules of different specifications or different orientation and tilt angles are to be used, then string or multi-string inverters with multiple MPP trackers may be recommended in order to minimise mismatch losses.[a] This may be especially relevant for rooftop applications where the orientation and tilt angle is often dictated by the properties of the roof space.
Maintainability and serviceability	Access constraints for PV plants in remote locations may influence the choice of inverter manufacturer: a manufacturer with a strong in-country presence may be able to provide better technical support. For PV plants in remote areas, string inverters offer ease of maintenance benefits.
System availability	If a fault arises with a string inverter, only a small proportion of the plant output is lost (i.e., 25kW). Spare inverters can be kept locally and replaced by a suitably-trained electrician. With central inverters, a larger proportion of the plant output will be lost until a replacement is obtained (e.g., 750kW).
Modularity	Ease of expanding the system capacity and flexibility of design should be considered when selecting inverters.
Shading conditions	String or multi-string inverters with multiple MPP trackers may be the preferred choice for sites that suffer from partial shading.
Installation location	Outdoor/indoor placement and site ambient conditions influence the IP rating and cooling requirements. Either forced ventilation or air-conditioning will usually be required for indoor inverters.
Monitoring / recording / telemetry	Plant monitoring, data logging and control requirements define a set of criteria that must be taken into account when choosing an inverter.

a Each PV string with a given tilt and orientation will have its own unique output characteristics and therefore needs to be "tracked" separately to maximize yield. An efficient design requires that only identically oriented sub-arrays are allocated to a single maximum power point tracker.

Inverter protection should include:

- Protection against incorrect polarity for the DC cable.
- Over-voltage and overload protection.
- Islanding detection for grid connected systems (depends on grid code requirements).
- Insulation monitoring.

Total harmonic distortion (THD)[40] is a measure of the harmonic content of the inverter output and is limited by most grid codes. For high quality inverters, THD is normally less than 5 percent. Inverters should be accompanied by the appropriate type of test certificates, which are defined by the national and international standards applicable for each project and country.

The inverter datasheet format and the information that should be included is standardised as covered by EN 50524:2009: “Data sheet and name plate for photovoltaic inverters." An example of the information expected in a datasheet is provided in Table 11.

7.3.3 TRANSFORMERS

Distribution and grid transformers are the two main types found on solar PV plants. Distribution transformers are used to step up the inverter output voltage for the plant collection system, which is normally at distribution voltage. If the plant is connected to the distribution network, power can then be exported to the grid directly. If the plant is connected to the transmission grid, grid transformers are used to step up the voltage even further. Further description of grid connection considerations is provided in Section 7.4.3.

The total cost of ownership (TCO), and the efficiency (directly related to the load and no-load losses) are major transformer selection criteria, directly affecting the annual revenue of the solar PV plant. As with inverters, several other factors should inform transformer selection, including power rating, construction, site conditions,

40 Total Harmonic Distortion is a measure of the harmonic content of the inverter output and is limited by most grid codes.

Table 11: Datasheet Information

Inverter Model	xxxxxxxxx
Inputs	
Maximum DC Power	954kW
MPP Voltage Range	681-850V
Maximum Input Voltage	1,000V
Maximum Input Current / MPPT	1,400A
Number of MPP Trackers	1
Outputs	
Rated AC Power at 25°C	935kVA
Maximum AC Output Current	1,411A
Rated AC Voltage	386V
AC Grid Frequency	50Hz
Efficiency	
Maximum Efficiency	98.6%
Euro Efficiency	98.4%
Standby Consumption	< 100W
Operation Consumption	1,900W
General Data	
IP Rating	IP54, IP43
Operating Temperature Range	-25°C to +62°C
Relative Humidity	15-95 %
Dimensions (H x W x D)	2,272 x 2,562 x 956mm
Weight (kg)	1,900kg

product reliability, maintainability, serviceability and sound power. A cost-benefit analysis is required to determine the optimal transformer option.

Amorphous core transformers have low losses under no-load conditions and as such can provide cost savings in solar applications where there are significant periods of time when the transformers are not loaded.

Selection criteria (technical and economic factors) include:

- Efficiency, load/no-loadlosses.
- Guarantee.
- Vector group.
- System voltage.
- Power rating.

- Site conditions.
- Sound power.
- Voltage control capability.
- Duty cycle.

7.3.3.1 Quality Benchmarks

The guarantee offered for transformers varies among manufacturers. A minimum guarantee of 18 months is typical, with optional extensions of up to 10 years or more.

Based on manufacturer data and academic studies looking at large populations of transformers, distribution transformers have mean time to failure (MTTF) of 30 years or more. This is dependent on the transformer load profile and duty cycle.

Protection for typical, oil-immersed transformers used on solar PV plants should include:

- Buchholz relay.
- Pressure relief device.
- Over temperature protection.
- Oil level monitoring.

At a minimum, transformers should be built according to the following standards:

- BS EN 50464-1:2007+A1:2012
- IEC 60076

An example of the information expected in a transformer datasheet is provided in Table 12.

7.3.4 MOUNTING STRUCTURES

The tilt angle and orientation and row spacing are generally optimised for each PV power plant according to location. This helps to maximise the total annual incident irradiation[41] and total annual energy yield. Depending on the latitude, the optimum tilt angle can vary between 10° and 45°. This is covered more fully in Section 7.2. The modules should face due south for the north hemisphere and due north for the south hemisphere. There are several off-the-shelf software packages (such as PVsyst[42] and PV*SOL[43]) that may be used to optimise the tilt angle and orientation according to specifics of the site location (latitude, longitude) and solar resource.

7.3.4.1 Quality Benchmarks

The warranty supplied with support structures varies, but may include a limited product warranty of 10-25 years. Warranties could include conditions that all parts are handled, installed, cleaned and maintained in the appropriate way, that the dimensioning is made according to the static loads and that the environmental conditions are not unusual.

The useful life of fixed support structures, though dependent on adequate maintenance and corrosion protection, could be expected to be beyond 25 years.

In marine environments or within 3km of the sea, additional corrosion protection or coatings on the structures may be required.

Tracker warranties vary between technologies and manufacturers, but a 5- to 10-year guarantee on parts and workmanship may be typical.

Tracking system life expectancy depends on appropriate maintenance. Key components of the actuation system such as bearings and motors may need to be serviced or replaced within the planned project life.

Steel driven piles should be hot-dip galvanised to reduce corrosion. In highly corrosive soil, a suitable proposed thickness of coating should be derived by means of calculation. Additional protection such as epoxy coating may sometimes be necessary in order for components to last for the 25- to 35-year system-design life.

41 Irradiation is the solar energy received on a unit area of surface. It is defined more fully in section 4.2.

42 PVsyst, http://www.pvsyst.com

43 http://www.valentin-software.com/

Table 12: Transformer Specification					
Electrical Characteristics					
Rated power	[kVA]	1250	Rated LV insulation level	[kV]	1.1
Insulation liquid		Mineral oil (IEC60296 class IA)	Applied voltage to industrial frequency	[kV]	3
Operation		Reversible	B.I.L. (1.2 / 50 µs)		N/A
Windings HV/LV		Aluminium/Aluminium	Frequency	[Hz]	50
Primary voltage at no load	[V]	33000	Number of phases		3
Primary taps type / tappings		Off load / ±2x2.5%	Vector group		Dyn05yn5
Rated HV insulation level	[kV]	36	No-load losses	[W]	1890
Applied voltage to industrial frequency	[kV]	70	Load losses (ONAN) at 75°C	[W]	14850
B.I.L. (1.2 / 50 µs)	[kV]	170	Impedance voltage (ONAN) at 75°C		6%
Secondary voltage at no load	[V]	380 / 380	Tolerances		IFC 60076-1 Tolerances
Thermal Characteristics					
Thermal insulation class		Class A	Surface treatment		Powder coating
Max. average temperature rise (Oil/Winding)	[K/K]	60/65	Surface colour		RAL7035
Mechanical Characteristics					
Technology		Hermetically sealed	Corrosivity category		C3 (medium corrosivity)
Tank type		With fins or with radiators	Durability (ISO 12944-6)		Medium (5-15 years)
Cover		Bolted	Bolts		Standard
Frame type		Standard	Final colour		RAL 7033 greenish-grey
Accessories/Qty					
Off-load tap changer		1	Pressure release valve		1
Oil filling tube		1	Gas relay		1
Oil drain valve		1	Oil temperature indicator		1
Thermometer pocket		1	Terminal box		1
Outline and Weight					
Overall dimension (L x W x D)	[mm]	2150 x 1350 x 2380	Total weight	[kg]	4900
Site Conditions					
Altitude	[m]	≤ 1000	Minimum standby temperature	[°C]	-25
Maximum ambient temperature	[°C]	40	Electrostatic screen		No
Daily average temperature	[°C]	30	Rectifier supply		No
Yearly average temperature	[°C]	20			

7.4 ELECTRICAL DESIGN

The electrical design of each plant should be considered on a case-by-case basis, as each site poses unique challenges and constraints. While general guidelines and best practices can be formulated, there are no "one-size-fits all" solutions. International standards and country-specific electrical codes should be followed in order to ensure that the installation is safe and compliant.

While the recommendations in the following sections are based on solar PV power plants with centralised inverter architectures, many of the concepts discussed also apply to plants with string inverters.

7.4.1 DC SYSTEM

The DC system comprises the following constituents:

- Arrays of PV modules.
- DC cabling (module, string and main cable).
- DC connectors (plugs and sockets).
- Junction boxes/combiner boxes.
- Disconnects/switches.
- Protection devices.
- Earthing.

When sizing the DC component of the plant, the maximum voltage and current of the individual strings and PV arrays should be calculated using the maximum output of the individual modules. Simulation programs can be used for sizing but their results should be cross checked manually.

DC components should be rated to allow for thermal and voltage limits. As a guide, for mono-crystalline and multi-crystalline silicon (multi-c-Si) modules, the following minimum ratings apply:

- Minimum Voltage Rating: $V_{OC(STC)} \times 1.15$
- Minimum Current Rating: $I_{SC(STC)} \times 1.25$

The multiplication factors used above (1.15 and 1.25) are location-dependent. Different multiplication factors may apply for specific locations. National standards and codes should be consulted.

For non-crystalline silicon modules, DC component ratings should be calculated from manufacturer's data, taking into account the temperature and irradiance coefficients. In addition, certain module technologies have an initial settling-in period during which the V_{OC} and I_{SC} is much higher. This effect should also be taken into consideration. If in doubt, a suitably qualified technical advisor should be consulted.

7.4.1.1 PV Array Design

The design of a PV array will depend on the inverter specifications and the chosen system architecture. Using many modules in series in high voltage (HV) arrays minimises ohmic losses. However, safety requirements, inverter voltage limits and national regulations also need to be considered.

- **Maximum number of modules in a string:** The maximum number of modules in a string is defined by the maximum DC input voltage of the inverter to which the string will be connected ($V_{MAX\ (INV,\ DC)}$). Under no circumstances should this voltage be exceeded. Crossing the limit can decrease the inverter's operational lifetime or render the device inoperable. The highest module voltage that can occur in operation is the open-circuit voltage in the coldest daytime temperatures at the site location. Design rules of thumb for Europe use -10°C as the minimum design temperature, but this will vary according to location. The maximum number of modules in a string (n_{max}) may therefore be calculated using the formula:

$$V_{OC(MODULE)@\text{coldest module operating temperature}} \times n_{max} < V_{MAX(INV,\ DC)}$$

- **Minimum number of modules in a string:** The minimum number of modules is governed by the requirement to keep the system voltage within the maximum power point (MPP) range of the inverter. If the string voltage drops below the minimum MPP inverter voltage, then the system will underperform.

In the worst case, the inverter may shut down. The lowest expected module voltage occurs during the highest operating module temperature conditions. Design rules of thumb for Europe use 70°C as the design benchmark, but this will vary according to site conditions. The minimum number of modules in a string (n_{min}) may therefore be calculated using the formula:

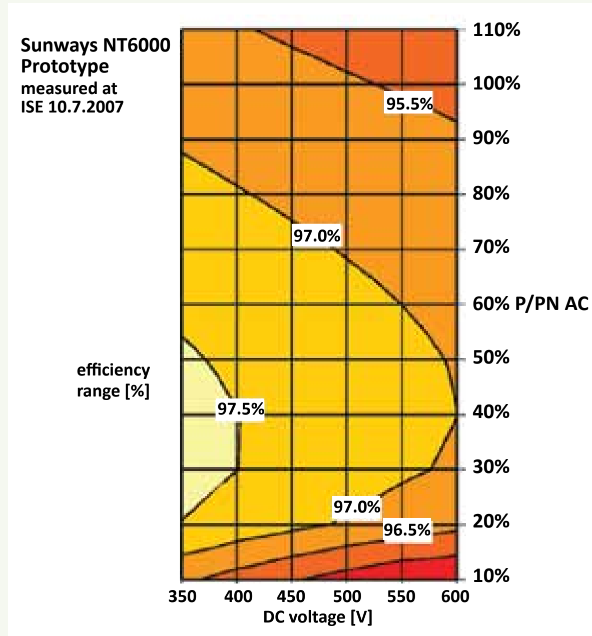
$$V_{MPP(MODULE)@highest\ module\ operating\ temperature} \times n_{min} > V_{MPP(INV\ min)}$$

- **Voltage optimisation:** As the inverter efficiency is dependent on the operating voltage, it is preferable to optimise the design by matching the array operating voltage and inverter optimum voltage as closely as possible. This will require voltage dependency graphs of inverter efficiency (see examples in Figure 17). If such graphs are not provided by inverter manufacturers, they may be obtained from independent sources. Substantial increases in the plant yield can be achieved by successfully matching the operating voltages of the PV array with the inverter.
- **Number of strings:** The maximum number of strings permitted in a PV array is a function of the maximum allowable PV array current and the maximum inverter current. In general, this limit should not be exceeded as it leads to premature inverter ageing and yield loss.

7.4.1.2 Inverter Sizing

It is not possible to formulate an optimal inverter sizing strategy that applies in all cases. Project specifics such as the solar resource and module tilt angle play a very important role when choosing a design. While the rule of thumb has been to use an inverter-to-array power ratio less than unity, this is not always the best design approach. For example, this option might lead to a situation where the inverter manages to curtail power spikes not anticipated by irradiance profiles (based on one-hour data). Or, it could fail to achieve grid code compliance in cases where reactive power injection to the grid is required.

Figure 17: Voltage and Power Dependency Graphs of Inverter Efficiency[a]



a F.P. Baumgartner, et al., "Status and Relevance of the DC Voltage Dependency of the Inverter Efficiency," 22nd European Photovoltaic Solar Energy Conference and Exhibition, 3-7 September 2007, Fiera Milano, Session 4DO.4.6, https://home.zhaw.ch/~bauf/pv/papers/baumgartner_2007_09_inverter_EUPVSEC_MILANO.pdf (accessed June 2014).

The optimal sizing is, therefore, dependent on the specifics of the plant design. Most plants will have an inverter sizing range within the limits defined by:

$$0.8 < Power\ Ratio < 1.2$$

Where:

$$Power\ Ratio = \frac{P_{(Inverter\ DC\ rated)}}{P_{(PV\ Peak)}}$$

$$P_{(Inverter\ DC\ rated)} = \frac{P_{(Inverter\ AC\ rated)}}{n_{(100\%)}}$$

Guidance on inverter and PV array sizing can be obtained from the inverter manufacturers, who offer system-sizing software. Such tools also provide an indication of the total number of inverters required. If in doubt, a suitably qualified technical advisor should be consulted.

A number of factors and guidelines must be assessed when sizing an inverter:

- The maximum V_{OC} in the coldest daytime temperature must be less than the inverter maximum DC input voltage ($V_{INV, DC MAX}$).
- The inverter must be able to safely withstand the maximum array current.
- The minimum V_{OC} in the hottest daytime temperature must be greater than the inverter DC turn-off voltage ($V_{INV, DC TURN-OFF}$).
- The maximum inverter DC current must be greater than the PV array(s) current.
- The inverter MPP range must include PV array MPP points at different temperatures.
- When first installed, some thin-film modules produce a voltage greater than the nominal voltage. This happens for a period of time until initial degradation has occurred, and must be taken into account.
- Grid code requirements, including reactive power injection specifications.
- The operating voltage should be optimised for maximum inverter efficiency.
- Site conditions of temperature and irradiation profiles.
- Economics and cost-effectiveness.

Inverters with reactive power control are recommended. Inverters can control reactive power by controlling the phase angle of the current injection. Moreover, aspects such as inverter ventilation, air conditioning, lighting and cabinet heating must be considered.

When optimising the voltage, it should be considered that the inverter efficiency is dependent on voltage. Specification sheets and voltage-dependency graphs are required for efficient voltage matching.

7.4.1.3 Cable Selection and Sizing

The selection and sizing of DC cables for solar PV power plants should take into account national codes and regulations applicable to each country. Cables specifically designed for solar PV installations ("solar" cables) are readily available and should be used. In general, three criteria must be observed when sizing cables:

1. **The cable voltage rating:** The voltage limits of the cable to which the PV string or array cable will be connected must be taken into account. Calculations of the maximum V_{OC} voltage of the modules, adjusted for the site minimum design temperature, are used for this calculation.
2. **The current carrying capacity of the cable:** The cable must be sized in accordance with the maximum current. It is important to remember to de-rate appropriately, taking into account the location of the cable, the method of laying, number of cores and temperature. Care must be taken to size the cable for the worst case of reverse current in an array.
3. **The minimisation of cable losses:** The cable voltage drop and the associated power losses must be as low possible. Normally, the voltage drop must be less than 3 percent. Cable losses of less than 1 percent are achievable.

In practice, the minimisation of voltage drop and associated losses will be the limiting factor in most cases.

7.4.1.4 Cable Management

Over-ground cables such as module cables and string cables need to be properly routed and secured to the mounting structure, either using dedicated cable trays or cable ties. Cables should be protected from direct sunshine, standing water and abrasion by the sharp edges of support structures. They should be kept as short as possible.

Plug cable connectors are standard in grid-connected solar PV power plants, due to the benefits they offer in terms of installation ease and speed. These connectors are normally touch-proof, which means they can be touched without risk of shock.

The laying of main DC cables in trenches must follow national codes and take into account specific ground conditions.

7.4.1.5 Module and String Cables

Single-conductor, double-insulation cables are preferable for module connections. Using such cables helps protect against short circuits. When sizing string cables, the number of modules and the number of strings per array need to be considered. The number of modules defines the voltage at which the cable should be rated. The number of strings is used to calculate the maximum reverse current that can flow through a string.

The cables should be rated to the highest temperature they may experience (for instance, 80°C). Appropriate de-rating factors for temperature, installation method and cable configuration should also be applied.

7.4.1.6 Main DC Cable

In order to reduce losses, the overall voltage drop between the PV array and the inverter should be minimised. A benchmark voltage drop of less than 3 percent (at STC) is suitable, and cables should be sized using this benchmark as a guide. In most cases, over-sizing cables to achieve lower losses is a worthwhile investment.

7.4.1.7 Combiner Boxes

Combiner boxes are needed at the point where the individual strings forming an array are marshalled and connected together in parallel before leaving for the inverter through the main DC cable. Junctions are usually made with screw terminals and must be of high quality to ensure lower losses and prevent overheating.

Combiner boxes have protective and isolation equipment, such as string fuses and disconnects[44] (also known as load break switches), and must be rated for outdoor placement using, for example, ingress protection (IP). An explanation of the IP bands is provided in Table 13. Depending on the solar PV plant architecture and size, multiple levels of junction boxes can be used.

It is important to remember that the module side of the terminals of a DC PV system remain live during the day. Therefore, clear and visible warning signs should be provided to inform anyone working on the junction box. For safety reasons all junction boxes should be correctly labelled.

Disconnects and string fuses should be provided. Disconnects permit the isolation of individual strings, while string fuses protect against faults, as discussed in Section 7.4.1.9. Disconnects should be capable of breaking normal load and should be segregated on both the positive and negative string cables.

44 Disconnects should be not confused with disconnectors/isolators that are dead circuit devices (or devices that operate when there is no current flowing through the circuit).

Table 13: Definition of Ingress Protection (IP) Ratings

Example: IP65 1st digit 6 (Dust tight) 2nd digit 5 (Protected against water jets)			
1st digit	Protection from solid objects	2nd digit	Protection from moisture
0	Non-protected	0	Non-protected
1	Protection against solid objects greater than 50mm	1	Protected against dripping water
2	Protection against solid objects greater than 12mm	2	Protected against dripping water when tilted
3	Protection against solid objects greater than 2.5mm	3	Protected against spraying water
4	Protection against solid objects greater than 1.0mm	4	Protected against splashing water
5	Dust protected	5	Protected against water jets
6	Dust tight	6	Protected against heavy seas
		7	Protected against immersion
		8	Protected against submersion

7.4.1.8 Connectors

Specialised plug and socket connections are normally pre-installed on module cables to facilitate assembly. These plug connectors provide secure and touch-proof connections.

Connectors should be correctly rated and used for DC applications. As a rule, the connector current and voltage ratings should be at least equal to those of the circuit they are installed on.

Connectors should carry appropriate safety signs that warn against disconnection under load. Such an event can lead to arcing (producing a luminous discharge across a gap in an electrical circuit), and put personnel and equipment in danger. Any disconnection should take place only after the circuit has been properly isolated.

7.4.1.9 String Fuses/Miniature Circuit Breakers (MCBs)

String fuses or miniature circuit breakers (MCBs) are required for over-current protection. They must be rated for DC operation. National codes and regulations may need to be consulted when selecting and sizing fuses and MCBs.

The following guidelines apply to string fuses/MCBs:

- All arrays formed of four or more strings should be equipped with breakers. Alternatively, breakers should be used where fault conditions could lead to significant reverse currents.
- Since faults can occur on both the positive and negative sides, breakers must be installed on all unearthed cables.
- To avoid nuisance tripping, the nominal current of the breaker should be at least 1.25 times greater than the nominal string current. National electrical codes should be consulted for recommendations. Overheating of breakers can cause nuisance tripping. For this reason, junction boxes should be kept in the shade.
- The string fuse/MCB must trip at less than twice the string short-circuit current (I_{SC}) at STC or at less than the string cable current carrying capability, whichever is the lower value.
- The trigger current of fuse/MCB should be taken into account when sizing string cables. It should not be larger than the current at which the string cable is rated.
- The string fuse/MCB should be rated for operation at the string voltage. The following formula is typically used to guide string fuse rating, although national codes of practice should be consulted:

  $$\textit{String Fuse Voltage Rating} = V_{OC(STC)} \times M \times 1.15$$

  where *M* is the number of modules in each string.

7.4.1.10 DC Switching

Switches are installed in the DC section of a solar PV plant to provide protection and isolation capabilities. DC switches/disconnects and DC circuit breakers (CBs) are discussed below.

- **DC Switches/Disconnects:** Judicious design practice calls for the installation of switching devices in PV array junction boxes. DC switches provide a manual means of electrically isolating entire PV arrays, which is required during installation and maintenance. DC switches must be:
  - Double-pole to isolate both the positive and negative PV array cables.
  - Rated for DC operation.
  - Capable of breaking under full load.
  - Rated for the system voltage and maximum current expected.
  - Equipped with safety signs.
- **DC Circuit Breaker (CB):** String fuses/MCBs cannot be relied upon for disconnection of supply in case of fault conditions. This is due to the fact that PV modules are current-limiting devices, with an I_{SC} only a little higher than the nominal current. In other words, the fuse would not blow, or the MCB would not trip since the fault current would be less than the trigger current. For this reason, most PV codes and regulations recommend

that main DC CBs should be installed between the PV array fields and the grid-connected inverters.

Certain inverter models are equipped with DC CBs. As such, installation of additional CBs may become redundant. However, national regulations must be consulted to confirm the standards.

7.4.1.11 *Quality Benchmarks*

Module cables must:

- Adhere to local and international standards including IEC 60502, IEC 60228, 60364-1, 60332-1-2, 60754-1 and -2, 61034.
- Be specified for a wide temperature range (e.g., -55 to 125°C).
- Be resistant to ultraviolet (UV) radiation and weather if laid outdoors without protection.
- Be single core and double insulated.
- Have mechanical resistance to animals, compression, tension and bending.
- Be attached to cable trays with cable ties to support their weight and prevent them from moving in the wind.
- Be protected from sharp support stricture edges with anti-abrasion pads.
- Use cable connectors that adhere to international protection rating IP67.

Sometimes specific cable options are preferable because they offer increased protection:

- Single conductor cable-insulated and sheathed. For example, properly rated HO7RNF cables.
- Single conductor cable in suitable conduit/trunking.
- Multi-core, steel wire armoured—only suitable for main DC cables and normally used where an underground or exposed run is required.

7.4.2 AC SYSTEM

7.4.2.1 *AC Cabling*

Cabling for AC systems should be designed to provide a safe and cost effective means of transmitting power from the inverters to the transformers and beyond. Cables should be rated for the correct voltage and have conductors sized, taking into account the operating currents and short-circuit currents (I_{SC}).

When specifying cabling the following design considerations should be taken into account:

- Cable must be rated for the maximum expected voltage.
- Conductor should be able to pass the operating and I_{SC} safely.
- Conductor should be sized appropriately to ensure that losses produced by the cable are within acceptable limits, and that the most economic balance is maintained between capital cost and operational cost (losses).
- Conductors should be sized to avoid voltage drop outside statutory limits and equipment performance.
- Insulation should be adequate for the environment of installation.
- A suitable number of cores should be chosen (either single or multi-core).
- Earthing and bonding should be suitably designed for the project application.
- Installation methods and mechanical protection of the cable should be suitably designed for the project.

Cables should comply with relevant IEC standards and appropriate national standards. Examples of these include:

- IEC 60502 for cables between 1kV and 36kV.
- IEC 60364 for LV cabling.
- IEC 60840 for cables rated for voltages above 30kV and up to 150kV.

7.4.2.2 AC Switchgear

Appropriately rated switchgear and protection systems should be included to provide disconnection, isolation, earthing and protection. On the output side of the inverters, provision of a switch disconnector is recommended as a means to isolate the PV array.

The appropriate type of switchgear will be dependent on the voltage of operation. Switchgear up to 33kV is likely to be an internal metal-clad, cubicle-type with gas- or air-insulated busbars and vacuum or SF6 breakers. For higher voltages, the preferred choice may be air-insulated outdoor switchgear or, if space is constrained, gas-insulated indoor switchgear.

All switchgear should:

- Be compliant with relevant IEC standards and national codes.
- Clearly show the ON and OFF positions with appropriate labels.
- Have the option to be secured by locks in off/earth positions.
- Be rated for operational and short-circuit currents.
- Be rated for the correct operational voltage.
- Be provided with suitable earthing.

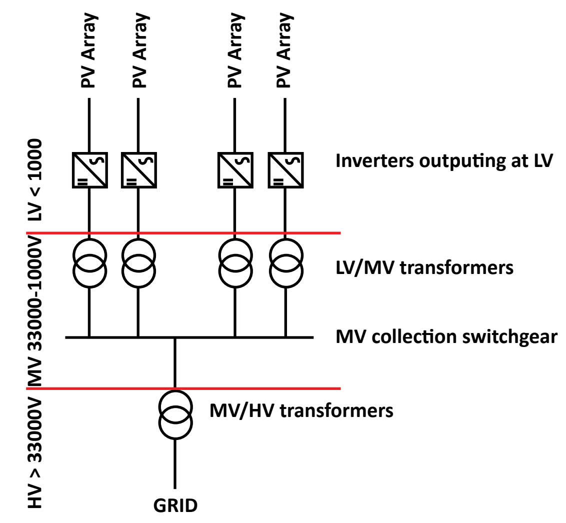
7.4.2.3 Sizing and Selecting Transformers

In general, the inverters supply power at low voltage (typically 300-450V). But for a commercial solar power plant, grid connection is typically made at 11kV and above (HV levels). It is therefore necessary to step up the voltage using one or more transformers between the inverter and the grid connection point.

The position of the transformer in the electrical system will define the required voltage on the primary and secondary sides of the transformer.

Figure 18 shows a high-level, single line diagram showing typical voltages of operation for the AC system of a solar power plant. Where there is a need to supply power from the grid back to the plant, an auxiliary transformer is required.

Figure 18: Typical Transformer Locations and Voltage Levels in a Solar Plant where Export to Grid is at HV



The selection of an appropriate transformer should consider several basic issues. These include the required capacity, position within the electrical system, physical location and environmental conditions under which the transformer will operate. The capacity of the transformer (specified in MVA) will depend on the projected maximum power exported from the solar array.

The main export transformers will form a major element of the main substation design and, as such, their selection should also consider the technical requirements of the grid company. Such transformers should conform to local and/or international specifications, as required.

Output power from PV arrays follows a well-understood cyclic duty corresponding to the path of the sun through the day. This allows consideration of a dynamic rating to be applied to the transformer selection.

The transformer solution should comply with national and international standards including IEC 60076. The design should consider the following points:

- **Losses:** Transformers can lose energy through magnetising current in the core, a phenomenon known as iron losses, and also copper losses in the windings. Minimising the losses in a transformer is a key requirement, as this will increase the energy supplied to the grid and thereby enhance the revenue of a solar PV power plant.
- **Test Requirements:** Transformers should be subjected to a number of routine and type tests performed on each model manufactured; these tests are set out in IEC 60076. The manufacturer also can be requested to undertake special tests mentioned in IEC 60076.
- **Delivery and Commission:** Consideration should be given to the period of time required for manufacture and delivery of transformers. Most large transformers (above 5MVA) will be designed and built on order, and will therefore have a lengthy lead-time, which can be in the order of years.

The delivery of large transformers (above 30MVA) to the site also needs to be planned. Large transformers can be dis-assembled to some extent, but the tank containing the core and winding will always need to be moved in one piece. In the case of transformers of 100MVA capacity, the burden of transportation will still be significant and road delivery may require special measures, such as police escort.

The positioning of the transformer in the power plant should also be decided at the planning stage. By doing this, a transformer can be easily and safely installed, maintained, and in the event of a failure, replaced. Liquid-filled transformers should be provided with a bund to catch any leakage. Oil-filled transformers, if sited indoors, are generally considered a special fire risk. As such, measures to reduce the risk to property and life should be considered.

7.4.2.4 Plant Substation

Equipment such as LV/MV transformers, MV switchgear, Supervisory Control and Data Acquisition (SCADA) systems, protection and metering systems can be placed within the plant substation.

The layout of the substation should optimise the use of space while still complying with all relevant building codes and standards. A safe working space should be provided around the plant for the operation and maintenance staff. Air conditioning should be considered due to the heat generated by the electronic equipment. In some cases, large substation facilities need to be designed and constructed according to the grid company's requirements and interconnect agreement specifications.

Separation between MV switch rooms, converter rooms, control rooms, storerooms and offices is a key requirement, in addition to providing safe access, lighting and welfare facilities.

Lightning protection should be considered to alleviate the effect of lightning strikes on equipment and buildings.

Metering: Tariff metering will be required to measure the export of power. This may be provided at the plant substation in addition to the point of connection to the grid.

Data monitoring/SCADA: SCADA systems provide control and status indication for the items included in the substation and across the solar PV power plant. The key equipment may be situated in the substation or in a dedicated control and protection room.

7.4.2.5 Earthing and Surge Protection

Earthing should be provided as a means to protect against electric shock, fire hazard and lightning. By connecting to the earth, charge accumulation in the system during an electrical storm is prevented. The earthing of a solar PV power plant encompasses the following:

- Array frame earthing.
- System earthing (DC conductor earthing).
- Inverter earthing.
- Lightning and surge protection.

National codes and regulations and the specific characteristics of each site location should be taken into account when designing the earthing solution. The solution should be designed to reduce the electric shock risk to people on site and the risk of damage and fire during a fault or lightning strike.

The entire solar PV power plant and the electrical room should be protected from lightning. Protection systems are usually based on early streamer emission and lightning conductor air terminals. The air terminal will be capable of handling multiple strikes of lightning current and should be maintenance-free after installation.

These air terminals will be connected to respective earthing stations. Subsequently, an earthing grid will be formed, connecting all the earthing stations through the required galvanised iron tapes.

The earthing arrangements on each site will vary, depending on a number of factors:

- National electricity requirements.
- Installation guidelines for module manufacturers.
- Mounting system requirements.
- Inverter requirements.
- Lightning risk.

While the system designer must decide the most appropriate earthing arrangement for the solar PV plant according to location specific requirements, one can follow the general guidelines given below:

- Ground rods should be placed close to junction boxes. Ground electrodes should be connected between the ground rod and the ground lug in the junction box.
- A continuous earth path is to be maintained throughout the PV array.
- Cable runs should be kept as short as possible.
- Surge suppression devices can be installed at the inverter end of the DC cable and at the array junction boxes.
- Many inverter models include internal surge arrestors. Separate additional surge protection devices may also be required.

7.4.3 GRID CONNECTION

Solar plants need to meet the requirements of the grid company of the network onto which they will export power. Technical requirements for connection are typically set out in grid codes, which are published by the grid company and cover topics including planning, connection and operation of the plant. Grid codes will vary by country and may include:

- Limits on harmonic emission.
- Limits on voltage flicker.
- Limits on frequency variation.
- Reactive power export requirements.
- Voltage regulation.
- Fault level requirements.
- System protection.

In addition to meeting the country grid code requirements, site-specific requirements may be requested by the grid company should there be any unusual network conditions at the precise site location.

When designing the grid connection solution, careful consideration should be given to the following constraints:

- **Scheduling:** The grid connection schedule will impact the planned energisation date and generation targets. Key electrical components such as transformers can have long lead and delivery times. Supplier locations and likely lead times should be investigated at the planning stage and carefully considered in the project plan (see Box 4 “Grid Connection - Experience in India”).

  In addition to local connection works, wider network upgrades and modifications beyond the point of connection can have significant influence on the date of energisation and commercial operation. Connection issues are case-dependent and usually outside the developer’s sphere of influence. It is therefore important that communication is established with the relevant grid companies and that discussions are undertaken to fully understand the implications and

Box 4: Grid Connection – Experience in India

Export Cable

In India, projects are typically required to be commissioned within 12 months from the date of execution of the PPA. This is intended to allow ample time for planning and executing the export cable works. However, there have been a number of projects in India where commissioning has been delayed because power evacuation could not commence due to unavailability of the export line. This can be avoided by planning the export line routes and signing right-of-way agreements with the property owners at an early stage of project development.

Grid Stability

The smooth operation of a grid-connected solar PV power plant is dependent on the voltage and frequency of the grid staying within certain limits that are acceptable for the inverter. Grid instability may result from varying loads applied on the utility substation. With no historical load data available at the local substation level for the majority of Indian utilities, grid availability can become a significant risk to project development. In order to understand the risk, it is recommended that the developer conduct a thorough grid quality evaluation by physically verifying the voltage and frequency variations for a minimum period of two weeks during the project planning phase.

In addition to monitoring, measures during the component selection phase can also mitigate the risk of grid instability causing downtime. These measures include:

1) Selecting inverters that have a dynamic grid support function with low voltage, high voltage and frequency ride-through features.

2) Using plant transformers equipped with on-load tap changers.

Reactive Power Compensation

While few of the Indian states force project developers to maintain a power factor close to unity, there are other states that charge for the reactive power consumed by the PV plant. Although most modern central inverters can be made to operate at leading power factor, supplying the reactive power during hours of high irradiance, there may be a need to include a capacitor bank to compensate reactive power during periods of low irradiance. It is advisable to select inverters that can compensate the reactive power.

the timescales involved in both local and regional connection timescales.

- **Connection Voltage:** The connection voltage must be suitable for the plant capacity. Different connection voltages will entail differing costs of electrical equipment, such as switchgear and transformers, as well as conductor specifications. Differing connection voltages may also impact on the time required to provide the connection.

  Excessive loading of local transmission or distribution network equipment, such as overhead lines or power transformers, may lead to grid instability. In this case, the voltage and frequency of the grid may fall outside the operational limits of the inverters and plant downtime may result. In less developed regional networks, the risk of downtime caused by grid instability should be assessed by developers with a grid quality evaluation. Lack of such an evaluation can have serious impacts on project economics and result in downtime exceeding the assumptions that were used in the project's financial model.

7.4.4 QUALITY BENCHMARKS

The AC cable should be supplied by a reputable manufacturer accredited to ISO 9001. The cable should have:

- Certification to current IEC and national standards such as IEC 60502 for cables between 1kV and 36kV, IEC 60364 for LV cabling and IEC 60840 for cables rated for voltages above 30kV and up to 150kV.
- Type testing completed to appropriate standards.
- A minimum warranty period of two years.
- A design life equivalent to the design life of the project.
- Ultraviolet (UV) radiation and weather resistance (if laid outdoors without protection).

- Mechanical resistance (for example, compression, tension, bending and resistance to animals).

AC switchgear should be supplied by a reputable manufacturer accredited to ISO 9001 and should have:

- Certification to current IEC and appropriate national standards such as IEC 62271 for HV switchgear and IEC 61439 for LV switchgear.
- Type testing to appropriate standards.
- A minimum warranty period of two years.
- An expected lifetime at least equivalent to the design life of the project.

Transformers should be supplied by reputable manufacturers accredited to ISO 9001 and should have:

- Certification to IEC and appropriate national standards such as IEC 60076 for the power transformer, IEC 60085 for electrical insulation and IEC 60214 for tap changers.
- Type testing to appropriate standards.
- A minimum warranty period of two years.
- An expected lifetime at least equivalent to the design life of the project.
- Efficiency of at least 96 percent.

7.5 SITE BUILDINGS

A utility-scale solar PV power plant requires infrastructure appropriate to the specifics of the design chosen. Locations should be selected in places where buildings will not cast shading on the PV modules. It may be possible to locate buildings on the perimeter of the plant. If they are located centrally, appropriate buffer zones should be allowed for. Depending on the size of the plant, infrastructure requirements may include:

- **Office:** A portable office and sanitary room with communication devices. This must be watertight and prevent entry of insects. It should be located near the site entrance so that vehicular traffic does not increase the risk of dust settling on the modules.
- **LV/MV station:** Inverters may either be placed among the module support structures (if string inverters are chosen) in specially designed cabinets or in an inverter house along with the medium voltage transformers, switchgear and metering system.[45] This LV/MV station may be equipped with an air conditioning system if it is required to keep the electrical devices within their design temperature envelopes.
- **MV/HV station:** An MV/HV station may be used to collect the AC power from the medium voltage transformers and interface to the high voltage power grid.
- **Communications:** The plant monitoring system and the security system will require a communications medium with remote access. There can also be a requirement from the grid network operator for specific telephone landlines for the grid connection. Often, an internet broadband (DSL) or satellite communications system is used for remote access. A GSM (Global System for Mobile Communications) connection or standard telephone line with modems are alternatives, although they have lower data transfer rates.

7.5.1 QUALITY BENCHMARKS

Some benchmark features of PV plant infrastructure include:

- Watertight, reinforced concrete stations or pre-fabricated steel containers. All buildings and foundations should be designed and constructed in accordance with the Structural Eurocodes (in Europe) or the appropriate country building codes, standards and local authority regulations.
- Sufficient space to house the equipment and facilitate its operation and maintenance.
- Inclusion of:
  - Ventilation grilles, secure doors and concrete foundations that allow cable access.

45 For string inverters, the "LV/MV station" may be used to collect the AC power.

- Interior lighting and electrical sockets that follow country-specific regulations.
- Either adequate forced ventilation or air conditioning with control thermostats, depending on environmental conditions.
- Weather bars or upstands to prevent flooding of electrical equipment buildings.

