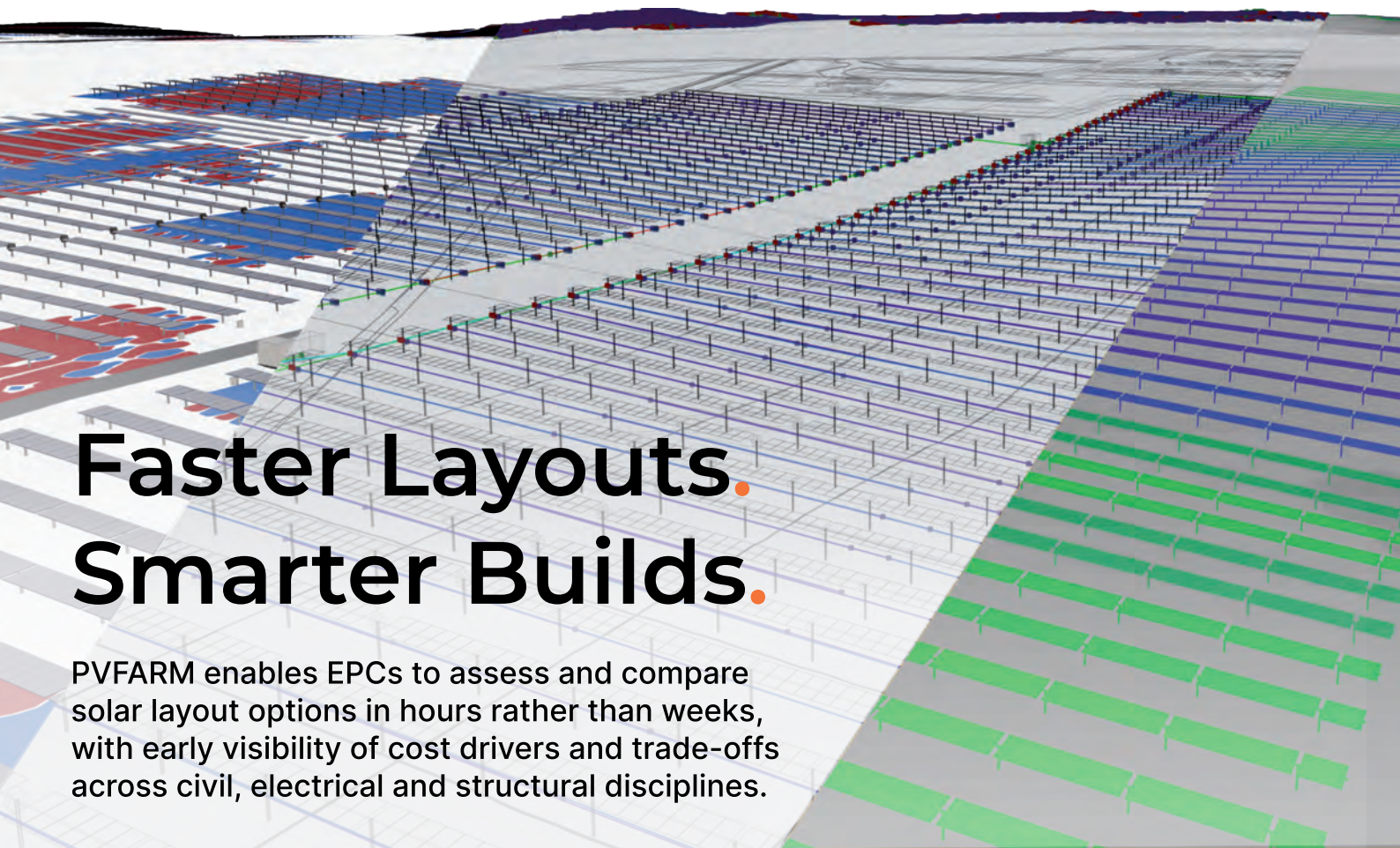


Engineering, Procurement & Construction

Best Practice Guidelines

For Solar PV + Battery *Version 3.0*





Faster Layouts. Smarter Builds.

PVFARM enables EPCs to assess and compare solar layout options in hours rather than weeks, with early visibility of cost drivers and trade-offs across civil, electrical and structural disciplines.



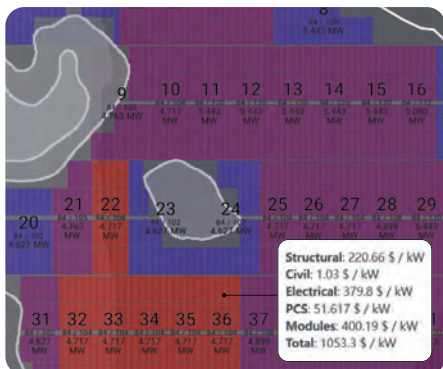
Accelerate layout iteration & scenario comparison



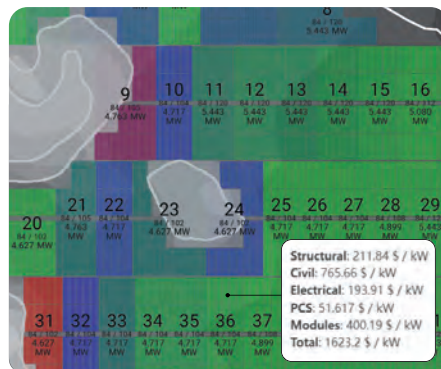
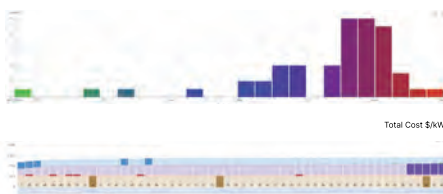
Optimise for EUR/W & LCOE - without hidden trade-offs



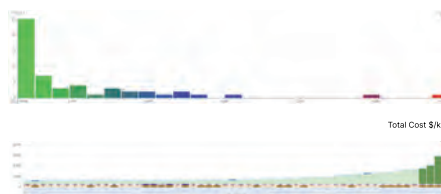
Reduce redesign & construction surprises with early visibility



Dominant category is ELECTRICAL



Dominant category is CIVIL



The Solar Cost Map

PVFARM provides a cross-disciplinary view that shows where costs concentrate across a solar site including earthworks, piling, cabling, terrain and layout decisions in a single, consistent picture.

By making cost distribution visible at block level, teams can identify higher-cost areas, compare layout strategies and align civil, electrical and layout decisions at an early stage.

www.pvfarm.io or scan QR above for more information on PVFARM.

Foreword

Welcome to the third edition of SolarPower Europe's Engineering, Procurement and Construction (EPC) Best Practice Guidelines.