7.6 SITE SECURITY

Solar PV power plants represent a large financial investment. The PV modules are not only valuable, but also portable. There have been many instances of module theft and also theft of copper cabling. Security solutions are required to reduce the risk of theft and tampering. These security systems will need to satisfy the insurance provider requirements and would typically include several of the following:

- **Security fence:** A galvanised steel wire mesh fence with anti-climb protection is typically recommended. A fence may also be part of the grid code requirements for public safety. Measures should be taken to allow small animals to pass underneath the fence at regular intervals.
- **CCTV cameras:** Security cameras are increasingly becoming a minimum requirement for any PV plant's security system. Several types of cameras are available, the most common being thermal and day/night cameras. Cameras should ideally have strong zooming capabilities and should be easy to manipulate remotely (e.g., with the help of pan-tilt-zoom support) for external users to be able to identify sources of intrusion with more ease. Day/night cameras typically have ranges of 50m to 100m and are coupled with infrared illuminators. Thermal cameras are more expensive, however, they have lower internal power consumption and a longer range (typically above 150m), which means that fewer cameras are needed to cover the entire perimeter fence.
- **Video analytics software:** Some security systems use video analytics software in conjunction with the CCTV cameras. This software can enable the user to define security areas and distinguish potential intruders from other alerts caused by weather, lighting conditions or motion associated with vegetation, traffic or animals. This system allows grazing livestock to remain within the plant boundary without alarms being raised. Video analytics software can considerably reduce the rate of security system false alarms.
- **Sensors:** There are a variety of detectors available on the market. These include photoelectric beams, trip wires, passive infrared (PIR), microwave, magnetic and motion sensors, among others. Although having many sensors independently controlled can be the cause of a higher false alarm rate, interlinking them and using digital signal processing (DSP) techniques can reduce this risk and provide a more robust security system. Care should be taken that the chosen system is not triggered by grazing animals.
- **Warning devices:** Simple devices warning of the use of CCTV cameras or monitoring of the site will dissuade most intruders. These can include warning signs, horns installed around the site and pre-recorded warning messages.
- **Security staff:** A permanent guarding station with a security guard often provides the level of security required in an insurance policy. This option is mostly used in particularly remote locations or areas of high crime or vandalism rates. Where armed guards are present and/or where public security forces are assigned to provide asset protection (typically in post-conflict contexts), screening and training of security staff members backed up by operational policies is recommended regarding the appropriate use of force/firearms and appropriate conduct towards workers and community members.
- **Remote alarm centre:** PV plants will transmit data via communication means such as satellite or landline to an alarm centre, usually located in a large town or city and potentially far away from the site. The security system should be monitored 24 hours a day. Any detection that is verified as an intrusion should raise alerts at the local police or security company for further action.

- **Other security measures:** Additional security measures may include:
  - Reducing the visibility of the power plant by planting shrubs or trees at appropriate locations. Care should be taken that these do not shade the PV modules.
  - Anti-theft module mounting bolts may be used and synthetic resin can be applied once tightened. The bolts can then only be released after heating the resin up to 300°C.
  - Anti-theft module fibre systems may be used. These systems work by looping a plastic fibre through all the modules in a string. If a module is removed, the fibre is broken, which triggers an alarm.

7.6.1 QUALITY BENCHMARKS

Some benchmark security features include:

- Metallic fence at least 2m high.
- Video surveillance system, which includes cameras with zooming and remote manipulating capabilities.
- Sensors and/or video analytics software.
- Warning signs.
- Digital video recorder, which records data for a minimum of 12 months.
- Alarm system fitted to the power plant gate, the medium voltage station, metering station and any portable cabins.

7.7 PLANT MONITORING

7.7.1 MONITORING TECHNOLOGY

A monitoring system is an essential part of a PV plant. Monitoring devices are crucial for the calculation of liquidated damages (LDs) and confirmation that the EPC contractor has fulfilled its obligations. Automatic data acquisition and monitoring technology is also essential during the operational phase in order to maintain a high level of performance, reduce downtime and ensure rapid fault detection.

A monitoring system allows the yield of the plant to be monitored and compared with theoretical calculations and raise warnings on a daily basis if there is a performance shortfall. Faults can therefore be detected and rectified before they have an appreciable effect on production. Without a reliable monitoring system it can take many months for a poorly performing plant to be identified. This can lead to unnecessary revenue loss.

The key to a reliable monitoring and fault detection methodology is to have good simultaneous measurements of the solar irradiance, environmental conditions and plant power output. This is achieved by incorporating a weather station on site to measure the plane of array irradiance, module and ambient temperature, and preferably global horizontal irradiance, humidity and wind speed.

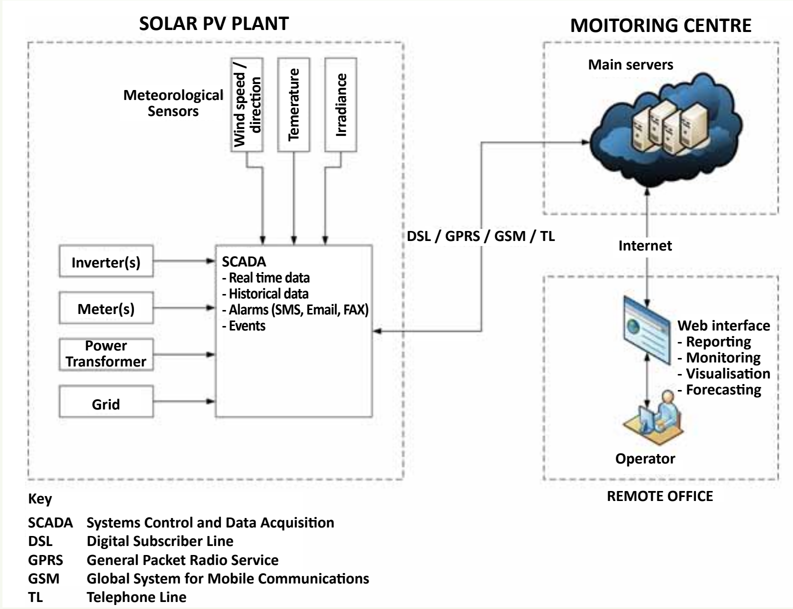
In large-scale solar PV power plants, voltage and current will typically be monitored at the inverter, combiner box or string level, each offering more granularity than the previous. Monitoring at the inverter level is the least complex system to install. However it only offers an overview of the plant's performance, while the other two options, although more expensive, provide more detailed information on the system components' performance and improved fault detection and identification.

Data from the weather station, inverters, combiner boxes, meters and transformers will be collected in data loggers and passed to a monitoring station, typically via Ethernet, CAT5/6, RS485 or RS232 cables. Communication protocols are varied, although the most commonly used worldwide are Modbus, TCP/IP and DNP3. If more than one communications protocol is considered for a monitoring system, protocol converters can be used.

Figure 19 illustrates the architecture of an internet portal-based monitoring system, which may include functionality for:

- **Operations management:** The performance management (either onsite or remote) of the solar PV power plant to enable the monitoring of inverters or strings at the combiner box level.

Figure 19: PV System Monitoring Schematic



- **Alarm management:** Flagging any element of the power plant that falls outside pre-determined performance bands. Failure or error messages can be automatically generated and sent to the power plant service team via fax, email or text message.
- **Reporting:** The generation of yield reports detailing individual component performance, and benchmarking the reports against those of other components or locations.

7.7.2 QUALITY BENCHMARKS

Monitoring systems should be based on commercially available software/hardware that is supplied with user manuals and appropriate technical support.

Depending on the size and type of the plant, minimum parameters to be measured include:

- **Plane of array irradiance and horizontal plane irradiance:** Measured using secondary standard pyranometers with a measurement tolerance within ±2 percent.[46] Plane of array pyranometers are essential for contractually-binding performance ratio (PR) calculations, while horizontal plane pyranometers are useful in order to compare measured irradiation with global horizontal irradiation resource predictions. It is considered best practice to install irradiation sensors at a variety of locations within multi-megawatt plants, while avoiding locations that are susceptible to shading. Table 14 gives a rule of thumb for the number of pyranometers recommended according to the plant capacity.
- **Ambient temperature:** Measured in a location representative of site conditions with accuracy better than ±1°C. Ideally, temperature sensors should be placed next to the irradiation sensors, particularly if the PR at provisional acceptance is calculated using a temperature compensation factor (see Section 9: EPC Contracts).
- **Module temperature:** Measured with accuracy better than ±1°C, PT1000 sensors should be thermally

46 For example, Kipp & Zonen CMP 11, http://www.kippzonen.com/Product/13/CMP-11-Pyranometer#.VBmlTGMgsuc

Table 14: Recommended Number of Pyranometers Depending on Plant Capacity					
Plant DC Capacity (MWp)	< 1	1–5	5–10	10–20	> 20
Number of Plane of Array Pyranometers	0	2	2	3	4
Number of Horizontal Pyranometers	0	0	1	1	1

bonded to the back of the module in a location positioned at the centre of a cell.

- **Array DC voltage:** Measured to an accuracy of within 1 percent.
- **Array DC current:** Measured to an accuracy of within 1 percent.
- **Inverter AC power:** Measured as close as possible to the inverter output terminals with an accuracy of within 1 percent.
- **Power to the utility grid.**
- **Power from the utility grid.**

Measurement of key parameters should be done at one-minute intervals.

7.8 OPTIMISING SYSTEM DESIGN

The performance of a PV power plant may be optimised by a combination of several enabling factors: premium modules and inverters, a good system design with high-quality and correctly-installed components and a good preventative maintenance and monitoring regime leading to low operational faults.

The aim is to minimise losses. Measures to achieve this are described in Table 15. Reducing the total loss increases the annual energy yield and hence the revenue, though in some cases it may increase the cost of the plant. Interestingly, efforts to reduce one type of loss may be antagonistic to efforts to reduce losses of a different type. It is the skill of the plant designer to make suitable compromises that result in a plant with a high performance at a reasonable cost according to the local conditions. The ultimate aim of the designer is to create a plant that maximises financial

Table 15: Performance Optimisation Strategies	
Loss	Mitigating Measure to Optimise Performance
Shading	• Choose a location without shading obstacles. • Ensure that the plant has sufficient space to reduce shading between modules. • Have a robust O&M strategy that removes the risk of shading due to vegetation growth.
Incident angle	• Use anti-reflection coatings, textured glass, or tracking.
Low irradiance	• Use modules with good performance at low light levels.
Module temperature	• Choose modules with an improved temperature coefficient for power at high ambient temperature locations.
Soiling	• Choose modules less sensitive to shading. • Ensure a suitable O&M contract that includes an appropriate cleaning regiment for the site conditions.
Module quality	• Choose modules with a low tolerance or positive tolerance.
Module mismatch	• Sort modules with similar characteristics into series strings where possible. • Avoid partial shading of a string. • Avoid variations in module tilt angle and orientation within the same string.
DC wiring resistance	• Use appropriately dimensioned cable. • Reduce the length of DC cabling.
Inverter performance	• Choose correctly sized, highly efficient inverters.
AC losses	• Use correctly dimensioned cable. • Reduce the length of AC cabling. • Use high-efficiency transformers.
Plant downtime	• Use a robust monitoring system that can identify faults quickly. • Choose an O&M contractor with good repair response time. • Keep spares holdings.
Grid availability	• Install PV plant capacity in areas where the grid is strong and has the potential to absorb PV power.
Degradation	• Choose modules with a low degradation rate and a linear power guarantee.
MPP tracking	• Choose high-efficiency inverters with maximum power point tracking technology on multiple inputs. • Avoid module mismatch.
Curtailment of tracking	• Ensure that tracking systems are suitable for the wind loads to which they will be subjected.

returns by minimising the levelised cost of electricity (LCOE).

7.9 DESIGN DOCUMENTATION REQUIREMENTS

There are a number of minimum requirements that should be included as part of design documentation. These include:

- Datasheets of modules, inverters, array mounting system and other system components.
- Wiring diagrams including, as a minimum, the information laid out in Table 16.
- Layout drawings showing the row spacing and location of site infrastructure.
- Mounting structure drawings with structural calculations reviewed and certified by a licensed engineer.
- A detailed resource assessment and energy yield prediction.
- A design report that will include information on the site location, site characteristics, solar resource, design work, energy yield prediction, and a summary of the results of the geotechnical survey.

Table 16: Annotated Wiring Diagram Requirements

Section	Required Details
Array	• Module type(s). • Total number of modules. • Number of strings. • Modules per string.
PV String Information	• String cable specifications—size and type. • String over-current protective device specifications (where fitted)—type and voltage/ current ratings. • Blocking diode type (if relevant).
Array electrical details	• Array main cable specifications—size and type. • Array junction box locations (where applicable). • DC isolator type, location and rating (voltage/ current). • Array over-current protective devices (where applicable)—type, location and rating (voltage/ current).
Earthing and protection devices	• Details of all earth/bonding conductors—size and connection points. This includes details of array frame equipotential bonding cable (where fitted). • Details of any connections to an existing Lightning Protection System (LPS). • Details of any surge protection device installed (both on AC and DC lines), to include location, type and rating.
AC system	• AC isolator location, type and rating. • AC overcurrent protective device location, type and rating. • Residual current device location, type and rating (where fitted). • Grid connection details and grid code requirements.
Data acquisition and communication system	• Details of the communication protocol. • Wiring requirements. • Sensors and data logging.

Box 5: Example of Poor Design

It is far cheaper and quicker to rectify design faults prior to construction than during or after construction. Therefore, it is vital to apply suitable technical expertise to every aspect of plant design. Should the developer not have all the required expertise in-house, then a suitably experienced technical advisor should be engaged. Regardless of the level of expertise in-house, it is good practice to carry out a full, independent technical due diligence of the design before construction commences. This will be an essential requirement if financing is being sought.

As an example, consider the faults that independent technical consultants identified with a 5MWp project that had been constructed in India in 2010:

- **Foundations:**
  - The foundations for the supporting structures consisted of concrete pillars, cast in situ, with steel reinforcing bars and threaded steel rods for fixing the support structure base plates. This type of foundation is not recommended due to the inherent difficulty in accurately aligning numerous small foundations.
  - Mild steel was specified for the fixing rods. As mild steel is prone to corrosion, stainless steel rods would have been preferable.
- **Support structures:**
  - The support structures were under-engineered for the loads they were intended to carry. In particular, the purlins sagged significantly under the load of the modules. Support structures should be designed to withstand wind loading and other dynamic loads over the life of the project. Extensive remedial work was required to retrofit additional supporting struts.
  - The supporting structure was not adjustable because no mechanism was included to allow adjustment in the positioning of modules. The combination of the choice of foundation type and choice of support structure led to extensive problems when it came to aligning the solar modules to the required tilt angle.
- **Electrical:**
  - String diodes were used for circuit protection instead of string fuses/MCBs. Current best practice is to use string fuses/MCBs, as diodes cause a voltage drop and power loss, as well as a higher failure rate.
  - No protection was provided at the combiner boxes. This meant that for any fault occurring between the array and the DC distribution boards (DBs), the DBs would trip, taking far more of the plant offline than necessary.
  - No-load break switches were included on the combiner boxes before the DBs. This meant it was not possible to isolate individual strings for installation or maintenance.

The design faults listed above cover a wide range of issues. However, the underlying lesson is that it is vital to apply suitable technical expertise on every aspect of the plant design through in-house or acquired technical expertise. Independent technical due diligence should be carried out on the design prior to construction.

Detailed below are checklists of basic requirements and procedures for plant design considerations. They are intended to assist solar PV plant developers during the development phase of a PV project.

PV Module Selection Checklist

- [ ] Supplier identification and track record checked.
- [ ] Minimum certification obtained.
- [ ] Product and power warranty terms and conditions in line with the market standards.
- [ ] Third-party warranty insurance provided (if available).
- [ ] Technology suitable for the environmental conditions (e.g., high temperatures, diffuse irradiation, humidity).
- [ ] Technology suitable for shading conditions (number of bypass diodes).
- [ ] Power tolerance in line with the market standards.

Inverter Selection Checklist

- [ ] Suitable capacity for project size.
- [ ] Compatible with national grid code.
- [ ] Supplier identification and track record checked.
- [ ] Minimum certification obtained.
- [ ] Product supply terms and conditions in line with the market standards.
- [ ] Technology and model suitable for the environmental conditions (e.g., outdoor/indoor, derate at high temperatures, MPP range).
- [ ] Compatible with thin-film modules (transformer or transformerless inverter).
- [ ] Efficiency in line with the market standards.

Transformer Selection Checklist

- [ ] Suitable capacity for project size.
- [ ] Compatibility with the national grid regulations.
- [ ] Supplier identification and track record checked.
- [ ] Minimum certification obtained.
- [ ] Product warranty terms and conditions in line with the market standards.
- [ ] Suitable for the environmental conditions (e.g., outdoor/ indoor, ambient temperature and altitude).
- [ ] Efficiency in line with the market standards.
- [ ] Load/no-load losses in line with market standards.

Mounting Structure Selection Checklist

- [ ] Supplier identification and track record checked.
- [ ] Minimum certification obtained.
- [ ] Product warranty terms and conditions in line with market standards.
- [ ] Suitable for the environmental and ground conditions (thermal expansion, marine atmosphere, soil acidity).

General Design Checklist

- [ ] Tilt angle and orientation of the PV array suitable for the geographical location.
- [ ] Inter-row distance suitable for the site.
- [ ] Shading from nearby objects considered and suitable buffer zone included.
- [ ] PV string size suitable for the inverter under the site environmental conditions.
- [ ] Inverter size suitable for the PV array size (power ratio and inverter MPP range).
- [ ] Transformer correctly sized.
- [ ] Combiner boxes (IP rating) suitable for the environmental conditions.
- [ ] DC and AC cables sized correctly.
- [ ] LV and HV protection equipment (fuses, switchgears, and circuit breakers) correctly sized.
- [ ] Suitable earthing and lightening protection designed for site specific conditions.
- [ ] Civil works (foundations, drainage) suitable for environmental risks.
- [ ] Monitoring system in line with market standards.
- [ ] Security system in line with market standards and accepted by insurance provider.

8 Permits, Licensing and Environmental Considerations

8.1 PERMITS, LICENSING AND ENVIRONMENT OVERVIEW

Permitting and licensing requirements for solar PV power plants vary greatly from country to country and within different country regions. It is important therefore to establish with the appropriate planning/government authority the relevant laws/regulations and associated permits that will be required for the project.

In order to deliver a project which will be acceptable to international lending institutions (e.g., to enable finance to be provided), environmental and social assessments should be carried out in accordance with the requirements of the key international standards and principles, namely the Equator Principles and IFC's Performance Standards (IFC PS). National standards should also be observed which may be more stringent than lender requirements.

A checklist of the basic requirements and procedures for permitting and licensing is at the end of Chapter 8.

The following sections describe permitting and licensing requirements.

8.2 PERMITTING AND LICENSING REQUIREMENTS

Permitting and licensing procedures vary depending on plant location and size. For small PV installations, permitting regimes are often simplified and obtained at a local authority level. However large-scale plants can have more extensive requirements that are determined at a national or regional level. The key permits, licences and agreements typically required for renewable energy projects include:

- Land lease agreement.
- Planning/land use consents.
- Building permits.

Permitting and licensing procedures vary depending on plant location and size. For small PV installations, permitting regimes are often simplified and obtained at a local authority level. However large-scale plants can have more extensive requirements that are determined at a national or regional level.

- Environmental permits.
- Grid connection application.
- Operator/generation licences.

In addition to the key permits, licences and agreements listed above, under the FiT requirements or other support, it may be necessary for a developer to register as a "qualified/privileged/special renewable energy generator" to obtain support. Depending on the country in question, there may also be a requirement for the developer to demonstrate compliance with these requirements.

The sequence of requirements can vary from country to country and it is recommended that an early meeting is held with the relevant planning/government authority to establish and confirm relevant laws and associated permits that will be necessary for the project. The timescales for obtaining relevant permissions should also be ascertained at an early date, as many permissions will be required to be in place prior to construction of the plant.

8.2.1 LAND LEASE AGREEMENT

If the land is not privately owned, an agreement to procure or lease the necessary land from the land owner is a key requirement. The land lease agreement must be secured as a first step to enable the project to be developed on the required land. This does not apply to rooftop locations. A lease agreement typically lasts for 25 years, often with a further extension clause.

The leases and option agreements should include restrictions on developments to be installed on land adjacent to the site that could have an effect on the performance of the solar PV arrays. Furthermore, the areas of land required for new access roads also need to be taken into consideration.

8.2.2 PLANNING AND LAND USE CONSENTS

All relevant planning consents/land-use authorisations must be in place prior to the construction of a project. Consenting requirements vary widely in different countries and regions and also depend on the size of the plant. Advice on planning-consent requirements in the project area can be obtained from the local planning department, relevant government department or from an experienced consultant. The type of information that needs to be considered includes:

- Planning consents/permits and land-use authorisations required to construct and operate a solar renewable energy development.
- Any standard planning restrictions for the area of the development (for example, land-use zoning regulations).
- Supporting information required to be submitted with planning application (location/layout/elevation plans, description of project, access details, environmental assessments, etc.—as required by the relevant authority).
- Method of submission (online or via the planning department office).
- Timescales for submission and determination.
- Process for making amendments to consent at a later date.

A permit from the roads authority may also be necessary, depending on the works required.

8.2.3 BUILDING PERMITS

Some countries may require a separate building permit to be obtained, depending on the nature of the project. Where this is required, it should be noted that the consenting authority may differ from the authority issuing the planning/land-use permits.

Before a building permit is obtained, it may be necessary to have other required permits in place or to complete a change in land-use categorisation. As above, consultation at an early stage with the relevant authority is recommended to establish country- and locally-specific requirements.

8.2.4 ENVIRONMENTAL PERMITS

All necessary environmental permits, licences and requirements must be obtained prior to commencing construction. Environmental permits are country- and project-specific. Consultation with the relevant environmental agencies and departments should be undertaken to determine the requirement for any environmental permits relevant to the project. A specialist environmental consultant can also provide advice on the specific requirements.

Environmental permits and licences that may be required include:

- Environmental impact assessment (EIA) permit.
- Endangered/protected species licence.
- Agricultural protection permits.
- Historic preservation permits.
- Forestry permits.

Further detail on environmental considerations is detailed in Section 8.3 below.

8.2.5 GRID CONNECTION APPLICATION

A grid connection permit is required for exporting power to the network, which normally specifies the point of connection and confirms the voltage-level that will be applied to that connection. The grid connection application should be submitted to the relevant transmission or distribution utility company for the project.

The permit must be in place well in advance of the date that first export to the grid is required in order to allow sufficient timescales for associated works to be completed. Solar PV power plants will need to meet the requirements of the grid company that operates the network onto which they will export power. This is discussed further in Section 10.4.

8.2.6 ELECTRICITY GENERATION LICENCE

The operator of an electricity generating facility is required to hold a generating licence, which permits an operator to generate, distribute and supply electricity.

Developers should be aware of the country-specific requirements and timeframes required for obtaining a generating licence. For example, in many European and Asian countries, an electricity generation licence is obtained after construction of the plant, while in some African countries the licence is required early in the project development process.

8.3 ENVIRONMENTAL AND SOCIAL REQUIREMENTS

Development of any solar project will have both environmental and social implications. The scale and nature of these impacts depends on a number of factors including plant size, location, proximity to settlements and applicable environmental designations. These issues are discussed further in the following sections.

8.3.1 APPLICABLE STANDARDS

In order to deliver a project that will be acceptable to international lending institutions (e.g., to enable finance to be provided), work should be carried out in accordance with the requirements of the key standards and principles set out in the following sections.

8.3.1.1 Equator Principles

The Equator Principles[47] (EP) consists of ten principles relating to environmental and social assessment and management. In addition, they include reporting and monitoring requirements for Equator Principles Financial Institutions (EPFIs). The EP set a financial industry benchmark that have been adopted by financial institutions for determining, assessing and managing environmental and social risk in projects.

There are currently 78 EPFIs in 34 different countries that have officially adopted the EP standards.[48] These institutions will not provide financing to clients that are unwilling or unable to comply with the EPs. Some of these

47 World Bank Group, "The Equator Principles: A financial industry benchmark for determining, assessing and managing environmental and social risk in projects," 2013. http://www.equator-principles.com/resources/equator_principles?III.pdf (accessed June 2014).

48 World Bank Group, "The Equator Principles: Members & Reporting," http://www.equator-principles.com/index.php/members-reporting

lenders, such as the European Bank for Reconstruction and Development (EBRD), may have additional standards to which borrowers must adhere. Further information on financing requirements can be found in Section 14 (Financing Solar PV Projects).

The EPs apply globally and to all industry sectors, hence their relevance to the solar industry. The ten EPs address the following topics:

- EP1 - Review and Categorisation
- EP2 - Environment and Social Assessment
- EP3 - Applicable Environmental and Social Standards
- EP4 - Environmental and Social Management System and Equator Principles Action Plan
- EP5 - Stakeholder Engagement
- EP6 - Grievance Mechanism
- EP7 - Independent Review
- EP8 - Covenants
- EP9 - Independent Monitoring and Reporting
- EP10 - Reporting and Transparency

8.3.1.2 IFC Performance Standards on Social and Environmental Sustainability

As set out in EP3, countries not designated as High Income Organization of Economic Cooperation and Development (OECD) countries should apply the social and environmental sustainability standards laid down by the IFC.[49] These standards have been developed for the IFC's own investment projects but have set an example for private companies and financial institutions worldwide.

The IFC PS relate to the following key topics:

- Performance Standard 1: Assessment and Management of Environmental and Social Risks and Impacts
- Performance Standard 2: Labour and Working Conditions
- Performance Standard 3: Resource Efficiency and Pollution Prevention
- Performance Standard 4: Community Health, Safety and Security
- Performance Standard 5: Land Acquisition and Involuntary Resettlement
- Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources
- Performance Standard 7: Indigenous Peoples
- Performance Standard 8: Cultural Heritage

Compliance with the IFC performance standards will not only ensure a socially and environmentally sustainable project but will also facilitate the sourcing of finance for a project.

8.3.1.3 World Bank Group General Environmental Health and Safety (EHS) Guidelines

The General EHS Guidelines is a technical reference document containing general and industry-specific examples of good international industry practice. The General EHS Guidelines contain guidance on environmental, health, and safety issues that are applicable across all industry sectors.

8.3.1.4 Local, National and International Environmental and Social Legislation and Regulations

Environmental and social legislation and regulations vary between countries and specific regions; however the EP and IFC PS set the minimum acceptable standard for project developments worldwide.

A large number of countries have national legislative requirements that are on par with or higher than the EP/IFC standards. If national requirements are more onerous, project developers should review and adhere to these standards.

49 IFC, "Performance Standards on Environmental and Social Sustainability," 2012, http://www.ifc.org/wps/wcm/connect/c8f524004a73daeca09afdf998895a12/IFC_Performance_Standards.pdf?MOD=AJPERES (accessed June 2014).

In countries where environmental and social legislation requirements are less demanding, a project must be developed in accordance with these requirements in addition to the lender's standards, which must as a minimum meet the EP/IFC standards.

8.3.2 ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT

Projects may be required to carry out an initial scoping or a full Environmental (and Social) Impact Assessment (EIA or ESIA), depending on national regulatory requirements.

Relevant in-country environmental and social impact assessment regulations and legislation should be reviewed in the first instance to determine country-specific requirements, alongside the requirements of the EPs and IFC PS. In general, in order to attract financing and meet regulatory requirements, a screening study variously referred to as an Initial Environmental Examination (IEE) or Environmental Scoping Study needs to be commissioned involving an independent environmental consultancy to establish the nature and scale of environmental impacts and extent of assessment required. Once the level of potential impacts and site sensitivity has been determined, it can then be confirmed if a full environmental and social assessment is required.

If deemed necessary, the likely environmental effects of the proposed development should be considered as part of a full ESIA and based upon current knowledge of the site and the surrounding environment. This information will determine what specific studies are required. The developer should then assess ways of avoiding, reducing or offsetting any potentially significant adverse effects as described in IFC PS 1. The studies will also provide a baseline that can be used in the future to monitor the impact of the project. Note that only impacts deemed to be "significant" need to be considered as part of an ESIA.

Key environmental considerations for solar PV power plants are detailed below. Note that the list of considerations is not exhaustive. Environmental and social topics for assessment should be determined on a project by project basis. It is recommended that the environmental assessment should be carried out by an experienced independent consultant familiar with conducting Environmental & Social Impact Assessment (ESIA) studies.

8.3.2.1 Construction Phase Impacts

Construction activities lead to temporary air emissions (dust and vehicle emissions), noise related to excavation, construction and vehicle transit, solid waste generation and wastewater generation from temporary building sites and worker accommodation. In addition, occupational health and safety (OHS) is an issue that needs to be properly managed during construction in order to minimize the risk of preventable accidents leading to injuries and/or fatalities—there have been a number of fatal incidents in recent history at solar power plant construction sites around the world. Proper OHS risk identification and management measures should be incorporated in every project's management plan and standard EPC contractual clauses. Where projects have construction worker-accommodation camps, accommodation should meet basic requirements in relation to space, water supply, adequate sewage and garbage disposal, protection against heat, cold, damp, noise, fire and disease-carrying animals, storage facilities, lighting and (as appropriate to size and location) access to basic medical facilities or personnel.

8.3.2.2 Water Usage

Although water use requirements are typically low for solar PV plants, Concentrated Solar Power (CSP) plants may have higher requirements and clusters of PV plants may have a high cumulative water use requirement in an arid area where local communities rely upon scarce groundwater resources. In such scenarios, water consumption should be estimated and compared to local water abstraction by communities (if any), to ensure no adverse impacts on local people. O&M methods in relation to water availability and use should be carefully reviewed where risks of adverse impacts to community usage are identified.

8.3.2.3 Land Matters

As solar power is one of the most land-intensive power generation technologies, land acquisition procedures and in particular the avoidance or proper mitigation of involuntary land acquisition/resettlement are critical to the success of the project(s). This includes land acquired either temporarily or permanently for the project site itself and any associated infrastructure—i.e., access roads, transmission lines, construction camps (if any) and switchyards. If involuntary land acquisition is unavoidable, a Resettlement Action Plan (dealing with physical displacement and any associated economic displacement) or Livelihood Restoration Plan (dealing with economic displacement only) is typically required by financiers to make the project bankable. This is often a crucial issue with respect to local social license to operate, and needs to be handled with due care and attention by suitably qualified persons.

8.3.2.4 Landscape and Visual Impacts

Key impacts can include the visibility of the solar panels within the wider landscape and associated impacts on landscape designations, character types and surrounding communities. Common mitigation measures to reduce impacts can include consideration of layout, size and scale during the design process and landscaping/planting in order to screen the modules from surrounding receptors. Note that it is important that the impact of shading on energy yield is considered for any new planting requirements.

Solar panels are designed to absorb, not reflect, irradiation. However, glint and glare should be a consideration in the environmental assessment process to account for potential impacts on landscape/visual and aviation aspects.

8.3.2.5 Ecology and Natural Resources

Potential impacts on ecology can include habitat loss/fragmentation, impacts on designated areas and disturbance or displacement of protected or vulnerable species. Receptors of key consideration are likely to include nationally and internationally important sites for wildlife and protected species such as bats, breeding birds and reptiles. Ecological baseline surveys should be carried out where potentially sensitive habitat, including undisturbed natural habitat, is to be impacted, to determine key receptors of relevance to each site. Mitigation measures can include careful site layout and design to avoid areas of high ecological value or translocation of valued ecological receptors. Habitat enhancement measures could be considered where appropriate to offset adverse impacts on sensitive habitat at a site, though avoidance of such habitats is a far more preferable option (as per the site selection discussion in Section 6.3).

8.3.2.6 Cultural Heritage

Potential impacts on cultural heritage can include impacts on the setting of designated sites or direct impacts on below-ground archaeological deposits as a result of ground disturbance during construction. Where indicated as a potential issue by the initial environmental review/scoping study, field surveys should be carried out prior to construction to determine key heritage and archaeological features at, or in proximity to, the site. Mitigation measures can include careful site layout and design to avoid areas of cultural heritage or archaeological value and implementation of a 'chance find' procedure that addresses and protects cultural heritage finds made during a project's construction and/or operation phases.

8.3.2.7 Transport and Access

The impacts of transportation of materials and personnel should be assessed in order to identify the most appropriate transport route to the site while minimizing the impacts on project-affected communities. The requirement for any oversized vehicles/abnormal loads should be considered to ensure access is appropriate. On-site access tracks should be permeable and developed to minimise disturbance to agricultural land. Where project construction traffic has to traverse local communities, traffic management plans should be incorporated into the environmental and social management plan and EPC requirements for the project.

8.3.2.8 *Drainage/Flooding*

A review of flood risk should be undertaken to determine if there are any areas of high flood risk associated with the site. Existing and new drainage should also be considered to ensure run-off is controlled to minimise erosion.

8.3.3 CONSULTATION AND DISCLOSURE

It is recommended that early stage consultation is sought with key authorities, statutory bodies, affected communities and other relevant stakeholders.[50] This is valuable in the assessment of project viability, and may guide and increase the efficiency of the development process. Early consultation can also inform the design process to minimise potential environmental impacts and maintain overall sustainability of the project.

The authorities, statutory bodies and stakeholders that should be consulted vary from country to country but usually include the following organisation types:

- Local and/or regional consenting authority.
- Government energy department/ministry.
- Environmental agencies/departments.
- Archaeological agencies/departments.
- Civil aviation authorities/Ministry of Defence (if located near an airport).
- Roads authority.
- Health and safety agencies/departments.
- Electricity utilities.
- Military authorities.

Community engagement is an important part of project development and should be an on-going process involving the disclosure of information to project-affected communities.[51] The purpose of community engagement is to build and maintain over time a constructive relationship with communities located in close proximity to the project and to identify and mitigate the key impacts on project-affected communities. The nature and frequency of community engagement should reflect the project's risks to, and adverse impacts on, the affected communities.

8.3.4 ENVIRONMENTAL AND SOCIAL MANAGEMENT PLAN (ESMP)

Whether or not an ESIA or equivalent has been completed for the site, an ESMP should be compiled to ensure that mitigation measures for relevant impacts of the type identified above (and any others) are identified and incorporated into project construction procedures and contracts. Mitigation measures may include, for example, dust suppression during construction, safety induction, training and monitoring programs for workers, traffic management measures where routes traverse local communities, implementation of proper waste management procedures, introduction of periodic community engagement activities, implementation of chance find procedures for cultural heritage, erosion control measures, fencing off of any vulnerable or threatened flora species, and so forth. The ESMP should indicate which party will be responsible for (a) funding, and (b) implementing each action, and how this will be monitored and reported on at the project level. The plan should be commensurate to the nature and type of impacts identified.

50 IFC, "Performance Standards on Environmental and Social Sustainability," 2012, Performance Standard 1, paragraphs 25-31, http://www.ifc.org/wps/wcm/connect/115482804a0255db96fbffd1a5d13d27/PS_English_2012_Full-Document.pdf?MOD=AJPERES (accessed June 2014).

51 IFC, "Stakeholder Engagement: A Good Practice Handbook for Companies Doing Business in Emerging Markets," 2007, http://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/ifc+sustainability/publications/publications_handbook_stakeholderengagement__wci__1319577185063 (accessed June 2014).

Box 6: Permits, Licensing and Environmental Considerations

There are many types of permits required for a multi-megawatt solar PV power plant, which in accordance with country requirements will vary in terms of purpose of requirements. Shown below is an indicative, non-exhaustive list of the key permits that were required to be obtained in South Africa for a ground-mounted fixed-tilt PV plant. These permits apply specifically to the case study; permitting requirements differ across other regions of South Africa and especially in different countries. Some of the case study's permits were issued with condition-requirements including time limits for commencing and rules for the processes of construction, operation and decommissioning. The majority of these permits were applied for and in place prior to the start of construction, as is deemed best practice.

An Environmental Impact Report was compiled for the project under the required Environmental Impact Assessment (EIA) Regulations and Natural Environmental Management Act. The EIA process was used to inform the preferred layout for the project in order to reduce the potential for significant environmental impacts. Elements of the project design thus reduced the potential for impact on water resources and included a visual buffer zone from nearby roads, railway lines and farms, in addition to avoiding sensitive areas/heritage resources. Mitigation measures proposed to further reduce impacts during construction included:

- Pre-construction ecological checks.
- Rehabilitation/re-vegetation of areas damaged by construction activities.
- Implementation of soil conservation measures, such as stockpiling topsoil or gravel for remediation of disturbed areas.
- Bunding of fuel, oil and used storage areas.

Implementing these mitigation measures ensured that the only significant impacts likely to arise from the project would be those associated with visual impacts.

International lending standards (Equator Principles and IFC Performance Standards) were also applicable, such that this project required an appropriate degree of environmental and social assessment to meet these standards. A principle finding of the environmental assessment work carried out to meet these international criteria was a recommendation for a bird breeding survey in order to assess fully the project impacts upon the population of a species of conservation concern. This recommendation was identified following the completion of the EIA, highlighting the importance of the consideration of Equator Principles and IFC Performance Standards alongside EIA preparation from the very outset of the project. This will help ensure reaching a standard that is acceptable to lenders.

The following table provides the key permits that were required in order to develop the project.

Permit	Authority	Requirements
Land-use Re-zoning	Relevant Municipality	• Standard condition requirements
Environmental Authorisation	Department of Environmental Affairs	30 condition requirements that included: • Work must commence within a period of five years from issue. • Requirement to appoint an independent Environmental Control Officer (ECO) for the construction phase of development to ensure all mitigation/rehabilitation measures are implemented.
Heritage Resources	South Africa Heritage Resources Agency (SAHRA)	SAHRA recommendations were incorporated into the condition requirements of the Environmental Authorisation to include avoidance of areas with important heritage resources.
Mineral Resources	Department of Mineral Resources	No condition requirements.
Aviation Consent	Civil Aviation Authority	No condition requirements.
Water Use Licence	Department of Water Affairs	No condition requirements.
Building Permit	Relevant Municipality	No condition requirements.

Permitting, Licensing and Environmental and Social Considerations Checklist

The checklist below details the basic requirements and procedures to assist developers with the permitting and licensing aspects of a project.

- [ ] Land lease agreement obtained.
- [ ] Advice sought on planning/consenting/permitting from local regulatory authorities and any environmental assessments required.
- [ ] Initial Environmental Examination (IEE) completed.
- [ ] Environmental and social assessments carried out (as required).
- [ ] Relevant supporting documents for consent/licensing applications completed (including environmental assessment reports, access details, drawings and plans).
- [ ] Community consultation undertaken.
- [ ] Consents, licences and permit applications completed.
- [ ] Grid connection application completed.
- [ ] Electricity generation licence obtained.

EPC Contracts

9

While multiple contracts could be signed to build a PV plant, the most common approach is a single EPC contract. Often, a standard form ("boilerplate contract") is used.

9.1 EPC CONTRACTS OVERVIEW

Engineering, procurement and construction (EPC) contracts are the most common form of contract for the construction of solar PV power plants. Under an EPC contract, a principal contractor is engaged to carry out the detailed engineering design of the project, procure all the equipment and materials necessary, and then construct and commission the plant for the client. In addition, the contractor commits to delivering the completed plant for a guaranteed price and by a guaranteed date and furthermore that the completed plant must perform to a guaranteed level. Failure to comply with any of these requirements will usually result in the contractor having to pay financial compensation to the owner in the form of liquidated damages (LDs). See the checklist at the end of the chapter highlighting the basic requirements that a developer may wish to consider during the EPC contracting process.

The following sections describe the most important features of an EPC contract. A full EPC contract term sheet detailing key contractual terms specific to solar PV power plant construction is presented in Annex 1.

9.2 BASIC FEATURES OF AN EPC CONTRACT

The EPC contract for any project-financed solar PV power plant will typically be held between a project company (the owner) and the EPC contractor (the contractor).

It is common practice to use a standard form of contract (sometimes referred to as a "boilerplate contract") as a template and basis for the EPC contract. The following standard form of contracts are considered good options for delivery of solar PV power plants on a turnkey basis:

- The Conditions of Contract for EPC/Turnkey Project First Edition, 1999, published by the Federation Internationale des Ingenieurs-Conseils (FIDIC).

- The Institution of Engineering and Technology's Model Form of General Conditions of Contract (MF/1 Rev. 4)

The key clauses for a project owner in any construction contract are those that relate to time, cost and quality. In the case of solar PV power plant construction, a strong EPC contract will address the following areas:

- A "turnkey" scope of work.
- A fixed completion price.
- A fixed completion date.
- Restrictions on the ability of the contractor to claim extensions of time and additional costs.
- A milestone payment profile that is suitably protective to the owner and based upon the completion of pre-defined sub-tasks.
- Plant PR guarantees.
- LDs for both delay and performance.
- Financial security from the contractor and/or its parent organisation.
- A defects warranty.

Each of these areas is discussed further below with specific reference to solar PV power plants.

9.3 SCOPE OF WORK

The benefit of an EPC contract to a plant owner is that the contractor assumes full responsibility for all design, engineering, procurement, construction, commissioning and testing activities. Given this transfer of risk, the scope of work detailed within the EPC contract should be sufficiently prescriptive to ensure that all key supply and engineering tasks relating to the construction of a solar PV power plant have been adequately considered and specified.

The contractor's scope of work should include all supervision, management, labour, plant equipment, temporary works and materials required to complete the works, including:

- Plant design.
- PV modules.
- Inverters.
- Mounting structures, including piled or ballasted foundations.
- DC cabling.
- AC cabling.
- Switchgear.
- Transformers.
- Grid connection interface.
- Substation building.
- Earthing and lightning protection.
- Metering equipment.
- Monitoring equipment.
- Permanent security fencing.
- Permanent security system.
- Temporary onsite security during construction.
- Temporary and permanent site works, including provision of water and power.
- Permanent access tracks (both internal and external).
- Site drainage.
- Plant commissioning.
- Handover documentation (including as-built drawings, O&M manual and commissioning certificates).
- Spare parts package.

All technical requirements should be fully specified within a schedule to the contract. These should be suitably prescriptive and unambiguous. The more detailed and accurate the scope of work, the lower the risk that requests for variation will be made by the contractor during the construction phase. The contract should also clearly define terminal points, or points that designate where the contractor's scope of work ends.

9.4 PRICE AND PAYMENT STRUCTURE

On signing of the contract, the contractor commits to delivering the works for a fixed price. The contract should make it explicitly clear that at the time of signing, the contractor is satisfied as to the correctness and sufficiency of the contract price to deliver the works in line with the contractually agreed specifications.

The contract price should cover all of the contractor's obligations under the contract and all items necessary for the proper design, execution and completion of the works. The owner should not be required to increase the contract price, other than in accordance with the express provisions of the contract.

During the construction phase, payment will typically be made to the contractor by way of milestones relating to the completion of individual work items. The payment schedule should be fair and reasonable for both parties and should allow the contractor to remain "cash neutral" throughout the build process, as the contractor will be paying the sub-contractors and equipment providers on a regular basis. Payment milestones should be drafted to be clear, measureable, and made on completion (rather than commencement) of the individual scope items.

Any advance payment made to the contractor on signing of the contract should be accompanied by an advance payment guarantee, usually in the form of a bond held within a bank that can be drawn upon in the event of contractor default or insolvency. The value of each milestone should roughly reflect the value of the completed works. It is normal that approximately 5-10 percent of the contract value should be held back until handover of the works (Provisional Acceptance) has been achieved.

An example payment schedule is shown in Table 17.

Table 17: Typical EPC Payment Schedule

Payment	Payment Due Upon	Percent of Contract Price
1	Advance payment (commencement date)	10-20
2	Civil works completed	10-20
3	Delivery of components to site (usually on a pro-rata basis)	40-60
4	Modules installed	5-15
5	Grid connection achieved (energisation)	5-15
6	Mechanical completion	5-10
7	Provisional acceptance—plant taken over	5-10

9.5 COMPLETION AND HANDOVER OF THE PLANT

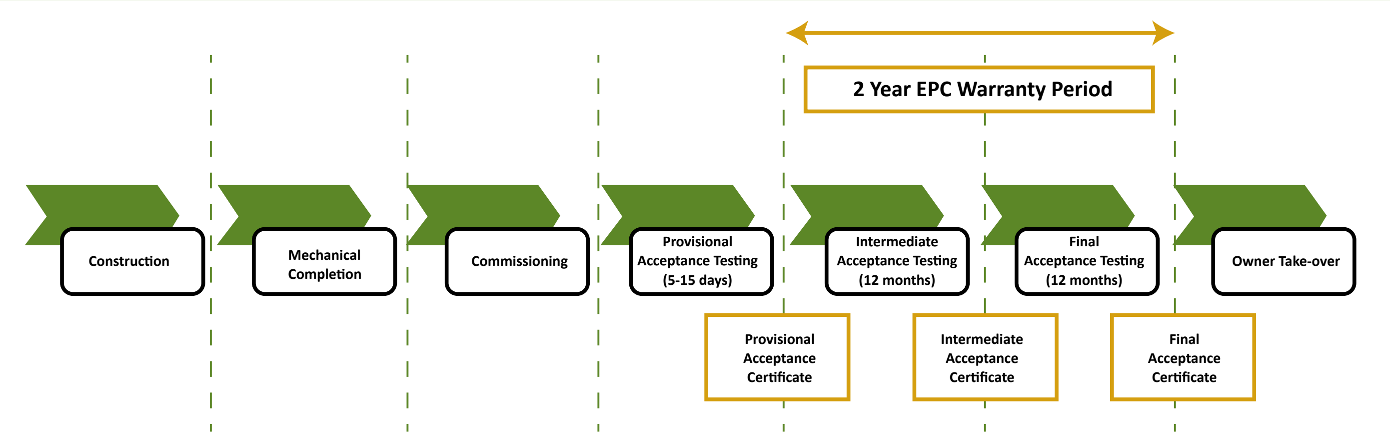
The contract should clearly outline the criteria for completing the contractor's scope of work and therefore when handover of the completed plant from contractor to owner can occur. Until this time, the contractor remains fully responsible for the site and construction activities. Completion typically takes the form of a number of acceptance tests and inspections to be conducted by the owner or an independent third party that demonstrates that the plant has been installed and is performing as per the contractually agreed specifications. The requirements in these areas are generally detailed in a dedicated testing and commissioning schedule.

A diagram outlining key completion events occurring during a solar PV plant construction project (in chronological order from left to right) is shown in Figure 20. These are described further below.

9.5.1 *GUARANTEED COMPLETION DATE*

The contract should include a guaranteed completion date, which is typically either specified as a fixed date or as a fixed period after commencement of the contract. The actual works stage to which the guaranteed completion date relates will be project-specific, and this may be driven by a country's regulatory regime as well as the date that projects become eligible for receiving tariff support. For example, the guaranteed completion date could coincide with the date the plant is scheduled to be connected to the local electricity grid, commissioned or is ready to be handed over to the owner. The key point is that the owner needs to be certain as to what date the plant

Figure 20: Typical EPC Construction Phase and Handover Protocol



will be exporting to the grid and therefore generating a return on the investment. Inability to meet the expected completion date for beginning to export power to the grid has important implications from a regulatory or financial perspective.

To mitigate the risk of the owner suffering financial loss resulting from the contractor failing to deliver a completed plant to the agreed timetable, the contract should include a provision for claiming financial compensation ("liquidated damages" or LDs) from the contractor. LDs should be sized to be a genuine pre-estimate of the loss or damage that the owner will suffer if the plant is not completed by the target completion date. Delay LDs are usually expressed as a rate per day that represents the estimated lost revenue for each day of delay. For a solar PV project, this is a relatively straightforward calculation and can be based upon an energy yield estimate for the completed plant utilising a long-term solar irradiation dataset for the project location.

If there is potential for the owner to suffer additional financial losses beyond lost revenue resulting from delay (perhaps due to the presence of a tariff reduction date) then provisions addressing the owner's right to collect LDs for any such losses should also be included in the contract.

9.5.2 *MECHANICAL COMPLETION*

Mechanical completion of a project refers to the stage whereby all principal sub-components forming the final power plant have been installed and are mechanically and structurally complete. At such a time, it would be advisable for the owner or a third party independent of the contractor to inspect the works in order to compile an initial list of construction defects (commonly referred to as a "punch list" or "snagging list").

Mechanical completion allows for commissioning activities to commence.

9.5.3 *COMMISSIONING*

Commissioning should be considered throughout the course of the construction phase, however, most of the commissioning activities will occur following mechanical completion when the system is ready to be energised.

The commissioning process certifies that the owner's requirements have been met, the power plant installation is complete and the power plant complies with grid and safety requirements. Successful completion of the commissioning process is crucial to achieving provisional acceptance, the process of handover of the plant from contractor to owner.

Commissioning should prove three main criteria:

1. The power plant is structurally and electrically safe.
2. The power plant is sufficiently robust (structurally and electrically) to operate for the specified lifetime.
3. The power plant operates as designed and its performance falls in line with pre-determined parameters.

Critical elements of a PV power plant that require commissioning include:

1. PV module strings.
2. Inverters.
3. Transformers.
4. Switchgear.
5. Lightning protection systems.
6. Earthing protection systems.
7. Electrical protection systems.
8. Grid connection compliance protection and disconnection systems.
9. Monitoring systems (including meteorological sensors).
10. Support structure and tracking systems (where employed).
11. Security systems.

9.5.3.1 Typical Commissioning Tests

Prior to connecting the power plant to the grid, electrical continuity and conductivity of the plant's various sub-components should be thoroughly checked by the contractor (or specialist electrical subcontractor). Once mechanically and electrically complete, the following tests should be conducted on all module strings and on the DC side of the inverters:

- **Polarity Check:** The polarity of all DC cables should be checked. This is one of the simplest and most important safety commissioning tests. Several rooftop fires involving PV systems have been traced back to reverse polarity.
- **Open Circuit Voltage (V_{oc}) Test:** This test checks whether all strings are properly connected and whether all modules are producing the voltage level as per the module data sheet. The V_{oc} of each string should be recorded and compared with temperature-adjusted theoretical values. For plants with multiple identical strings, voltages between strings should be compared to detect anomalies during stable irradiance conditions. Values from individual strings should fall within 5 percent of each other.
- **Short Circuit Current Test (I_{sc}):** This test verifies whether all strings are properly connected and the modules are producing the expected current. The I_{sc} of each string should be recorded and compared with temperature-adjusted theoretical values. For plants with multiple identical strings, voltages between strings should be compared to detect anomalies during stable irradiance conditions. Values from individual strings should fall within 5 percent of each other.
- **Insulation Resistance Test:** The insulation resistance of all DC and AC cabling installed should be tested with a megohmmeter. The purpose of the test is to verify the electrical continuity of the conductor and verify the integrity of its insulation.
- **Earth Continuity Check:** Where protective or bonding conductors are fitted on the DC side, such as bonding of the array frame, an electrical continuity test should be carried out on all such conductors. The connection to the main earthing terminal should also be verified.

After the above commissioning tests have been successfully completed and the correct functioning and safe operation of subsystems have been demonstrated, commissioning of the inverters may commence. The inverter manufacturer's directions for initial start-up should always be adhered to.

9.5.3.2 Grid Connection Interface

Grid connection should only be performed once all DC string testing has been completed. It is likely that the distribution or transmission system operator will wish to witness the connection of the grid and/or the protection relay. Such a preference should be agreed in advance as part of the connection agreement.

The grid connection agreement often stipulates certain requirements, such as electrical protection, disconnection and fault, to which the solar PV power plant is required to adhere. Usually, these conditions need to be met and demonstrated before commissioning the grid connection interface and energisation of the plant.

9.5.3.3 General Commissioning Recommendations

Commissioning activities should commence following mechanical completion of the plant's various sub-components or, where appropriate, sequentially as module strings are connected. One exception to this rule is for power plants employing modules that require a settling-in period, such as thin-film amorphous silicon (a-Si) modules. In this case, performance testing should begin once the settling-in period has been completed and the modules have undergone initial degradation.

Since irradiance has an impact on performance, commissioning should be carried out under stable sky conditions and ideally at irradiance levels above 500W/m^2. The temperature of the cells within the modules should be recorded in addition to the irradiance and time during all testing.

Commissioning activities should incorporate both visual inspection and functional testing. Such testing should be conducted by experienced and specialist organisations, typically sub-contractors to the EPC contractor.

The testing outlined in this section does not preclude local norms, which will vary from country to country.

Test results should be recorded as part of a signed-off commissioning record. While the contractor would be expected to carry out these tests, it is important that the owner is aware of them and makes sure that the required documentation is completed, submitted and recorded.

A useful reference for commissioning of PV systems can be found in IEC standard 62446:2009 *Grid connected photovoltaic systems—Minimum requirements for system documentation, commissioning tests and inspection*.

9.6 PROVISIONAL ACCEPTANCE

Provisional acceptance is a common term used to refer to the stage at which the contractor has complied with all of its construction-related obligations and the plant is ready to be handed over to the owner. The criteria for achieving provisional acceptance should be clearly outlined in the contract and may include:

- Mechanical completion having taken place in accordance with the agreed technical specification and the plant being free from defects (other than non-critical punch list items).
- The aggregate value of the punch list items does not exceed a pre-determined value (typically 1–2 percent of the contract price).
- Grid connection and energisation of the plant have been achieved.
- All commissioning tests have been successfully completed.
- The provisional acceptance performance ratio (PR) test has been passed.
- All equipment and sub-contractor warranties have been assigned to the project company.
- All handover documentation is in place and hard and soft copies provided to the owner.
- Operation and maintenance training of the owner's personnel has taken place.
- Any delay or performance-related liquidated damages (LDs) incurred by the contractor during the construction phase have been paid to the owner.
- Any performance security or bond required during the EPC warranty period has been delivered to the owner.

Once provisional acceptance has been achieved, the owner would typically be obliged to make the final milestone payment to the contractor, at which point 100 percent of the contract value would have been paid.

The provisional acceptance date would also mark the commencement of the contractor's EPC warranty period, which commonly lasts for 24 months.

9.6.1 PERFORMANCE RATIO TESTING

Prior to granting provisional acceptance, the owner needs confirmation that the completed plant will perform in line with the contractually agreed criteria (in terms of output, efficiency and reliability). The industry standard for achieving this within solar EPC contracts is through testing of the plant's PR.

A standard PR test period at the stage of provisional acceptance would be for a minimum of five consecutive days (commonly up to 15 days) of continuous testing. It is desirable to test plant efficiency and reliability over a range of meteorological conditions.

Calculation of the plant PR is determined using the contractually agreed formulae. Attempting to predict the plant performance during varying environmental conditions experienced over the years with just several days of testing is a complex task and different methodologies are used (e.g., temperature compensation or seasonal adjustment). For this reason, an independent technical advisor is often employed to draft the formulae defining the provisional acceptance performance tests.

The PR measured over the test period should be compared against the guaranteed value stated in the contract. If the measured PR exceeds the guaranteed value then the test is passed. If the measured PR is below the guaranteed value, the contractor should perform investigations into the reasons for plant under-performance and rectify these prior to repeating the test.

Given the short duration of the test, it would be unusual that performance LDs would be attached to the result. It is normal that LDs are instead linked to the results of the annual PR tests measured at the end of one or two years of plant operation. It is unusual for PR guarantees to extend beyond two years within an EPC contract, although they sometimes may be part of a long-term O&M contract.

9.6.2 INTERMEDIATE AND FINAL ACCEPTANCE

The contractor will typically be required to deliver a number of guarantees in relation to their works. These are described below.

- **Defects Warranty:** It would be normal for the contractor to provide a fully-wrapped plant defects warranty for a period of at least two years following the date of provisional acceptance. This makes the contractor responsible for the rectification of any defects that may be identified during this period.
- **Performance Warranty:** In addition to the short-term PR test at provisional acceptance, it is industry standard for the contractor to provide a PR guarantee to be measured at one or two separate occasions within the defects warranty period. Industry best practice is for the PR to be tested annually over the first year and then over the second year of plant operation. Testing plant PR annually removes the risk of seasonable bias affecting the PR calculation and allows for a true appraisal of plant performance.

Given that an EPC warranty period typically lasts two years from the date the plant is accepted by the owner, PR testing over the first year of operation is commonly referred to as the intermediate acceptance test. PR testing during the second year of plant operation is commonly referred to as final acceptance testing. If these performance tests are passed (along with other contractual conditions) then an Intermediate Acceptance Certificate (IAC) and Final Acceptance Certificate (FAC) may be signed.

If the PR measured during the IAC or FAC tests were less than the guaranteed levels, then the contractor would be required to pay LDs to the owner to compensate for anticipated revenue losses over the project lifetime. To be enforceable in common law jurisdictions, LDs must be a genuine pre-estimate of the loss that the owner would suffer over the life of the project as a result of the plant not achieving the specified performance guarantees. LDs are usually a net present value (NPV) calculation based on the revenue forgone over the life of the project as a result of the shortfall in performance.

At the end of typically two years of plant operation (following the provisional acceptance date) and assuming successful IAC and FAC PR tests, rectification of any observed defects and payment of any incurred delay or performance-related LDs, the owner is obliged to sign the FAC. This has the effect of discharging the contractor's construction-related obligations and handing the plant over to the owner. At such a time, any performance bond that may have been in place to secure the contractor's obligations during the EPC warranty period would be returned to the contractor.

EPC Contracting Checklist

Below is a checklist of basic requirements that a developer may wish to consider during the EPC contracting process.

- ☐ Legal and Technical Advisors engaged to advise on form of contract.
- ☐ Scope of work drafted to include all engineering, procurement, construction, commissioning and testing tasks.
- ☐ Proposed contractor able to provide security by way of performance bond or parent company guarantee. Security to remain in place until Final Acceptance (FA) is achieved.
- ☐ Payment milestone profile drafted to be suitably protective; milestone amounts sized to accurately reflect works completed with sufficient funds held back until plant is taken over.
- ☐ Contractor provides a defects warranty period of at least two years commencing on the date of provisional acceptance.
- ☐ Defined terms, such as 'commissioning,' 'work completion,' 'provisional acceptance' and 'final acceptance' are clear and measureable.
- ☐ Contract contains provision for PR testing at two to three stages during the contractor's warranty period. Performance ratio (PR) test prior to provisional acceptance should be conducted over a period of at least five days. Repeat PR tests at IAC and FAC to be over full 12-month periods.
- ☐ Contract contains provision for obtaining LDs in event of delay or plant underperformance.
- ☐ LDs sized to be a genuine pre-estimate of losses likely to be incurred.

10 Construction

10.1 CONSTRUCTION OVERVIEW

The construction phase of a solar PV power plant should be managed so that the project attains the required standards of quality within the time and cost constraints. During construction, issues such as environmental impact, and health and safety of the workforce (and other affected people) should be carefully managed.

Key project management activities that will need to be carried out, either by the developer or a contractor, include interface management, project planning and task sequencing, management of quality, management of environmental aspects, and health and safety.

There are a number of common issues that may arise during the construction phase. Most of these can be avoided through appropriate design, monitoring, quality control and testing onsite.

Provided at the end of the chapter is a checklist of both basic required procedures and recommended actions, which should assist developers during the construction phase of a solar PV project.

The following sections summarise critical considerations for the construction of a megawatt-scale solar PV power plant.

10.2 CONSTRUCTION MANAGEMENT

The management of the construction phase of a solar PV project should be in accordance with general construction-project management best practices.

The approach to construction project management for a solar PV power plant will depend on many factors. Of these, one of the most important is the project contract strategy, whether multi-contract or full turnkey EPC. The vast majority of megawatt-scale solar PV power plants are built using a fully-wrapped EPC approach.

There are a number of common issues that may arise during the construction phase. Most of these can be avoided through appropriate design, monitoring, quality control and testing onsite.

- From a developer's perspective, construction project management for a full turnkey EPC contract will be significantly less onerous than that required for a multi-contract approach.
- An EPC contract is nearly always more expensive than an equivalent, well-managed multi-contract approach.
- A multi-contract approach gives the developer greater control over the final plant configuration.
- EPC avoids interface issues between contractors and shifts risks to the EPC contractor instead of the project developer.

Regardless of the contract strategy selected, there are a number of key activities that will need to be carried out, either by the developer or a contractor. These activities are described in the following sections.

Typical EPC contract terms may be found in Annex 2: Contract Heads of Terms.

Figure 21: O&M Workers at a Large-scale Solar PV Power Plant

Image courtesy of First Solar

10.3 INTERFACE MANAGEMENT

Interface management is of central importance to the delivery of any complex engineering project, and solar PV projects are no exception. The main interfaces to be considered in a solar PV project are listed in Table 18. It should be noted that the interfaces may differ, depending on the contracting structure and specific requirements of particular projects.

For a multi-contract strategy, the developer should develop a robust plan for interface management. This plan should list all project interfaces, describe which organisations are involved, allocate responsibility for each interface to a particular individual, and explicitly state when the interface will be reviewed. In general, design and construction programmes should be developed to minimise interfaces wherever possible.

Opting for a turnkey EPC contract strategy will, in effect, pass the onus for interface management from the developer to the EPC contractor. But interface management will remain an important issue and one that requires on-going supervision. To some extent interfaces between the project and its surroundings (for example, grid connection) will remain the responsibility of the developer. Furthermore, in many countries legal responsibility will remain with the developer regardless of the form of contract that is put in place with the contractor.

If a turnkey EPC strategy is chosen, then a contractor with a suitable track record in the delivery of complex projects should be selected to minimise this type of legal risk. Information should also be sought from potential contractors on their understanding of the project interfaces and their proposed approach to managing them.

10.4 PROGRAMME AND SCHEDULING

A realistic and comprehensive construction programme is a vital tool for the construction planning and management of a solar PV project. The programme should be sufficiently detailed to show:

- Tasks and durations.
- Restrictions placed on any task.

Table 18: Solar PV Project Interfaces			
Item	Element	Organisations	Interface / Comments
1	Consents/Permits	• All contractors • Landowner • Planning authority	Monitoring of compliance with all consent conditions and permits.
2	Civil Works	• Civil contractor • Mounting or tracking system supplier • Central inverter supplier • Electrical contractor • Grid connection contractor • Security contractor • Installation/crane contractor	Site clearance. Layout and requirements for foundations, plinths, hardstandings, cable trenches, earthing, ducts, roads and access tracks.
3	Security	• Civil contractor • Electrical contractor • Security contractor • Communications contractor	Layout of the security system, including power cabling and communications to the central monitoring system.
4	Module Mounting or Tracking System	• Mounting or Tracking system supplier • Civil contractor • Module supplier • Electrical contractor	Foundations for the mounting or tracking system, suitability for the module type and electrical connections, and security of the modules. Earthing and protection of the mounting or tracking system.
5	Inverter	• Civil contractor (for central inverters) • Mounting system supplier (for string inverters) • Module supplier • Inverter supplier • Electrical contractor • Grid network operator • Communications contractor	Foundations for larger central inverters, or suitability for the mounting system. Suitability of the module string design for the inverter. Interface with the communications for remote monitoring and input into the SCADA system. Many grid requirements or constraints can be managed within the design.
6	AC/DC and Communications Cabling	• Electrical contractor • Civil contractor • Communications contractor • Security contractor • Power purchase (off-taker) company • Grid network operator	Liaison with regard to cable redundancy, routes, sizes, weights, attachments and strain relief requirements. Liaison with regards to the signalling requirements within the site and to be provided to external parties throughout operation.
7	Grid Interface	• Civil contractor • Electrical contractor • Inverter supplier • Network operator	Liaison with regard to required layout of building equipment and interface with site cabling installed by the site contractor. More interface outside the site boundary for the grid connection cable/line to the network operator's facilities.
8	Communications	• Electrical contractor • Security contractor • Communications Contractor • Owner and commercial operator	Interface between the security system, inverter system, central monitoring (SCADA), the monitoring company, and the owner or commercial operator of the PV plant.
9	Commissioning	• All contractors	Commissioning of all systems will have several interface issues particularly if problems are encountered.

- Contingency of each task.
- Milestones and key dates.
- Interdependencies between tasks.
- Parties responsible for tasks.
- Project critical path.
- Actual progress against plan.

All tasks and the expected timescales for completion should be detailed along with any restrictions on a particular task. For example, if permits or weather constraints are predicted to potentially stop construction during particular months, this should be noted.

For a solar PV project, it is likely that the programme will incorporate different levels of detail around each of the following main work areas:

- Final design works.
- Procurement and manufacture of equipment.
- Site access.
- Security.
- Foundation construction.
- Mounting frame construction.
- Module installation.
- Substation construction.
- Electrical site works.
- Grid interconnection works.
- Commissioning and testing.

A high-level programme should be produced to outline the timescales of each task, the ordering of the tasks and any key deadlines. This should be completed as part of the detailed design.

The programme will then be built up to detail all the associated tasks and sub-tasks, ensuring that they will be completed within the critical timescale. A thorough programme will keep aside time and resources for any contingency. It will also allocate allowance for weather risk or permit restrictions for each task.

Interdependencies between tasks will allow the programme to clearly define the ordering of tasks. A project-scheduling package will then indicate the start date of dependent tasks and highlight the critical path.

Critical path analysis is important to ensure that tasks that can affect the overall delivery date of the project are highlighted and prioritised. A comprehensive programme should also take into account resource availability. This will ensure that tasks are scheduled when required staff or plant components are available. For example, when exporting to a high voltage transmission line, a large substation facility may need to be designed and built according to the grid company requirements and interconnect agreement specifications. The outage date for connecting to the transmission line will be planned well in advance. If the developer misses the outage date, significant delays can be incurred, which can have a major impact on the development. The outage date is thus a critical path item around which the project development and construction timeline may need to be planned.

Incorporating a procurement schedule that focuses on items with a long manufacturing lead-time (such as transformers, central inverters and modules) will ensure that they are ordered and delivered to schedule. It will also highlight any issues with the timing between delivery and construction, and the need for storage onsite.

To share this information and to save time and effort, it is strongly recommended that an "off-the-shelf" project-scheduling package is used and that the programme is monitored against site progress regularly.

To obtain visibility of the works on a day-to-day basis, and receive early notice of any slippage in programme, a good management and tracking tool to use is a weekly look-ahead programme. This can be drawn up either by the EPC contractor or the project management team onsite.

10.4.1 MILESTONES

Milestones are goals that are tied in with contractual obligations, incentives or penalties. Incorporating milestones in the programme helps the project team to focus on achieving these goals. In effect, construction must be planned around certain milestones or fixed dates (for example, the grid connection date).

If the contracted milestones are included in the programme, the impact of slippage on these dates will be apparent. Appropriate budgetary and resourcing decisions can then be made to address those delays. The milestones can also indicate when payments are due to a contractor. Payment of contracted milestones should be associated with the delivery of all relevant documentation to ensure the work has been built to specification and quality standards. This will ensure that the contractors are focused on delivering the paperwork as well as the physical works. It will also help to minimise the potential for programme slippage later in the works due to awaiting documentation.

10.4.2 PLANNING AND TASK SEQUENCING

Appropriate sequencing of tasks is a vital part of the planning process. The tasks must be sequenced logically and efficiently. The overall sequence of works is generally site access, site clearance, security, foundation construction, cable trenches and ducts, substation construction, mounting frame construction, module installation, electrical site works, communications, site grid works and finally, testing and commissioning. Each of these work areas should be broken down into a series of sub-tasks. Alongside these, an assessment of the inputs required for each task (especially when interfaces are involved) will help develop a logical and efficient sequence.

Consideration should also be given to any factors that could prevent or limit possible overlap of tasks. These factors could include:

- Access requirements.
- Resource availability (plant, equipment and manpower).
- Training and learning curve of manpower, especially if in a new market or if local resources are being utilised.
- Consenting (or other regulatory) restrictions.
- Safety considerations.
- Grid availability.

10.4.3 RISK MANAGEMENT

The risks associated with the project should be identified, assessed and managed throughout the construction process. The hazards need to be incorporated in the planning and scheduling of the project. Each aspect of the project should be assessed for likelihood and impact of potential risks. The next step would be to develop a suitable action plan to mitigate identified risks. If a particular risk could affect the delivery of the whole project, alternatives for contingency (in terms of time and budget) should be included.

Risk items may include timing delays, weather risk, grid connection delays, staff and equipment availability, transportation, ground conditions and environmental or health and safety incidents. Many of these risks will have been mitigated during the planning and design stage, for example, by completing studies and plant design.

Some risks will remain until the equipment is on site: lost equipment or equipment damaged in transport, for example. This risk is reduced by selecting an experienced supplier with suitable transport equipment. Insurance will cover the cost associated with sourcing replacement equipment, however if a key component such as the grid transformer is lost, then insurance will not compensate for the time delays and loss of generation associated with the component not being available. Such risks should be considered when drafting the EPC contract terms.

10.5 QUALITY MANAGEMENT

Controlling construction quality is essential for the success of the project. The required level of quality should be defined clearly and in detail in the contract specifications.

A quality plan is an overview document (generally in a tabular form), that details all works, deliveries and tests to be completed within the project. This allows work to be signed off by the contractor and enables the developer to confirm if the required quality procedures are being met. A quality plan will generally include the following information:

- Tasks (broken into sections, if required).
- Contractor completing each task or accepting equipment.
- Acceptance criteria.
- Completion date.
- Details of any records to be kept (for example, photographs or test results).
- Signature or confirmation of contractor completing tasks or accepting delivery.
- Signature of person who is confirming tasks or tests on behalf of the developer.

Quality audits should be completed regularly. These will help developers verify if contractors are completing their works in line with their quality plans. Audits also highlight quality issues that need to be addressed at an early stage. Suitably experienced personnel should undertake these audits.

10.6 ENVIRONMENTAL AND SOCIAL MANAGEMENT

As noted in Section 8.3.4, the environmental and social impact assessment (ESIA) or equivalent undertaken for each project should result in an associated Environmental and Social Management Plan (ESMP), which sets out key environmental, health, safety and social impacts identified for the project and addresses how these will be mitigated. It is important that this document is referenced or incorporated into the EPC contract so that the construction contractor(s) can take appropriate steps that adhere to the mitigation strategy. Implementation of the ESMP is necessary to ensure that all national and lender-specific conditions related to environmental, health, safety and social impacts of the project are met. Contractor performance should be monitored and corrected as necessary. Further details on health and safety aspects of the ESMP are provided below in Section 10.7.

10.7 HEALTH AND SAFETY MANAGEMENT

The health and safety (H&S) of the project work force should be carefully overseen by the project developer. Apart from ethical considerations, the costs of not complying with H&S legislation can represent a major risk to the project. Furthermore, a project with a sensitive approach to H&S issues is more likely to obtain international financing.

The World Bank Group General EHS Guidelines cover H&S during construction, including:

- General facility design and operation.
- Communication and training.
- Physical hazards.
- Chemical hazards.
- Biological hazards.
- Personal protective equipment (PPE).
- Special hazard environments.
- Monitoring.

Solar-specific construction experience indicates that falls from height, electrocution, incidents involving heavy lifting machinery (i.e., cranes) and traffic accidents are the most common causes of serious worker injuries or fatalities in solar projects.

The EHS guidelines give guidance on how each of these aspects of H&S should be approached, outlining minimum requirements for each aspect and listing appropriate control measures that can be put in place to reduce risks.

Furthermore, IFC PS2 sets out requirements in relation to occupational H&S.

As a minimum standard, compliance with local H&S legislation should be documented and rigorously enforced. Where local legal requirements are not as demanding as the EHS guidelines, it is recommended that the EHS guidelines and requirements within IFC PS2 are followed.

10.8 SPECIFIC SOLAR PV CONSTRUCTION ISSUES

The following sections describe common pitfalls or mistakes that can occur during the construction phase of a solar PV project. Most of these pitfalls can be avoided by appropriate design, monitoring, quality control and onsite testing.

10.8.1 CIVIL WORKS

The civil works relating to the construction of a solar PV plant are relatively straightforward. However, there can be serious and expensive consequences if the foundations and road networks are not adequately designed for the site. The main risks lie with the ground conditions. Importantly, inadequate ground investigation reports that do not provide sufficient detailed ground information may result in misinterpretation of ground conditions leading to inappropriate foundation design. Importantly, ground surveys lacking meticulous detailing or proper data interpretation could lead to risks such as installing unsuitable foundations.

Brownfield sites pose a risk during the civil engineering works. Due to the nature of the excavation works digging or pile driving for foundations, it is important to be aware of hazardous obstacles or substances below ground level. This is especially important when considering former industrial sites or military bases. Typical hazards may include ground gases and leachate from former landfill operations, contaminated land due to historical industrial works or processes and unexploded ordnance from previous wartime activities, such as on or near active/retired military bases or other sites that may have been mined or bombed.

10.8.2 MECHANICAL

The mechanical construction phase usually involves the installation and assembly of mounting structures on the site. Some simple mistakes can turn out to be costly, especially if these include:

- Incorrect use of torque wrenches.
- Cross bracing not applied.
- Incorrect orientation.
- Misalignment of structures.
- Lack of anti-corrosion paint applied to structures.

If a tracking system is being used for the mounting structure, other risks include:

- Lack of clearance for rotation of modules.
- Actuator being incorrectly installed (or specified), resulting in the modules moving or vibrating instead of locking effectively in the desired position.

These mistakes are likely to result in remedial work being required before hand-over and involve extra cost.

10.8.3 ELECTRICAL

Cables should be installed in line with the manufacturer's recommendations. Installation should be done with care as damage can occur when pulling the cable into position. The correct pulling tensions and bending radii should be adhered to by the installation contractor to prevent damage to the cable. Similarly, cables attached to the mounting structure require the correct protection, attachment and strain relief to make sure that they are not damaged.

Underground cables should be buried at a suitable depth (generally between 500mm and 1,000mm) with warning tape or tiles placed above and marking posts at suitable intervals on the surface. Cables may either be buried directly or in ducts. If cables are buried directly, they should be enveloped in a layer of sand or sifted soil in order to avoid damage by backfill material.

Comprehensive tests should be undertaken prior to energisation to verify that there has been no damage to the cables.

In markets where electrical standards are being updated or have been recently updated the developer should consider obtaining expert advice from an electrical engineer or consultant to confirm prior to order that any electrical equipment imported into the country, including cables, will meet the local requirements.

10.8.4 GRID CONNECTION

The grid connection will generally be carried out by a third party over whom the project developer may have limited control. Close communication with the grid connection contractor is essential to ensure that the grid requirements are met. Delay in the completion of the grid connection will affect the energisation date, which will delay the start of commercial operation.

Where the grid network contains only traditional generation sources there is an additional risk that the grid code requirements for renewable generation will not have been fully established at the time of contract signature. In these cases, certain provisions may need to be included in the PPA; also, it is especially important to maintain regular communication with the grid operator and if possible engage the support of local consultants. Communicating with other solar plant developers in the area, if there are any, is strongly recommended and may enable the developer to benefit from the lessons learned during the implementation of these other projects that have already been constructed.

10.8.5 LOGISTICAL

Logistical issues can arise if designs or schedules have not been well thought through. Issues that may arise include:

- Lack of adequate clearance between rows of modules for access (*see* Figure 22).
- Constrained access due to inclement weather conditions.

For larger tracking systems, central inverters, or pre-manufactured inverter stations, cranes may be required. Therefore, suitable access and space for manoeuvrability, including room for the crane to extend its legs for stability within the site, is essential (*see* Figure 23). This issue should also be assessed from an operational perspective to ensure any equipment can be replaced upon failure or end of life.

10.8.6 SECURITY

A robust security plan needs to be put in place, especially in areas where there may have been objections to the works or where unemployment or crime is an issue. The project is likely to have a substantial quantity of metal including copper with significant scrap value. The modules themselves can be the targets of theft and may also be damaged by malicious acts.

The security arrangements for the site need planning and adequate budgeting. Security arrangements can provide a sustained benefit to the region by creating jobs for local personnel.

Figure 22: Spacing between Module Rows

Image courtesy of First Solar

Figure 23: Module Installation on a Large Tracking System

Image courtesy of a+f GmbH

10.8.7 EMERGING MARKET ISSUES

In new markets, there may be limited options for obtaining/importing the equipment required, starting up new manufacturing plants, or modifying construction facilities to satisfy local demand. Any supply solution that is adopted has associated risks.

Imported equipment can be subject to long transport times and customs delays, especially if this is the first import for a company or project.

New manufacturing suppliers in emerging markets can have quality issues associated with the work; additional time and monitoring is generally required to ensure that the products being delivered by such suppliers meet quality requirements. The packaging and transportation of these products to the construction site also requires careful consideration of how to prevent damage during transportation.

Employees for project installation companies in emerging markets are often inexperienced. This can lead to incorrect installation methods or procedures, and may include a lack of knowledge of the possible impact of completing works in the wrong order, which can have a costly impact on the project. However, with appropriate training, the use of inexperienced local staff can present a low-cost and locally-beneficial method of developing a solar PV power plant.

Strict quality management is required. A rigorous plan should be developed to ensure that risks and problems are identified early and quickly so that they can be resolved in a timely way.

10.9 CONSTRUCTION SUPERVISION

It is recommended that the owner of and lenders to the project are kept informed of developments during construction. Construction supervision may be carried out by in-house resources. Alternatively, a "technical advisor" or "Owner's Engineer" may be commissioned to carry out the work on their behalf.

The role of the technical advisor during the construction phase involves ensuring contractor compliance with the relevant contracts, as well as reporting on progress and budget. The construction supervision team generally comprises a site engineer supported by technical experts based in an office. The main parts of the technical advisor's role are: review of proposed designs, construction monitoring and witnessing of key tests.

Design reviews will generally be carried out on:

- Design basis statements.
- Studies/investigations.
- Design specifications.
- Design of structures.
- Drawings (all revisions).
- Calculations.
- Execution plans.
- Risk assessments and method statements.
- Quality plans.

- Safety plans/reports.
- Material and equipment selection.
- O&M manuals.
- Test reports.

The objective of the design review is to ensure that the contractor has designed the works in accordance with the contract agreements and relevant industry standards. The review also aims to ascertain that the works will be suitably resourced and sequenced to deliver the project as specified. The design review can also cover specific areas such as grid compliance or geotechnical issues, depending upon the specific project requirements and experience of the developers.

Key stages and tests for witnessing include:

- Inspection of road construction.
- Inspection of foundations.
- Verification of cable routes.
- Inspection of cable tracks.
- Witnessing of delivery/off-load of solar modules, transformers, inverters and switchgear.
- Inspection of module, switchgear and inverter installation.
- Witnessing of site acceptance tests.
- Witnessing of completion tests.
- Monitoring and expediting defects.

Besides the Owner's Engineer, the lender's engineer has the additional role of signing off and issuing certificates that state the percentage of the project completed. The lenders will require these certificates prior to releasing funds in accordance with the project payment milestones. In some cases there is a requirement for an independent or consulting engineer to verify that the works meet all standards and codes on behalf of the grid company or power purchaser.

Box 7: Construction Lessons Learned

The construction of a solar PV power plant is a relatively straightforward process. However, there are common mistakes that EPC contractors can easily avoid with correct planning and training procedures. Examples of such mistakes are itemised below.

PV Module Installation

Common issues during installation of modules include:

- Inadequate number of clamps used, or incorrect positioning resulting in reduced module load-bearing capacity.
- Modified or wrong type of clamp used as a result of inadequate spacing between modules, compromising integrity of the fixing and leading to invalidation of warranty.
- Module clamp bolts initially hand tightened and then tightened to the correct torque after a period of delay. There is a risk that strong winds can blow the modules off the structure if the time lag between assembly and tightening is too long. Tightening of bolts should occur shortly after assembly.
- Over-tightening of clamp bolts with power tools leading to deformation of clamp and damage to corrosion-resistant coatings.
- Damaged or scratched modules due to poor installation technique. The front and rear surface of modules should not come into contact with support structures.

Mounting Structure

Common issues in relation to the construction of the mounting structures include:

- Dissimilar metals not isolated from one another leading to material incompatibility issues in the form of galvanic corrosion. Isolation solutions such as neoprene pads can be used.
- Deformation of mounting structure during piling process, compromising galvanisation or structure.
- Piles installed out of position, leading to piles and steel sections being forced or bent out of alignment in order to line up with framing sections.

Civil Works

Common issues in relation to the construction of the mounting structures include:

- Poor dust suppression leading to excessive accumulation of dirt on modules.
- Missing or delayed perimeter fencing leading to animal or human intrusion. A fence should be installed prior to construction commencing.
- Drains becoming blocked with silt during earth works.
- Inadequate surface water run-off management during construction, leading to delays caused by flooded and waterlogged sites.
- Exceeding load-bearing capacity of exiting public tracks, causing damage.
- Lack of levelling works after installation.

Equipment Enclosures / Housings

The integrity of the controlled environment within equipment enclosures/housings can be compromised if not installed correctly. Examples of common issues include:

- Unused glands not sealed or replaced with dummies.
- Unsealed cable conduits.
- Damaged or missing gaskets on entrance doors.
- Unsealed cable trenches leading into inverter housings.
- Water ingress due to any/all of the above, leading to a humid atmosphere causing corrosion damage to electrical components.

Environmental Monitoring

Incorrect positioning of the environmental monitoring equipment can lead to inaccuracies during performance assessment. The most common reasons for these inaccuracies include:

- Pyranometers not positioned at the same tilt angle as the modules.
- Pyranometers subject to shading, causing reporting of elevated performance ratio (PR) calculations.

(continued)

Box 7: Construction Lessons Learned (continued)

Cable Management

The most common issues in relation to cable management include:

- Cables crossing over sharp edges of mounting structures without suitable padding.
- Insufficient labelling of cable ends.
- Long unsupported spans due to an insufficient number of cable ties.
- Cable bending radius too tight.
- Inadequate cable burial depths.
- Inadequate conduit cable protection.

Signage

Basic information requirements which are often omitted include:

- General health and safety information including emergency contact numbers.
- Lack of warning labels on electrical components.
- Lack of warning labels on perimeter fence.
- Support structure identification labelling.