As Europe accelerates its energy transition and advances its renewable energy and energy system resilience objectives, utility-scale solar has evolved from rapid capacity build-out to smarter, hybrid project delivery. Solar PV assets are increasingly co-located and integrated with battery energy storage systems (BESS) to provide flexibility, reliability, and value across the grid.

This edition responds to that shift by consolidating the latest industry practices for hybrid PV+BESS EPC delivery, while reaffirming the fundamentals of high-quality engineering, robust procurement, disciplined construction, and bankable commissioning. Getting the basics right, including design integrity, fit-for-purpose component selection, clear risk allocation, rigorous quality assurance and quality control, and verifiable performance baselines, remains the cornerstone of lifecycle reliability and cost control.

Driven by the Lifecycle Quality Workstream, these guidelines complement and cross-reference the wider best-practice suite covering O&M, Asset Management, and End-of-Life Management. They also explicitly align with SolarPower Europe's new Technical Due Diligence Best Practice Guidelines, strengthening bankability and stakeholder confidence from pre-development through procurement, construction, and handover to operations.

This document introduces expanded chapters on risk management—including bankability, country and regulatory risk, and climate risk alongside an updated Health, Safety, Security, and Environment (HSSE) approach that embeds biodiversity protection and cybersecurity. The principal innovation of this edition is its comprehensive treatment of utility-scale solar projects integrated with battery energy storage systems (BESS), with substantially expanded guidance on hybrid PV+BESS engineering, delivery, and operational interfaces.

Building on this integration focus, the guidelines provide increased guidance on electrical safety and update skills requirements to reflect evolving technologies and human-machine collaboration. They also address BESS operations, procurement governance, third-party factory and traceability audits (including ESG considerations), construction readiness and quality gates, commissioning gateways with digital systems validation, and structured handover to operations and maintenance (O&M). These recommendations are supported by practical annexes, including design documentation, commissioning and test procedures, standards, and templates.

This publication is the result of sustained collaboration across EPC providers, asset owners, O&M providers, manufacturers, technical advisors, legal experts, and insurers. It reflects hands-on experience with utility-scale projects and the realities of hybridisation, grid code evolution, and growing ESG expectations. We thank our members and contributors for their commitment to lifecycle quality and invite all stakeholders to adopt, adapt, and continuously improve these practices as technologies, regulations, and markets evolve.

By integrating quality, risk discipline, and transparent due diligence into EPC delivery, Europe's solar industry can continue to scale reliably, safely, and competitively. On behalf of SolarPower Europe and all contributors, thank you for your commitment to technical excellence and for advancing the future of sustainable energy.



Walburga Hemetsberger
Chief Executive Officer,
SolarPower Europe.



Timo Franz
Head of Project Business
Europe, Astronergy.
Chair of the SolarPower
Europe, Lifecycle Quality
Workstream.



Huang Kangqiao
Senior Director of Policy
Research and Public
Affairs, CATL.
Vice-Chair of the Lifecycle
Quality Workstream.



Wojtek Swietochowski
General Manager, Abo Energy.
Vice-Chair of the Lifecycle
Quality Workstream.

Chair of the SolarPower Europe Lifecycle Quality Workstream:

Timo Franz, Astronergy.

Vice-Chairs of the SolarPower Lifecycle Quality Workstream:

Huang Kangqiao, CATL; Wojtek Swietochowski, ABO Energy.

Coordinator of the SolarPower Europe Lifecycle Quality Workstream:

Nikoletta Fodor, SolarPower Europe.

Contributors and co-authors:

Margaux Plurien (SSI), Shirley Jiaqi Wang (CATL), Kefalidis Georgios (Metlen), Valerio Mazzone (EGGA), Jeremie Sanchez (UNEX), David Melgar (Fraunhofer), Calin Sas (Sunrock), Inno Energy, Thomas Garabetian (SPE), Andras Horvath (Conia Kft.), Marcello Passaro (Sunzest Solar), Ismam Bin Hasnat (Inno Energy), Lars Stephan (Fluence), Andrew Morse (Straylight Venture), Dimitra Maleka (Inno Energy), Paul Gereon Thomas (Abo Energy), Wojtek Swietochowski (Abo Energy), Timo Franz (Astronergy), Thomas Sauer (TEXSECURE), Wielant Jan (ENGIE R&I).

Acknowledgements:

SolarPower Europe would like to extend a special thanks to all members that contributed their knowledge and experience to this report. This would never have been possible without their continuous support.

Please cite as:

SolarPower Europe (2026): *Engineering, Procurement and Construction Best Practice Guidelines/Version 3.0*

Contact:

info@solarpowereurope.org

For media use and queries:

Bethany Meban, SolarPower Europe b.meban@solarpowereurope.org

Date of publication:

February 2026

ISBN:

9789464669411

Design:

Onehemisphere, Sweden. contact@onehemisphere.se

Cover image:

© harhar38/Shutterstock.com

Supported by:



Thanks to our Sponsor Members:



Project information:

The SolarPower Europe O&M Task Force officially started its work in April 2015, and it became the Lifecycle Quality Workstream in 2020, to cover O&M, Asset Management and EPC. It operates through frequent exchanges and meetings. The Workstream's flagship reports are the O&M Best Practice Guidelines, the Asset Management Best Practice Guidelines, the EPC Best Practice Guidelines, the End-of-Life Management Best Practice Guidelines, the Lifecycle Quality Guidelines and the new Technical Due Diligence Best Practice Guidelines. They reflect the experience and views of a considerable share of the European solar industry today.

Disclaimer:

Adherence to SolarPower Europe's Best Practice Guidelines is voluntary. Stakeholders wishing to adhere to these guidelines are responsible for self-certifying compliance via the "Solar Best Practices Mark" (www.solarbestpractices.com). This report is provided for general information purposes only and does not constitute technical, investment, legal, tax, or other advice. Recipients should seek appropriate professional guidance. While based on sources believed to be accurate, SolarPower Europe makes no warranty regarding the completeness or accuracy of the information and assumes no obligation to update it. SolarPower Europe shall not be liable for any damages arising from the use of this report. All content is the intellectual property of SolarPower Europe. Monetisation of this report or its contents by third parties is strictly prohibited without prior written approval from SolarPower Europe.