Spare Parts

- The permanent storage area for spare components is often not available when such components are delivered to the site, leading to damage from poor temporary storage conditions.

Construction Phase Checklist

Provided below is a checklist of basic required procedures in addition to a list of recommended actions. It is intended to assist solar PV power plant developers during the construction phase of a PV project.

Required

- [ ] Contract, fully signed and reviewed by technical advisor covering all interfaces.
- [ ] Design documentation completed.
- [ ] Detailed programme of works completed.
- [ ] Quality plan completed.
- [ ] Health and safety plan completed.
- [ ] Monthly reporting in place.
- [ ] All consenting, permitting and financing requirements in place.
- [ ] Commissioning and testing plan agreed to by all parties, detailing requirements and any tests needing witnesses or sign-off.

Recommended

- [ ] Interface matrix drawn up.
- [ ] Deliverables schedule prepared for all documentation.
- [ ] Weekly look-ahead programme in place.
- [ ] Risk register detailing all potential risks and any mitigation measures in place.
- [ ] Environmental plan completed.
- [ ] Monthly report structure completed.
- [ ] Matrix detailing the requirements and due dates prepared.

Operation and Maintenance

11

An operation and maintenance (O&M) contract is crucial for the successful performance of the PV plant during its operating life.

11.1 OPERATION AND MAINTENANCE (O&M) OVERVIEW

Compared to other power generating technologies, solar PV power plants have low maintenance and servicing requirements. However, proper maintenance of a PV plant is essential to maximise both energy yield and the plant's useful life. Optimal operations must strike a balance between maximising production and minimising cost.

The presence of an operation and maintenance (O&M) contract is crucial to define the parameters for the operation and maintenance of a project during its life. If an O&M contractor is being employed to undertake these tasks, it is important that all requirements relating to preventative and corrective maintenance, performance monitoring and reporting are clearly stated in the contract along with the frequency with which these activities need to be conducted. This allows contractor performance to be measured and if necessary challenged.

It is normal for an O&M contractor to guarantee plant performance during the contract term. Typically this is achieved through the presence of an availability- or performance-ratio warranty covering the entire plant. In the event of the contractor not honouring its obligations, resulting in the plant performing below the guaranteed value, the owner would be eligible to claim for compensation to cover lost revenues.

The basic requirements for drafting an O&M contract for a Solar PV power plant are set out in a checklist at the end of the chapter.

11.2 O&M CONTRACTS

It is common practice on solar PV projects that O&M is carried out by a principal contractor, who is responsible for all aspects of O&M, including any of the works performed by subcontractors that may be engaged to deliver specialist services, such as inverter servicing, ground-keeping, security or module cleaning.

An O&M contract is required between the project company and the O&M provider that details the legal and technical aspects of the O&M provision. More information on O&M contracts is provided in Section 11.7, with typical O&M terms outlined in Annex 2.

Maintenance can be broken down as follows:

- **Scheduled maintenance:** Planned in advance and aimed at fault prevention, as well as ensuring that the plant is operated at its optimum level.
- **Unscheduled maintenance:** Carried out in response to failures.

Suitably thorough and regularly scheduled maintenance should minimise the requirement for unscheduled maintenance although, inevitably, some unforeseen failures will still occur. A robust and well-planned approach to both scheduled and unscheduled maintenance is therefore important.

11.3 SCHEDULED/PREVENTATIVE MAINTENANCE

Appropriate scheduling and frequency of preventative maintenance is dictated by a number of factors. These include the technology selected, environmental conditions of the site, warranty terms and seasonal variances. Scheduled maintenance is generally carried out at intervals planned in accordance with the manufacturer's recommendations, and as required by equipment warranties. Scheduled maintenance that requires plant shutdown should be conducted where possible during non-peak production periods, such as early morning or evening.

Although scheduled maintenance will both maximise production and prolong the life of the plant, it does represent a cost to the project both in terms of expenses incurred and lost revenue due to reduced power generation. Therefore, the aim should be to seek the optimum balance between the cost of scheduled maintenance and increased yield over the life of the system.

Specific scheduled maintenance tasks are covered in the following sections.

11.3.1 MODULE CLEANING

Module cleaning is a simple but important task. It can produce significant and immediate benefits in terms of energy yield.

The frequency of module cleaning will depend on local site conditions and the time of year. As the level of module soiling is site-specific, the duration between cleans will vary significantly between sites. The frequency to clean modules will be dictated by factors such as site and surrounding area ground covering (dusty and arid sites will result in more soiling) and local rainfall patterns (drier areas will result in more soiling).

Figure 24 illustrates the cleaning of modules in a large tracking installation (water is seen being sprayed on the module surface).

Other, lower-tech methods of cleaning include the use of a brush trolley, shown in Figure 25, and use of a dust broom, shown in Figure 26.

Figure 24: Module Cleaning Using Crane

Image courtesy of a+f GmbH

When scheduling module cleaning, consideration should be given to the following:

- Environmental and human factors (for instance, autumn fall debris and soiling from local agricultural and industrial activities).
- Weather patterns: cleaning during rainy periods is less likely to be required.
- Dust carried from deserts by wind that may also appear following rain.
- Dust caused by vehicular traffic.
- Site accessibility based upon weather predictions.
- Availability of water and cleaning materials.[52]

If the system efficiency is found to be below the expected level, then the cleanliness of the modules should be checked and cleaning conducted as necessary.

The optimum frequency of module cleaning can be determined by assessing the costs and benefits of conducting the procedure. The benefit of cleaning should be seen in an improved system performance ratio (PR) due to the lower soiling loss and resultant increase in revenue. A cost estimate to clean the PV modules should be obtained from the O&M contractor and compared with the potential increase in revenue. The agreed O&M contract should detail an agreed number of cleans per annum and their frequency. It should also outline the labour rate or unit price at which the owner may request an additional plant-wide clean of modules to allow this cost-benefit analysis to be conducted.

Figure 25: Module Cleaning Using Brush Trolley

Image courtesy of First Solar

Figure 26 : Module Cleaning Using Dust Broom

Image courtesy of First Solar

11.3.2 MODULE CONNECTION INTEGRITY

Checking module connection integrity is important for systems that do not incorporate monitoring at the module string level. This is more likely for plants utilising central inverter technology. In such cases, faults within each string of modules may be difficult to detect given that the current within each string is not being monitored and continuously compared to other strings.

If string level monitoring is not used, then the O&M contractor should check the connections between modules within each string periodically, at least on an annual basis.

52 Water in the amount of about 1.6 l/m2 of module surface may be required for each module clean, dependent on the method adopted.

11.3.3 JUNCTION OR STRING COMBINER BOX

All junction boxes or string combiner boxes should be checked periodically for water ingress, dirt or dust accumulation and integrity of the connections within the boxes. Loose connections could affect the overall performance of the PV plant. Any accumulation of water, dirt or dust could cause corrosion or short circuit within the junction box.

Where string level monitoring is not used, the O&M contractor should conduct periodic checks, at least on an annual basis, of the integrity of the fuses in the junction boxes, combiner boxes and, in some cases, the module connection box.

11.3.4 HOT SPOTS

Potential faults across the PV plant can often be detected through thermography. This technique helps identify weak and loose connections in junction boxes and inverter connections, which is a common problem in hot climates where large variations between day and night temperatures can cause contacts to loosen. Thermography may also detect hot spots within inverter components and on modules that are not performing as expected.

A trained specialist should conduct thermography using a thermographic camera at least on an annual basis.

11.3.5 INVERTER SERVICING

Generally, inverter faults are the most common cause of system downtime in PV power plants. Therefore, the scheduled maintenance of inverters should be treated as a centrally important part of the O&M strategy.

The maintenance requirements of inverters vary with size, type and manufacturer. The specific requirements of any particular inverter should be confirmed by the manufacturer and used as the basis for planning the maintenance schedule.

Regular preventative maintenance for an inverter should, as a minimum, include:

- Visual inspections.
- Cleaning/replacing cooling fan filters.
- Removal of dust from electronic components.
- Tightening of any loose connections.
- Any additional analysis and diagnostics recommended by the manufacturer.

11.3.6 STRUCTURAL INTEGRITY

The module mounting assembly, cable conduits and any other structures built for the solar PV power plant should be checked periodically for mechanical integrity and signs of corrosion. This will include an inspection of support structure foundations for evidence of erosion from water run-off.

11.3.7 TRACKER SERVICING

Similarly, tracking systems also require maintenance checks. These checks will be outlined in the manufacturer's documentation and defined within the warranty conditions. In general, the checks will include inspection for wear and tear on the moving parts, servicing of the motors or actuators, checks on the integrity of the control and power cables, servicing of the gearboxes and ensuring that the levels of lubricating fluids are appropriate.

The alignment and positioning of the tracking system should also be checked to ensure that it is functioning optimally. Sensors and controllers should be checked periodically for calibration and alignment.

11.3.8 BALANCE OF PLANT

The remaining systems within a solar PV power plant, including the monitoring and security systems, auxiliary power supplies, and communication systems, should be checked and serviced regularly. Communications systems within and externally connected to the PV plant should be checked for signal strength and connection.

11.3.9 VEGETATION CONTROL

Vegetation control and grounds keeping are important scheduled tasks for solar PV power plants. Vegetation (for example, long grass, trees or shrubs) has the potential to shade the modules and reduce performance. Prudent grounds keeping can also reduce the risk of soiling on the modules from leaves, pollen or dust.

11.4 UNSCHEDULED MAINTENANCE

Unscheduled maintenance is carried out in response to failures. As such, the key parameters when considering unscheduled maintenance are diagnosis, speed of response and repair time. Although the shortest possible response is preferable for increasing energy yield, this should be balanced against the likelihood of increased contractual costs of achieving shorter response times.

The agreed response times should be clearly stated within the O&M contract and will depend on the site location—and whether it is manned. Depending on the type of fault, an indicative response time may be within 48 hours, with liquidated damages payable by the contractor if this limit is exceeded. The presence of an availability guarantee within the O&M contract will also provide motivation for the contractor to provide an efficient and speedy repair in the event of equipment failure and resulting plant downtime.

For a well-designed and well-constructed plant, a large proportion of unscheduled maintenance issues may be related to inverter faults. Depending on the nature of the fault, it may be possible to rectify the failure remotely. This option is clearly preferable, if possible.

Other common unscheduled maintenance requirements include:

- Tightening cable connections that have loosened.
- Replacing blown fuses.
- Repairing lightning damage.
- Repairing equipment damaged by intruders or during module cleaning.
- Rectifying SCADA faults.
- Repairing mounting structure faults.
- Rectifying tracking system faults.

The contractual aspects of unscheduled O&M are described in more detail below.

11.5 SPARE PARTS

In order to facilitate a rapid response in the event of equipment failure, a suitably stocked spare parts inventory is essential. Because spare parts cost money, their purchase should be justified by the benefit they bring in reducing plant downtime and avoiding revenue loss. The optimum spare parts strategy will depend on the size of the plant, local availability of replacement parts and the potential for sharing critical equipment across a number of plants under common ownership. In general, adequate supplies of the following essential components should be held:

- Mounting structure pieces.
- Junction/combiner boxes.
- Fuses.
- DC and AC cabling components.
- Communications equipment.
- Modules (in case of module damage).
- Spare inverters (if string inverters are being used) or components according to manufacturer's recommendations in the case of central inverters.
- Spare motors, actuators and sensors where tracking systems are used.

It is important that spares stock levels are maintained. Therefore, when the O&M contractor uses components from the spares inventory, the contractor should be responsible for replenishing the stocks as soon as is feasible. This arrangement will reduce the time gap between the identification of the fault and replacement of the non-operational component. This can be of particular importance for remote locations where poor accessibility or adverse weather conditions can delay the delivery of components to the site. Consultation with manufacturers to detail the spare parts inventory, based upon estimated component lifetimes and failure rates, is recommended.

11.6 PERFORMANCE MONITORING, EVALUATION AND OPTIMISATION

To optimise system performance, there is a need to ensure that the plant components function efficiently throughout the lifetime of the plant. Continuous monitoring of PV systems is essential to maximise the availability and yield of the system.

Section 7.7 describes monitoring systems for PV plants. A SCADA system is able to monitor the real-time efficiency of the PV system and continuously compare it with the theoretical efficiency to assess if the system is operating optimally. This information can be used by the O&M contractor to establish the general condition of the system and schedule urgent repair or maintenance activities such as cleaning.

11.7 O&M CONTRACTS FOR SOLAR PV PLANTS

This section describes the key issues with O&M contracts for solar PV power plants. For reference, the typical terms commonly seen in O&M contracts are included in Annex 3: O&M Term Sheet.

It is common for the PV plant O&M to be carried out by specialist contractors. The contractor will be responsible for the O&M of the whole plant, its subcomponents and also the work of any subcontractors. In addition to operating the plant and maintaining all equipment, the O&M contractor may also be responsible for the provision of plant security and grounds keeping.

The duration of O&M contracts will vary on a project-by-project basis. Some plant owners (typically investment funds) like the cost surety and predictability that a lengthy contract term can bring. As such, contract durations in excess of 20 years, covering the anticipated project lifetime are often seen. For other owners, a shorter duration, such as one to five years, may be more desirable because it allows owners to take advantage of falling market costs and negotiate more favourable terms when their current contract expires. In all cases, termination events should be clearly defined to allow the owner to terminate the contract, irrespective of its duration, in the event of contractor default, underperformance or insolvency.

11.7.1 PURPOSE OF AN O&M CONTRACT

The purpose of an O&M contract is to optimise the performance of the plant within established cost parameters. To do this effectively, the contract must be suitably detailed and comprehensive. In particular, the O&M contract should clearly set out:

- Services to be carried out by, and obligations of, the contractor.
- Frequency of the services.
- Obligations of the owner.
- Standards, legislation and guidelines with which the contractor must comply.
- Payment structure.
- Performance guarantees and operational targets.
- Methodologies for calculating plant availability and/or performance ratio.
- Methodologies for calculating liquidated damages/bonus payments in the event of plant under- or over-performance.
- Terms and conditions.
- Legal aspects.
- Insurance requirements and responsibilities.

These issues are discussed in the following sections.

11.7.2 CONTRACTOR SERVICES AND OBLIGATIONS

The O&M contract should list the services to be performed by the contractor. This list should be site- and equipment-specific, and include the following:

- Plant monitoring requirements.
- Scheduled maintenance requirements.
- Unscheduled maintenance requirements.
- Agreed targets and/or guarantees (for example, response time or system availability figure)

- Reporting requirements (including performance, environmental, health and safety, and labour relations reporting).

While the O&M contractor's primary role is to maintain the plant, ensuring that it and all subcomponents are functioning and able to export electrical energy to the grid, the contractor should also be contractually obliged to optimise plant performance. Additionally, it should be stipulated that all maintenance tasks should be performed in such a way that their impact on the productivity of the system is minimised. In particular, the contract should state that preventative maintenance tasks that require the removal of equipment from service should be kept to a minimum and performed during low irradiation hours.

The O&M contract will typically define the terms by which the contractor is to:

- Provide, at intervals, a visual check of the system components for visible damage and defects.
- Provide, at intervals, a functional test of the system components.
- Ensure that the required maintenance will be conducted on all components of the system. As a minimum, these activities should be in line with manufacturer recommendations and the conditions of the equipment warranties.
- Provide appropriate cleaning of the modules and the removal of snow (site-specific).
- Make sure that the natural environment of the system is maintained to avoid shading and aid maintenance activities.
- Replace defective system components and system components whose failure is deemed imminent.
- Provide daily (typically during business hours) remote monitoring of the performance of the PV plant to identify when performance drops below set trigger levels.

A schedule of preventative maintenance activities should be prepared and appended to the O&M contract to easily track whether the agreed timetable is being met. As well as ensuring that all equipment is being serviced in line with manufacturer's guidelines, this also allows for contractor performance to be measured.

11.7.3 OBLIGATIONS ON THE OWNER

In an O&M contract, the obligations of the owner/developer are generally limited to:

- Granting the O&M contractor access to the system and all the associated land and access points.
- Obtaining all approvals, licences and permits necessary for the legal operation of the plant.
- Providing the O&M contractor with all relevant documents and information, such as those detailed above, that are necessary for the operational management of the plant.

11.7.4 STANDARDS, LEGISLATION AND GUIDELINES

This section of the contract outlines the various conditions with which the O&M contractor must comply while carrying out the O&M of the plant. These conditions should be drawn from the following documentation:

- Building or construction permits.
- Planning consents and licences.
- Grid connection statement, the grid connection agreement and power purchase agreement.
- Operating manuals for system components.
- Applicable legislation.
- Local engineering practices (unless the documents and conditions listed above require a higher standard).

11.7.5 PAYMENT

The cost and remuneration of the O&M contract are generally broken down into:

- Fixed remuneration and payment dates.
- Other services remuneration and expenditure reimbursement.

Fixed remuneration outlines the payment for the basic services that are to be provided by the contractor under the O&M contract. This section should include the following:

- Cost—usually a fixed price per kWp installed.
- Payment structure (monthly or quarterly, generally in arrears).
- Payment indexation over the duration of the contract.

Remuneration for other services includes payment for any services beyond the scope of the contract. This should include:

- Method for determining level of other services carried out.
- Agreed rates for conducting these services.
- Agreed method for approving additional expenses or services with the owner.
- Any required spare parts and other components not covered by individual warranties or held in the owner's inventory.

11.7.6 WARRANTIES/PERFORMANCE GUARANTEES

The contract should include a plant-wide performance guarantee to be calculated on a regular basis. On large-scale solar PV power plants this typically takes the form of an availability or performance ratio (PR) warranty. An availability warranty provides a measure of plant 'uptime' and how successful the contractor is in keeping the plant functional and capable of exporting electrical energy to the grid. A PR warranty provides a measure of plant efficiency at converting solar irradiation into electrical energy. While a PR warranty may be preferable because it incentivizes the contractor to optimise plant performance rather than just ensure its operational readiness, some third-party O&M providers are reluctant to provide such a warranty on systems they did not design or construct.

A PR guarantee is an industry standard and is considered a pre-requisite to a suitable long-term O&M strategy. The guarantee makes it the responsibility of the O&M contractor to ensure that the plant achieves a PR level greater than the guaranteed value. If the plant operates below this value, the contractor will be liable to pay compensation in the form of liquidated damages to the owner. Damages should be set at a level that is a genuine estimate of the loss or damage that the owner will suffer in the event of plant under-performance.

11.7.7 LEGAL

The contract will have a section outlining the governing law and jurisdiction of the O&M contract. The governing law is normally the law of the country in which the project is located. A legal succession or a transfer of rights condition is required for the developer to reserve the right to assign the O&M contract to a third party.

It is also recommended that every contract have a non-disclosure agreement. This agreement between the O&M contractor and the developer will outline the information that is to be treated as confidential, as well as that information which can be disclosed to third parties.

11.7.8 INSURANCE

The contract should have a section outlining the insurance responsibilities of the contractor for the O&M activities. This insurance should cover damage to the plant, as well as provide cover for employees conducting maintenance.

It is normal for the O&M contractor to arrange and pay for the full site insurance.

11.7.9 TERM OF AGREEMENT

Every O&M contract needs to have a section that outlines when the contract shall become effective and the duration of the contract from the effective date. This section should also include provisions to renew or extend the contract upon conclusion of the originally agreed term.

It is also recommended that this section include the circumstances in which either the maintenance contractor or the developer would be entitled to terminate the contract.

11.7.10 RESPONSE TIME

The guaranteed response time of a maintenance contractor is an important component of the O&M contract. As soon as notification of a fault occurs, it is the responsibility of the contractor to go to the site within a set period of time. The faster the response time, the swifter the issues can be diagnosed and the system returned to full production. The distance between the PV plant and the contractor's premises has a direct correlation with the duration of the guaranteed response time.

The time of year coupled with the accessibility to the site can have a bearing on the actual response time for any unscheduled maintenance event. Restrictions to access roads at certain times of the year can delay response. Adverse conditions can also reduce the size of the payload that can be transported to the site, thus extending the duration of the maintenance work.

The presence of a strong PR guarantee also ensures that the contractor is motivated to undertake an efficient response and restore system performance when alerted to a fault. If such guarantees are sufficiently strong, the need for explicit response times within a contract may be reduced.

11.7.11 SELECTING A CONTRACTOR

When choosing an O&M contractor, the capability of the company should be thoroughly examined. In particular, the following aspects should be considered:

- Familiarity of the contractor with the site and technology.
- Location of the contractor's premises.
- Number and competency of staff.
- Experience and track record.
- Financial strength and ability to honour warranty obligations.

The intention should be to select a suitably experienced contractor able to meet the requirements of the contract for the duration of the project.

O&M Contracting Checklist

The checklist below sets out the basic requirements for the drafting of a strong solar PV power plant O&M contract.

- ☐ Legal and technical advisors engaged to advise on form of contract.
- ☐ The O&M contractor is suitably experienced on a similar scale plant and familiar with the technology.
- ☐ Performance guarantees included to allow owner to claim liquidated damages (LDs) in the event of low availability or PR.
- ☐ Payments are made to the contractor in arrears to allow for deduction of any LDs over the corresponding period.
- ☐ LDs sized to be a genuine pre-estimate of losses likely to be incurred.
- ☐ Rules for spare parts management are clearly defined. Contractor is responsible for replenishing stock and ensuring original level is maintained.
- ☐ Rules for subcontracting clearly defined to ensure principal contractor is fully responsible for all sub-contractor works.
- ☐ The O&M contract requires the contractor to maintain all equipment in line with manufacturer guidelines (to ensure that all equipment warranties remain valid).
- ☐ Preventative maintenance regime defined in contract is comprehensive, helping to minimize the need for corrective maintenance.

Policies and Support Mechanisms for Solar PV 12

Developers should consider how policy provisions are designed and what specific support mechanisms for solar PV projects are available to bridge the gap between the costs of conventional power sources and solar PV.

12.1 POLICIES AND SUPPORT MECHANISMS OVERVIEW

While the cost per kWh of solar PV power has come down dramatically and continues to fall, in most cases direct or indirect financial incentives are still required in order to increase the commercial attractiveness of solar PV projects so that there is sufficient investment in new projects to meet national goals for renewable energy production.

Price-based incentives such as FiTs remain among the most common instruments to boost the commercial case for solar. In place of price-based incentives, quantity-based mechanisms use binding policy provisions to establish quotas that require power utilities to purchase a specific percentage of their power from a renewable source. Quotas translate into investment opportunities for developers, who are able to supply utilities with the required electricity generated by renewable energy facilities. Complementing the arsenal of policy instruments available to governments are fiscal incentives—e.g., investment or production tax credits, and direct public support schemes, such as soft loans or an equity participation by a public entity. Policies that guarantee and facilitate connection and access of PV plants to the grid are also important for the viability of PV projects by removing common barriers.

Developers should consider how policy provisions are designed and what specific support mechanisms for solar PV projects are available to bridge the gap between the costs of conventional power sources and solar PV power.

It is important for developers to understand the conditions under which they may access support schemes and the requirements they must fulfil to do so within a given market. The process a developer must follow to meet the requirements for obtaining support differ from country to country, reflecting the priorities of the regulatory regime and the structure of the power market. Levels, types, and duration of support that developers can access will vary. Incentives are generally offered at the national level.

Sometimes state and provincial authorities offer additional incentives.

The critical mandate for any developer is to:

- Learn what support mechanisms are available.
- Determine whether the project will be able to meet the criteria for securing support and understand the historical reliability of the delivery of these supports.
- Factor all this information into the business plan and demonstrate to investors that the discounted cash flows are appealing.
- Follow through meeting the requirements to secure the support available.

Refer also to the checklist at the end of the chapter for key considerations in accessing support mechanisms in any market.

12.2 POLICIES AND SUPPORT MECHANISMS OVERVIEW

12.2.1 *TYPES OF SUPPORT MECHANISMS*

This sub-section provides an overview of the six common types of renewable energy support mechanisms used by governments, including both mechanisms that help developers to improve cash flow and those that offer opportunities to competitively enter the market:

- **Feed-in Tariffs (FiTs):** A FiT is a predetermined price for every unit of electricity generated by a solar PV power plant, paid through a long-term contract. Typically, projects must meet certain eligibility criteria and receive authorization from a government body to receive the FiT (and usually preferential grid access as well); smaller projects may automatically receive the FiT up to a certain maximum level of MWs (maximum capacity).
- **Reverse Auctions and Tenders:** Reverse auctions for independent power producers (IPPs) involve the competitive procurement of energy, whether at a specific site or without specifying where a new plant must be built. Renewable energy auctions can be technology-neutral where solar competes with other renewable energy sources, or technology-specific where different solar projects compete with each other. A tender of a specific site is a call for bids for the rights to develop a PV project on a site pre-selected by the government or utility.
- **Market-based Instruments:** These accompany quantity-based mechanisms, such as renewable portfolio standards or quota obligations. Certificates associated with renewable energy production are traded on a market and result in additional revenue for renewable energy producers. Examples include tradable renewable certificates or carbon certificates.
- **Tax Incentives:** Tax incentives can be used by a project owner to offset capital costs or profits, or to reduce specific taxes such as VAT or import duties. Accelerated depreciation is another option intended to attenuate the high capital costs of renewable energy projects.
- **Soft Loans:** Soft loans—i.e. those with a below-market interest rate or extended tenor—are sometimes made available, especially in the early stage of technology deployment by government-backed institutions.
- **Capital Grants:** Capital grants from public sources reduce the upfront financing burden and can stimulate interest in a new market. This option was used in the early stages of PV development. As the technology has matured, it is not necessary and now very rare.

The above provide direct and indirect financial supports designed to cover the incremental costs of solar PV power against conventional power supply options. The relative merits and conditions of different energy policy frameworks vary widely between countries and regions. Hence, it is crucial for developers to consider the effect on the commercial viability of their project, including the private investment risk of policies within a specific political and economic context.[53] The International

53 For more on this topic, see IEA, IRENA, the US National Laboratories (including Lawrence Berkeley, Sandia, and the National Renewable Energy Laboratory) and the World Bank's Energy Management Assistance Program. See also, IRENA's "Evaluating Policies in Support of the Deployment of Renewable Power" (2012), and the World Bank's Renewable Energy Financial Instrument Tool (REFINe).

Renewable Energy Agency and the International Energy Agency host a joint database that provides relatively comprehensive and up-to-date information on the types of support mechanisms and corresponding incentives available for renewable energy projects in different countries.[54]

12.3 SOLAR PV SUPPORT MECHANISMS

This sub-section discusses in detail the six types of support mechanisms that may be available to solar PV power plant developers. It explains the nature of support provided by each mechanism, as well its advantages and disadvantages. Key concerns for the developer are also discussed for each mechanism.

12.3.1 FEED-IN TARIFFS (FiTs)

FiTs offer a fixed, typically long-term (10–25 years) electricity sales price, often combined with preferential grid access and other favourable off-take terms, such as priority dispatch. This fixed price, typically linked to inflation, is intended to cover the actual cost of renewable energy generation (typically higher than conventional power sources) and allow a sufficient margin to enable investors to make a return commensurate with the risk profile of the project. Box 8 provides an example of FiTs in Thailand for both rooftop and utility-scale solar PV projects.

FiTs played a critical role in stimulating the early growth of solar PV energy, especially in Europe and Japan, and remain a widespread tool to support PV projects in many markets. FiTs protect a PV project from competition with other sources of generation and from price fluctuations on the wholesale electricity market, stabilizing revenues.[55]

FiTs are generally attractive to lenders because they are secure and stable. The long-term revenues for a project with a FiT can be modelled with a high degree of certainty, making such projects easier to finance. However, in accepting a FiT, the developer takes on policy and credit risk, and must assess whether the off-taker is required, willing, and able to provide support at the contracted level over the project's life; this is especially critical if the FiT is substantially higher than prevailing power prices. The key issues and risks related to FiTs are summarized below.

12.3.1.1 The Level of FiT and Sustainability of Support

It is wise to assess the sustainability of the FiT—specifically, whether the mechanism is sustainable through which the incremental cost of a PV project is recovered. For example, if the regulatory framework specifies that the incremental costs will be covered through a specific component in the energy bill of the consumers, this may be viewed as sustainable and lower risk. However, if the incremental cost is covered by sources that are not certain, the sustainability of the FiT may be viewed with some caution. Countries that adopted FiTs early on, when the PV costs were still high, had to absorb substantial incremental costs, burdening either the end-user tariffs or the government's fiscal situation. As PV costs declined substantially (especially over the period 2010–2014), these countries were under pressure to revise the FiTs. Revision for future projects is rational, especially if PV costs decline, but retroactive revision (affecting PV plants already built) is not rational and has affected developers who have incurred high costs. For example, due to the fiscal strain under which governments found themselves after the financial crisis in 2008, Spain in 2010 retroactively altered their FiT, impacting contracted projects. Spain was followed by Bulgaria in 2012 and Greece in 2014.[56] In late 2013, several Australian state governments proposed retroactive cuts to FiT schemes, although these were withdrawn due to unpopular public reactions.

54 http://www.iea.org/policiesandmeasures/renewableenergy/

55 There are many publications analyzing feed-in tariffs. Among them, see "Feed-in Tariffs as a Policy Instrument for Promoting Renewable Energy and Green Economies in Developing Countries," United Nations Environment Programme (UNEP), 2012.

56 Legislation: Royal Decree 1565/2010 adopted on 19 November 2010 by the Council of Ministers. For more details, see the European Photovoltaic Industry Association's "Retrospective Measures at the National Level and their impact on the photovoltaic sector." 10 December 2013. Available at www.epia.org.

Even for technologies where costs haven't dropped as dramatically over the past decade, most governments will today put in place cost containment measures for FiT schemes to cap the overall fiscal costs. In particular, tariff levels may decrease on a sliding scale over years or the support for new sites will be capped in terms of the total fiscal cost they represent. Also, some FiTs are envisioned to be updated periodically (every 2–3 years); in this case, changes should affect future contracts and will not be retroactive. Retroactive changes to FiT schemes are rare, but they can be extremely detrimental to the projects affected. It is more common for policies to be abruptly

Box 8: Thailand's Feed-in Tariff (FiT) Policies

The solar market in Thailand is currently driven by two key Feed-in Tariff (FiT) policies designed to help the country meet its ambitious targets for solar development by 2021.[a]

1. Rooftop solar projects policy.[b]
2. Ground-mounted solar projects policy.

The rooftop FiT policy provides an incentive for developing rooftop and community ground-mounted solar systems, and is capped at an installed capacity of 200 MW. The FiT rate is scaled dependent on the project size. The FiT rates below are granted to projects that were fully commissioned before December 2013 and are valid for a 25-year operational period.

FiT Rates for Rooftop Solar Projects in Thailand		
Project Size (kW)	FiT Rate (Baht/kWh)	FiT Rate (USD/kWh) (1 Thai Bhat = 0.0310 USD)
0–10	6.96	0.22
10–250	6.55	0.20
250–1000	6.16	0.19

The ground-mounted FiT policy provides an incentive for up to 800 MW of projects to be commissioned by the end of 2014. The FiT rate varies throughout the lifetime of a developed project and is presented below.

FiT Rates for Ground-mounted Solar Projects in Thailand		
Year	FiT Rate (Baht/kWh)	FiT Rate (USD/kWh) (1 Thai Bhat = 0.0310 USD)
1–3	9.75	0.30
4–10	6.50	0.20
11–25	4.50	0.14

For both the rooftop and ground-mounted FiT policies, the FiT rate can be considered relatively generous and project IRRs should be attractive to investors. The Thai government has periodically revised the FiT rates and current information on incentives for projects developed beyond 2014 can be found online.[c]

a http://thaisolarpvroadmap.org/wordpress/?p=940

b http://www.eppo.go.th/nepc/kpc/kpc-145.html

c http://www.iea.org/policiesandmeasures/renewableenergy/?country=Thailand cancelled or altered, impacting un-contracted projects under development more than those already in operation.

There are several types of existing insurances for project risks. The risk of retroactive changes in the regulatory support framework has surfaced in recent years and attempts have been made to provide insurance coevrage. For example, the World Bank Group may cover such risks through Partial Risk Guarantees. In many cases, a lender will require appointing an insurance advisor who can ensure the adequacy of insurance for a solar power project.

12.3.1.2 FiT Limitations

Commensurate with the determination of the tariff, the regulator or utility usually set a maximum level of capacity (MW) or energy (GWh) eligible for the FiT. For distributed generation, i.e., small-scale energy generated close to its point of use, the volume of power and number of projects eligible for the tariff may be open-ended (although, given the experience of several European countries overwhelmed by an unexpected response to such incentives, setting a cap in line with public budget priorities seems wise). For utility-scale projects (the focus of this guide), it is more common for the FiT to set limits, i.e., 200 MW of capacity in a given technology category, whereby the threshold is often a function of the national target a government intends to reach for its renewable energy production.

In addition to transparently-announced capacity limits, there may also be de-facto limits on securing the FiT. If particular permits are required prior to FiT application, bottlenecks may develop around key approval points, for example authorizations from local or national planning authorities, energy regulators or environmental authorities. Developers should also consider the available transmission capacity to carry power from their project site/the areas suited for solar PV project development to the areas that require power.[57] In Chile, for example, an extraordinarily rapid increase in solar development in the North may lead to strained grid capacity, while in Japan, utilities concerned about maintaining power reliability (and the price of solar PV power) have demonstrated reluctance to embrace high volumes of solar energy and have delayed grid connection.

12.3.1.3 Off-take Agreement

The tariff with its feed-in provisions is secured through a PPA between the solar producer and the off-taker, which can be the utility, the system operator, or the specially-created institution. As with any power sale agreement, the main risk factor to consider is the creditworthiness of the off-taker. For example, Kazakhstan has adopted relatively attractive FiTs for renewable technologies, but private projects cannot get commercial financing because the bankability of the PPA with the off-taker Cost Settlement Center (CSC) is a key concern. The CSC is a newly-created entity with no assets, credit history or established cash flows. More information on the PPA is provided in Section 13.

12.3.1.4 Currency Exchange Risk

Considering that in many countries a substantial percentage of the investment requirement is in hard currency while the revenue is in the local currency, there may be substantial risk associated with foreign exchange fluctuations. Some countries have recognized this and have indexed the FiT to a hard currency. This reduces the risk exposure of the developer. If such protection is not provided, the developer needs to assess the risk exposure and take appropriate precautions.

12.3.1.5 Sustainability of the Power Sector

It is always advisable for a developer to consider the financial sustainability of the tariff in the context of the local power market, including the forecasted demand for power, the current and projected levelized cost of energy from the existing power mix, the marginal cost of power supply (present and future), the ability of the utility to pass on the costs to consumers, and public willingness to pay for renewable energy. When the FiT is out of line with other trends in the market or significant price distortions

57 While solar is less site-specific than other renewables like hydro or wind, utility-scale ground-mounted projects require large plots of un-shaded land, ideally of relatively low value. These areas are more likely to be in remote areas than in large urban areas where demand for power is growing, particularly in rapidly urbanizing developing countries.

exist, extra caution is merited, and it is wise to consider the project economics in the event of policy changes.

12.3.2 REVERSE AUCTIONS AND TENDERS

The alternative to a policymaker or off-taker pre-determining the FiT to be offered for a solar PVproject is to conduct a reverse auction (or tender) for new capacity. Developers bidding for the opportunity to construct the project determine the level of the FiT. In this way, the price that the off-taker pays the developer that wins the bid is competitively determined. Sometimes reverse auctions allow for developers to propose project sites, while other times a tender will be announced with sites pre-selected by the off-taker. Conducting such a process requires specialized expertise and can incur higher transaction costs, but ultimately may be more cost-effective, as competition can drive the tariff to the lowest level necessary to support projects.

12.3.2.1 Procedure

A reverse auction starts with an announcement from a government or utility that has responsibility for this task. The government or utility then invites developers to bid the tariff they are willing to receive to provide solar energy. The tender will seek an announced number of MW and may be limited to (or sub-divided by) projects of a certain size (i.e., above or below 10MW), in certain regions (i.e., near an area with need for more capacity), and for certain technology (solar PV rather than CSP). In order to participate in a tender, a developer must qualify by fulfilling certain criteria to demonstrate the ability to finance and implement the project. As a rule, qualification requirements include providing financial information about the developer's business and relevant technical experience. Additional criteria aimed at maximizing the beneficial impact of the investment on the local economy can also play a role in the process, e.g., the nationality of key staff, employees, relationships with local suppliers/content providers, etc. [58]

58 For a good example of renewable energy tenders generally, and the inclusion of local content requirements more specifically, in the context of South Africa, see: Eberhard, A., 2013. *Feed-In Tariffs or Auctions, Procuring Renewable Energy Supply in South Africa*, Viewpoint, The World Bank, Washington, D.C.

Tender awards will be allocated to developers who have the lowest tariff bid, starting with the lowest electricity sales price bid. For example:

- Solar PV Project A: 25 MW @ $0.10/kWh
- Solar PV Project B: 15 MW @ $0.12/kWh
- Solar PV Project C: 10 MW @ $0.14/kWh

The developer with the lowest electricity production costs will be best positioned to bid the lowest tariff, and most likely to be awarded a contract. If the cap set in the tender was for 40 MWs, for example, only Projects A and B would be awarded a contract.

The details of tender award allocation will differ between countries and potentially even within rounds of the same country program. Awards may be made until the quota for that technology has been fully allocated, or sometimes only partially completed tenders take place.

When a tendered bid has been confirmed, the project developer and the off-taker will sign a PPA based on the proposed tariff over the predefined period of time.

12.3.2.2 Risks and Issues

The main risk for a developer under a tender scheme is that s/he will not win the bid. Preparing a bid for a large-scale PV installation can be costly. Developers must be willing to expend considerable time and resources in costing projects and potentially optioning land lease rights without any certainty that their bid will be successful. These costs are non-refundable if the project fails to win the tender. Developers must therefore balance their expenditure against the risk that their bid will be unsuccessful. Tender issuers can promote an efficient market by being transparent and sharing information on the number of qualified bidders, expectations of whether the tender will be oversubscribed, and information on future tenders. A second major risk is that competition becomes so great that margins are eroded to unsustainable levels, driving developers with lesser resources out of the market.

Box 9: South Africa'a REIPPP

South Africa has in place policies and initiatives that are aimed at accelerating growth in the solar PV power sector, including REIPPP and the Eskom Standard Offer.

REIPPP

South Africa's REIPPP is split into different bidding rounds. The allocated resources are shown below for Rounds 1 to 3. The decreasing trend in average PV bid price and the increase in local content is indicative of the policy's success in incentivizing solar development, although it remains to be seen whether developers can truly sustain operation at such low prices.[a]

Under Round 1 of the REIPPP, construction has commenced on 18 large-scale solar PV projects with a combined installed capacity of 630 MW. In Round 2, a total of nine projects with a combined capacity of 417 MW were awarded preferred bidder status and are currently under construction. An additional six projects with a capacity of 435 MW have achieved preferred bidder status in Round 3 and are approaching financial close. In 2013, nearly all of South Africa's solar PV power market consisted of large ground-mounted systems and it is expected that this market will remain strong.

However, historically there have been a number of delays with the bidding process. In September 2012, the Department of Energy announced delays to Round 3 of the REIPPP due mainly to difficulty in progressing the first round projects to financial close. The need to focus on financial closure for projects selected during the first two bidding rounds had a knock-on effect.[b]

In 2013, the government delayed an announcement on a final list of preferred bidders in the third round of its national renewable energy programme. This was finally completed in November 2013, more than 12 mosnths later than expected.

The Department of Energy is now in the process of finalising the financial close protocol for the Round 3 preferred bidders.

Allocated Resources for Rounds 1 to 3[c]

Parameter	Bid Window 1	Bid Window 2	Bid Window 3[d]
Date	5 November 2012	9 May 2013	4 November 2013
MW allocated for Bid Window	632	417	435
Average Bid Price/kWh	$0.26	$0.15	$0.097
Local Content	28.5%	47.5%	53.8%

a http://www.esi-africa.com/sas-third-round-bidding-sees-prices-drop-dramatically/

b http://irp2.files.wordpress.com/2011/10/pvsouthafricamap-2013-04-17.pdf

c www.esi-africa.com/sas-third-round-bidding-sees-prices-drop-dramatically/

d www.ey.com/UK/en/Industries/Cleantech/Renewable-Energy-Country-Attractiveness-Index---country-focus---South-Africa

Competitive bidding processes have been successfully implemented recently in several emerging markets, including India and South Africa. In South Africa, the Renewable Energy Independent Power Producer Procurement (REIPPP) scheme (see Box 9) is a bidding process in which proponents bid to be awarded a power sale agreement until a certain MW quota (announced for each round) is reached. Similarly, India operated a reverse auction to award successful proponents a PPA as part of the Jawaharlal Nehru National Solar Mission (JNNSM).