Members of the Lifecycle Quality Workstream

SolarPower Europe would like to thank the members of its Lifecycle Quality Workstream that contributed to this report including:



Table of Contents

Foreword	3	Chapter 6. Technical Due Diligence	55
Table of Contents	6	Chapter 7. Engineering	59
List of Tables and Figures	8	7.1 Basic Design	61
List of Abbreviations	9	7.1.1 Hybrid System Definition and Duty Cycle	61
Chapter 1. Introduction	11	7.1.2 Key Elements of a Basic Design	65
Chapter 2. Risk Management	16	1. Preliminary layout and electrical concept	65
2.1 Quantification of Risks	17	2. Energy yield estimation	66
2.2 Financial Risk Factors and Bankability	19	3. Grid connection pre-study	66
2.3 Country and Regulatory Risk Factors	20	4. Preliminary Bill of Materials (BOM)	66
2.4 Contractual Risk Factors	21	5. Site and permitting considerations	67
2.5 Technical Risk Factors	22	6. Maintainability and operational design requirements	68
2.6 Climate Risk Factors	23	7.1.3 Outputs of the Basic Design	68
2.7 Other Risk Factors	24	7.2 Preliminary Design	69
Chapter 3. Health, Safety, Security and Environment	28	7.3 Executive Design	71
3.1 Health, Safety and Security	29	7.4 As-built Design	72
3.1.1 Pre-Construction and Design	29	Chapter 8. Procurement	73
3.1.2 Construction Phase	32	8.1 General Procurement Guidelines	74
3.1.3 Project Review	37	8.1.1 Site-specific Resilience for Hybrid Systems	74
3.1.4 Decommissioning	37	8.1.2 Use of Third Parties	75
3.2 Environment	39	8.2 Integration of Quality Management into the Procurement Process	76
3.2.1 Biodiversity	39	8.3 Management of Suppliers	76
3.3 Electrical Safety During Construction	41	8.3.1 Selection of Suppliers	76
Chapter 4. Personnel & Training	44	8.3.2 Qualification of Suppliers	77
4.1 Selection of EPC projects	45	8.4 Supply Review	79
Chapter 5. Transition from Development to EPC	48	8.4.1 Pre-production Review	79
5.1 Selection of EPC projects	49	8.4.2 During Production Inspections	80
5.1.1 Profitability	50	8.5 Delivery	80
5.1.2 Technical Quality	50	8.5.1 Post-production Monitoring	80
5.2 Selection of EPC Service Provider	51	8.5.2 Pre-shipment Inspection	80
5.2.1 Financial Stability	51	8.5.3 Pre-shipment Testing, Factory Acceptance Testing	81
5.2.2 References and Expertise	53	8.5.4 Post-shipment Inspection	81
5.2.3 Price and Performance of Procurement	53	8.6 Specific Requirements per Key Component	82
5.3 Handover from Project Developer to EPC Service Provider	53	8.6.1 Modules	82
5.3.1 Site Description (including site surveys and site data)	53	8.6.2 Inverters	86
5.3.2 Permitting Process	54	8.6.3 Mounting Structure (fixed tilt)	87
5.3.3 Grid Connection Process	54	8.6.4 Mounting Structure (trackers)	88
		8.6.5 Cabling (including connectors and cable management systems)	90

Table of Contents

8.6.6	Transformers	91	10.3.4	Digital Systems Commissioning	118
8.6.7	Battery Energy Storage Systems (BESS) and Associated Equipment	92	10.4	COD, PAC, and Performance Baseline	119
			10.4.1	Commercial Operation Date (COD)	119
			10.4.2	Performance Baseline Establishment	119
			10.4.3	Provisional Acceptance Certificate (PAC)	120
			10.4.4	PAC Gateway (Gateway 5)	120
	Chapter 9. Construction	96		Chapter 11. Handover to O&M	122
9.1	Construction Preparatory Phase	97	11.1	Gradual Engagement Model	124
9.1.1	Site Survey	98	11.2	O&M Independent Audit	125
9.1.2	Stakeholder Management	99	11.2.1	Documentation Audit	125
9.1.3	Construction Plan Preparation	100	11.2.2	Monitoring Data Audit	125
9.1.4	Check and Finalisation of Works Permits	102	11.2.3	Digital Twin Verification	126
9.1.5	Activation of External Suppliers (services and materials)	102	11.2.4	Punch List Audit	126
9.1.6	Soil Protection and Erosion Control	103	11.2.5	Onsite Independent Inspection	126
9.1.7	Waste Management	103	11.2.6	Audit Deliverables	126
9.1.8	Special Site-specific Requirements (e.g. sheep grazing protection)	103	11.3	O&M During Defects Liability Period	127
9.2	Construction Implementation Phase	104	11.3.1	DLP O&M Models and Coordination	127
9.2.1	Construction Site Organisation	104	11.3.2	KPI Responsibility Split	127
9.2.2	Civil Works	104	11.3.3	O&M Supporting FAC Achievement	127
9.2.3	Electro-mechanical Works	105	11.4	Documentation and Knowledge Transfer	128
9.2.4	Ancillary Works	106	11.4.1	Progressive Transfer via Data Room	128
9.2.5	Grid Connection	106	11.4.2	Documentation Package Requirements	128
9.2.6	Checks and Functional Tests	106	11.4.3	DLP Operational Records	129
9.2.7	Mechanical Completion	107	11.5	Digital Infrastructure Handover	129
9.2.8	Training of Asset Owner and O&M Service Provider	107	11.5.1	SCADA and Monitoring Systems	129
			11.5.2	Cybersecurity Handover	129
			11.5.3	Communication and Remote Access	130
			11.6	Operational Readiness and Inspection	130
			11.6.1	EPC Assessment of O&M Readiness	130
			11.6.2	O&M Internal Readiness Planning	130
			11.6.3	Handover Inspection Scope	131
			11.6.4	Handover Report and Acceptance	131
			11.7	Post-FAC Handover to Third-Party O&M	132
			11.7.1	When Third-Party Handover Applies	132
			11.7.2	Third-Party Handover Requirements	132
			11.7.3	Continuity Considerations	132
			11.8	Training and Capacity Building	132
			11.8.1	Handover-Specific Training	132
			11.8.2	Asset Owner Coordination	133
			11.9	Final Acceptance and Warranty Transition	133
			11.9.1	FAC Audit	133
			11.9.2	Post-FAC Warranty Transition	133

Table of Contents

Chapter 12. Key Performance Indicators	134
12.1.1 Project performance KPIs	136
12.1.2 Deviation in Time	137
12.1.3 Deviation in Budget	138
12.1.4 Deviation in Quality	138
12.1.5 Ex-post KPIs	139
12.1.6 Performance Ratio	139
12.1.7 Overall project performance	139
12.1.8 Warranty KPIs	139
Chapter 13. Contractual Framework	140
13.1 Interface between EPC Contract and Regulatory Framework	143
13.2 Contractual Risk Allocation	144
13.3 Price and Payment	145
13.4 Bonds and Guarantees	146
13.5 Limitation of Liability and Liquidated Damages	147
13.6 Termination, Withdrawal and Force Majeure	148
13.7 Ownership, Expiration of Warranties and Transfer of Risk	149
13.8 Assignment and Set-off	149
Annex A List of Applicable Standards	150
Annex B Skills Matrix, Personnel and Training	154

List of Figures and Tables

Figure 1	Annual Solar PV installed capacity 2000-2024	12
Figure 2	Standalone and Hybrid BESS annual installations in Europe	13
Figure 3	Stakeholder Map for Solar BESS Project Risk Management	18
Figure 4	Overview of Engineering Design Stages, Milestones and Deliverables	60
Figure 5	AC-coupled ESS	62
Figure 6	DC-coupled ESS	63
Figure 7	Stakeholder Responsibility Matrix Overview	111
Figure 8	Commissioning Process Timeline with Activities and Gateways	112
Figure 9	Handover Process as Shadow Process to Commissioning Gates	123
Figure 10	Key Performance Indicators in different project phases relevant for EPC	136
Figure 11	Full-wrap contract vs split EPC contract with Umbrella agreement	143
Table 1	Overview of front-of-the-meter (FTM) and behind-the-meter(BTM) applications and definitions	62
Table 2	Overview of front-of-the-meter (FTM) and behind-the-meter(BTM) applications and definitions	65
Table 3	Types of quality tests for PV modules	85
Table 4	Tests to be performed for transformers	91

List of Abbreviations

AC	Alternating Current	HAZOP	Hazard & Operability Study
AM	Asset Management	H&S	Health and Safety
ASCE	American Society of Civil Engineers	HSSE	Health, Safety, Security, and Environment
BESS	Battery Energy Storage Systems	HV	High Voltage
BMS	Battery Management System	HVAC	Heating, Ventilation, Air Conditioning
BIM	Building Information Modeling	HVRT	High Voltage Ride Through
BOM	Bill of Materials	IEC	International Electrotechnical Commission
BOS	Balance of System	IECRE	IEC system for certification to standards relating to equipment for use in Renewable Energy applications
BRP	Balance Responsible Party	IEEE	Institute of Electrical and Electronics Engineers
BTM	Behind-the-Meter	IFC	Issue for Construction
C&I	Commercial & Industrial	IOSH	Institution of Occupational Safety and Health
CAD	Computer Aided Design	IP	Inverter Protection, Internet Protocol
CAPEX	Capital Expenses	IRR	Internal Rate of Return
CCTV	Closed Circuit Television	ISO	International Organisation for Standardisation
CFD	Computational Fluid Dynamics	IT	Information Technology
CMMS	Computerised Maintenance Management System	IVPD	Induced Voltage test with Partial Discharge measurement
COD	Commercial Operation Date	KPI	Key Performance Indicator
CPN	Cost Priority Number	kW	Kilowatt
DC	Direct Current	kWh	kilowatt-hour
D/E	Debt-to-Equity ratio	kWp	kilowatt-peak
DEM	Digital Elevation Models	LCOE	Levelised Cost of Electricity
DLP	Defects Liability Period	LD	Liquidated Damages
DoD	Depth of Discharge	LeTID	Light and elevated Temperature Induced Degradation
DSM	Demand-side Management	LFP	Lithium Ferro (iron) Phosphate
DSO	Distribution System Operator	LID	Light Induced Degradation
EBIT	Earnings Before Interest and Taxes	LV	Low Voltage
EIA	Environmental Impact Assessment	MCC	Mechanical Completion Certificate
EL	Electroluminescence	MTTR	Mean Time to Repair
EMS	Energy Management System	MV	Medium Voltage
EPC	Engineering, Procurement, Construction	MW	Megawatt
ERP	Emergency Response Plan	MWh	Megawatt-hour
ESS	Energy Storage System	NCU	Network Control Unit
FAC	Final Acceptance Certificate	NEBOSH	National Examination Board in Occupational Safety and Health
FAT	Factory Acceptance Test		
FMEA	Failure Modes and Effects Analysis		
FTM	Front-of-the-Meter		
GIS	Geographic Information System		
HA	Hectare (unit of area)		

List of Abbreviations

NIS2	Network and Information Security Directive (EU "NIS2" cybersecurity directive)	RFP	Request for proposal
NMC	Nickel Manganese Cobalt	RFQ	Request for quotation
NPM	Net Profit Margin	RFT	Request for tender
NTP	Notice To Proceed	RPN	Risk Priority Number
O&M	Operation and Maintenance	ROCE	Return On Capital Employed
OD	Operational Document	ROS	Return On Sales
OPEX	Operational Expenses	SCADA	Supervisory Control and Data Acquisition
PAC	Provisional Acceptance Certificate; Pac: AC Power	SDS	Safety Data Sheet
PCS	Power Conversion System	SLA	Service-Level agreement
PD	Partial Discharge	SLD	Single-Line Diagram
PHSSER	Project Health, Safety, Security, Environment review	SOC	State of Charge
PID	Potential Induced Degradation	SoH	State of Health
PLC	Programmable Logic Controllers	SPV	Special Purpose Vehicle
PMI	Project Management Institute	SSSP	Site-Specific Safety Plan
POD	Point of Delivery	STC	Standard Test Conditions (1000 W/m ² , 25°C)
POI	Point of Interconnection	STEM	Science, technology, engineering, and mathematics
PPA	Power Purchase Agreement	TA/SWMS	Task Analysis/Safe Work Method Statement
PPE	Personal Protective Equipment	TCU	Tracker Control Unit
PR	Performance Ratio	TDD	Technical Due Diligence
PV	Photovoltaic	TSO	Transmission System Operator
QA	Quality Assurance	UPS	Uninterruptible Power Supply
QC	Quality Control	UL	Underwriters Laboratories (safety certification organisation; UL 9540/9540A are battery system safety standards)
QI	Quality Improvement	UV	Ultraviolet
QM	Quality Management	VPP	Virtual Power Plant
QP	Quality Planning	WBS	Work Breakdown Structure
QR	Quality Review	WP	Work Package
RACI	Responsible, Accountable, Consulted, Informed		
RFSU	Ready for Start Up		