While involving higher preparation costs for the entity running the tender, and higher risks for the parties bidding, the competitive bidding process does offer a greater level of assurance that projects are being incentivized at the minimum levels required ("revealed prices"). As such, it can be a good strategy for larger markets that have established interest and are looking to scale up installed capacity.

Box 10 summarises key elements of India's regulatory support framework, which has evolved over time and used multiple options, including FiTs, tenders and renewable

Box 10: India's Evolving Regulatory Support Mechanisms

India has implemented a number of different regulatory support schemes including FiTs, renewable obligations and reverse auctions.

The National Action Plan on Climate Change (NAPCC) of India sets Renewable Purchase Obligation (RPO) targets for each state in India. This provides a minimum level of the total power that electricity distribution companies need to purchase from renewable energy sources. Although this is not directly related to solar projects, it requires the states to incentivise the development of renewable energy projects. Among the states, Gujarat has offered the highest FiT, at 12 Rupees ($0.20), resulting in an installed capacity of 916.4 MW as of 31 March 2014. Below is a short summary of the FiT rates by state awarded by individual state-based solar energy policies.[a]

Feed-in Tariffs of Selected States	
State	**Feed-in Tariff (in Rupees)**
Rajasthan	Flat rate of 6.45/kWh (USD 0.106) for 25 years.
Gujarat	Flat rate of 12/kWh (USD 0.198) for first 12years and 3/kWh (USD 0.049) from 13 to 25 years.[b]
Bihar	Flat rate of 9.85/kWh (USD 0.163) for 25 years.
Punjab	Minimum FiT awarded was 7.40/kWh (USD 0.122) and highest was 8.70/kWh (USD 0.144).
Karnataka	Minimum FiT awarded was 5.5/kWh (USD 0.091) and highest was 8.0/kWh (USD 0.132).
Tamil Nadu	6.48/kWh (USD 0.107) with an escalation of 5 percent every year.
Andhra Pradesh	Fixed 6.49/kWh (USD 0.107).
Madhya Pradesh	Minimum FiT awarded was 6.47/kWh (USD 0.107) and highest was 6.97/kWh (USD 0.115).

The national Jawaharlal Nehru National Solar Mission (JNNSM),[c] also referred to as the National Solar Mission, was launched in January 2010 to specifically incentivise the development of solar power as part of the broader national renewable energy targets. JNNSM set a target of 20GW of grid-connected solar power by 2022. It aims to reduce the cost of solar energy-to-grid parity by supporting large-scale deployment (through a reverse auction scheme in Phases 1 and 2), long-term policy, research and development and domestic production. The development road map of JNNSM is divided into three phases, presented below.

JNNSM Road Map and Solar PV Targets		
Timeline	**Grid connected, including Roof-Top Plan**	**Status as of March 2014**
Phase 1 (2010–2013)	1,100MW	67% of the projects commissioned.
Phase 2 (2013–2017)	10,000MW	750 MW projects selected after bidding.
Phase 3 (2017–2022)	20,000MW	Details not yet announced.

In the first phase, selected developers were awarded a PPA with the Central Electricity Regulatory Commission (CERC) through a reverse auction scheme. The average tariff was approximately US$0.15/kWh, representing a 43 percent decrease on the benchmark tariff approved by the CERC. It is noted that only 67 percent of Phase 1 projects were commissioned as of March 2014. There are a variety of reasons for this, including delays to financial close, land acquisition and grid connection issues. Reverse auction was used in Phase 2[d] through which 10,000 MW are expected to be awarded.

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a http://mnre.gov.in/file-manager/UserFiles/guidelines_sbd_tariff_gridconnected_res/salient_features_for_State-wise_solar_policies.pdf

b http://geda.gujarat.gov.in/policy_files/Solar%20Power%20policy%202009.pdf

c Ministry of New and Renewable Energy, Towards Building SOLAR INDIA Available at: http://mnre.gov.in/pdf/mission-document-JNNSM.pdf

d http://seci.gov.in/content/innerpage/phase-ii--batch-i-log-of-documents-releasednotifications-issued.php purchase obligations. Also, it shows that in India (as in many other countries), the regulatory support framework of the federal/central government may be supplemented by initiatives of the state/local governments.

12.3.3 *MARKET BASED INSTRUMENTS*

Market-based instruments accompany quantity-based mechanisms such as renewable portfolio standards or **quota** obligations. They involve the creation of a credit/certificate, which can be traded in the open market. Renewable energy credits and carbon credits are the most common of such certificates.

Market-based mechanisms are appealing because they promise greater cost-efficiency in reaching a renewables target set by a government, by providing regulated entities with greater flexibility to achieve compliance with renewable energy obligations. However, as discussed in the two examples below of renewable energy credits and carbon credits, they can also be complex and demand a fairly high level of sophistication both from the regulator and covered entities. They are best suited for markets where the power sector is already highly competitive and there is sufficient capacity amongst market players to implement the system.

Quotas require electricity suppliers (typically utilities) to derive a specific percentage of the electricity they sell from renewable sources. Quotas are different from government targets/political goals because they have legal force and some form of penalty for non-compliance. For example, if an electricity supplier sells 100 GWh of electricity per year and 10 percent of that must be generated by renewable sources, the supplier would either need to generate or purchase 10 GWh from renewable facilities.

In some instances, a quota will require that the supplier purchase renewable power from within a certain jurisdiction, for example within regional or national borders. Other quotas require only that the supplier purchase a certain proportion of renewable electricity, which can be sourced from anywhere within reach of the transmission network. Yet another model for quotas is one that allows for the renewable energy to be "stripped" from the electricity itself and be traded in the form of renewable energy credits (RECs), also called green certificates. (More on RECs is provided in sub-section 12.3.3.1).

A quota system instructs electricity utility companies to comply with quota obligations, but may or may not specify how the quota is to be achieved. The utility may build renewable generation capacity itself or it may procure it through a tender process. The utility also may negotiate power prices with IPPs independent of government, or off-take renewable energy at a FiT determined by government.

By design, quotas only provide an incentive to produce renewable energy up to the level stipulated. For a developer, the major risk of operating in response to a renewable quota is that the project may not be approved before the quota cap is exceeded. This is especially an issue if there is limited transparency on future quotas or incentives. For this reason, markets with smaller quotas can struggle to attract interest from private sector developers and investors, as the business opportunity is not sufficiently large to justify the transaction costs of entering the market. In such instances, quotas may need to be combined with other incentive programs and reforms.

12.3.3.1 Renewable Energy Credits

Market-based instruments encourage investment in renewable energy by setting a specified quota of renewable energy to be developed by the market players, usually utilities or generators. These utilities or generators can meet their quota obligations either by developing renewable energy projects themselves or by purchasing from other market players the "proofs" for specific amounts of renewable energy electricity, which are commonly referred to as Renewable Energy Credits (RECs), Renewable Obligation Certificates (ROCs) and Tradable Green Certificates (TGCs). As with other mechanisms, the quota is typically split into technology types. If there is no technology type split, the market will seek the cheapest form of renewable energy first, which is the purpose of an efficient market, yet may not fulfil public policy goals to support a range of technologies.

Under a REC program, a government announces a quota, or series of quotas (annual or multi-annual), for renewable energy supply, which electricity suppliers are obligated to meet over a given time period. Unlike a traditional quota or renewable portfolio standard though, the renewable aspect of electricity can be "stripped" from the energy itself. In other words, a PV power plant will be awarded RECs based on its generated energy or installed capacity. These RECs can be traded in the market separately from the electricity that is generated by the same facility. Depending on the rules of each specific market, the covered entity does not necessarily have to deliver the energy generated by the renewable plant into the central market. Sometimes the electricity can be sold to a third-party (which may be physically closer or have better transmission networks) at prevailing power prices, while the renewable aspect embodied in the REC can be sold separately on a dedicated exchange. This allows for greater flexibility in developing solar PV power plants where the resource or transmission capacity may be best, rather than requiring them to be developed within the physical reach of the covered entities' transmission networks, which ultimately are expected to reduce overall compliance costs.

By setting a quota that increases over time, the demand for certificates should increase, stimulating the market to deliver more certificates through investment in renewable energy. If the market is "short" (i.e., demand is greater than supply), prices will go up, and if the market is "long" (i.e., there are more certificates than needed), prices will go down. In theory, the fluctuating price of RECs provides a "real-time" calibration of market needs and guides new investment prospects.

In order to enforce a REC scheme, penalties are required to ensure compliance by the off-taking utilities. Penalties need to be considerably higher than the expected value of certificates in order to motivate quota compliance. If penalties are set too low, they will become a price ceiling.

In practice, it has proven challenging in many situations to match a solar PV project developer's need for long-term revenue certainty with the short-term demand and price signal provided by RECs, which in many markets are only traded in significant volume a few years in advance. A developer seeking to hedge price risk by selling their RECs forward over the lifetime of the power project will often have to accept a price well below the current forward price, if they are able to find a buyer at all.

The REC model has been popular in the United States (with multiple state and voluntary schemes in existence) and the United Kingdom (with varying degrees of success). Several emerging markets, including India, Romania, and El Salvador have introduced REC trading schemes as well.

Market-based mechanisms represent significantly more risk for developers than other incentives. In small markets, if there is insufficient active trading (low liquidity), then REC markets are especially prone to experience boom and bust cycles. Banks are likely to highly (even entirely) discount the potential value of RECs unless they are sold forward to a highly credit-worthy off-taker, effectively making them pure "upside" for the developer, i.e. a potential benefit to a project that cannot be borrowed against in the same manner as power revenue. If REC markets evolve and deepen, they may become bankable, but it is wise for developers to approach RECs with some caution.

12.3.3.2 Carbon Credits

Unlike the other incentives described here, carbon credits are an indirect form of support for solar energy, primarily designed to reduce greenhouse gas (GHG) emissions. Electricity generated by renewable facilities replaces electricity generated by energy sources, which utilize fossil fuels and release CO_2 emissions. The renewable facility is awarded carbon credits for the avoided CO_2 emissions.

Carbon markets seek to price GHG emissions and incentivize their reduction. However, in the markets that have (or had) a robust carbon price, namely the EU-ETS and the state of California, that price has recently been insufficient to act as the main driver for solar energy projects because the price for carbon is driven by the lowest-cost technology (typically energy efficiency or fuel-switching).

The Kyoto Protocol's Clean Development Mechanism did briefly provide an incentive for renewable energy (although very little solar)[59] in developing countries, but for various reasons, this incentive effectively no longer exists, and it has not yet been replaced by national carbon markets. However, numerous countries, provinces, and cities are considering or beginning implementation of carbon pricing policies, including South Africa, Chile, and China (see the World Bank's Partnership for Market Readiness for examples).[60] In addition to carbon credit trading, carbon taxes or reductions in fossil fuel subsidies are also under consideration to incentivize energy efficiency and lower emissions.[61] Thus, while the price of carbon in most countries is absent or too low to be the main driver for solar energy at present, there is a possibility that carbon pricing will again become more relevant in the future.[62]

12.3.4 TAX INCENTIVES

Tax incentives are a common tool to promote solar and other renewable energy, including tax credits for capital expenditure, reduced Value-Added Tax (VAT), reduced corporate income tax, import/customs and excise tax holidays, accelerated depreciation, and (though not exactly a tax incentive) relaxed rules on foreign exchange borrowing and foreign investment.[63] Due to the differing tax bases and nature of taxes levied, the tax incentives, which have been successful in developed economies such as the United States, may or may not be relevant to emerging markets.

Developers should undertake a thorough review of the local tax laws with qualified professionals to ensure they take advantage of all potential tax efficiencies. Tax benefits are often difficult to find, and it can be challenging to determine the criteria for eligibility and to understand the related administrative procedures. Appropriate time to consider local tax issues should always be built into the project timeline.

The largest market with tax credit support for solar PV projects is the United States. The U.S. investment tax credit provides owners of a project with a 30 percent tax credit on the capital expenditure of a solar PV project to offset against their tax liabilities. The United States also offers wind developers a production tax credit based on the energy generated rather than the initial capital investment. In order to take advantage of either tax credit, the project owner must have a substantial or tradable tax burden. While this model has been quite successful at incentivizing solar power (both distributed and utility-scale) in the United States, it is generally recognized that the form of the incentive generates significant transaction costs and is attractive only to investors with a large tax burden. Further, it would be of limited relevance in economies where collection of corporate income tax remains low. A similar outcome could be achieved with a capital grant (see Section 12.3.5 below on soft loans).

Other tax policies that reduce the amount of tax paid on equipment or reduce the rate of tax on corporate profit have been utilized in emerging markets, including Thailand and India. An important consideration is import duties. Some countries have elected to eliminate them or reduce them to reduce the cost of renewables. Other countries may have very high import duties whereby the motivation for the latter can be the protection of local industries (or the promotion of their emergence).

As with all renewable energy policies, there is a risk of policy expiration, which can be mitigated by closely following policy discussions and considering project economics should the incentive be phased out.

59 As of February 2015, 369 out of 7,598 registered CDM projects were solar, less than 5%. See www.cdmpipeline.org.

60 The Partnership for Market Readiness (PMR), for which the World Banks acts as Secretariat, trustee and delivery partner "supports countries to prepare and implement climate change mitigation policies—including carbon pricing instruments— in order to scale up GHG mitigation. It also serves as a platform where countries share lessons learned and work together to shape the future of cost-effective GHG mitigation." See www.thepmr.org for more information.

61 For more analysis on this, see Moarif, S and Rastogi, N. "Market-Based Climate Mitigation Policies in Emerging Economies," Center for Climate and Energy Solutions (C2ES). December 2012.

62 See "2014 State and Trends of Carbon Pricing," The World Bank (Publication 88284). May 2014

63 For an overview of numerous countries tax incentives, see for example "Taxes and incentives for renewable energy," by KPMG (2014). Available at kpmg.com/energytax.

12.3.5 SOFT LOANS

Loans with low interest rates and other concessionary terms, such as extended tenors or risk sharing, have also been deployed by governments to support solar PV development. Such loans are typically available only to a small volume of projects and only through certain designated financial intermediaries, typically a national, regional or multilateral development bank. To obtain concessionary loans, certain criteria must be fulfilled, potentially constricting the type of technology employed, or the contractors to be employed in the development of a project. Soft loans are often part of a broader renewable energy policy platform that also includes other incentives, such as a guaranteed Feed-in Tariff (FiT).

National governments that play a strong role in the banking sector often take a more policy-driven perspective, seeing subsidized loans as a direct method of achieving renewable energy targets. For example, China has stimulated renewable energy development through state-mandated concessional loans.[64] Depending on how soft loans are implemented, they can be a relatively cost-efficient means of achieving a policy goal.[65]

Soft loans are generally offered only at early stages of a technology's introduction into a new market. Unlike a policy-based incentive, which is applied uniformly across all projects meeting certain criteria, soft loans require individual, project-specific due diligence to avoid financing projects that will not be well-implemented or operated as efficiently as possible. As such, soft loans have relatively high transaction costs. The use of soft loans to support broader market development is typically achieved through financial intermediaries at a large scale, as the use of a wide-reaching banking instrument is able to bring down transaction costs associated with individual loans. This approach becomes difficult in particular markets where loan provision is limited to a single or small set of financing entities and it is not possible to engage the broader commercial banking sector.[66] Soft loans can play a role in building interest in solar technology in new markets, and offer few risks to developers, other than constraints that are typically presented clearly in policy statements and loan documents.

12.3.6 CAPITAL GRANT SCHEMES

Capital grants awarded through a tender or application process have also helped support solar PV projects, especially in the early stages of PV power commercialization when its costs were very high, the awareness of its characteristics limited, and the perceived risks high. Grants can be awarded based on a fixed incentive amount per MW or as a percentage of capital cost. Capital grant schemes are often introduced by governments on a temporary basis or for limited capacity, with the intention of providing market traction for a specific technology that is unproven or considered high-risk.

Capital grants present few risks for developers or financers. However, as with other incentives offered on a short-term basis, grants can create a "boom and bust" cycle, with prices for services and equipment bid up in the period prior to the incentive expiration, only to crash when it is no longer available and the number of profitable project opportunities is reduced. To mitigate these business cycle risks, developers can consider longer-term contracts with equipment suppliers and service providers and seek out opportunities (perhaps in niche markets) where solar projects are viable with no support.

The "1603" federal cash grant program introduced in the United States in 2009 is one example of a large-scale capital grant program for solar PV projects, introduced in recognition that the tax-based incentives typically provided were ineffective during a recessionary period.[67]

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64 For more, see B. Shen et al., "China's Approaches to Financing Sustainable Development: Policies, Practices, and Issues," Lawrence Berkeley National Lab paper LBNL-5579E. June 2012.

65 For one assessment of policies in India, see G. Shrimali, et al., "Solving India's Renewable Energy Financing Challenge: Which Federal Policies can be Most Effective?," *Climate Policy Initiative*. March 2014.

66 The Green Climate Fund's stated intention to work directly with the private sector raises the interesting possibility of combining multilateral donor funding with local implementation, but is still in early stages.

67 "1603 Treasury Program," section of the Solar Energy Industry Associations website, available online at http://www.seia.org/policy/finance-tax/1603-treasury-program

India has also provided capital grants at both the national and state level over many years.

12.4 FURTHER GUIDANCE TO DEVELOPERS ON REGULATORY SUPPORT FRAMEWORKS

Developers need to be aware of secondary regulations that may influence project transaction costs. For example, a lengthy waiting period for generation permits could significantly delay the start-up of the new plant, and thus create financial losses for the developer. Another example is power quality regulations, which may include frequency regulation (defined by a grid code) that applies to all electricity producers. While power quality requirements are not solar specific, they can make it more difficult for sources of intermittent power, such as solar, to meet criteria for grid integration.[68] Further examples of regulations that are secondary to solar, including important aspects of the grid connection process, are covered in Section 8 on Permits and Licenses.

Renewable energy policies need to be considered in the context of the broader power market in which the project is being developed. Is the market fully de-regulated with generation, transmission, and distribution each operated independently? Or is the project being developed for a vertically-integrated, state-owned utility through a Public Private Partnership?

In markets where a state-owned entity controls generation, the major opportunity for a developer is likely to be in response to a public tender or a Public Private Partnership, such as a Build-Operate-Transfer (BOT) or a Build-Own-Operate (BOO) with a PPA. The structure of the power market defines the types of project development opportunities available. However, while having this broader context on the structure of the relevant power market is critical, this topic will not be discussed further here, as the purpose of this guide is to focus on aspects of project development unique to solar PV power plants.[69]

Given how rapidly solar PV power costs have dropped in the last five years (2009–2014), it is especially important for solar energy developers to consider the possibility that solar energy incentives will evolve as well, either through anticipated policy expirations and adjustments or unexpected policy changes. By the end of 2014, most FiTs in Europe were reduced substantially from the peak levels observed in 2008, reflecting the reduction in capital cost of a solar PV power installation. Interestingly, thus far, it is governments in developed economies (such as Spain, Italy, and Greece) that have made retroactive changes to pre-existing support mechanisms in order to reduce levels of support provided to existing solar PV projects. While retroactive changes of this kind are not common (and, in the case of the countries cited above, were influenced by the strained financial situation of a number of European countries in the global recession after 2008), it is wise to consider the risk that policies may change.

If the share of renewable energy in a market coming from variable output power plants is high or expected to become high (over 5–10 percent), it is important to understand not only the support policies for solar power per se, but also the policies that have an impact on the overall power system, including the grid development, investment in storage and flexible power generation, and demand-side management. In other words, support mechanisms for solar PV power cannot be considered in isolation because integration of solar and other types of renewables into a given power system and electricity market creates additional challenges that may affect a developer, if the level of penetration of intermittent renewable power grows to high levels.

68 In many emerging markets, where maintaining the power supply is the predominate concern and the penetration of intermittent renewables such as solar is low, power quality and variable energy integration may not be top concerns. However, as the share of renewables grows in global markets, power quality may become more of a priority.

69 While not the focus of this publication, electricity market structure and reform is a priority topic for the World Bank Group. World Bank's Energy Sector Management Assistance Program (ESMAP) and the World Bank Energy Practice Group have many publications and activities covering this important issue from the perspective of the government/regulator. Many have a specific country or regional focus.

Leveraging Financial Incentives Checklist

The checklist below identifies key considerations for developers seeking to access support mechanisms for solar PV projects in any market.

- [ ] Review structure of electricity market, dynamics of energy pricing, and potential for near-term changes in market prices.
- [ ] Review energy generation regulations, including specific policies for renewables and evidence of application in current market.
- [ ] Identify specific support mechanisms for utility-scale solar PV power projects, evidence of their utilization and government adherence to terms in the current market, as well as project qualification criteria, application cut-off dates, and other potential risks.
- [ ] Understand the grid regulatory regime, including integration of regulatory and approval processes for new generation projects using renewables, specifically solar PV power projects.
- [ ] Develop a PPA model based on best understanding of viable public incentives.
- [ ] Mitigate policy risks by considering project economics without incentives, which may include hedging on market-based instruments and/or political risk insurance.

Power Purchase Agreements 13

The PPA is the most important agreement for financing a solar PV project. All other related agreements—the loan agreement, grid connection agreement, and EPC contract—should be aligned with the PPA.

13.1 POWER PURCHASE AGREEMENT OVERVIEW

Solar PV power plant projects generate revenue by selling power. How power is sold to the end users or an intermediary depends mainly on the power sector structure (vertically integrated or deregulated) and the regulatory framework that governs PV projects. Power can be sold either through a long-term PPA or through participation in an open market ("merchant" plant).

At the writing of this guide (early 2015), there were only a few merchant solar projects in the world; the vast majority of PV power plants are developed using longer-term PPAs. Merchant PV power plants are rare because PV costs typically result in power that is more expensive than other energy sources and excessively risky to financiers. Also, regulations (support mechanisms) promoting PV technology and other renewables are usually based on some form of long-term PPA. However, as PV costs continue to decline, merchant PV plants may become more common. For example, in 2014, IFC and other partners financed the first merchant solar PV project in Chile, the La Huayca II project, with no subsidy and no PPA. Merchant plants, depending on how the power sector is structured, may be able to sell both energy and capacity (the latter in a day-ahead market). Including La Huayca, as of early 2015, IFC had financed four large-scale PV projects in Chile, of which three were merchant projects and only one had a PPA. These projects are described briefly in Table 19.

This section looks at the key elements of the typical PPA for large-scale PV projects, and describes how small solar power plants (distributed generation) can utilize similar contractual arrangements.

PPAs are legally binding agreements between a power seller and power purchaser (off-taker). The party that is selling the power is, in most cases, the owner of the solar PV plant. The purchaser of power could be a power company, power trading company, or individual consumer, depending on the structure

Table 19: IFC-financed, Utility-scale PV Plants in Chile	
Project Name	**Description**
Sun Edison Cap *PPA (2014)*	The Project consists of the construction and operation of an approximately 100 MW solar PV power plant in the municipality of Copiapo in Chile's Atacama Region. Energy produced from the project will be injected into the Chilean Central Interconnected System. The project has a 20-year Contract for Differences with Compania Minera Del Pacifico S.A., an iron ore mining company.
La Huayca II *Merchant (2014)*	The Project is to expand the existing 1.4 MW La Huayca I PV solar power plant, to a total capacity of 30.5 MW. The plant is being developed by Selray Energias Ltda. and would be the first large-scale merchant solar project in Chile's SING (Northern Interconnected Electricity) system.
Luz del Norte *Merchant (2014)*	The Project consists of the construction and operation of a 141 MW-ac solar photovoltaic power plant in the municipality of Copiapo in Chile's Atacama Region. Energy produced from the project will be injected into the Chilean Central Interconnected System at prevailing spot market prices.
Sun Edison MER *Merchant (2015)*	The Project consists of the construction and operation of an approximately 50 MW solar PV power plant in the municipality of Copiapo in Chile's Atacama Region. Energy produced from the project is to be injected into the Chilean Central Interconnected System at prevailing spot market prices.

of the power market. For renewables (including PV) that are supported by regulatory mechanisms (see Section 12), the most common option is to sell all electricity generated to a power company (vertically integrated, transmission or distribution), often wholly or partially government-owned. However, a solar PV plant may also sell electricity to a trading company or a consumer, provided that this is allowed by market rules. In the latter case, wheeling charges may have to be paid by one of the two parties of the PPA.

The PPA is the most important agreement for financing a solar PV project. All other related agreements—the loan agreement, grid connection agreement, and EPC contract—should be aligned with the PPA. The PPA should define all of the commercial terms affecting the sale of electricity between the two parties, including the date the project will begin commercial operation, the schedule for delivery of electricity, the tariff, the volume of energy expected to be delivered, payment terms, penalties for underperformance on either side, and provisions for termination.

As such, the PPA is the principal agreement that defines the revenue stream, and thus the credit quality of an electricity-generating project, and is therefore a key instrument of project financing. A robust PPA helps de-risk projects by clearly specifying rights and responsibilities, and creating greater certainty around the revenue stream. Off-taker credit-worthiness is a factor whose importance cannot be overemphasized. It is one of the most critical elements considered when developing a PPA and the focus of thorough due diligence.

PPAs may be standardized and non-negotiable (except possibly for the tariff); standardized to provide an initial framework for negotiations; or open to bilateral negotiations. PPAs for solar PV projects have historically been shaped by the supporting regulatory framework, as described in Section 12. For example, it has been common for the tariff, off-take terms (take or pay), and contract duration to be pre-defined by a national or regional policy (see sub-section 12.3).

While the classic PPA model of a utility off-taker paying a fixed price to the producer is likely to remain common in the coming years, developers and financers should stay abreast of market developments, and consider both the risks and opportunities introduced by changes in pricing and business models. Box 11, at the end of this section, considers the recent rise in opportunities for distributed generation projects, sometimes referred to as "Commercial PPAs."

Refer also to the checklist at the end of this section for basic requirements specific to PPAs for solar PV projects.

The remainder of this section describes the key elements of a typical PPA. There are numerous sources that readers can consult for more in-depth coverage,[70] as well as several brief overviews on the topic.[71]

13.2 MAIN POWER PURCHASE AGREEMENT TERMS

The PPA sets out the terms of the power purchase, including the tariff, the volume of power to be sold, and the duration of the agreement. Some of the key commercial, legal, and technical terms to be considered while reviewing a PPA are described below. Where appropriate, these descriptions include comments on the potential risks associated with the key terms.

13.2.1 TARIFF OF ENERGY SOLD

The methodology for calculating the electricity price will depend on the market within which the project is operating and the prevailing regulatory regime. Under a FiT regime, a flat-fixed rate price could be offered for the life of the project. Alternatively, the tariff may be set through a reverse auction, negotiated or based on power market parameters (e.g., marginal cost of power supply).

The tariff may be adjusted based on an index that reflects annual inflation and foreign exchange fluctuations. If indexation is not included, the developer should assess the risks associated with inflation and changes in foreign exchange rates. Long-term operating costs for solar projects are very low, making inflation less of a concern than for other technologies, but should still be considered. In markets where it is difficult to obtain long-term financing in local currency, foreign exchange rates reflect substantial risk exposure. Foreign exchange is also a substantial risk linked to repatriation of profits.

Tariffs for solar power projects may continue to be determined through regulations, but as the cost of electricity from PV power approaches that of conventional power tariffs (often referred to as "grid parity"), tariff setting may change. For example, in South Africa, the average solar PV tariff fell 68 percent, from over US$0.34/kWh to $0.10/kWh between Round I auctions conducted over 2011–2012 and Round 3 auctions in 2013.[72] Tariffs around $0.10/kWh were also reached in other locations around the world, such as India and Brazil, and fell still lower to $0.06/kWh in an auction in Dubai.[73]

Also, as the solar PV market evolves, PPAs are likely to introduce increasing levels of exposure to market risk. For example, in 2013, IFC financed the Aura Solar Project in Mexico, a 38.6 MWp greenfield PV project with a 20-year PPA in which the off-taker pays a tariff determined by marginal cost of power supply, with no subsidy. Aura is the largest PV solar power plant to be built to date in Mexico.

The PPA also specifies the expected installed capacity of the solar PV project (in MW) and the predicted annual electricity production in MWh. The installed capacity of a solar PV plant is simply the maximum power of the PV plant, as specified and warranted by the PV plant supplier.

The predicted annual energy production is estimated based on the project's installed capacity, solar irradiation, and the resulting capacity factor or performance ratio, as described in detail in Section 5 on Energy Yield. The predicted annual production should take into account seasonal variations in solar irradiation and system losses to the point of metering. Also, panel degradation loss should be taken into account reflecting how efficiency and annual energy production may be reduced year-on-year over the life of the plant.

An accurate annual production prediction gives the off-taker comfort in knowing how much energy it will receive and the seller comfort knowing how much it can sell. The

70 The World Bank Group has publicly available PPA resources at http://ppp.worldbank.org/public-private-partnership/solar-power-energy

71 For example, see "Understanding Power Purchase Agreements," funded by the U.S. government's Power Africa initiative, available at no cost online at http://go.usa.gov/FBzH

72 Ebehard, A., Kolker, J. and Leigland, J. "South Africa's Renewable Energy IPP Procurement Program: Success Factors and Lessons." Public-Private Infrastructure Advisory Facility (PPIAF) of the World Bank. May 2014.

73 Upadhyay, A. "Dubai Shatters Solar Price Records Worldwide — Lowest Ever!" Cleantechnica Website, November 29th, 2014.

level of accuracy required of this prediction is dependent on the market in which the project operates. For small distributed solar PV installations operating under a FiT regime, it may be acceptable to use software tools made available by the regulator. However, utility-scale projects should include a professional independent energy yield assessment, produced and/or verified by an experienced consultant with a track record of producing "bank grade" data, and a confidence interval of at least P75, if not P90.

The project's actual energy generated will be based on meter readings. However, the energy yield prediction gives both parties a reference against which any anomalies in production can be checked and is sometimes used as a back-up to meter readings in the event of meter failure or discrepancies. Thus, energy yield prediction is important both during project planning and during operation.

Most solar and other renewable energy, as non-dispatchable forms of power, are sold on an "obligation to take" or "take or pay" basis, whereby all power they generate must be accepted by the grid. If this is not the case, then the volume of power being transacted should also be specified, with clarity on any penalties due should that volume of power not be delivered.

13.2.2 PPA DURATION

The PPA specifies the expected start and termination dates of the agreement. The duration of the PPA should be equal to and ideally longer than the period of time required to repay the project's lenders and to meet expected equity returns. In some cases, the duration will be determined by the regulatory support mechanism under which the solar PV project is developed; in other cases, the PPA duration can be negotiated. PPAs covering a 15- to 25-year period are desirable for PV plants and are relatively common. The longer the term of the PPA, the less exposure the project has to future changes in power prices, and the more secure its revenue stream. A sufficiently long PPA duration is especially critical for solar PV plants because the vast majority of costs are incurred up front and must be repaid over the project's life. PV power plants are expected to operate with fairly predictable degradation rates for 20 years or more, which is also suited to PPAs with long duration.

13.2.3 RIGHTS TO ENVIRONMENTAL CREDITS

Some regulatory frameworks may offer environmental credits (i.e., RECs) as part of an incentives package for new solar PV projects. The developer should determine the eligibility of the PV project for receiving environmental credits and ensure the assignment of rights to any credits linked to the project is clearly specified in the PPA. This should include the term for which these rights will be assigned (usually the project lifetime or duration of project eligibility), as well as provisions for the assignment of environmental credits that may potentially become available in the future.

13.2.4 CONDITIONS TO COMMENCEMENT

"Conditions to commencement" or "conditions precedent" define conditions that must be satisfied by the developer prior to commencement of the PPA term.

These conditions generally include securing the required project permits/approvals, the execution of an O&M agreement (covering civil works for land maintenance, module and balance of system routine inspections), a secure grid connection, and issuance of a takeover certificate.

The conditions to commencement set out a common understanding of the requirements of the project before commissioning. If the project developer does not satisfy all conditions, the off-taker may have the right to terminate the PPA. However, conditions to commencement often define requirements for the developer that, if not met, might leave the project legally exposed. Therefore, it is in all parties' interest for the conditions to commencement to be met.

13.2.5 GRID CONNECTION AGREEMENT

The PPA will typically reference and summarise the terms of the Grid Connection Agreement, often in an annex. It is very common for grid connection to be delayed, and where the off-taker or grid company is responsible, the seller will want to clearly specify the method for calculating liquidated damages related to such delays.

13.2.6 GRID CODE COMPLIANCE

The grid code, controlled by the grid operator, specifies how a generating plant must connect to and interface with the electricity distribution network. The PPA should reference the grid code and clearly specify how compliance with that code is determined as a condition for commercial operation. There may be room to negotiate relaxation of grid code requirements for solar projects if specific code for renewables has not yet been adopted. If the grid code has not been updated to cover intermittent energy sources, such as solar, certain provisions may need to be included in the PPA.

13.2.7 USE OF NETWORK CHARGES

The owners of the electricity distribution and/or transmission networks normally charge a fee for facilitating the evacuation of electricity from the generating plant and delivering it to the consumer. Renewable facilities may be exempt by the regulatory support framework. In some cases, the owner of the local distribution network may be different than the owner of the transmission network and different fees may be payable to each owner. The size of the solar PV plant can dictate whether fees are payable to one or both owners. For example, a fee may be payable only to the distribution network owner if the installed capacity is below a specified level. If the rated capacity is above the specified level, then a fee will be payable to both the transmission and distribution owners, recognising that the electricity generated will not necessarily be consumed locally. The associated costs will be specified in the grid connection agreement and referenced in the PPA.

13.2.8 METERING ARRANGEMENTS IN COMPLIANCE WITH GRID OPERATOR

Metering arrangements are critical to ensure the project owner is fully compensated for electricity generated. However, metering arrangements are often poorly defined in PPAs, with weaknesses only brought to light when there is a dispute.

Metering arrangements are usually defined in the country's grid code or metering code and ownership of the meter will normally reside with the grid operator or the off-taker. The PPA should define how electricity generation will be measured or calculated in the event that the meter is damaged or found to be inaccurate or there is a dispute over the reading. Even if the PPA or grid code does not require a back-up meter, it is good practice to install one, in the event of failure of the main meter or inaccurate operation. Generally, in the event of a faulty or damaged meter, output will be based on historic data or on predicted energy yield values.

It is usually the project developer's responsibility to install meters, but it is not uncommon for the off-taker to be responsible for metering arrangements and for ownership of the meter to pass to the grid operator or off-taker.

13.2.9 PRODUCTION FORECASTING

The PPA may define additional responsibilities of the seller and the buyer beyond delivering and paying for power, such as production forecasting. Production forecasting is a future prediction of energy production from a generating plant. Forecasting time horizons can vary from hours to days depending on the requirements specified in the grid code. The grid operator uses regular updates of production forecasts from across its distribution and transmission network to balance the flow of electricity across the network, which will require other electricity generators (typically thermal plants) to reduce or increase production to accommodate the varying output from renewable sources, such as solar.

Production forecasting becomes more necessary as the size of the renewable energy generator increases and the proportion of intermittent generation on the distribution and transmission networks increases. Consequently, it may not be necessary for smaller solar PV plants to implement production forecasting for a solar PV facility, and this requirement may therefore be a negotiable part of the PPA.

13.2.10 SCHEDULED & UNSCHEDULED OUTAGES

Just as the PPA addresses periods when the off-taker may be unable to accept delivery (curtailment), it should also address periods when the project will be unable to deliver energy. A scheduled outage is one that is planned and is reasonably under the control of the solar PV facility's owner. An example is periodic inspection of electrical infrastructure. Unscheduled outages are unpredictable and random events, for example an electrical fault within the solar PV facility that forces it to shutdown suddenly.

As an outage will disconnect all or part of a solar PV facility, the grid operator will normally require advance notification so it can plan accordingly. The notification requirements should be specified in the PPA. In turn, these notification requirements should be reflected in the project's O&M contract, as the O&M contractor will likely be responsible for notifying the grid operator.

The PPA may also specify the number and timing of scheduled outages and this can often be negotiated. For example, it would best suit a solar PV facility to plan scheduled outages at night or in the least sunny season in order to minimise the impact on electricity production.

Depending on the size of a solar PV facility, repeated unscheduled outages could cause problems with regard to the stability of the electrical distribution and transmission network. Consequently, the PPA may detail punitive measures that will be enforced on the solar PV facility should its production be unstable, and it is recommended that the criteria that might trigger any punitive measures are negotiated with the off-taker.

Finally, the PPA should include a methodology to determine the amount of energy that could have been delivered by the generator and that could not be accepted by the off-taker, often referred to as deemed generation. The energy yield prediction, updated based on actual operational performance, may be used as the basis for determining deemed generation. This is discussed further in sub-section 13.2.11, Curtailment, Grid Downtime & Network Maintenance.

13.2.11 CURTAILMENT, GRID DOWNTIME & NETWORK MAINTENANCE

As discussed earlier in this section, power delivery can be reduced both by project outages (by the seller), as well as by the grid operator (who may or may not be the same party as the buyer). The grid operator provides access to the distribution and transmission network to allow for electricity export from the solar PV plant. This network requires maintenance (scheduled or unscheduled); also, unexpected operating conditions may happen requiring curtailment of power in-flows locally or to the grid in general. In such cases, the grid operator may require that the solar PV plant be disconnected from the grid temporarily.

The grid operator should be obligated in the PPA to advise the solar PV plant operator of scheduled grid downtime, with sufficient notice to allow the operator to plan accordingly. The duration and frequency of downtime events must be clearly specified in the PPA.

Unscheduled grid downtime, also referred to as curtailment, is even more critical to address. The PPA should specify the level of availability that the grid operator expects to provide. The PPA should either identify how to determine deemed generation or another form of compensation/penalty if the grid operator fails to maintain the agreed level of grid availability, with a clear methodology for calculating the compensation due to lost production caused by grid downtime.

The PPA should outline clearly how curtailment will be addressed. In markets with very high penetration rates of renewable energy (e.g., Germany and some remote regional or island grids), curtailment may be due specifically to the volume of intermittent energy. However, some amount of curtailment is to be expected as part of routine operations due to grid constraints and load balancing needs. The amount of curtailment can generally be expected to be higher in many emerging economies where transmission networks are more constrained. Also, in emerging markets, it is more common for the power off-taker to also be the grid system operator, making them the responsible party for grid availability. If the roles of power off-taker and grid operator are separate, then curtailment might instead be dealt with under the grid connection contract. It is common for PPAs to allow up to a certain level of curtailment for which the solar PV plant owner is not compensated; however, the PPA states the terms of payment above this level. In some cases, the solar PV plant owner is getting paid for all the curtailed generation.

13.2.12 CHANGE OF LAW AND QUALIFIED CHANGE IN LAW

The change in law clause protects the developer against changes to applicable laws and regulations or new laws introduced after the PPA is executed and that have a financial impact on the project. "Law" refers broadly to legislation—for example, commitments and incentives for renewable energy—as well as regulations and technical guidance, such as the grid code or interconnection procedure. The PPA should also address how any appropriate compensation should be determined in response to a change of law.

13.2.13 ASSIGNMENT AND STEP-IN RIGHTS

It is important for the PPA to contain assignment rights empowering the project owner to assign the present/future rights, bank receivables, and interest from the project to the financing institutions (both equity and debt) to serve as security. In the event the developer runs into serious problems, step-in rights facilitate a smoother transfer of control over a project to its creditors. The lenders will seek to resolve the issue and if possible, also "step-out" of the developer's role. Including assignment rights in the PPA improves bankability by improving the worst-case scenario, and can improve financial terms for the developer.

13.2.14 ARBITRATION

While a good PPA will help identify potential areas of disagreement and provide clarity on how defaults can be remedied, disputes are always possible. After informal steps like closed-door negotiation or the appointment of an independent engineer for technical disputes, arbitration is the next step towards dispute resolution. The venue and rules of arbitration should be specified in the PPA.

Arbitration is generally considered to be preferable to going to court as it is faster, offers privacy and is typically less expensive. Further, for projects in emerging markets, it can be the only realistic approach to dispute resolution in light of overly-burdened local courts. From a lender's perspective, it is preferable for arbitration to be conducted internationally for large projects to ensure that the arbitration panel is neutral. For small projects, international arbitration is unrealistic due to the potentially high costs of dispute resolution. Different arbitral rules may be selected, such as the World Banks' International Centre for Settlement of Investment Disputes (ICSID), the United Nations' Commission on International Trade Law (UNCITRAL) model provisions or International Chamber of Commerce (ICC) rules. National/state-owned off takers are often reluctant to accept foreign jurisdiction.