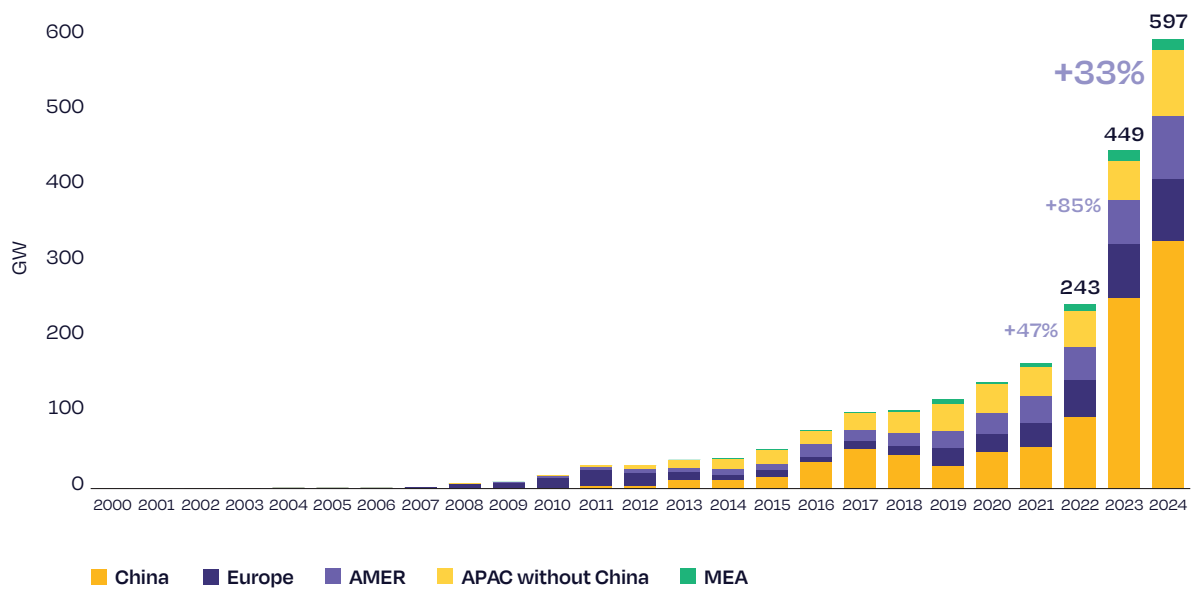
Introduction

This third edition of the EPC Best Practice Guidelines reflects the evolving needs of the solar industry, driven by rapid technological progress, market expansion, and most notably the increasing integration of battery energy storage systems (BESS) with photovoltaic (PV) projects. Solar PV has matured into a central pillar of the global energy transition, with its development accelerating sharply over the past three decades. In 2024 alone, the world grid-connected 597 GW of new solar PV capacity, more than doubling the global installed solar capacity in just two years. Solar accounted for 81% of all new renewable power capacity added worldwide in 2024, and its contribution to global electricity generation has nearly doubled in just three years, now providing about 7% of the world's electricity.

In 2024 alone, the world grid-connected 597 GW of new solar PV capacity, more than doubling the global installed solar capacity in just two years

Figure 1

Annual solar PV installed capacity 2000-2024



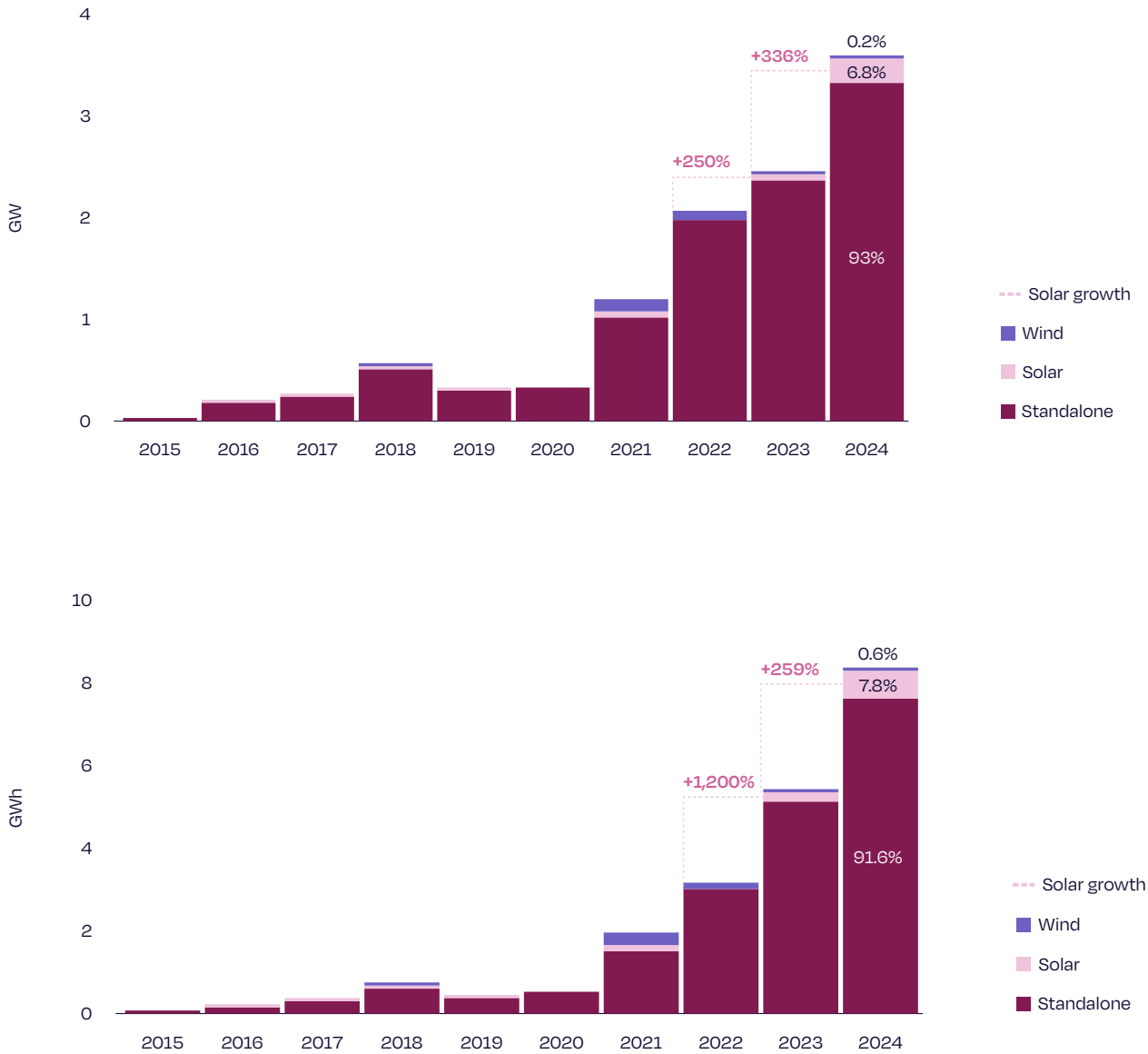
© SolarPower Europe

These milestones confirm solar PV's position as the leading renewable technology driving the clean energy transition. This record deployment has been enabled by rapid technology improvements, continuous cost reductions, and historically low equipment prices. Global manufacturing overcapacity across the solar PV value chain has driven module prices to record lows, making solar the lowest-cost power generation technology in many regions. Sustaining this cost-reduction trajectory is critical for solar to maintain its competitiveness as the industry scales up to multi-terawatt levels. However, as solar's share of the energy mix grows, so do the grid integration challenges, intermittency, and value capture. The next phase of the energy transition requires not only more solar, but smarter solar systems that can deliver flexibility, reliability, and value to the grid and consumers. This is where hybrid systems PV co-located or integrated with BESS have become essential.