13.2.15 FORCE MAJEURE

Force majeure events are those events that are completely beyond the control of either party and have a material impact on a project, such as wars, natural disasters, and extreme weather events. Events of force majeure should be listed in all PPAs to exclude situations over which either party has reasonable control.

The duration for which a force majeure event can continue prior to a party seeking termination of the PPA should also be defined. This is termed *Prolonged Force Majeure,* which may have its own definition in a PPA. Termination due to force majeure can generally occur if the event continues for a continuous six- to 12-month period, or an aggregate period of 12 to 18 months.

It is important that neither party be defined in the PPA as being liable to the other party in the case of a force majeure event. At the same time, the recognition of force majeure does not mean that parties should not seek out appropriate insurance to cover such risks.

13.2.16 LIMIT OF LIABILITY

The overall limit of liability of either party to the other party will be defined in a PPA. There is no industry standard for limits of liability and these vary widely. Limits may be an aggregate value over the full PPA term, limited on an annual basis or limited per event. Although it is beneficial for liability not to be limited on an annual basis but instead as an aggregate limit, it is more common for an annual limit to be in place. The key risk associated with the limit of liability is that the limit is too low and does not cover potential lost revenue or costs incurred due to an act or omission of the other party. The suitability of a limit of liability can be determined by comparing the liability limit with the revenue assumptions in the financial model.

13.2.17 TERMINATION

The contract will specify an end date, which is its natural termination. In addition to this, the PPA should list early termination events, along with a clear methodology for determining termination payments. Termination events generally include:

- Insolvency events or similar.
- Default in performance of obligations under the PPA when not cured or remedied within the specified period including:
  - *Failure to meet conditions precedent.*
  - *Failure to meet licensing or permitting requirements.*
  - *Failure to make payments due.*
  - *Reaching the limit of liability.*

This section focused on aspects of a typical PPA for grid-connected utility-scale solar PV power projects. PPAs for distributed generation PV installations have many similarities with utility-scale PV plants, and some important differences too. Box 11 provides information on PPAs for distributed PV systems, even though this report does not cover such installations in a comprehensive manner.

Box 11: Distributed Generation and Commercial PPAs

As a modular technology, solar power can easily be scaled up to meet a range of power needs. While this publication focuses on financing and business models suited to utility-scale solar power projects, informally defined as 5 MW or larger, much of the technical guidance it contains also applies to smaller projects (see Annex 4 on Rooftop PV Systems). As the price of solar power has fallen, there are increasingly interesting opportunities for distributed generation of solar power in emerging economies. This is especially true in economies where the price of power is high and/or reliability of the grid is low, and solar power can effectively compete with diesel generators and other forms of back-up power generation.

Distributed generation refers to power generation that occurs close to the load or end user, and involves plants with typically small generating capacity located on the off-taker's land or nearby. In a traditional utility model, power generation takes place at a large central plant and is transmitted through the grid and sold by a distribution company to end-users. In contrast, distributed generation projects sell power directly to the end user and can exist independent of the grid, although sometimes power is delivered to the end user (e.g., off-taker) over the grid, in a process known as "wheeling." Depending on local regulations, wheeling may or may not require paying a fee to the grid company.

Distributed generation projects still require purchasing agreements, sometimes called "Commercial PPAs," which obligate the customer to purchase power for a period of time suitable to pay off project debt and earn a suitable return. There are a variety of business models, the potential of which depends on the particular power market and its regulations. Commercial PPAs may govern the sale of electricity to a range of customers, from individual residences[a] to large-scale industrial facilities. However, a very large project selling to a single buyer is more commonly referred to as "captive power".[b] In many emerging economies, the credit worthiness of individual commercial or industrial customers may be superior to that of the utility, and customers may be willing to pay a tariff higher than that offered by the utility to ensure they have an adequate and high-quality supply of power.

An opportunity sometimes exists to sell excess power from distributed generation to the grid. This model of distributed generation represents over half the recent growth of solar energy in Germany[c] and between a quarter and half of recent solar PV growth in the United States.[d] In Germany, this growth was driven by a national feed-in tariff (FiT) for distributed solar. In the U.S., distributed solar has been largely driven by regulations that allow net-metering.[e] Also referred to as "behind the meter" pricing, net metering allows the customer to sell electricity back to the grid, typically at the same rate as a utility tariff, and pay only for the net amount of grid power consumed.

Several distributed generation sites may collectively function similarly to a utility-scale project if they have significant exposure to the utility alongside private buyers as a key off-taker. The terms of sale to the grid from distributed PV projects are often standardized, with a pre-determined price and a requirement for the utility to purchase all electricity from projects under a certain installed capacity.

The amount of distributed solar power in emerging markets at present is very small, but there is significant potential for growth. While the models that proved successful in the United States and Europe may be taken as starting points, new business models are likely to develop in response to unique local conditions. In many emerging markets, insulation levels for solar power are high (increasing capacity factors), and utility efficiency and reliability are low—factors that improve the competitive position for distributed solar power. Improvements in energy storage will drive further innovation. While still in its infancy, the potential for distributed solar power (and other distributed renewable energy) presents interesting opportunities. Thailand, the Philippines, and Pakistan have recently introduced legislation permitting distributed generation.

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a Although this publication does not address business models for off-grid or mini-grid solar PV, this topic is addressed in IFC's publication From Gap to Opportunity: Business Models for Scaling Up Energy Access.

b Whether an opportunity exists to serve different customer types in a specific market depends on many factors, including whether it is permitted under local regulation.

c Trabish, Herman K. "Why Germany's Solar is Distributed." Greentech Media, May 29, 2013.

d Solar Energy Industries Association (SEIA), "Solar Market Insight Report 2014 Q4."

e The Investment Tax Credit (ITC), representing a 30% tax credit on allowed capital investment, also plays a key role in promoting both utility-scale and distributed solar within the United States, but the focus here is on the specific incentive for distributed (as opposed to utility-scale) solar.

Solar-Specific Power Purchase Agreement (PPA) Checklist

The checklist below sets out some of the basic requirements that are specific to solar PV for drafting of a PPA.

- ☐ PPA terms specify the expected installed capacity of the solar PV project (in MW) and the predicted annual electricity production in MWh.
- ☐ PPA includes "take-or-pay" provision, or otherwise specifies volume of power to be transacted and penalties for failure to deliver.
- ☐ PPA term meets or exceeds the term of debt repayment.
- ☐ Conditions to commencement agreed with off-taker.
- ☐ Metering arrangements in place that align with national code, including for installation and ownership.
- ☐ Terms of loan agreement, grid connection agreement, EPC contract, and O&M contract are aligned with the terms of PPA.
- ☐ Obligations for grid code compliance included in PPA.
- ☐ PPA outlines clearly how curtailment will be addressed, including how liquidated damages will be calculated.
- ☐ Assignment and step-in rights established.
- ☐ PPA defines limits of liabilities, early termination events, and methods to calculate termination payments.

Financing Solar PV Power Projects

14

This section focuses on forms of financing, key considerations of project financing, and the due diligence process that are unique to solar PV power projects.

14.1 FINANCING SOLAR PV POWER PROJECTS OVERVIEW

In order to obtain financing, the developer must prepare comprehensive documentation of the project details so that potential financiers are able to assess the risk of the investment. This is particularly true of project financing, as the lender depends entirely on the cash flow of the project for repayment rather than on the balance sheet of the sponsor.

A range of financing structures can be used for solar PV development, however project finance is the most common. The appropriate structure will be influenced by the commercial and financial needs of investors, as well as the market and incentives available for solar PV power projects in a particular geography. At early stages, equity financing is used to explore and develop a project opportunity, and later, debt is typically brought in for project construction. In general, most financing structures will involve two key components:

- Equity from one or more investors, injected directly or via the project developer into a special purpose vehicle (SPV or "project company").
- Non- or limited-recourse debt from one or more lenders, secured against the assets owned by the SPV.

This section provides an overview of the financing process, focusing on aspects that are unique to solar PV projects.[74] This includes forms of financing (debt versus equity), key considerations of project finance (requirements, timing, and structure), and the due diligence process (risks and ways to mitigate them). Issues related to project costs and revenues, as well as solar PV-specific aspects of the project's financial model are discussed in Section 15.

74 Two well-known textbooks on this subject: E.R. Yescombe, *Principles of Project Finance*, 2nd Edition, 2002, Elsevier Academic Press; Scott Hoffman, *The Law and Business of International Project Finance*, 3rd Edition, 2008. Cambridge University Press.

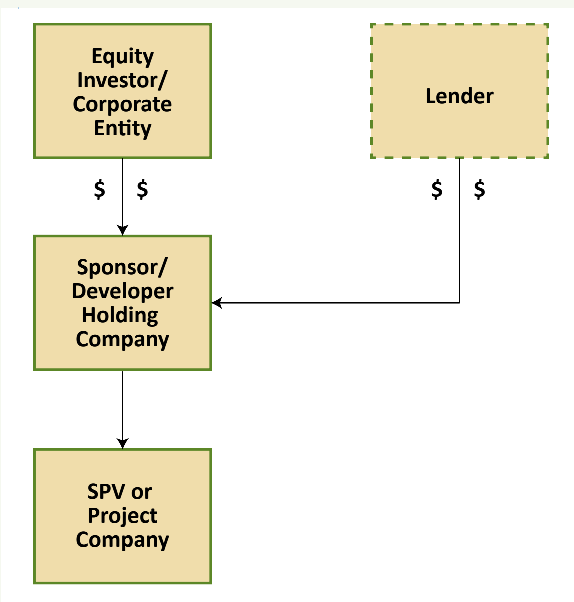
Refer to the checklist at the end of this section for the basic steps in seeking project financing for solar PV projects.

14.2 FORMS OF FINANCING

14.2.1 CORPORATE FINANCING

Large companies may fund solar plants "on balance sheet," providing equity themselves and obtaining debt as part of their broader operations and corporate financing. This model would be typical for self-generation (i.e., for a single user's own power needs), rather than the larger utility-scale projects that this guide focuses on. This type of financing can also be an appropriate model when the project developer is a large entity that has access to very low-cost financing, which might be the case for a highly-rated utility or conglomerate. It is also utilized, even for large projects, in economies that do not have a strong tradition of off-balance-sheet financing, such as Japan. Figure 27 illustrates corporate financing.

Figure 27: Corporate Financing



Corporate Financing

- Single ownership structure.
- May be suitable for developers that can finance an entire project to completion and then re-finance the development to free up equity.
- A project sponsor has full ownership of the project but is also exposed fully to the risks.
- May be applicable for companies with a large balance sheet or for smaller projects.

14.2.2 100 PERCENT EQUITY FINANCING

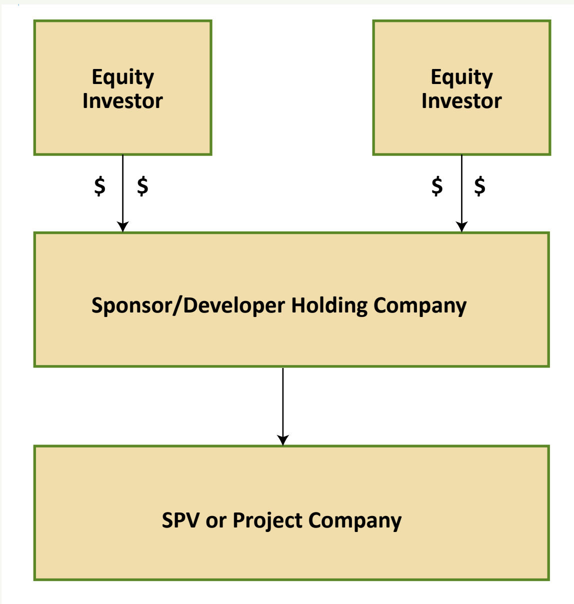
In general, debt is cheaper than equity, and thus it is more attractive to finance projects using debt financing. However, in certain circumstances, solar PV power projects may be financed entirely with equity. If debt is not available at attractive pricing or tenors, all-equity financing may be pursued, especially for smaller projects.

For example, in Europe following the global financial crisis, many banks previously active in the project financing space were no longer lending, or were only lending for shorter tenors than in earlier years. However, due to strong policy incentives, renewable energy projects still offered sufficiently high returns in comparison with other investment opportunities available at the time to make all-equity investment in solar projects attractive, and all-equity deals took place.

Today, in many developing countries, the local market for long-term financing is still not very deep, and developers may be obliged to finance a larger portion of the project with their own equity. Whether this is attractive ultimately comes down to a project's expected return and the developer's other options to deploy capital.

Equity financing may also be opportunistic; equity can often be deployed more rapidly than debt, so if there is a high-return opportunity and strict timelines to secure incentives such as feed-in tariffs (FiTs) by a certain date, a developer may be willing to finance the entire project out of pocket or in partnership with a co-sponsor such as an infrastructure fund. Once the project is built and operational and the risk profile is reduced, the equity holders can then seek to refinance it using cheaper debt financing. Figure 28 illustrates equity financing options.

Figure 28: Equity Financing



100% Equity Financing

- Development funds secured internally or from a third party equity partner.
- Often can be deployed rapidly.
- Independent developers can use their local or solar technology experience to attract equity from new equity providers who have the capital but not necessarily the solar experience.

14.3 PROJECT FINANCING

Project financing is the most common approach to long-term financing of utility-scale solar projects. The main distinguishing feature of project financing is that loans are made based on the strength of ring-fenced project revenue, with no or limited recourse to the project sponsor. This approach separates an individual project from other activities of the sponsor. Project financing is attractive for developers as it can allow for higher rates of leverage (thereby maximising return on equity) and move liabilities to a project company rather than keeping them with the developer. It also allows developers to free up equity in order to develop more projects. With a project financing structure, projects are normally held in a project company or a special purpose vehicle (SPV) that holds all project assets and liabilities.

Given the limited recourse to the parent company, lenders require that there is a secure revenue stream from the project, and will undertake in-depth due diligence of the project to gain confidence on the project's ability to service debt repayments. This will include a thorough technical and legal review of the project and all associated contracts, especially the PPA, so that confidence can be placed in project revenues. Due diligence is described in sub-section 14.4. PPAs are described in Section 13.

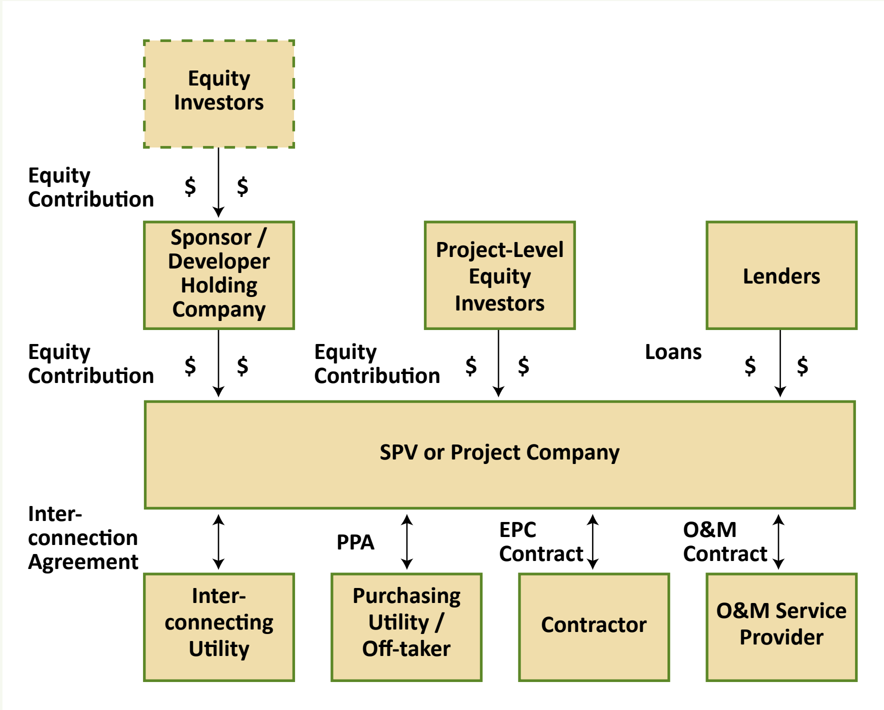
Project financing can be particularly useful in emerging markets where perceived and actual risks may be higher and guarantees from the host country government or another party may be required. Bilateral and multilateral lending agencies (such as the IFC) are also able to provide credit enhancement and other support, and in some instances (typically in less developed countries) may also be able to mobilize some concessional financing to mitigate certain risks.

Solar PV projects have historically been well suited to project financing because many sell power at a fixed tariff (as opposed to a fluctuating price on a merchant market) and often on a "take-or-pay" basis whereby the off-taker purchases whatever volume of power is produced, thus mitigating both price and volume risk. Further, as there is no fuel, there is no price uncertainty to be hedged on any feedstock. While project financing can be obtained even in the absence of these conditions with appropriate risk mitigation, these favourable off-take conditions have helped smooth the introduction of solar technology into new markets. If recent price declines of solar technology continue, it can be expected that solar will be increasingly competitive even with contractual conditions that today are typical for fossil-fuel power plants. Figure 29 illustrates project financing options.

14.3.1 THE ROLE OF THE SPV

Developers and equity partners typically begin the development process by forming a project company or SPV, which is assigned all the rights and obligations of the project. The SPV owns the project and plant when

Figure 29: Project Financing



Project Financing

- Lenders loan money for the development of the project based on projected cash flows of the project.
- Enables developers and equity partners to leverage their funds by securing debt against the revenues of a solar PV project.
- In the event of default, recourse is against the SPV.
- Pricing and structuring of the debt based on the forecasted cash flows.
- Lenders require extensive due diligence to gain confidence in the projected cash flows

constructed, signs the EPC contract, O&M contract, the PPA, and is paid project revenues.

Such project structures offer businesses the opportunity to isolate the solar PV project from the rest of the developer's business activities. The working capital requirements and debt servicing are taken from project cash flows as well (although the sponsor may be required to inject capital in the event that required debt coverage ratios are in danger of being breached). A debt service reserve account is typically required (usually six months of debt service), which functions as the support mechanism on the debt coverage. Covenants are also typically required by the lenders to prevent equity holders from receiving dividends when debt service ratios fall below a specified point. Only when other financial obligations have been met (typically laid out in a highly-specified cash "waterfall") will the equity partners realize their return, often in the form of dividends. SPVs can be governed by local law or may refer to appropriate international law, depending on the requirements of the country in which the project is being developed and the preferences of the shareholders.

14.3.2 EQUITY AND DEBT POINT OF ENTRY

The terms of financing for a solar power project will evolve over the course of its development. Initially, the project is not well defined: there are risks and uncertainties with regards to many aspects of the project, including solar resource, expected yield, grid connection, and land lease and development rights with the landowner. As a project progresses, it becomes better defined: the solar

Box 12: Equity Investment and Joint Development Support from IFC InfraVentures

IFC InfraVentures—the IFC Global Infrastructure Project Development Fund—helps develop public-private partnerships and private projects for infrastructure in developing countries. It provides early-stage risk capital and actively participates in the project development phase to create private infrastructure projects that are commercially viable and able to more rapidly achieve financial close.

Through IFC InfraVentures, the World Bank Group has set aside a $150 million fund, from which IFC can draw to initiate project development in the infrastructure sector. IFC serves as a co-developer and provides expertise in critical areas, while partially funding the project's development.

IFC InfraVentures is an additional resource for addressing the limited availability of funds and for providing experienced professionals dedicated to infrastructure project development, both of which are key constraints to private participation in infrastructure projects in frontier markets.

http://www.ifc.org/wps/wcm/connect/Industry_EXT_Content/IFC_External_Corporate_Site/Industries/Infrastructure/IFC_InfraVentures/

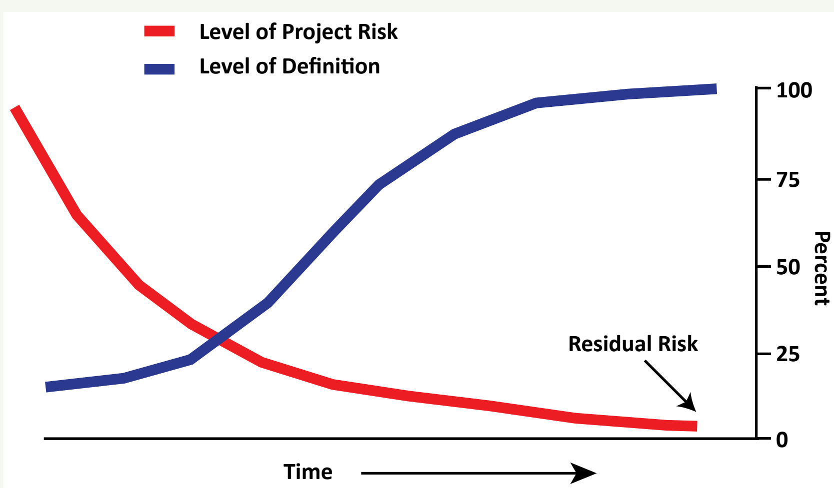
resource assessment is carried out and the outline design allows an energy yield prediction to be performed.

A solar PV project developer entering a new geography may assess the feasibility of numerous potential solar PV project sites, but many will not be selected. As the project progresses and is defined in more detail, the risks are reduced and the project becomes more valuable and attractive to potential investors.

The balance of risk and definition as the development progresses is illustrated in Figure 30. At the start, there is little project definition and high associated risk. As time progresses and development activities are performed, the project becomes better defined, and the associated risk falls.

If an early-stage developer does not have sufficient capital to bring a project to completion, the developer must consider when in the project cycle to seek additional financing from other equity investors. The earlier equity investors are involved in the project, the higher the risk they take, and the higher the return they will demand, commensurate with that risk. A debt provider will not loan to a project until there is a high degree of certainty that the project can proceed and it has been sufficiently de-risked.

Figure 30: Project Risk versus Project Definition



Source: Holland and Holland Enterprise Ltd, "Project Risk versus Project Definition," 2011, http://www.successful-project-management.com/images/risk-vs-definition.jpg (accessed June 2014).

14.3.3 THE PROJECT DEVELOPMENT CYCLE & PROJECT VALUATION

Different developers play different roles in the project development cycle. Some developers focus solely on the early stages of project development and the local knowledge required to secure land, permits, and a grid connection. Especially if they do not have access to their own capital, their business model may be selling their project for a success fee to another (typically larger) developer, who then takes on construction of the "shovel-ready" project.

In another example, smaller developers might initiate project development and desire to carry the project through to commercial operation, but lack sufficient financing of their own prior to the stage where it would be possible to seek project debt. The developer might then seek additional equity from a second project sponsor, either from a "passive" financial investor looking for a return, or a specialized fund providing both financing and implementation expertise. As a condition of external equity investment, the first developer is often expected to remain partially invested so that all parties have an incentive to ensure that the project reaches completion.

When a project or equity stake in a project is sold, the two parties must agree on a project valuation. The earlier a project is in its development, the less certain it is to be successfully realized, the less certain its revenue stream, and the more discussion there is likely to be between the buyer and seller on the value of the project. The challenge of agreeing on a project price is certainly not unique to solar PV power projects, but it can be more difficult in new markets, where "industry standards" have not yet developed and there is a lack of clear information on different steps in the development process and the value each step adds. Solar PV is also unique in that the technology has experienced dramatic drops in cost, leaving developers who purchased panels only 18 months earlier than other developers with a comparatively expensive and un-competitive project.

14.3.4 PROJECT FINANCING STRUCTURE

As shown in Figure 32, in a typical project financing structure, there will be one or more equity investors injecting funds directly or via the project developer into the project company (SPV). Lenders, typically a consortium of banks, provide debt, which is secured against the assets contained within the SPV.

When considering project financing, developers should consider the following:

- The usual term of a project financing loan ranges from 10 to 15 years or longer. For solar PV projects, the term may be limited to the period of the PPA or FiT,

Box 13: IFC Financing of Solar Energy

IFC is the largest global development institution focused on the private sector, bringing its AAA credit rating to 108 offices around the globe. As of May 2015 IFC has made over 350 investments in power in more than 65 countries, and is often at the forefront of markets opening to private participation.

The majority of IFC's current portfolio in power generation is in renewable energy (76 percent in fiscal year 2014, and renewable energy consistently makes up two-thirds of IFCs portfolio), including more than $500 million in solar power projects. IFC has invested in more than 55 solar projects that generate more than 1,397 MW, with key transactions in Thailand, the Philippines, India, China, Jordan, Mexico, South Africa, Honduras, and Chile.

IFC provides a range of financing solutions, including debt and equity at the project or corporate level. IFC can offer long maturities tailored to meet project needs, flexible amortization schedules, fixed or floating interest rates, and lending in many local currencies. IFC also helps to mobilize additional sources of financing through syndications as well as third-party capital managed by the IFC Asset Management Corporation (AMC).

IFC works with experienced and best-in-class new developers who demonstrate commitment to project success through their equity contribution to the project.

potentially introducing re-financing risks should the project require debt financing beyond that period.

- Lenders may have requirements or conditions related to the term (duration) and form of the PPA structure, making it ideal to finalize contracts after discussions of key terms with the lender have taken place. However, the PPA is essential to bankability and some lenders may not sign mandates or proceed with appraisal without a PPA in place, in which case it is necessary to sign a direct agreement that will allow the PPA to later be amended with lender requirements.
- Long-term financing for solar PV projects is increasingly available for projects meeting certain criteria, but in many emerging markets, may take longer to obtain.
- Individual projects from smaller developers may receive financing with a loan-to-value ratio of 75 percent (e.g., leverage ratio of 75 percent), whereas portfolios of solar PV projects from experienced developers may be financed with leverage up to 80 percent.
- Depending on the sponsor, the market, and the project financing fees, project financing may not be attractive for projects less than approximately 10 MW. Developers can consider consolidating several solar PV plants in a portfolio to obtain financing on a larger portfolio. For example, a developer may aggregate ten 5 MWp solar PV projects and seek financing on a 50 MWp portfolio.
- Lenders will conduct due diligence on the project prior to achieving financial close, and will include particular covenants that mitigate debt service risk throughout the life of the loan. Lenders will also include conditions precedent (requirements to be achieved prior to the disbursement of funds), such as a permit being obtained or a PPA being executed.
- Equity investors may rely on the lender's due diligence or conduct their own.

Developers should be aware that due to the global financial crisis and introduction of Basel III reforms[75] there are tighter restrictions on bank reserve requirements. Banks may have a reduced risk appetite and may be less willing to provide loans of long duration.

In new solar PV markets, local banks may not be familiar with solar PV projects and may be less willing to lend. Global development finance institutions (such as IFC) and regional development finance institutions (such as the Asian Development Bank and African Development Bank) can play a role in helping to build a local bank's confidence in new technologies and business models by investing in projects themselves, by offering risk-sharing products, and, under certain circumstances, by offering concessional financing.

14.4 DUE DILIGENCE

As with all investments, investors and lenders in a solar PV project need to understand the risks. This is especially important for lenders providing project financing, as loan repayments depend upon the cash flow of the project, with no or limited recourse to the balance sheet of the sponsor. Lenders require that due diligence is carried out on projects before they are willing to close the financing and fund the loan.

The process of due diligence can require considerable effort from the developer to satisfy the requirements of commercial lenders. Developers should plan to commence the financing process several months prior to the expected date that financing is required (frequently six months, in the case of IFC).

The due diligence process will identify risks and help develop solutions to mitigate the risks identified, typically including the following disciplines:

75 Bank for International Settlements, "International Regulatory Framework for Banks (Basel III)," 2011 & 2013, http://www.bis.org/bcbs/basel3.htm (accessed June 2014).

- **Legal due diligence** to assess the permits and project contracts (EPC and O&M), including assignability and step-in rights.
- **Environmental and social due diligence** to assess environmental and social impacts and risk mitigation, including relevant stakeholder consultations. This is discussed briefly in Box 10, and in greater detail in Section 8.
- **Technical due diligence** to assess the technology, energy production profile, design, construction risks, integration, and technical aspects of the permits and contracts (EPC and O&M). Technical due diligence will cover technical concepts discussed throughout this guidebook and summarised in sub-section 14.4.1. The technical due diligence process may identify risks that are unacceptable to the lender, in which case changes in the design, components or contracts may be required in order to make the project "bankable" for the lenders.
- **Financial/commercial due diligence** to assess the financial health of the project company. This will include an assessment of the quality and commercial viability of the PPA. Section 14 discusses the financial analysis process and analysis required to secure external financing. It is important that the developers have realistic financial models with contingencies clearly shown.

The due diligence conducted at the equity stage may be based on preliminary technical information that is provided by the developer. As the due diligence for lenders of project financing is conducted at a later stage in the development process, it will often be supported with more detailed technical information and designs, and a higher level of certainty.

As banks in new markets may not be familiar with solar PV technology, developers should be prepared for a rigorous due diligence process and incorporate sufficient time to discuss and address the lender's requirements. While risk is inherent in every project, the developer should reduce and mitigate these risks where possible. Those projects deemed to be low risk are capable of attracting debt at a lower cost.

Lenders and equity partners may often want to influence the choice of the equipment technology, design, and terms of contracts based on what they perceive to be "bankable." They may require consent on key decisions, such as the panel manufacturer or selection of inverter. It is therefore advisable to have discussions with the potential project financing partners early in the design phase to help satisfy the requirements of all partners and to avoid revisions. However, engaging fully with the due diligence process too early can result in excessive and unnecessary expenditure if changes in project technology, design, or even choice of lender is required. This cost will ultimately be borne by the developer.

Box 14: Environmental, Social, and Governance Issues in Financing

While solar PV projects are often considered to be inherently socially beneficial based on their potential to reduce greenhouse gas (GHG) emissions and local pollution, it is still important to consider the full scope of environmental, social, and governance impacts of any project. In addition, lenders often require compliance with social and environmental standards, such as the Equator Principles (EPs)[a] before agreeing to finance a project (see Section 8 for further details on EP requirements).

International development finance institutions, such as the IFC, have their own social and environmental standards (IFC Performance Standards directly inform the Equator Principles). Government bodies may aim to mitigate the adverse impact of developments through permitting requirements. Developers should strive to follow best practices to mitigate environmental and social risks even when this is not required or enforced by national law.

a The Equator Principles (EPs) are a set of 10 environmental and social principles adopted by the Equator Principle Financing Institutions (EPFIs). These principles are criteria that must be met by projects seeking financing from these institutions. EPs ensure that the projects that receive finance are developed in a manner that is socially responsible and reflect sound environmental management practices. The full set of principles can be accessed through the following link: http://www.equator-principles.com

Dedicating sufficient time at the negotiation stage of PPA and EPC agreements to achieve favourable terms will save time and money at the financing stage by avoiding extensive re-negotiation.

14.4.1 TECHNICAL DUE DILIGENCE

Investors and project financing lenders, in particular, will require technical due diligence to be carried out on the solar PV project in order to understand the risk to investment. The technical due diligence process can take several weeks and as a minimum will involve technical experts carrying out the following tasks:

- Site visit to assess the suitability of the site for the installation of a solar PV power plant.
- Solar resource assessment and energy yield prediction with uncertainty analysis.
- Review of system design to confirm viability.
- Technology review of modules, inverters, transformers, and mounting or trackers, including warranties and design life.
- Contracts review (EPC, O&M and PPA), including acceptance testing procedures and liabilities within the EPC contract.
- Assessing the warranty and guarantee positions within the contracts.
- Review of grid connection agreement and timelines.
- Review of permitting status to confirm compliance with all necessary permits and approvals, and absence of serious environmental issues.
- Review of financial model inputs to help ensure financial projections are realistic.
- Review of acceptance testing procedures.

The process of technical due diligence typically requires the sponsor to place project documentation in an online "data room" and culminates in the delivery of a technical due diligence report.

14.4.2 RISK MITIGATION STRATEGIES

Developers and investors should make every effort to understand, and where possible, mitigate the project risks. Advice from independent experts will in some instances be required. Table 20 summarises the key risks and corresponding strategies for risk mitigation that a developer should consider when seeking financing for a solar PV project.

14.4.3 RISK MITIGATION PRODUCTS

Demand for solar PV project insurance is increasing. However, in most countries, the insurance industry has not standardised insurance products for PV projects or components. A number of insurers provide solar PV project insurance policies, but underwriters' risk models have not yet been standardised. The data required for the development of fair and comprehensive insurance policies are lacking as insurance companies often have little or no experience with solar PV projects. As a consequence, developers should seek insurance offers from a number of parties in order to drive competitive terms and expose potentially punitive conditions.

In general, large solar PV systems require liability and property insurance, and many developers may also opt to have coverage for environmental risks too. Various types of insurance available to developers are:

- **General Liability Insurance** covers policyholders for death or injury to persons or damage to property owned by third parties. General liability coverage is especially important for solar system installers, as the risk to personnel or property is at its greatest during installation.
- **Property Risk Insurance** protects against risks not covered by the warranty or to extend the coverage period. The property risk insurance often includes theft and catastrophic risks, and typically covers PV system components beyond the terms of the manufacturer's warranty. For example, if a PV module fails due to factors covered by the warranty, the manufacturer is responsible for replacing it, not the insurer. However, if the module fails for a reason not accounted for in the warranty, or if the failure occurs after the

Table 20: Solar PV Project Risk Matrix		
Risk	Description	Mitigation
Interest rate risk	If debt is provided on a variable rather than a fixed rate, the interest payable may increase if rates rise.	• Finance projects on long-term fixed interest rate loans, as opposed to variable rate loans. • Obtain an interest rate swap; development finance institutions, such as the IFC, provide swaps even in markets where a strong commercial swap market does not yet exist.
Foreign exchange risk	Debt may be denominated in a different currency from the cash flows generated by the solar PV project. This can create gains or losses for the developer and project owners.	• Use hedging to reduce exposure (however, this does entail a cost). • Transfer the risk through bonds, contracts, and insurance. • Obtain local currency financing when possible if the PPA or project revenues will be in local currency. • See Box 15.
Debt structure	Should the project not proceed as expected, the project may be unable to repay debt.	• Structure debt payment to maintain adequate liquidity. • Create a contingency account in case of short-term cash flow issues. • Limit leverage (ratio of debt to equity). • Seek financing of the appropriate tenor to avoid re-financing risks.
Quality of off-take agreement	The reliability of revenue payment is dependent on the terms of the power off-take agreement.	• Use PPA with a term in excess of the debt term. • Reduce exposure to power market risk. • For cross-border transactions, ensure both local and international counsel have reviewed the contract for enforceability.
Counterparty Credit Risk	In many emerging markets, there is only one or a small number of power off-takers, and this entity may not have a strong balance sheet or credit history.	• Carry out thorough evaluation of the off-taker creditworthiness. • Consider options to sell power to alternative off-takers in the event of default. • Seek a guarantee from the government or a multilateral institution; see Box 15 "World Bank Group Risk Mitigation Products." • Reserve account may need to be set up.
Technology	Risk that the system (especially modules, inverters, and transformers) do not function as expected, or performance degrades more rapidly than projected.	• Carefully select technology and pursue technical due diligence (see Box 7 on "Construction Lessons Learned"). • Ensure proper contracting, maintenance, warranties, and third party insurance, as described in Box 1, "Module Risk".
Solar resource	Variation of the solar resource from that predicted in the pre-construction financial models.	• Use services of a technical consultant to ensure high quality resource data is used and covers a sufficient time period. • Carry out an uncertainty analysis (P90 resource estimate) as discussed in Section 5.
Reduced energy yield	Failure to deliver the projected energy yield (and therefore cash flow) to service the debt requirements.	• Ensure pre-construction technical due diligence, including analysis of confidence in the energy yield. • Choose technology with reliable and known performance. • Include maintenance, performance penalties, and warranties within O&M contracts. • Reduce exposure to revenue losses due to grid curtailment by addressing this issue pro-actively in the PPA.
Cost escalation	Exposure to changes in the prices of components.	• Use fixed-price EPC contracts. • Include a contingency fund for construction and operation.
Delay	Contractors or third-party suppliers delay commercial operation, including delays with the grid connection. Delay will impact project cash flows and could impact project eligibility for tariff incentives.	• Use a "fully wrapped" EPC contract. • Contractually define liquidated damages. • Reduced price paid to the contractor if delays miss subsidy support cut-off dates. • Use experienced contractors. • Schedule allowance for delays. • Thoroughly research grid connection procedures, import/duty procedures for equipment and other local regulations in each market to ensure appropriate timelines are built into the EPC's schedule.

Continued

Table 20: Solar PV Project Risk Matrix *(Continued)*		
Risk	**Description**	**Mitigation**
Construction Permitting	Risk that construction has not been carried out in compliance with permits.	• Engage early with the relevant agency responsible for granting permits. • Thoroughly complete the technical due diligence.
Grid connection	Risk that the connection to the distribution or transmission network has not been completed or is not approved by the relevant authority before the expected date of commercial operation.	• Become familiar and follow required design specifications and procedures. • Submit grid connection applications early in development phase. • Define grid connection deadlines in contracts. • Thoroughly research grid connection procedures to ensure appropriate timelines are built into the EPC's schedule.
Incentive eligibility	Special tariffs, tax credits/holidays, and other incentives for renewable energy development may have strict cut-off dates and eligibility criteria.	• Ensure familiarity with the regulatory environment. • Insert clauses in EPC contracts to ensure eligibility based on timeline.
Policy change	Change in government policy towards solar energy, including retroactive subsidy cuts or new taxes that have a material impact upon project revenues.	• Choose politically stable countries with strong regulatory frameworks and evidence of long-standing support to solar PV projects. • Be wary of excessive dependence on the incentive system.
Operation and Maintenance	Poor operation and maintenance (O&M) can give rise to poorly performing plants with a material impact on project revenues.	• Include performance tests within the O&M contract, with associated liquidated damages. This is described further in Section 11 and Annex 3. • Use experienced contractors. • Seek advice from technical advisors when negotiating contract scope. • Consider performance incentives within the O&M contract. • Ensure plant performance is monitored. • Ensure spare parts are readily available. • Include maintenance reserve accounts and/or extended component warranties.

warranty period has expired, the insurer must provide compensation for the replacement of the PV module.

- **Environmental Risk Insurance** provides environmental damage coverage, and indemnifies solar PV system owners against the risk of either environmental damage inflicted by their development or pre-existing damage on the development site.
- **Business Interruption Insurance** provides coverage for the risk of business interruption, and is often required to protect the cash flow of the solar PV project. This insurance policy can often be a requirement of the financing process.

Though solar PV project insurance costs can be quite high, it is likely that rates will drop as insurers become familiar with solar PV projects and as installed capacity increases. A 2010 study by the United States National Renewable Energy Laboratory (NREL), referring to solar PV systems installed in the USA, stated:

> *"Insurance premiums make up approximately 25% of a PV system's annual operating expense. Annual insurance premiums typically range from 0.25% to 0.5% of the total installed cost of a project, depending on the geographic location of the installation. PV developers report that insurance costs comprise 5% to 10% of the total cost of energy from their installations, a significant sum for a capital-intensive technology with no moving parts."*

The benefits of insurance need to be weighed against the price; for small projects, some developers may feel

Box 15: World Bank Group Risk Mitigation Products

IFC Risk Management Tools

The International Finance Corporation (IFC) provides **financing in nearly 60 local currencies**, at both fixed and variable rates, which allows a company with local currency revenues (such as tariff payments under a PPA) to obtain long-term financing denominated in that currency, reducing foreign exchange risks. IFC also provides **interest rate and currency swaps** and **credit enhancement structures** that enable clients to borrow in local currency from other sources. IFC is one of the few multilateral development banks prepared to extend long-maturity risk management products to clients in emerging markets. More information can be found at http://www.ifc.org/wps/wcm/connect/Topics_Ext_Content/IFC_External_Corporate_Site/Structured+Finance.

World Bank Guarantees

World Bank Guarantees are risk mitigation instruments intended to diversify the financing options of the governments and government-owned entities through credit enhancement. They protect the beneficiaries against the risk of default by sovereign or sub-sovereign governments with respect to their obligations arising from contracts, law, or regulations. There is a wide range of risks that could be covered by World Bank Guarantees, such as off-take/payment risk, regulatory risk, change in law, political force majeure (including war, revolution, and expropriation), transferability & convertibility of foreign exchange, etc. The World Bank Guarantee can be issued in foreign or local currency.

World Bank Guarantees are only given for projects that are strongly supported by the government, which is embodied in a counter-guarantee from the government to the World Bank. They are anchored on the strong day-to-day relationship of the World Bank with the government, through policy dialogue, loans, grants, technical assistance, etc., which enables the World Bank to pre-empt an event that could result in the materialization of a risk. In the event that a claim is made under a guarantee, the World Bank does not require an arbitral award or any other formal decision from a court of law as a condition to pay. Guarantees are paid promptly upon recognition by the parties that amounts are owed and are undisputed. More information on the World Bank's Private Risk Guarantee group can be found at http://web.worldbank.org/external/default/main?menuPK=64143540&pagePK=64143532&piPK=64143559&theSitePK=3985219.

Political Risk Insurance with MIGA

The Multilateral Investment Guarantee Agency (MIGA) provides political risk insurance to private sector investors on a commercial basis through insurance products, with the exception of the Non Honoring of Sovereign Financial Obligations (NHSFO), which operates as a guarantee. These risks include **currency inconvertibility and transfer restriction, expropriation, war, terrorism, civil disturbance, breach of contract, and non-honoring of financial obligations**. MIGA's objective is to compensate investors in the event of a loss. The baseline relationship is between MIGA and the private investor, with no government involvement. The government is required to provide a no-objection clause for MIGA participation but does not provide specific support to MIGA or the project. Claims under MIGA insurance, including NHSFO, are paid once the claimant has obtained the respective award from a judicial court or an arbitration tribunal, which usually takes several months or years depending on the jurisdiction. More information on MIGA can be found at http://www.miga.org/investmentguarantees/index.cfm.

comfortable bearing certain risks. For larger projects, lenders may require insurance as a means of reducing the risk they bear by transferring it to the insurance provider. Some types of insurance may also be required as part of the national permitting process. However, insurance is never a substitute for quality design, equipment or contracts. Risk mitigation products may be needed to increase lender confidence, however the appropriate product or mix of products will depend entirely on details of the specific project and context. Box 15 describes risk mitigation products offered by three institutions of the World Bank Group.

14.5 RE-FINANCING

Once a project is operational, particularly after one or two years, the project risks, including construction, technology, energy yield, and performance risk are significantly reduced and there is an opportunity to refinance a project by seeking debt at a lower interest rate.

Less risk means that banks will often accept less return from their loan, so it may be possible to negotiate better debt terms, either from the original lender or another lender. A rather new development in the area of solar PV projects is the use of securitization, a process that enables a developer to exit the investment, which is described in Box 16.

Box 16: Refinancing, Solar Securitization and the Rise of the Yieldco

Since 2013 there has been rapid development in securitisation of solar and other power generation assets. Securitisation is the process of pooling multiple projects and packaging the portfolio as a tradable asset (a security). This can either be in the form of a project-backed bond or a "yieldco." A yieldco is an exchange-listed entity designed to hold cash-generating assets, generally with stable expected dividends. While securitisation is common for other assets, such as mortgages and automobile financing, and for infrastructure in countries like Australia and Canada, it is a relatively new tool for solar energy projects.

Solar projects are well suited for securitisation because they typically have predictable long-term revenues secured through a PPA and have mitigated many project uncertainties and risks through their project finance structure. These stable, low-risk cash flows are desirable for institutional investors, such as pension fund managers.

Once a project is operational, developers often want to exit the project so that they can focus on deploying their capital and creating value with new projects. Securitization allows developers to create their own vehicle to hold projects so that they can sell the project to the securitized vehicle and exit their investment. While this can also be achieved through sale to another buyer, by creating their own securitized pool of assets, developers are able to retain more value. Securitisation is also attractive for large pools of smaller projects, as it can reduce the transaction costs of selling these projects individually.

While these relatively sophisticated vehicles are still in nascent stages in developed markets, they may also become relevant in emerging markets. For example, SunEdison's Terraform announced they will launch a second emerging markets-focused yieldco in mid-2015.

Steps to Securing Project Finance Checklist

The checklist below sets out basic steps that developers and owners must complete if they are seeking project finance for solar PV projects.

- [ ] Seek equity funding (if required).
- [ ] Develop project to the point where it is ready for debt finance.
- [ ] Prepare due diligence documentation.
- [ ] Mitigate risks to reduce debt interest rates.
- [ ] Work with investors and lenders to achieve financial close.

Financial Analysis – Project Costs and Revenue 15

The commercial viability of a solar PV project is determined through a financial analysis that takes into account the expected costs, including investment requirements and O&M costs, as well as revenues.

15.1 PROJECT COSTS AND REVENUES OVERVIEW

Project financing is only possible when a solar PV plant is capable of generating enough revenue to pay for debt obligations and the overall costs of O&M, and to yield a reasonable return for the equity invested. The decision to proceed with the development of a solar PV project rests upon the commercial viability of the project, as determined through a financial analysis. This analysis takes into account the expected costs, including investment requirements and O&M costs, as well as revenues. The key inputs are investment requirements and assumptions about the future performance of the solar PV power plant. As such, they should be based upon verifiable and objectively collected data, and backed up by real-world experience and local knowledge.

The checklist at the end of this section sets out the basic financial modelling requirements for developers of solar PV projects.

The following sub-sections provide information on the key inputs to and outputs from the financial analysis that are specific to solar PV, including a breakdown of typical project costs and revenues.

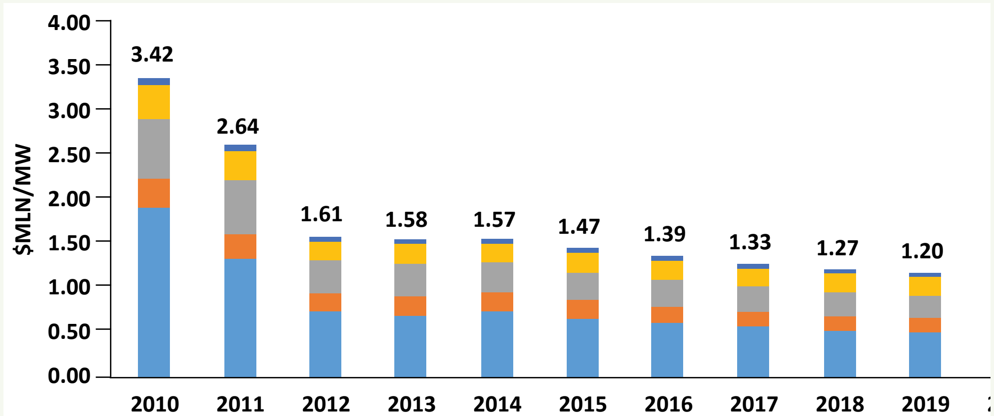
15.2 SOLAR PV PROJECT CAPITAL AND OPERATIONAL COSTS

Capital expenditure (capex) and O&M costs are site-specific and should be assessed as part of the prefeasibility and feasibility studies. Initially, these costs are established as evidence-based assumptions, and they will only be finalized with the signing of the EPC contract. Nevertheless, they are essential inputs for the financial model. For illustrative purposes, some indicative estimates for solar PV project costs (both capex and operating expenditures, or opex) are provided in this section.

15.2.1 CAPITAL EXPENDITURE (CAPEX)

Figure 34 shows the historical and forecasted values for solar PV project capital costs (excluding fees and taxes) for a ten-year

Figure 31: Forecasted average Capex Costs for Multi-MW Solar PV Park, 2010–2020 (based on data from 2014)



Source: BNEF, SgurrEnergy, collected from project developer and installers. Not including developer fees, taxes, legal costs, corporate finance fees.

period starting in 2010. Note that significant module price declines were achieved from 2010 to 2012. As Figure 31 illustrates, further price reductions can be expected going forward. However, the developer should equally consider that the rate of cost decline is impossible to predict with complete accuracy.

The historical data referenced in Figure 31 comes from larger, more developed solar PV power markets (principally Europe, North America, and Asia). Hence, the forecasts for capex pricing are useful in other markets primarily for benchmarking purposes.

Table 21 illustrates the variability of capex and opex based on actual project costs observed during 2013 and 2014. The spread in capex costs is explained on the low end by the inclusion of data from projects using low-cost, domestically-installed, Chinese solar PV installations. Values on the high end reflect the highest installed costs in the U.S. solar PV market. Variations in capex costs are also a result of differences in labour costs, local taxes, local content rules, and the level of subsidy or other pre-operating incentives provided to project developers within a specific policy/regulatory context.

In countries where solar PV technology has been only recently introduced, prices may vary widely as a result of the early process of supply chain development in a given market. However, greater pricing transparency and competition across the global supply chain, from raw materials like polysilicon to inverters and balance of systems, has allowed developers to make more informed assumptions about capital costs before hiring an EPC contractor. This is advantageous to the developer, as more accurate cost-input assumptions will be reflected in the perceived accuracy of the financial model outputs from an investor's viewpoint.

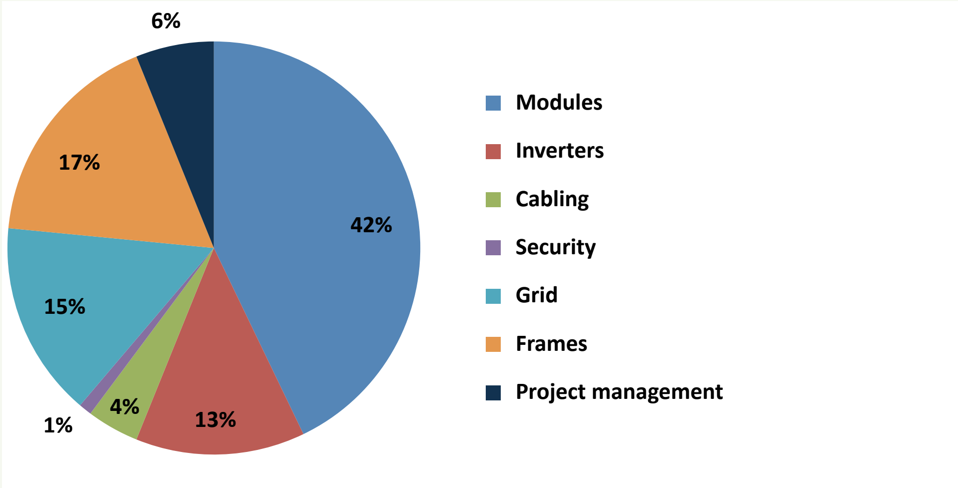
A breakdown of costs for a typical solar PV project is presented in Figure 32, which is based on a standard

Table 21: 2013/14 Solar PV Capex and Opex Cost Variations

Value $/MW	Min	Average	Max	Percent Variation
Capex	$1.5 million	$1.6 million:	$2.2 million	47 percent
Opex	$2,200	$4,200	$7,500	241 percent

Source: SgurrEnergy 2014

Figure 32: Average Breakdown Costs for a Ground-Mounted Solar PV Project



Source: The dataset is extracted mainly from the mature markets of Europe and North America, 2014.

multi-megawatt, ground-mounted installation (excluding trackers). Average installed costs in emerging markets are broadly similar, particularly the costs of PV modules, inverters, and cables. Deviations from the average may occur due to local taxes, local content rules, and variable labour rates for construction and project management.

In the example above, 55 percent of solar PV project capital costs arise from modules and inverters, and excluding local tax and content rules, these capex costs appear the most consistent over time for the majority of projects.

It is widely recognized that economies of scale are delivering lower pricing for modules, inverters, and balance of systems such as framing and support structures. There has also been a less dramatic, but still significant reduction in "soft costs," such as construction and financing costs for new project development, as more local service providers have developed their offerings. These cost reductions were first seen in more developed markets, but it is possible that they are representative of near-term trends in emerging markets.

As opportunities for solar PV project development have increased, the number of qualified installers has commensurately expanded. Compared to the EPC process used for other forms of power generation, solar is relatively straightforward and local construction companies have been able to build capacity quickly. This has resulted in competitive pricing for EPC activities and shorter construction and commissioning periods. As solar PV project developers grow in size and number, their processes are also becoming more efficient and they are able to reduce transaction costs, including costs related to business development.

The cost of financing has also fallen in more established solar PV markets as they have grown and proven to be reliable sources of cash flow. A developer's cost of financing has become a critical distinguishing factor for success as the solar PV market becomes increasingly competitive.

Total capital costs also include the cost of land and support infrastructure, such as roads and drainage, as well as the project company's start-up costs. The extent of cost variation largely depends on the project location (reflecting host country costs), the project design (such as the type of power cables), and the technology utilised (i.e., use of a tracking system, or selection of monoverses multi-crystalline modules). Solar PV technology in particular is a source of significant variation in system component costs. A project with crystalline solar PV technology requires less surface area per kWp installed capacity compared to thin-film modules. As a result, the mounting structure and DC cabling costs are lower (other cost components should not change significantly). Grid connection costs are another element of capex and can be highly variable; these costs should be investigated early during the feasibility stage.

Table 22 shows a typical breakdown of costs for a multi-mega-watt (MW) European ground-mounted solar PV power plant at the time of writing in late 2014. Total costs for a European solar PV plant average around US $1.7 million per MW. However, European costs are only a partial proxy for costs in other markets, and project costs must be adjusted for local duties and taxes and logistics/transport costs.[76]

It is advisable for developers to seek pricing for modules and inverters from multiple vendors and to balance the security of fixed prices and delivery dates against the opportunity for future price reductions and technology improvements. Also, during the past few years, module oversupply and industry reorganization led to some inconsistency in module quality and concerns about the value of manufacturer warranties. While the industry has now stabilized, seeking modules from a reputable manufacturer with a proven track record is still critical.

Further price reductions in solar PV technology are expected in the future, yet project developers are advised to be cautious about making predictions. These price

76 Bloomberg New Energy Finance is a source of data on costs in emerging markets: http://www.newenergyfinance.com.

Table 22: Average Benchmark Costs for Ground-mounted Solar PV Development

Cost Item	Cost ($/MWp)	Details
Land	8,300	It is assumed that 2 acres/MWp is required. This estimate will vary according to the technology chosen and land costs.
PV Modules	720,000	Crystalline-based solar PV modules have an average global factory gate price of $550-930k/MW[a] and this can vary depending upon the perceived quality of the supplier. An average module price of $720k/MWp has been assumed based upon collected third-party data. Thin-film modules such as Cadmium Telluride are available at an 8 percent to 10 percent discount to this price. However, this economic benefit is often lost due to increased land and balance of system cost requirements.
Mounting structure	306,000	This is the cost assumed for the mounting structure irrespective of the type of technology.
Power conditioning unit/ inverters	220,000	This is for the power conditioning unit/inverters, including the required controls and instrumentation.
Grid connection	255,000	This cost includes supply, erection, and commissioning of all cabling, transformers, and evacuation infrastructure up to the grid connection point. This is a highly variable cost depending on the distance to the point of connection.
Preliminary and operating expenses	11,000	This cost includes services related to design, project management, insurance, and interest during construction, among others. Though it is expected to vary with project size, the cost assumed is for a generic multi-megawatt site.
Civil and general work	120,000	This includes general infrastructure development, application for permits and approvals, and preparation of project reports per MW.
Developer fee[b]	100,000	This is an average figure for the EU and dependent on market conditions.
TOTAL	**1,740,300**	

a PVinsights, 2014, www.pvinsights.com (accessed June 2014).

b SgurrEnergy compiled data sources in the EU around 2013.

Source: Source Data : SgurrEnergy, collected from project developers and installers in addition to PV Insights and Photon Consulting.

declines are being driven by improved manufacturing techniques, cell efficiency innovation, and cost reductions in the balance of systems. However, short-term volatility in pricing is likely to occur.

By following current and expected costs for major components, developers will be better informed when developing their financial model. The model should include a capex sensitivity analysis to account particularly for the forward cost curve on solar PV equipment. This will help the developer assess the potential impact of project delays against the possibility of changing equipment costs. However, it is important to remember that it is impossible to accurately predict the magnitude or timing of price changes.

15.2.2 OPERATIONS AND MAINTENANCE COST (OPEX)

Operation and maintenance (O&M) costs for solar PV projects are significantly lower than other renewable energy and conventional technologies due to the simple engineering and relatively minor maintenance required. The average O&M costs in the developed European market are currently around $4,200/MW per annum.[77] This figure will vary according to local labour costs, but is much lower as both an absolute number and a relative number than for other types of power projects.

O&M costs also depend on other factors, including the project location and the surrounding environment. For example, a site located in a dusty environment is likely to suffer higher soiling and require more frequent module cleaning. Given that wages are generally lower in most emerging markets, O&M costs can be expected to be consistent with or less than the European norm. However, early stage developing markets may not initially possess the industry structure/supply chain and economies of scale to fully exploit lower costs. For example, generally lower country cost may be offset by the need to bring technical experts from another country in the event of a major issue and if no local experts are available. It may be necessary to reserve funds for this contingency.

In addition to labour, operational expenditure includes comprehensive insurance, administration costs, professional fees, and land rental. Insurance costs vary considerably in new markets, and in some cases will not be available as a standard product.

The wide variation in opex costs between markets (shown in Table 21) reflects differing levels of market penetration (and therefore pricing competition), costs driven by lack of infrastructure, site transportation costs, subsidies, land rental costs, and labour costs.

15.3 SOLAR PV PROJECT REVENUES

Electricity from a solar PV project is converted to revenue by selling it to an off-taker. The amount of revenue will depend on the amount of energy generated and delivered and the price per unit of energy. Having a strong forecast of both these inputs is therefore central to the strength of financial model outputs and to obtaining outside financing.

15.3.1 ANNUAL ENERGY YIELD

There are a number of factors that affect the annual energy yield of a solar PV project, as discussed in detail in Section 5 (Energy Yield Prediction).

Annual energy yield directly drives the revenue line in the cash flow model and income statement. As such, accurate energy yield predictions are critical. Annual energy yield must be calculated by an experienced, independent, and suitably-qualified solar energy consultant who is able to provide "bank grade" energy yield analysis.

The confidence level of the yield forecast (or uncertainty) is also important, as the annual energy yield directly affects the annual revenue and therefore project viability. A P90 assessment is typically required. However, utility-scale projects that include a professional independent energy yield assessment, produced and/or verified by an experienced consultant with a track record of producing

77 SgurrEnergy compiled developer data and market provider quotations around 2013.

"bank grade" data, are sometimes bankable with a confidence interval of P75. As mentioned previously, additional sensitivity analysis may be advisable in markets with less data and project history.

15.3.2 *ELECTRICITY TARIFFS*

The key revenue stream for most solar power plants is the fee (tariff) paid for each kWh of electricity generated. As discussed in Section 12, sometimes there are other sources of revenue, such as renewable energy credits, tax credits, and other financial incentives available to developers. The stability and durability of such incentives should be assessed carefully.

At present, most utility-scale solar power plants sell electricity to an off-taker (in most cases a power company) through long-term PPAs. In many emerging economies, the power company is a state-owned enterprise. Increasingly, there are also opportunities to sell power to large private off-takers, such as industrial groups. The creditworthiness of the off-taker should be assessed carefully, particularly when the price of power in the PPA is higher than the average retail tariff in the respective power market. Off-taker credit risk and potential mitigation of those risks are covered in Table 20 and Section 12.

15.4 FINANCIAL MODELLING

A financial model is needed to assess the viability of the project. Such a model is requested by financial institutions and it is an essential piece in the preparation of the project for financing.

Table 23 lists key inputs for the financial model of a solar PV project relying on both equity and debt. Each input described below should be supported by robust and independently-verified evidence.

The financial model estimates the key parameters that are needed to decide whether or not to proceed with the project. Such parameters include (but are not limited to): economic and financial rate of return, return on equity (equity IRR), payback period, etc. Also, the model should prove that the project is able to service the debt.

15.4.1 *SOLAR PV PROJECT FINANCIAL ANALYSIS-LENDER'S MODEL*

Lenders are primarily concerned with the ability of the project to meet debt service requirements. The financial model that a developer or their agent prepares for lenders must address this concern and should include the following metrics:

- Cash Flow Available for Debt Service (CFADS) is calculated by subtracting operating expenditure

Table 23: Key Inputs to the Financial Model

Inputs	Comments
Project size (MW)	Based upon feasibility/technical study reflecting the constraints of grid capacity and land, in addition to energy yield prediction reference project capacity (e.g., MW's).
Energy yield/capacity factor	Calculated to reflect module efficiency, lifetime degradation, inverter losses, module soiling, and the potential for shading losses.
Tariff and other revenue streams	The price for power in the PPA along with other incentives is needed to determine project revenues.
Capex costs	One-off costs for the construction and commissioning of the project, generally based on an EPC contract.
Opex costs	Normally a 25-year view of costs, which are based upon initial contract agreements (e.g., O&M, land rent/lease, and corporate overheads) that will be subject to adjustments for inflation and other variables.
Debt service and repayment costs	This involves the repayment of debt interest and capital over a defined pre-agreed period with the lender (debt length is normally equal to contractual period of the PPA).
Grid tolling costs	Potential grid access fee, if applicable.
Taxes	Payment of central and local government taxes.

(opex), working capital adjustment, interest, and tax from revenue. It does not include non-cash items such as depreciation or cash that is already committed elsewhere. CFADS is used as an indicator of how much cash the project will produce, and thus how much debt can comfortably be serviced.

- Debt Service Coverage Ratio (DSCR) is a simple measure of the ability of a project to meet interest and capital repayments over the term of the debt. It is calculated as CFADS divided by the amount of expected debt service over a certain period.
- Loan Life Coverage Ratio (LLCR) provides another measure of the credit quality of the project, looking at the project's ability to pay over the total project life. It is calculated by dividing the net present value (NPV) of the CFADS over the project life by the remaining amount of debt owed.
- Maintenance Reserve Account (MRA) is an amount to cover operational contingencies, such as inverter replacements.
- Debt Service Reserve Account (DSRA) is a fund, often equivalent to 6 months of debt service, designed to cover any shortfalls in debt. If drawn on, it is then replenished on an on-going basis.

The most important measure to analyse is the DSCR. The average DSCR represents the average debt serviceability of the project over the debt term. A high DSCR indicates a higher capacity of the project to service the debt, while the minimum DSCR represents the minimum repayment ability of the project over the debt term. The lender's model should contain analysis on the minimum and average DSCR over a range of scenarios, including over discrete periods of time in the project's development. A minimum DSCR value of less than 1.0 indicates the project is unable to service the debt in at least one year.

15.4.2 *SENSITIVITY ANALYSIS*

Sensitivity analysis involves changing the inputs in the financial model (such as power tariff, capital cost and energy yield) to analyse how the cash flow of the project is impacted. Lenders will conduct sensitivity analyses around these key variables in order to determine whether the project will be able to service the debt in a bad year, for example if the energy yield is lower than expected, or if operational expenditure is higher than expected. Sensitivity analysis gives lenders and investors a greater understanding of the effects of changes in inputs, such as power tariffs, on the project's profitability and bankability. It helps lenders and investors understand the key risks associated with the project.

Typical variables investigated during sensitivity analysis include:

- Capital costs, especially on the panels and inverters.
- Operational costs (less critical for solar PV projects).
- Annual energy production.
- Interest rate.

15.4.3 *FINANCIAL BENCHMARKS AND HURDLE RATES FOR INVESTMENT*

The project financing structure generally comprises both debt and equity, as described in Section 14 (Financing Solar PV Projects).

Solar PV projects typically have a debt-equity mix with the following broad terms:

- Financing structure—equity 30 percent (or higher) with a corresponding debt element of 70 percent or less.
- Equity levered IRR's in excess of 10 percent, and significantly so in higher-risk markets.
- Debt repayment period of between 8 and 18 years.
- Debt service cover ratio (DSCR) of at least 1.3, or 1.5 for merchant solar PV projects.

15.4.4 CARRYING OUT A FINANCIAL ANALYSIS

A financial model's output determines not only the structure of the project's financing, but also the project company's maximum supportable level of debt. Performing financial modelling requires a highly specialized skillset. In order to build a financial model, a developer will require the services of a financial analyst with advanced knowledge of Excel spread sheets, or alternatively, someone with experience building models in one of the several other sophisticated software tools designed for this purpose.

Yet the ability to construct the mechanical aspects (e.g., the functions/calculations) of the financial model is itself not the only or necessarily even the most important key requirement.

It is critical that the developer understand the importance of reliable inputs to the financial model, as well as the significance of the model's key outputs from an investor's perspective. The developer should have a clear understanding of the probable degree of variation for different inputs, as well as the cause(s) of variation. Furthermore, a firm grasp of the terms used by investors to describe key outputs from the financial model will be necessary for the developer to enter into informed negotiations on project financing.

Financial Modelling Requirements/Procedures Checklist

The checklist below is for developers, and sets out basic financial modelling requirements and procedures that investors in solar PV projects typically expect.

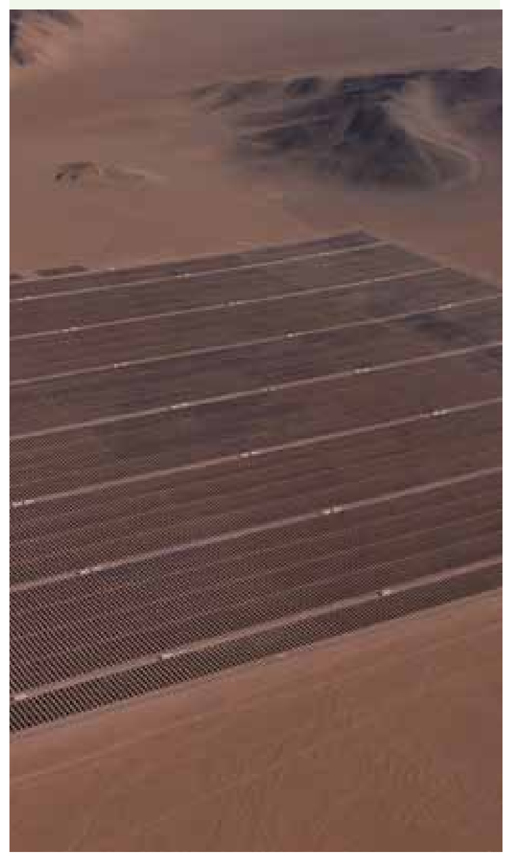
- [ ] Independently verify key assumptions in the financial model, including EPC and O&M costs, energy yield, off-take pricing, and terms of financing.
- [ ] Prepare financial model covering full lifecycle of the project.
- [ ] Include stress tested results and scenario analysis for debt service for potential lenders and equity investors.
- [ ] Clearly present cash flow analysis and relevant indicators, such as IRR, DSCR, CFADS, LLCR, MRA calculations, etc.
- [ ] Provide a sensitivity analysis for key inputs on capex, opex, and financing costs.

ANNEX

1

Common Construction Mistakes

The following images have been taken from megawatt-scale, ground-mounted solar PV power plants constructed in the U.K., India and South Africa. The images show a variety of common construction mistakes and issues that may arise under a variety of environmental conditions during operation. They are intended to illustrate topics that have been discussed throughout the guidebook and inform readers so that the mistakes may be avoided.



Photographs of common construction mistakes		
ID	Picture	Comment
1		Soiled pyranometers give conservative solar irradiation measurements, which can lead to over-estimated performance ratio measurements. Pyranometers must be well-maintained, kept calibrated and placed in locations where they will not be shaded by nearby obstacles.
2		Soiled modules will result in lower performance and can cause unexpected growth of vegetation, with associated shading loss.
3		Heavy rainfall, including monsoons, can restrict vehicular access and delay construction. Effective planning will avoid construction during heavy rain or incorporate mitigating measures such as sealing access routes before construction begins.
4		Poor waste management can lead to environmental damage and represents a risk to health and safety.

(continued)

Photographs of common construction mistakes (continued)		
ID	**Picture**	**Comment**
5		Inadequate pre-construction design and due diligence can result in sagging support structures with misaligned modules.
6		Inadequate pre-construction design and due diligence can lead to the need for costly post-construction remedial design alterations, such as on the pictured support structures.
7		Inadequate temporary security fencing can let livestock enter a site with associated risk of damage.
8		Poorly designed foundations and improper anchor bolts can result in mounting structures that are not properly bolted/secured and therefore unstable under heavy load conditions.
9		Heavy rains can erode the construction site when the risk of flood has been poorly assessed/mitigated.

(continued)

Photographs of common construction mistakes (continued)		
ID	Picture	Comment
10		Heavy soiling in desert conditions needs to be considered as part of the O&M strategy. Shading of modules by adjacent rows can be avoided at the design stage.
11		Poor DC cable management. DC cables should be kept neat and secured with cable ties, respecting cable-bending radii.
12		All plastic glands entering primary combiner boxes should be properly affixed to prevent slippage.
13		All plastic conduits should be filled with a suitable material, for example expanding foam, to reduce the risk of water ingress and rodents.
14		Cables should be protected from sharp metallic edges using appropriate padding.

(continued)

Photographs of common construction mistakes		
ID	Picture	Comment
15		Glands should be used for all cables entering combiner boxes, to prevent cable movement and damage to cable insulation.
16		Drainage issues should be solved early in the construction phase. Water is seen here jetting through the foam sealant in the flooded inspection chamber.
17		Landscaping, re-seeding and vegetation control is required to remove the risk of vegetation shading modules and reducing performance.

ANNEX

2

EPC Contract Heads of Terms

This Annex provides a summary of the key technical terms to be discussed between a potential EPC contractor (the "Contractor") and the potential owner ("Owner") of a megawatt-scale, ground-mounted solar photovoltaic (PV) power plant. It is expected that the term sheet that follows will be used to guide discussions between the Owner and the Contractor. Throughout the term sheet, [x] is used to indicate a value that needs to be determined through an agreement between the Contractor and the Owner, and in some cases an indicative value [such as 10 percent] is provided in place of [x]. Once all the details have been agreed upon, lawyers will typically use the term sheet to draft the full contract.

It is assumed that all plant equipment will be sourced by the EPC contractor and that the EPC contract has separately been provided with "Employer's Requirements" documentation, which specifies minimum technical requirements for the plant construction, including technical specifications for modules, inverters, transformers, cables, civil works, and procedures for safety, quality control, monitoring, and security.

EPC Contract Heads of Terms	
Topic	**Nature of Agreement**
Project Name	
Capacity	
Owner	
Contractor	
Type of Contract	Turnkey Engineer, Procure and Construct contract for implementation of a solar photovoltaic (PV) power plant with a design life of [25] years.
Contract Price	The Contract price is [XX].
Scope of Work	• The provision of all plant materials (including, support structures and PV modules). • Site preparation, ground and civil works including drainage. • Assembly and installation. • Grid connection infrastructure. • Equipment (including construction equipment). • Labour and the performance of all works and services. • Design, engineering, construction, commissioning, start-up, and testing according to industry standards. • Procurement and construction of fencing, security arrangements, and monitoring system. • Construction of all balance of plant. • Removal of debris. • Remedying defects.
Owner Responsibilities	Owner shall be responsible for: • Ensuring that the Contractor has right of access to the site. • Obtaining all permits and consents required for the operation of the plant (including planning permission and grid connection permits). Owner shall provide Contractor with all existing site information for review. Contractor shall be responsible for interpreting this data and for additional site investigations required. Owner shall pay the Contract Price to Contractor according to the Payment Schedule.
Contractor's Responsibilities	Contractor will review all relevant permits and authorisations obtained by the Owner and declare that they are acceptable. Works shall comply with requirements of the technical specifications as described in the Owners Requirements document. Works shall comply with all applicable laws, consents, and permits (including regional and local laws). All materials, equipment, and plant components shall be new. The Works will be performed so as to ensure the safety and health of the workers. The works/facility shall achieve the performance requirements and Guaranteed Performance levels. Contractor will be responsible for: • All activities necessary for the completion of the PV plant. • Compliance with all applicable laws. • Technical design and specifications. • Quality control of PV modules, and ensuring they are installed in accordance with the module installation manual. • Safeguarding all equipment and materials, including transport and storage. • Engineering, technical design, drawings, and manuals. The Contractor is responsible for obtaining and maintaining: • Consents and permits required to perform the works. • Export/import licences for materials, plant, equipment, and similar consents. • Consents and permits for transporting materials, plant and equipment to site, and unloading. • Labour necessary for the assembly and installation of all of the equipment, accessories, and materials provided.

(continued)

EPC Contract Heads of Terms (continued)	
Topic	**Nature of Agreement**
Quality Standards	Contractor shall provide a comprehensive Quality Standards document describing plant acceptance criteria. This shall be reviewed and approved by the Owner and will include a description of factory acceptance test procedures and site acceptance test procedures for major plant components, including transformers and inverters.
Project Schedule	Contractor shall provide a Gantt chart construction schedule. Contractor shall provide progress report updates on a weekly basis during construction.
Subcontracting	The Contractor remains fully responsible for all works completed by subcontractors. The Contractor additionally confirms that the work of its subcontractors meets the specifications set forth in the EPC Contract and complies with the law.
Implementation	• Contractor warrants ability to complete the plant, the electrical infrastructure and connection infrastructure in accordance with the project schedule. • Liquidated damages will apply if scheduled completion dates are not achieved. • Contractor shall supply manuals, documents and records as per industry norms. • Contractor to be responsible for storage and disposal of hazardous materials and rectification of any contamination caused by performance of the plant. • Contractor to provide spare parts and consumables. • Contractor to provide tools necessary for commissioning and testing and to make provision for commissioning and testing to be witnessed by the Owner's representative.
Site Conditions	• Owner is to provide Contractor with all available site information describing the physical characteristics of the site. • Contractor to carry out further site investigations as required. • Contractor takes full responsibility and risk for further site investigations and ensures that it has studied and inspected to its full satisfaction the geotechnical, geo-morphological, and hydrogeological studies and accessed conditions and environmental characteristics of the site. • Contractor shall declare in the EPC contract that the site is suitable for the execution of the works but will not be responsible for costs arising from the discovery of: a) pre–existing toxic waste; b) artistic, historical or archaeological findings; c) underground pipelines; or d) munitions, where these were not detected in the information provided by Owner.
Completion Date	The Completion Date (date of signing the Provisional Acceptance Certificate) will be achieved within [x] months from the date of the EPC contract Notice To Proceed.

(continued)

EPC Contract Heads of Terms (continued)	
Topic	**Nature of Agreement**
Acceptance	**Acceptance Tests** The Contractor will perform: a) tests required under the applicable law; b) commissioning tests according to IEC 62446; c) performance tests. Performance tests will be carried out to determine whether the plant: a) has achieved the requirements for completion; b) is compliant with quality standards; c) is compliant with technical specifications; and d) to ascertain whether the guaranteed performance has been attained. The testing process shall be clearly described. A test sample of modules shall be taken from the plant and sent to an independent testing institute for flash testing. **Provisional Acceptance** The Owner shall provide a Provisional Acceptance Certificate when all of the requirements for completion have been achieved and testing has been completed. A punch list of outstanding items will be prepared. To pass provisional acceptance, the value of outstanding items must be less than 1% of the Contract Price. Items on the punch list will be remedied within [x] months from signing of the Provisional Acceptance Certificate. Signing of the Provisional Acceptance Certificate shall trigger the start of the Performance Warranty Period. **Intermediate Acceptance** The parties shall agree to requirements for Intermediate Acceptance. These will include: • A performance ratio test, averaged over one year of operation since provisional acceptance, taking into account an agreed rate of degradation. **Final Acceptance** The parties shall agree to requirements for final acceptance. These will include: • A performance ratio test, averaged over the two years of operation since provisional acceptance, taking into account an agreed rate of annual degradation. The Owner shall provide a Final Acceptance Certificate when all of the requirements for completion have been achieved.
Transfer of Title	The ownership of the plant, materials, equipment and warranties will transfer from the Contractor to the Owner at provisional acceptance. The Contractor shall be responsible for any materials or other items delivered by the Owner or by third parties up to provisional acceptance.
Warranty Periods	The **Performance Warranty Period** will be 2 years, starting from the signing of the Provisional Acceptance Certificate. The Contractor shall transfer all the guarantees and warranties directly from suppliers and sub-suppliers in favour of the Owner. This shall include: **Module Power Performance Warranty**: [25] years [90% until year 10, 80% until year 25, or linear power warranty according to the manufacturer's specifications]. **Inverter Warranty:** [5] years. **Support Structure Warranty:** [10] years. The **Defect Warranty Period** will have a duration of [2] years from issue of Provisional Acceptance Certificate. During this period the Contractor will remedy defects and omissions at its own cost. The period will be extended by a further period of [1] year for any defect that is remedied during the initial period.
Guaranteed Performance	A minimum Guaranteed Performance Ratio of [81]% will be achieved at provisional acceptance. The Performance Ratio (PR) shall be measured at the export meter over a period of [15] days prior to issue of the Provisional Acceptance Certificate. The PR measurement shall be temperature compensated and irradiation measured using secondary standard thermal pyranometers. A minimum of [x]% of test time shall be at a measured irradiance above [x]W/m^2. A minimum Guaranteed Performance Ratio of [80]% will be achieved during the Performance Warranty Period. Liquidated damages for PR shortfalls will be provided by the Contractor, according to agreed formulae.

(continued)

EPC Contract Heads of Terms (continued)	
Topic	**Nature of Agreement**
Payment Schedule	A schedule of milestones will be defined in the contract. The Owner will transfer a percentage of the Contract Price to the Contractor when milestones are achieved: Advance [10]% Civil Works completed [10]% Mounting System installed [10]% Modules and inverters delivered [40]% Inverters and modules Installed [10]% Grid connection achieved [5]% Mechanical Acceptance [5]% Provisional Acceptance [10]%
Performance Bond	At the signing of the contract, the Contractor will procure a performance bond (bank guarantee) of value [10]% of the contract price. The purpose of this is to guarantee funds for the Owner in case: a) delay liquidated damages are payable; b) Guaranteed Performance Ratio is not achieved at provisional acceptance; c) the Contractor has defaulted in its obligations under the contract. The performance bond will be returned to the Contractor at the signing of the Provisional Acceptance Certificate
Warranty Bond	Upon signing of the Provisional Acceptance Certificate, the Contractor will provide a warranty bond (bank guarantee) with a value of [5]% of the contract price. The warranty bond will guarantee the Owner funds in case liquidated damages that are payable or the Contractor do not meet obligations during the Defect Warranty Period. The warranty bond will be returned to the Contractor at the signing of the Final Acceptance Certificate.
Liquidated Damages	**Delay Liquidated Damages**: Delay liquidated damages of [0.25]% of the EPC contract price will be provided per week of delay beyond the agreed completion date, up to a maximum cap of [10]%. **Performance Liquidated Damages:** A price adjustment will apply if the Contractor fails to meet the Guaranteed Performance Ratio during acceptance tests and does not rectify such under-performance. The liquidated damages will be agreed as [1.5]% of the contract price for each [1]% shortfall in the PR below the Guaranteed Performance Ratio. The cap on the performance liquidated damages will be [10]% of the contract price.
Maximum Penalty Cap	The maximum aggregate liability of the Contractor for delay liquidated damages and performance liquidated damages will be [20]% of Contract Price.
Insurance	The Contractor shall procure insurance policies as follows: a) Construction All Risk Insurance; b) Marine Transit Insurance; c) Third Party Liability Insurance; d) all other compulsory insurances according to the applicable law.
Termination	The Owner shall be entitled to terminate the contract if: • The performance liquidated damages owed by the Contractor exceeds the agreed maximum cap. • The delay liquidated damages owed by the Contractor for late delivery of the plant exceeds the agreed maximum cap. • In case of justified refusal of issuance of the Provisional or Final Acceptance Certificates.

ANNEX
3

O&M Contract Heads of Terms

This document summarises the key terms to be discussed between the potential Operations and Maintenance (O&M) contractor (the "Contractor") and the potential owner ("Owner") of a megawatt-scale, ground-mounted solar photovoltaic (PV) power plant. When all the details have been agreed upon, lawyers will typically use the term sheet to draft the full contract.