Hybrid systems, defined in this document as solar PV installations co-located or integrated with battery energy storage systems (BESS), either through AC or DC coupling, are increasingly becoming the standard in utility-scale project development. In 2024 and 2025, hybrid PV + BESS projects accounted for a significant share of new capacity additions in several key markets, underscoring the industry's shift away from stand-alone solar PV.

Figure 2

Standalone and Hybrid BESS annual installations in Europe



Source: Rystad Energy Powercube

The focus on hybrid systems is not simply a reflection of market trends, but a response to the evolving technical and economic requirements of the energy system. Hybrid projects unlock multiple layers of cost savings and value creation. By maximising the use of existing grid connections, land, and infrastructure, hybrid systems can achieve levelised cost of electricity (LCOE) reductions of up to 10% compared to stand-alone assets. Recent modelling shows that solar plus storage is now more cost-effective than new coal or gas plants in key markets, and this cost advantage is expected to widen as battery prices continue to fall. Storage enables surplus solar energy to be stored and dispatched during periods of high demand or low sunlight, reducing curtailment losses and allowing projects to capture higher market prices. Hybridisation also reduces the need for additional grid upgrades and leverages economies of scale in procurement, construction, and operations. The predictability and flexibility of hybrid assets improve project bankability and attract more favourable financing terms.

However, these benefits are not automatic. Achieving the full cost and performance potential of hybrid systems requires a rigorous approach to quality, risk management, and technical integration. Poor design, inadequate component selection, or weak quality assurance can quickly erode the economic advantages of hybridisation leading to higher O&M costs, accelerated degradation, or even safety incidents.

This is where the EPC Best Practice Guidelines play a critical role. As hybrid projects introduce new layers of technical, contractual, and regulatory complexity, the need for robust, industry-aligned best practices has never been greater. This document provides comprehensive guidance on engineering, procurement, construction, and commissioning of hybrid PV + BESS projects, reflecting the latest European and international standards. It offers practical strategies for cost control, quality assurance, and risk mitigation across the project lifecycle, and establishes clear benchmarks for minimum requirements, best practices, and recommendations empowering stakeholders to make informed decisions that safeguard both performance and profitability.



© harhar38/Shutterstock.com

How to benefit from this document

These guidelines present the essential considerations for delivering successful and professional EPC services in today's rapidly evolving solar sector. While not tailored to any single stakeholder group, their purpose is universal: to clarify mandatory requirements, highlight the necessity of high-quality EPC practices, and provide actionable recommendations that can be incorporated into service offerings for more effective project delivery. All relevant stakeholders whether EPC contractors, asset owners, investors, or service providers can leverage this document to tailor approaches to their specific needs, without compromising on quality or performance. The guidelines are especially valuable for anyone involved in assessing or minimising project risks, ensuring that assets are both robust and bankable.

Although the guidelines are developed with a European focus, their principles and requirements are broadly applicable worldwide. Most content can be directly adopted in other regions, and where unique local conditions exist, additional requirements or modifications can be easily integrated to address specific national or regulatory contexts.

In line with other SolarPower Europe Best Practice Guidelines, the strength of this document lies in its industry-led foundation. It brings together the collective knowledge and experience of leading companies across EPC, asset management, O&M, utilities, manufacturing, digital solutions, and insurance. This third edition builds on previous versions, reflecting the latest sector developments including the widespread deployment of hybrid PV + Battery Energy Storage System (BESS) projects. The scope is focused on the utility-scale segment, particularly systems above 1 MW, and now explicitly addresses the technical, operational, and regulatory complexities of hybrid PV + BESS configurations. The guidelines are informed by the experience of globally active companies, ensuring that the high-level requirements identified here can be applied internationally. However, specific national legal requirements are not covered and should be considered separately when applying these guidelines in particular countries.

The content addresses both technical and non-technical requirements, and, where possible, classifies them into three categories:

- Minimum requirements establish the baseline for a professional and bankable EPC service. Falling below these standards is considered insufficient and may compromise project quality or financial viability.
- Best practices represent state-of-the-art methods that deliver optimal results by balancing technical excellence with financial efficiency.
- Recommendations are enhancements that can further improve service quality, but their adoption may depend on the asset owner's priorities, budget, or project-specific considerations.

To distinguish between these categories, the guidelines use verbs such as "should" to indicate minimum requirements, unless otherwise specified (e.g., "should, as a best practice" or "as a recommendation").

By following these guidelines, stakeholders can confidently navigate the complexities of modern solar and hybrid project delivery, ensuring that quality, cost-effectiveness, and risk management remain at the forefront of every EPC engagement.

Risk Management

This chapter builds on Chapter 4 of SolarPower Europe's *Lifecycle Quality Guidelines, Fundamentals of Lifecycle Project Management* by mapping out techniques for identifying and mitigating risks. Whilst risks are present throughout all stages of a project's lifecycle, they must be mapped and mitigated in the project development phase to reduce the likelihood of their occurrence and the weight of their impact further down the line. There are always multiple points of view on the size and likelihood of a risk. To better understand the risk perspective of an Asset Owner, consult SolarPower Europe's **Asset Management Best Practice Guidelines (Version 2.0)**. This chapter now explicitly addresses hybrid PV systems with Battery Energy Storage Systems (BESS). Hybrid systems introduce additional layers of technical, contractual, financial, and regulatory risk due to the integration of PV, storage, and grid services.

Effective risk management requires clear risk ownership. Each stakeholder must understand their responsibility for risk mitigation throughout the lifecycle of a hybrid PV system

2.1 Quantification of Risks

The typical approach in risk analysis in technical projects is to apply a classic Failure Modes and Effects Analysis (FMEA) where the various risks, belonging to a certain phase and component, can be prioritised through their Risk Priority Number (RPN). In the FMEA, each identified risk is typically evaluated for its severity (S), occurrence (O) and detectability (D); numbers are used to score each of these evaluation parameters. Typically, the RPN is then obtained by multiplying these three factors with the following formula:

Risk Priority Number is defined as:

$$RPN = S_{RPN} \times O_{RPN} \times D_{RPN}$$

For hybrid PV systems, technical risks arise not only from PV modules, inverters, mounting structures, and cabling, but also from battery energy storage components such as battery modules, racks, the Battery Management System (BMS), the Energy Management System (EMS), and associated safety systems (e.g., fire detection and suppression). Technical risks may be specific to one project phase, such as construction-related risks, or persist across the full lifecycle, such as interoperability failures or default risks. For more information on the quantification of technical risks using FMEA, refer to the Solar Bankability project.