O&M Contract Heads of Terms	
Topic	**Nature of Agreement**
Project Name	
Capacity	
Owner	
Contractor	
Remuneration	The Owner shall pay the Contractor a fixed remuneration of [x] per MWp installed capacity for each year of operation. This will be escalated at an annual rate to be agreed upon by both parties. Remuneration shall be paid monthly/quarterly in arrears.
Commencement Date	The Contractor shall perform the services commencing on the date of issuing of the Plant Taking-Over Certificate in accordance with the terms of the EPC contract.
Scope of Services	The performance of all preventative and corrective maintenance required to ensure the plant achieves the guaranteed availability level and/or Guaranteed Performance Ratio during each and every operational year of the Contract term. The Contractor shall monitor plant performance on an ongoing basis throughout the Contract term to detect abnormal operation and implement appropriate maintenance actions. Preventative maintenance: • The examination of solar PV plant components for operational and performance capability on an ongoing basis during the contract term, and the performance of tasks that are aimed at preventing the possible occurrence of future errors, disruptions or reduction in performance, in particular through the replacement of consumable parts, or the maintenance of individual components of the solar PV plant. • Without exception, maintain the plant and its components in line with manufacturer guidelines (such that third party warranty terms remain valid), the O&M manual and grid operator requirements. These shall be communicated to the Owner by the Contractor within a preventative maintenance schedule held as an appendix within the plant O&M Manual. • Preventive maintenance to be coordinated and scheduled in order to minimise the impact on the operation and performance of the plant. Corrective maintenance: • Shall be performed to ensure achievement of the Guaranteed Availability Level and/or Guaranteed Performance Ratio. • When a failure or malfunction is detected that impacts plant operations, Contractor shall promptly commence the required corrective maintenance actions in order to return the plant to operation under normal conditions of service in accordance with agreed response times.
Monitoring	The Contractor shall monitor the operation of the plant between the hours of [xx]am and [xx]pm every day, checking its operational readiness and generation capacity. Monitoring will be performed using on-site monitoring software and systems provided under the EPC Contract. The Contractor will ensure that any disruption messages generated by the plant are received and analysed every day. In particular the Contractor will carry out monitoring to at least the [DC combiner box] level. Measures for correction of fault messages in the case of those which cannot be rectified remotely will be undertaken in accordance with the severity of the fault and agreed upon response times.
Reporting	The Contractor shall provide the Owner with the following reports, the contents of which will be detailed within the O&M contract: • Monthly report to be delivered to Owner by the seventh calendar day of each month. • Annual report to be delivered to Owner not later than 21 calendar days following the end of an operational year. • Reports on Significant Disruptions—If during monitoring or testing the Contractor determines serious disruptions, damage or defects, the Contractor shall inform the Owner immediately and at the latest within 24 hours of the defect becoming known to the Contractor, detailing the type of the damage, and the anticipated time and duration for repair. Reports on any major maintenance to be delivered to the Owner within 7 days of completion. Report on the rectification of defects or interruptions to the operation of the plant issued within 7 days.

(continued)

O&M Contract Heads of Terms	
Topic	**Nature of Agreement**
Ground keeping	The Contractor shall perform ground keeping and vegetation control at the plant such that plant performance is not impeded through shading. Ground keeping shall be conducted in a manner and frequency that adheres to permit and lease obligations and component manufacturer's recommendations.
Security	The Contractor will be responsible for plant security and surveillance provision during the contract term. This will be provided on a 24 hours/day, 365 days/year basis.
Spare Parts Management	The Owner will make available to the Contractor an inventory of spare parts for use in performing the Services (The spare parts will have been previously provided by the EPC Contractor.) The Contractor is responsible for providing all other material, equipment, tools and consumables necessary to perform the Services. The Contractor shall ensure that all Spare Parts are labelled and maintained in a log when received into or withdrawn from the inventory. Contractor shall, at its own cost, replace any Spare Parts that it uses with new parts of equal or better quality and warranty levels. All Spare Parts remain the sole property of the Owner and shall be returned to Owner at the end of the Contract term. All Spare Parts shall be kept by the Contractor on the Site or within an acceptable distance for prompt transportation to the Site. The Contractor warrants to Owner that each installation or repair performed shall be free of defects in material or workmanship for a period of 12 months following the date of its installation or repair
Availability Guarantee	The Contractor guarantees that the Availability Level of the Plant shall be at least [99] % (Guaranteed Availability Level) during each operational year of the Contract Term starting at the Commencement date. Plant availability shall be calculated at the [inverter] level in accordance with the methodology contained within the O&M Contract. Measured Plant Availability shall be compared with the Guaranteed Availability Level. If Measured Plant Availability falls below the Guaranteed Availability Level, liquidated damages shall be payable to the Owner in accordance with the O&M Contract.
Performance Ratio Guarantee	The Contractor guarantees that the Performance Ratio (PR) of the Plant shall be at least [x]% (Guaranteed Performance Ratio) during each operational year of the Contract Term starting at the Commencement date, taking into account an agreed upon rate of annual degradation. For the purposes of calculating PR, plant energy output will be measured at the utility meter and plane-of-array irradiation will be measured by at least two secondary standard pyranometers, both in accordance with the methodology contained in the O&M Contract. Measured Plant PR shall be compared with the Guaranteed PR value. If Measured Plant PR falls below the Guaranteed Performance Ratio, liquidated damages shall be payable to the Owner in accordance with the O&M Contract.
Liquidated Damages	If it is established that the plant is performing in deficit of the Guaranteed Availability Level and/or Guaranteed Performance Ratio during the Contract terms, the Contractor shall pay to Owner liquidated damages by way of compensation. Both parties agree that liquidated damages will be sized at a level that represents a genuine pre-estimate of losses that may be anticipated from failure to achieve the Guaranteed Availability Level and/or Guaranteed Performance Ratio.
Limit of Liability	The Contractor's liability under the Contract is limited to the Contract price.
Health and Safety	The Contractor shall be responsible for the safety of all Contractor and Subcontractor personnel at the Site. The Contractor shall be responsible for ensuring the safety of all maintenance activities performed at the Site.

Rooftop Solar PV Systems

ANNEX 4

Rooftop solar applications are a substantial part of the deployment of PV technology and are expected to grow substantially in the future.

A4.1 ROOFTOP SOLAR PV SYSTEMS OVERVIEW

A4.1.1 INTRODUCTION

Rooftop solar PV systems can significantly vary in size from kW-scale systems on domestic properties to multi-megawatt-scale installations on non-domestic buildings such as commercial warehouses, factories or office parks. The modular nature of solar PV modules makes them highly adaptable for use on roof spaces. Benefits of roof-mounted solar PV system for a developer can include reduced land cost, the opportunity to offset electricity consumed on site and reduced connection cost due to close proximity to a connection point.

From a public benefit perspective, rooftop solar PV technology is a source of distributed generation that is by its nature close to the source of load demand. It also reduces stress on use of scarce ground surface, especially in urban settings. With the benefits come additional challenges in the design, construction and operation. These additional complexities are explored in the following sections.

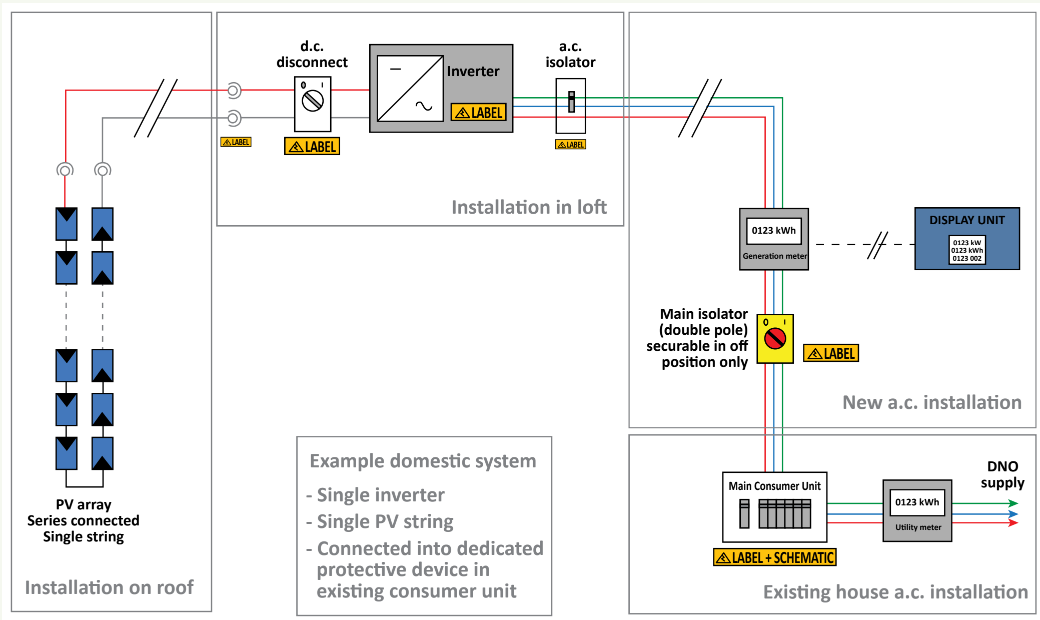
While this guidebook makes mention of aspects relating to small-scale residential systems, the main focus is on larger-scale systems for non-domestic rooftops. The guide focus is on the grid-connected sector and therefore does not address the additional challenges of off-grid systems, for which battery or other energy storage systems are required.

A4.1.2 SYSTEM SIZES

A4.1.2.1 Small-scale Residential Systems

A typical small (kW scale) residential system might consist of a single string of PV modules connected to a single string inverter as illustrated in Figure 33. The grid connection for a residential system can often make use of existing infrastructure (for example the existing power box) at the building.

Figure 33: Small-scale PV System Schematic



A number of design considerations are common across all rooftop solar PV applications. However, some aspects are simplified for small rooftop systems. For example, the electrical design for small systems is less complex than for large systems because small systems can often be connected to a single phase at low voltage (LV). This means the need for complexity in transformer and switch gear design is reduced or avoided.

The project structure can be simple, as small-scale residential systems are often funded by building owners who wish to offset their electricity use or export energy to the grid to benefit from incentives such as a FiT scheme. In some markets "third party leases" or loan structures offered by solar system supply companies or banks help residential owners overcome the high upfront cost of a system.

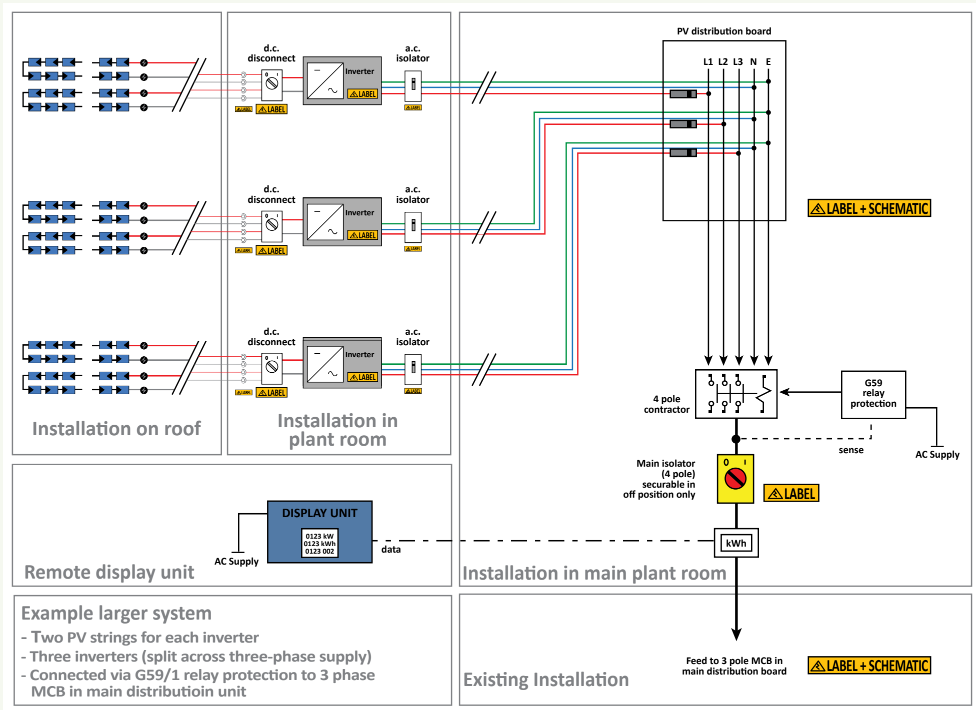
In a number of global markets, the design and installation of residential systems can unfortunately attract inexperienced contractors and therefore there have been cases of poorly designed, ineffective or unsafe installations. It is important that residential systems are designed to local and international standards (e.g., IEC 62548: 2013—Design Requirements for Photovoltaic (PV) Arrays, or local equivalents) and installed by experienced professionals. In a number of markets, incentives require a contractor to be certified and this helps to promote the quality and safety of PV design and installation.

A4.1.2.2 Medium to Large Scale Non-domestic Systems

Non-domestic solar PV rooftop systems can vary in scale, and may range from tens of kW to multi-megawatt scale. A medium to large non-domestic system would typically incorporate several strings of PV modules, combined into numerous string inverters, as illustrated in Figure 34.

While large-scale, ground-mounted PV systems can utilise central inverter systems, this is not common on rooftop arrays. Instead, string inverters are favoured in the interest of minimising DC cable runs from the roof space to the inverter, and thus minimising DC cable losses. When compared with a small residential system, the grid connection for a non-domestic system is likely to involve additional infrastructure, including marshalling boxes,

Figure 34: Non-domestic PV Rooftop Schematic



transformer(s), and more substantial electrical protection. The grid connection process is likely to be more lengthy and detailed. Recent advances in inverter technology have introduced the possibility of using micro-inverter technology, transforming DC current to AC at the module level, and thereby avoiding the need for central inverters. Other benefits include module-level controls that allow for instant adjustments to a string should any module be affected by debris or other performance reduction factors.

A4.1.3 SYSTEM TYPES

Rooftop solar PV systems generally fit into two categories: Building Applied PV (BAPV) and Building Integrated PV (BIPV). Figure 35 illustrates the difference between a BAPV and BIPV system.

BAPV is applicable for an existing building, while BIPV can be utilised for new buildings incorporating a solar PV system as part of the design.

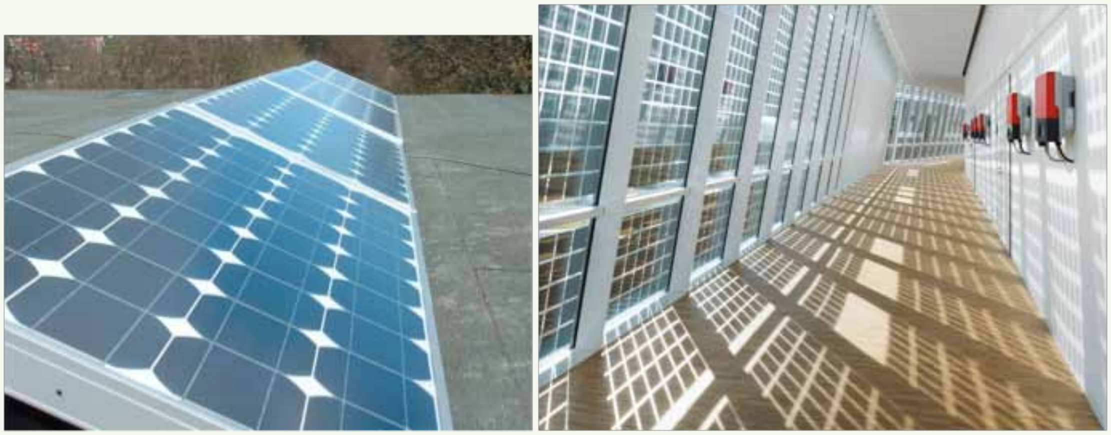
BIPV systems can make use of a number of versatile PV module types and mounting options including:

- Flexible PV roofing.
- PV used to create the facade of a building.
- PV used to create awnings for buildings (therefore also benefitting the passive solar design).
- Integrated glass/glass PV sky lights.
- PV tiles or slates, which can be used as substitute roofing materials.

PV panel-covered parking spaces/car ports are a popular way of integrating PV panels into a functional structure and while not covered here in detail, can be used in combination with electric car charging stations.

BIPV can be a good way to achieve desired aesthetic outcomes on building facades. Some commercially-available PV modules even allow custom PV cell colours (such as purple, yellow or green). BIPV applications

Figure 35: BAPV (Left) and BIPV (Right) Systems



Source: SMA Solar Technology AG

however, are more expensive than applied PV and result in sacrificed energy yield due to a reduced module efficiency or compromised tilt/orientation. BAPV is simpler and easier to install than BIPV. A greater number of building spaces are available with the potential for BAPV because BIPV is predominantly applicable to new buildings. For these reasons, the majority of systems installed globally are BAPV.

A4.2 ENERGY YIELD

There are a number of considerations for rooftop solar PV system energy yields. These include:

- Non-optimal tilts and orientation (azimuth).[80]
- Potential for increased module temperature losses.
- More complexity near shading elements.
- Potential for snow cover/bird droppings/dust build up.

The potential for a rooftop installation to be more difficult to access than a ground-mounted plant should be considered in the energy yield prediction with respect to cleaning (soiling losses) and plant availability (maintenance time to repair). The safety of personnel in gaining rooftop access should also be considered.

A4.2.1 SYSTEM TILT AND AZIMUTH

Wind loading and rooftop dimension constraints may limit the tilt angle that can be used. Tilt angles are therefore often lower for rooftop systems. While some system designs may aim for higher tilt angles to increase the yield, greater utilisation of the available roof space is possible with lower tilt angles. This is because it is possible to reduce the inter-row spacing of modules for a lower tilt angle without adversely affecting shading from row to row.

For countries near the equator, such as Indonesia, a low-tilt angle coincides with the optimal for annual energy yield.[81] However, with increasing distance from the equator, low-tilt angles can reduce the overall specific yield for the system.

Rooftops themselves are also often oriented with non-optimal azimuth and tilt angles. The reduction in total annual irradiation can be calculated on a site-by-site basis

80 The azimuth is the location of the sun in terms of north, south, east and west. Definitions may vary but 0° represents true south, -90° represents east, 180° represents north, and 90° represents west.

81 Tilt angles below 10° are not recommended as natural rainwater run-off has a less effective cleaning effect leading to increased soiling losses.

using knowledge of the diffuse and direct components of irradiation and the albedo of the ground. In general the reduction in annual energy yield is usually within acceptable limits if the azimuth remains within 45 degrees of the optimum orientation.

A4.2.1.1 Module Temperature Losses

Compared to a ground mount system, integrating a solar PV system on a roof space can increase the temperature of the PV modules, due to a reduction in wind cooling and absorption of heat emitted by the rooftop surface and other building surfaces. The range of temperature loss corrections on solar PV plants could range from a 14 percent loss to a 2 percent gain, depending on the climate, and therefore this consideration is significant. PV module efficiency decreases as the temperature increases. This effect is more pronounced with crystalline silicon as compared to thin-film technologies. A typical temperature co-efficient for silicon modules is in the order of -0.43 percent power loss per degree Celsius above a 25°C module temperature. Figure 36 shows the relationship between module efficiency at Standard Test Conditions (STC)[82] and temperature for a standard multi-crystalline silicon module.

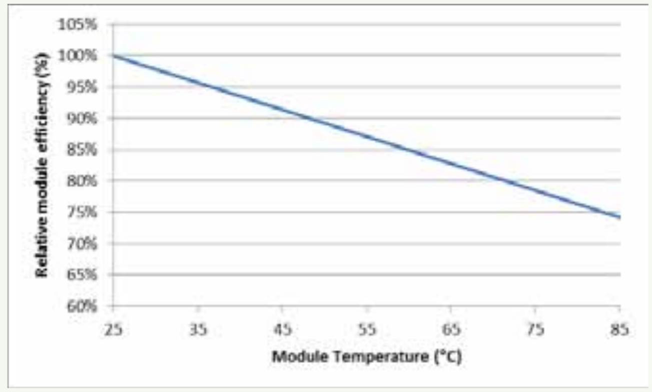
To ensure that rooftop systems do not reach excessive temperatures, suitable spacing between the roof and PV modules must be considered in the design specifications to allow ventilation.

A4.2.1.2 Near Shading Losses

Near shading losses can be significant for rooftop PV systems due to the location of nearby buildings, chimneys, air vents, trees, adjoining roof spaces, overhead lines and other potential shading objects. Such shading should be avoided. If shading is unavoidable, the use of string inverters rather than central inverters is one way to minimise the impact of shading loss on the overall system performance.

82 Standard Test Conditions: 1,000 W/m², Air Mass 1.5, Module Temperature 25°C

Figure 36: Reduction in Module Efficiency with Average Temperature Coefficient



It is important to model shading accurately prior to construction, incorporating all shading objects so that the expected energy yield and financial return may be accurately assessed. Developers should conduct site inspections of the rooftop to determine current obstructions and gather feedback on potential nearby high-rise buildings to be constructed. In case of negative feedback, such sites should be given a low priority for development.

A4.2.1.3 Snow Loss

For solar PV energy yield predictions in regions that experience snow fall, it is important to consider the effect of snow on system performance. For a rooftop solar PV system, roof objects such as gutters, vents or adjoining roof spaces can act as traps where snow accumulates. Due to the internal wiring of typical solar PV modules, it may be advantageous to mount modules in a landscape profile in situations where snow may build up along the bottom edge of the array. This allows by-pass diodes to be effective and therefore reduces losses.

A4.3 PLANT DESIGN

Some design risks are elevated for rooftop PV systems because of their potential to impact rooftop integrity, personnel or contents within a building. The plant design should adhere to local and international standards (such as IEC 62548: 2013, and the International Building

Code). The following sections explore plant design aspects that are particularly relevant to roof-mounted systems. Electrical designs must consider appropriate cabling layouts, lightning protection, and inverter selection. The civil designs must safely and effectively secure the system to the roof, while considering maintenance requirements for the PV array and the roof. Waterproofing is an important installation consideration. It is important to avoid negative impacts on roof longevity, which can in turn have negative impacts on roofing warranties and insurance. This is discussed further in sub-section 3.2 of this Annex.

A4.3.1 ELECTRICAL DESIGN

Many of the electrical design ratings required for ground-mounted systems, such as voltage and current sizing and isolation protection levels, are applicable for rooftop systems. However there are some additional issues that should be considered in the electrical design phase.

Minimising cable runs is more difficult for large-scale rooftop systems and this may lead to slightly higher cable losses due to longer cable lengths or increased costs from thicker cables. Cable placement needs to be carefully considered with appropriate cable ties holding cables in place. Loose cables are a hazard and may suffer from damage during windy conditions. Cables may also reach higher temperatures for rooftop systems due to less ventilation, increasing the resistance and, hence, cable losses. It is recommended cables meet or exceed the following requirements defined in IEC 61730-1:

- Size: minimum 4.0 mm^2 (12 AWG) for modules connected in series.
- Temperature rating from -40°C to +90°C.
- Type PV-wire, USE-2 or equivalent.

The correct fuse specification is also very important for rooftop systems, as failure to appropriately size a fuse can lead to a significant fire risk.

Lightning protection may be required for locations with a high risk of thunderstorms; standard IEC 62305 and UL2703 form the basis of grounding requirements. Buildings may already be fitted with a lightning protection system (LPS), in which case the PV installation will need to be integrated into this system. This may require bonding, provision of earth tape, and surge arrestors, subject to the arrangement of the installation.

As with ground-mounted systems, an earthing or grounding system should be applied to a roof-mounted solar PV system for safety and to allow proper functioning of the system. As there is no direct connection to earth via ground piles, a bonding system to earth the mounting structures should be considered. All earthing requirements of the PV installation will need to be integrated into the building earth requirements. The design of earthing systems should avoid breaching the building envelope and damaging either the waterproofing system or building electrical systems.

For system designs incorporating multiple tilts and orientations, it is important to ensure that, in the inverter design, only identically oriented sub-arrays are allocated to a single maximum power point tracker[83] (which usually implies the use of a single string inverter). Each PV array tilt and orientation will have its own unique output characteristics and therefore needs to be "tracked" separately to maximise yield.

Reactive power control may be required by a grid operator, with power factors lagging to leading at levels below unity. Most PV inverters have the capability to supply reactive power support. If reactive power is incorporated into the system design then it is important that electrical component and inverter sizings are conducted appropriately (generally higher ratings required for all electrical balance of plant and inverters).

Consideration should be given to other works on the building that could interface with the PV system installation. Cable runs inside buildings may need to be

83 A maximum power point tracker is a component of a PV inverter (some larger inverters have more than one) that varies the current and voltage of the PV array to achieve the maximum power output.

installed in heavy duty conduits for mechanical protection and marked as “solar” to avoid confusion with other wiring.

A grid connection application is typically required for the system even if all of the energy generated by the plant is consumed in the building itself. In particular, grid operators often use a grid connection application to verify that anti-islanding and other safety mechanisms are appropriate. Grid connection applications should be made well in advance of the installation date and ensure that the maximum export capacity is greater than or equal to the proposed plant installed capacity.

A4.3.2 CIVIL DESIGN

The civil design of a roof-mounted system must carefully consider an appropriate mounting concept that secures the PV array, minimises adverse effects on the water proofing of the roof, and resists uplift. In addition, a careful assessment of the added roof load must be made.

There have been a number of systems globally which have failed due to the incorrect design and sizing of the support structure on rooftop systems. These failures tend to be high profile as there is a significant risk of endangerment to humans compared to ground-mounted systems.

There are three main foundation options in securing a PV system to a roof:

- Structural fixing.
- Ballasted.
- Hybrid of ballast and structural attachment.

A4.3.2.1 Fixed Foundations

A foundation with structural fixing normally consists of penetrations in the roof surface and connections to the module framing.

Fixed foundations are beneficial as they reduce the dead loading to the structure and are often more flexible than other solutions. The main disadvantage of a fixed system is that penetrations into a roof surface can interfere with waterproofing materials and cause leaks. This is less of an issue for slopped roofs but the design of fixed systems on flat roofs, which are particularly attractive for utility-scale solar PV use, will need particular care. Existing warranties relating to the roof should also be checked because making any penetrations risks invalidating the warranty. Water damage from a punctured rooftop can lead to rot in buildings with wood foundations and loss of structural integrity.

A number of different fixing approaches are available depending on the roof type. Examples include standoffs welded or screwed in place, curbs integrated into the roofing or steel grids suspended above the roof surface. In the case of ceramic or slate tiles it is not considered appropriate to drill through the tile from a water-proofing perspective, and therefore custom-made clips or hooks can offer a solution. It should be ensured that fixings are made to structural components that are designed to accommodate extra weight.

A4.3.2.2 Ballasted Foundations

A ballasted foundation holds down solar PV systems with heavy materials such as concrete slabs. This is a relatively simple approach; however the roof load capacity needs to be considered due to the additional weight of the ballast. As a result, the tilt angle of the system is normally limited to 20° because a higher title angle increases the wind loading and therefore increases the ballast weight required.

Wind pressure distributions vary with location on the PV array structure. Corner and perimeter arrays tend to be loaded the highest and so require much more ballast than interior arrays. One method of reducing the effect of this is to interconnect the support structures so that the ballast weight can be better distributed across the roof. The foundation system must be adequately designed so that it is rigid enough to spread any such forces.

The ballasted system relies on the friction between the roof surface and the array in order to prevent it from sliding. The level of friction can have a significant impact on the amount of ballast required. It is possible to test the potential friction of a roof using specially designed tools in order to optimise the ballast design.

A4.3.2.3 Loading Assessment

A qualified engineer should conduct structural load calculations; this should be done for every rooftop solar PV system. The structural integrity of the existing roof space should be assessed by means of design drawing review and visual inspection. Visual inspection can reveal damage or degradation of existing structural members.

Load assessment calculations should consider:

- Assessment of the loads acting on the PV array and roof, including wind, snow, and seismic loads. The existence of the array will cause additional vertical wind loads onto the roof.
- Assessment of the roof structure to determine its spare load capacity.
- Comparison of the roof structure capacity with the new and existing applied loads.

Load assessments may reveal that the roof structure cannot accommodate the added weight of the solar PV system. In this case, structural reinforcements should be incorporated into the system design.

The solar PV system should not allow water to collect at certain areas of the roof because this will cause additional loading. Water should be rapidly distributed to the overall building drainage system.

The wind loading can cause sliding, uplift, and downward loads on the PV array and roof structure. The load magnitude tends to be dependent on a number of site-specific factors, such as distance to sea, character of the surrounding terrain and location of the array on the roof. A rooftop solar PV system may be split into three areas for wind loading considerations:

1. Interior zone.
2. Perimeter zone.
3. Corner zone.

Corner zones experience the highest wind loads, while interior zones have the lowest wind loads.

Generally, there are national or international standards, such as the International Building Code, which can be used as a basis for structural calculations for loading on buildings. Examples include the Eurocodes in Europe and the ASCE codes in the United States.

Existing design guides and codes can be used to estimate these forces, but as the wind load acting on the array is specific to the particular array and mounting system used, the loads derived by these codes tend to be very simplified. If optimisation is required, as is often the case for ballasted systems where ballast weight must be kept to a minimum, then wind tunnel testing tends to be undertaken and used alongside the relevant country design codes. A number of solar PV foundation providers have already undertaken wind tunnel tests on their products. A qualified structural engineer can apply these to site-specific conditions.

A4.3.2.4 Monitoring and Security

As is the case with large ground-mounted systems, a comprehensive monitoring system is required on roof-mounted systems. Because building systems are located close to end users, there is the opportunity for education and marketing. Real time displays inside the building, which inform building users of the amount of electricity generated and other environmental attributes, can be a good way to promote an organisation's green credentials. Faults and downtime can also be monitored without having to inspect the rooftop system. There are also remote tracking systems, which allow a developer with many rooftop installations to monitor generation from multiple locations.

Generally, system security against module and inverter theft is increased due to roof spaces being generally inaccessible to the public. Where rooftops are accessible from other rooftops, additional security measures can be considered, such as security bolts.

A4.4 PERMITS, LICENSING AND AGREEMENTS

Planning requirements for large-scale rooftop solar PV systems differ from those for ground-mounted systems. For small systems, there is often very little permitting required, other than perhaps residential construction. Aspects of the approval process are generally less onerous due to the PV array having zero land impact, and therefore less effect on fauna or flora. A BAPV system may have minimal or no visual impact. Construction activities and site access impacts still need to be assessed, however, and some environmental assessments may be required depending on the location and the requirements of the consenting authority. There may be restrictions to development within historic districts to preserve aesthetic harmony, which should be investigated prior to any project development. Similarly, installers should note the impact of glare from PV modules on neighbouring businesses or residences.

Building permits are likely to assess structural designs and potentially the roof upgrade design if structural reinforcement is required to accommodate the additional weight of the PV system.

The ease with which any consents can be obtained will vary from country to country and depend on the complexity of the planned installation. Central government renewable energy targets can feed down to the local level and impact the approval process positively.

A4.5 CONSTRUCTION

PV modules are live as soon as they are exposed to daylight, and as such, pose a hazard to installers. Due to the location of installation, particular consideration should be given to ensuring that personnel accessing roofs for maintenance and other activities are not exposed to electrocution hazard. The design of the system should limit open circuit voltages and ensure that live parts are suitably insulated from contact.

There is additional complexity due to the awkward size and weight of modules while working at height. Therefore, extra care needs to be taken during installation and maintenance of a rooftop solar PV system as workers may not be experienced in dealing with working at height.

When assessing the risks associated with working at height and developing control measures, the following hierarchy should be followed:

1. **Avoid:** working at height unless it is essential.
2. **Use existing platforms:** if there is an existing purpose-built platform, then it must be used.
3. **Prevent:** falls by using work equipment that protects all those at risk (e.g., access equipment with guard rails, use mobile elevated working platforms, use scaffolding).
4. **Prevent:** falls by using equipment that protects the individual (e.g., harness with a fall restraint lanyard).
5. **Mitigate:** minimise the distance or consequence of a fall by employing personal protective equipment, fall arrest systems, nets or soft landing systems.

Training, instruction and supervision should be provided to the workforce at each stage of the hierarchy.

A4.6 COMMISSIONING

The commissioning requirements for rooftop PV systems are similar to ground-mount systems. Standards such as IEC 62446: "Grid connection photovoltaic systems—Minimum requirements for system documentation, commissioning tests and inspection" should be used for guidance. Further specific national requirements vary between countries and grid operators.

A4.7 OPERATION AND MAINTENANCE

Fixed solar PV rooftop systems, such as fixed, ground-mounted PV systems, are low maintenance in nature; they have no moving parts and PV modules have a design life of in excess of 25 years. All solar PV systems require some maintenance, which includes regular checks of wiring and components, replacement of faulty modules and inverters and in some cases, module cleaning.

A detailed O&M manual for a rooftop PV system should outline the procedure for carrying out maintenance activities safely at height. There are operational considerations pertaining to the roof space. A problem such as a leak in the roof can be exacerbated due to the difficulty of maintaining the roof integrity with a solar PV system in place. Therefore, the operation and maintenance plan, in combination with the lease, should define responsibilities and procedures for maintenance for the roof space and PV system.

A4.8 ECONOMICS AND PROJECT STRUCTURE

Installing PV systems on rooftops allows a direct feed into a nearby load (often the building on which the system itself is mounted) or fed into the grid. Both have the potential to reduce transmission and distribution losses, thus utilising the rooftop PV generated power efficiently. Because of the ability to offset electricity purchased to supply the building, the system has the opportunity to compete with residential and commercial electricity rates.

A4.8.1 METERING

The electricity generated by a solar PV rooftop system can be exported according to a number of metering configurations, depending on the specific project requirements and power purchase or FiT arrangements. Two common and distinctly different metering arrangements are:

1. **Net metering:** The PV system supplies the building load and exports any excess energy to the grid. When there is insufficient sunlight to generate power (e.g., at night) the building load needs are met by energy imports from the grid. A bi-directional meter is installed to measure and record the net result. If there is a PPA in place for the solar power, a second dedicated meter might be used to record the energy generated and exported by the solar array. "Smart Meters" or time-of-use meters are more commonly being used by retailers and utilities, and determine the value of the energy based on the time of day. If peak demand occurs at the same time as solar generation, smart metering could add value to solar power generated during peak demand times, and this can support the business case for projects.

   Net metering has been controversial in the United States because, though it provides a successful incentive for distributed generation, it ignores the ancillary benefits the transmission and distribution system provide. In countries where the grid operator does not have the option of charging for the benefits of transmission, a net metering scheme may not be wise from a public policy perspective.

2. **Gross metering:** All of the PV generation is exported to the grid. This is common where governments offer a FiT to PV system owners. The building energy requirement is drawn from the grid, and metered separately on regular (non-FiT) rates.

FA4.8.2 FEED-IN TARIFFS (FiTs)

In some markets, governments offer FiT schemes that provide a premium price for solar generation. Often FiT schemes offer a higher premium for rooftop systems over ground-mounted systems, which recognises the additional complexity as well as operational costs of rooftop design and installation. The FiT is usually regulated by government and executed by a government electricity retailer or utility.

A4.8.3 POWER PURCHASE AGREEMENTS

There is the opportunity to sign a PPA with the building user, in which case the system would typically be designed to supply an amount less than or equal to the building load. Alternatively the building owner may also be the system owner and a PPA could be made with an electricity retailer or utility, which would not limit the design system size to the building load.

A4.8.4 LEASE AGREEMENTS

If a third party owns the solar PV system, leasehold with the rooftop owner is required for the project term. The project term is dictated by the project financial business case and is commonly defined in a power purchase

Box 17: Lessons Learned from a 1 MWp Rooftop PV Array, India

As the market penetration of larger rooftop solar PV installations increases, the issues and differences between rooftop PV systems and ground-mount systems become more apparent. The siting, physical integration, interconnection and installation of rooftop PV systems all typically require more detailed field work, analysis, and planning compared to ground-mount systems. Several of the issues may be categorised as follows:

- Siting to maximise generation.
- Roof loading and method of attachment.
- Interconnection.
- Construction requirements.
- Access and safety.

Experience with rooftop arrays in India has yielded solutions to many of these issues.

Siting to Maximize Generation

- Location is often a trade-off as the roofs are not oriented optimally to the solar resource and adjacent structures can shade the array for significant periods of the day. A detailed site visit and measurement of dimensions are required for input into a shading model for the yield analysis. Large periods of shading can significantly alter the economics by reducing yield. Shading models require effort and expertise, but can prevent underperforming installations. Beyond failing to meet profit goals, contractual obligations can come forth where the building owner may not be receiving the output that was warranted in the PPA. An instance was highlighted in a project where shading from a building structure shaded half the array for several months each year. While there was not an easy solution, the energy yield prediction could have identified this.

Roof Loading and Method of Attachment

- The building structure design must be reviewed to ascertain its ability to accept the additional dead weight loads and potential lifting loads of PV arrays during high winds. While there is typically a margin in the roof load capacity, one must consider the individual frames and various sheathing and membrane on which the array will rest. The choice to use a ballasted array versus a mechanically secured frame utilising penetrations avoided concerns of leakage and the need to seek approval for the attachment method from the architect and the roof membrane provider, thereby saving on cost and reducing risk.

Interconnection

- Building power and facility areas are often built with minimal future expansion in mind, and require codes for access and open space. When a PV system must run power conductors via conduit and establish correct disconnects, metering and entrance into the main power panel, the job is often more difficult and requires preplanning and design. While one project had wall space for the correct PV system disconnects, there was no available space on the main panel and a larger panel had to be incorporated.

Construction Requirements

- Rooftop installations require clear and practiced planning for items such as:
  - Any required roof penetrations as the underlying substrate must be known.
  - Conduit runs to the power room and potential to interrupt fire blocks by the conduit installation, and assessing the run to not damage other conduits/services.
  - An outage may be required in the building, and interrupt services.
  - Precautions to protect the roof membrane and related structures.
  - Access for cranes or material lift equipment, including a material storage plan during installation.
- Roof space was tight on one project and this made construction in a small area more difficult. Because the crane was only available for a short period of time, all of the modules were delivered onto the roof space at once. This became problematic as it left very limited room for assembly activities. While there may not have been an alternative, further planning would have been beneficial.

Safety

- Safety is paramount because working at height, working with live modules, and working with high voltages present multiple hazards.
- As with the installation planning, safety is an integral part of any job and the various hazards must be inventoried, reviewed, and discussed with all personal.
- With multiple workers on the roof, various staff were working concurrently on the DC array string wiring. This led to uncontrolled voltage and current rises. Working practices had to be changed to reduce the electric shock risk.

agreement (typically 15–25 years). It is important that the lease terms are well defined and that they ensure:

- All construction activities can be undertaken.
- Solar access is maintained i.e., activities that shade the array are not permitted for the duration of the project.
- Access is granted to the array, inverters, monitoring equipment and electrical balance of plant.
- A clear definition is established for responsibilities and roof membrane impacts and roof maintenance requirements.
- A clear definition is made for what happens at the end of the lease term. The system might be de-commissioned or offered for sale to the building owner.

Legal and technical advisers may be required to ensure the system design is compliant with the terms of the lease. Rooftop solar PV systems are generally designed for a 25–30 year lifetime. The lease should therefore consider the building requirements during this period including re-roofing and maintenance. It should be noted that some module warranties are voided if a PV system is moved, and therefore any plans to move modules should be discussed with the manufacturer to ensure warranty requirements are met.

A4.8.5 THIRD-PARTY LEASES AND LOANS

For smaller residential systems, FiTs, capital grants or simply lower electricity bills might provide economic justification for a system. In global markets, in particular the United States, innovative loan or third-party lease schemes are becoming more common. These schemes can be offered by solar PV system providers, financial institutions or utilities as a means to address the capital cost barrier to homeowners installing PV systems.

In the United States, third-party lease structures are very common. The host does not pay for the electricity produced by the solar PV system, but instead pays a lease payment to a PV system provider. This may be a regular payment, which increases annually, although typically below the rate increase of grid-supplied electricity. The system owner is responsible for capital and maintenance costs and benefits from the lease payments and any tax incentives to achieve an overall savings compared to not having a solar PV system.

The uptake of third-party leases is most successful where the host saves money as compared to paying their normal electricity bill, i.e., in situations where PV generation is at grid parity or has been brought to grid parity[84] via government renewable energy incentives. The system depends on hosts being creditworthy off-takers, and therefore, credit checks are a prudent pre-requisite for the owner when selecting appropriate hosts.

A4.9 CONCLUSIONS

Rooftop solar PV systems offer an attractive option for future development. While using a roof space introduces some degree of complexity to a project, there are also technical and commercial benefits. Commercial benefits for developers include avoidance of land costs, offsetting electricity consumed on site at a higher value than exporting, and the opportunity for an onsite grid connection point.

Consenting timeframes and costs for the project may be reduced due to avoidance of land impact. There are also educational, marketing, and entrepreneurial opportunities introduced by implementing renewable energy at the point of use as well as local job demand.

It is paramount that qualified professionals carry out design work, particularly with regard to structural assessments and energy yield. Waterproofing is an important design and installation consideration for rooftop systems. It is important to avoid negative impacts on roof longevity and existing warranties and insurance. A number of project financing structures and metering arrangements are available which can help to support the business case for rooftop solar PV installation.

84 Grid parity occurs when the levelized cost of electricity is less than or equal to the price of purchasing power from the electricity grid.

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