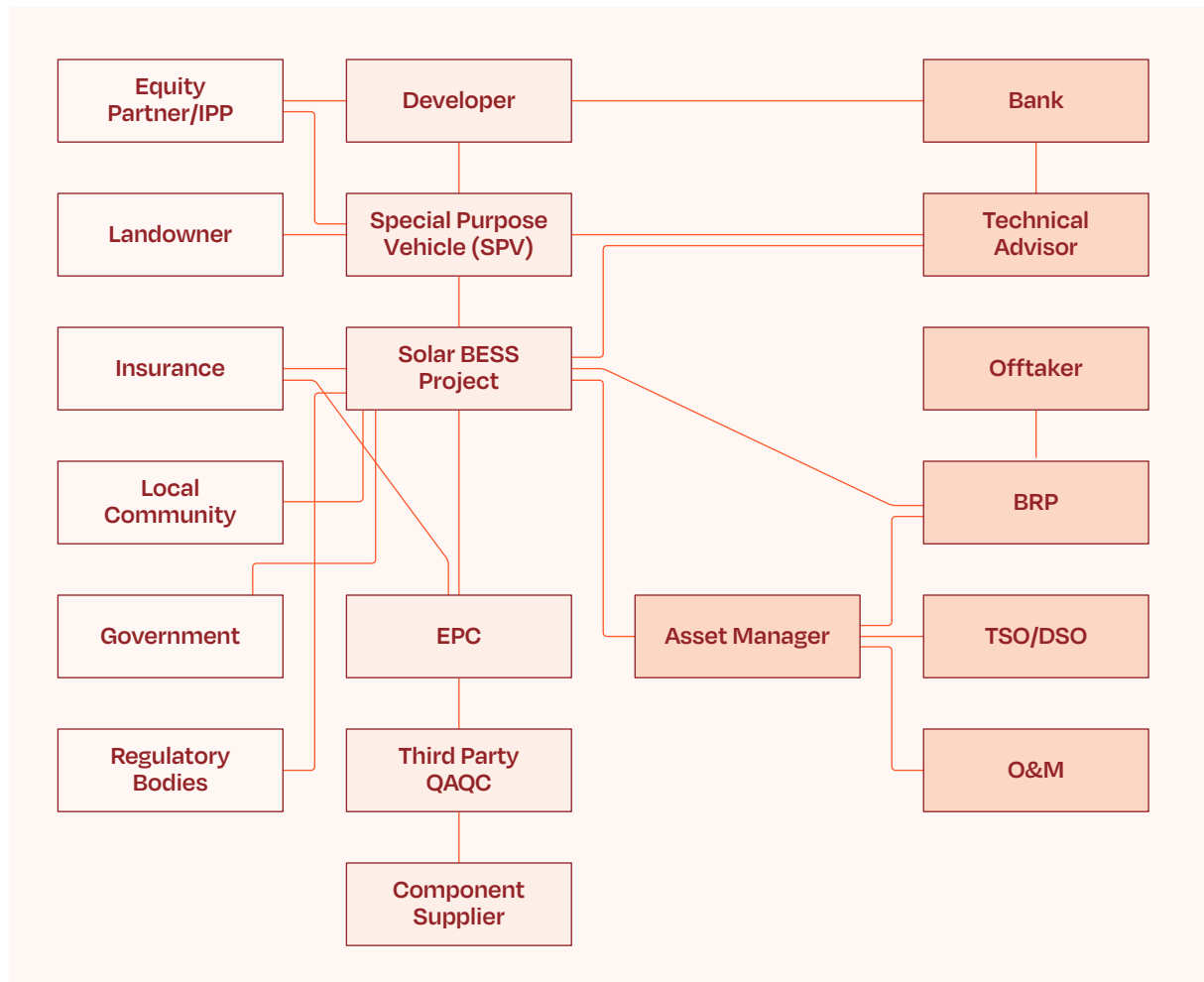
In addition to conventional FMEA, hybrid projects increasingly apply probabilistic and scenario-based risk analysis methods, including Monte Carlo simulations and stochastic degradation models. These methods help capture the complexity of hybrid systems, particularly the uncertainty around battery degradation, cycle life, and dispatch optimisation strategies. Digital twins and advanced analytics tools are also being used to model hybrid system performance under different operating conditions, grid requirements, and market scenarios.

The cost of mitigation measures needs to be included in a cost-benefit analysis, which must consider the expectations of the stakeholders that are involved in a PV project. Mitigation measures must be identified along the entire hybrid value chain and assigned to various technical risks. In the design phase, mitigation may include the selection of proven and certified components, designs that facilitate operation and maintenance (e.g., safe site access, state-of-the-art monitoring and control systems), and system layouts optimised for both LCOE and battery utilisation. During transportation and installation, mitigation measures include robust supply chain management, quality assurance procedures, and adherence to logical grid code requirements. For hybrid projects, it is particularly important to ensure safe transport and handling of batteries, compliance with fire safety regulations, and the correct integration of PV and BESS systems.

Effective risk management also requires clear risk ownership. Each stakeholder must understand their responsibility for risk mitigation throughout the lifecycle of a hybrid PV system. As illustrated in the diagram below, the development and operation of a Solar BESS project involves a wide array of stakeholders including developers, equity partners, banks, technical advisors, landowners, insurers, regulators, EPC contractors, component suppliers, asset managers, offtakers, and more each with distinct roles, interests, and risk exposures. This complexity increases the importance of robust coordination and transparent assignment of responsibilities.

Figure 3

Stakeholder Map for Solar BESS Project Risk Management



Source: Sunzest Solar

Suitable planning, supervision, and quality assurance actions at all stages: design, construction, commissioning, and operation are essential to minimise the risk of damages or outages, optimise warranty usage, and maximise overall system performance. In practice, it is important to assess the combined effect of multiple mitigation measures, as these may interact to either enhance or diminish their effectiveness. Cost-benefit analysis should therefore evaluate bundled mitigation strategies to identify the optimal approach for a given market segment and hybrid system typology.

Finally, particular attention should be given to risks linked to Health, Safety, Security, and Environment (HSSE). In hybrid projects, these include not only electrical safety risks but also thermal runaway and fire hazards in BESS, which may not directly affect system performance but can cause significant harm to people, assets, and the environment.

2.2 Financial Risk Factors and Bankability

Across the lifecycle of a hybrid PV project, the development and EPC phases continue to present the highest levels of financial risk. For hybrid PV systems with integrated battery storage, financial risk is more complex due to the interplay between long-term solar generation revenues and shorter-term storage revenues.

Financial risks include market, modelling, credit, liquidity, operational, reputational, legal, and IT-related factors. A recurring challenge is financial modelling itself: overly optimistic assumptions, particularly regarding energy storage revenues or degradation profiles, can lead to underestimation of risk. Robust sensitivity analyses should be performed, accounting for key variables such as electricity market volatility, frequency response prices, capacity payments, and evolving regulatory frameworks for energy storage participation.

For EPC-related financial risk assessment, the following aspects are particularly important:

- **Market risks:** Price and currency fluctuations between engineering/design and Commercial Operation Date (COD) can significantly impact costs, especially for batteries given their exposure to global critical raw material markets.
- **Revenue risks:** Storage revenues are subject to high volatility due to changing rules for ancillary services, evolving market design, and the risk of regulatory intervention. Merchant risk exposure must be explicitly considered.
- **Warranty alignment risk:** PV modules typically offer long-term performance warranties (often 25 years or more), while BESS warranty terms may vary significantly depending on technology, configuration, and cycling profile. Misalignment between PV and storage warranty durations and conditions can expose investors to performance, replacement, or augmentation risk in later project years. It is therefore critical to assess and, where possible, align warranty timelines, coverage, and assumptions across all major components.
- **Counterparty risks:** The solvency and reliability of partners including EPC contractors, integrators, and technology suppliers are critical. First-time interactions with new partners increase risk and require enhanced due diligence.
- **Transaction risks:** Prepayments and milestone payments must be secured through instruments such as escrow accounts, performance bonds, or parent company guarantees.

Mitigation measures include performance bonds issued by reputable international financial institutions, escrow arrangements, and rigorous financial due diligence, including credit checks and reference assessments of new partners.

Insurance is another evolving dimension of financial risk. Insurers increasingly require evidence of BESS-specific risk management, including documented fire suppression systems, thermal runaway prevention, and emergency response protocols, before underwriting hybrid projects. Failure to meet these requirements may restrict access to affordable insurance and, by extension, financing.

Bankability remains a key consideration. Different banks apply varying standards when assessing hybrid PV projects, particularly in how they treat storage revenues and warranty structures. From an EPC perspective, two aspects are critical:

- Ensuring that any performance or warranty bonds issued by a partner's bank are acceptable to the project's financing bank.
- Understanding and complying with the technical requirements imposed by the lending bank, including those relating specifically to BESS design, safety, and lifecycle guarantees.

In summary, hybrid PV + BESS projects introduce new layers of financial risk that extend beyond conventional PV projects. Addressing these proactively through conservative modelling, contract structuring, and insurance alignment is essential to secure bankability and long-term financial stability.

2.3 Country and Regulatory Risk Factors

Country risk refers to risks associated with investing or lending in a given jurisdiction. These risks include financial factors such as currency controls, devaluation, or abrupt regulatory changes, as well as broader stability concerns such as civil unrest, corruption, or political violence. Collectively, these risks – often termed political or sovereign risk – directly influence the visibility of hybrid projects.

For hybrid projects, regulatory complexity is greater than for stand-alone PV. In addition to conventional PV permitting and compliance, energy storage assets are subject to specific safety, environmental, and operational regulations. Examples include:

- **Battery-specific regulation:** In the European Union, the EU Battery Regulation (2023/1542) introduces mandatory requirements for sustainability, carbon footprint declaration, performance durability, and recycling of batteries. Similar frameworks are emerging in other regions, affecting import, deployment, and end-of-life obligations.
- **Permitting and safety approvals:** BESS installations often require fire safety certification, hazardous materials management permits, and alignment with local building and environmental codes. These processes may differ significantly by jurisdiction and can introduce project delays.
- **Grid code compliance:** Hybrid systems must adhere to evolving grid codes, including requirements for fast frequency response, black start capability, and reactive power support. Such requirements may change during project development, adding compliance risk.
- **Trade and customs risk:** Restrictions on the import and export of lithium, gallium, cobalt, or other critical raw materials can impact supply chains, costs, and delivery schedules.
- **Currency and repatriation risk:** In markets with restrictions on foreign currency trade or repatriation of profits, hybrid projects face additional financing and liquidity challenges.

On the soft side, cultural factors remain influential. For example, business practices around contractual enforcement, transparency, and dispute resolution vary significantly across markets. In some countries, reluctance to acknowledge underperformance or failure can complicate timely risk resolution.

For EPC service providers, the most tangible country risks include:

- Customs clearance and import duties, particularly for batteries.
- Local law (including labour, environmental, and fire safety law) and the effectiveness of enforcement.
- Local content requirements that may apply separately to PV and storage components.
- Political stability, including corruption and bribery risks, measurable through tools such as Transparency International's Corruption Perceptions Index.

In summary, hybrid PV + BESS projects face layered country and regulatory risks that extend beyond traditional solar deployment. Proactive due diligence, continuous monitoring of evolving regulations, and early engagement with local authorities are essential to minimise delays, avoid compliance gaps, and ensure project bankability.

2.4 Contractual Risk Factors

Contracts play a critical role in allocating and managing risk in hybrid PV projects. Poorly defined or incomplete contracts can create significant interpretation risks, leading to disputes during construction and operation.

For hybrid PV + BESS projects, contractual risks are heightened due to the involvement of multiple technologies, suppliers, and integrators. Unlike stand-alone PV projects, hybrid EPC arrangements often combine PV modules, inverters, mounting structures, and balance-of-system equipment with battery modules, racks, battery management systems (BMS), energy management systems (EMS), fire protection systems, and grid interconnection assets. This technological and contractual complexity increases the risk of interface gaps, where responsibilities between PV and BESS suppliers, EPC contractors, and integrators are unclear or inconsistently defined.

Beyond construction-phase interface risks, contractual risk in hybrid projects also extends to the definition of the overall contractual framework of the plant and the long-term enforceability of contractual obligations over the project lifetime. Contractual decisions taken during the development and EPC phase such as scope allocation, liability caps, performance guarantees, and warranty structures may have lasting implications for asset performance, operational flexibility, and bankability. In particular, misalignment between PV and BESS warranty regimes, battery performance and throughput guarantees, long-term service agreements, and O&M obligations may expose project owners to uncovered degradation, availability, or revenue risks during operation.

To prevent unexpected risks and disputes during both construction and operation, international contractors and project sponsors should pay close attention to local project characteristics, applicable law, and market-standard contract practices, while ensuring consistency across EPC, O&M, warranty, and service agreements. For an off-the-shelf O&M contract template designed to distribute risk in a balanced manner among signatories, reference may also be made to Open Solar Contracts (available at <https://opensolarcontracts.org/>).

2.5 Technical Risk Factors

The main technical risks associated with EPC are related to using key components properly. For hybrid systems, these components include both traditional PV elements and storage-specific equipment:

- PV Modules
- Inverters
- Mounting structure
- Cabling - including connectors
- Transformers and switchgear
- Battery modules and racks
- BMS
- EMS
- Fire detection and suppression systems

International and local standards (e.g. IEC, UL) provide baseline requirements for design, testing, and safety. However, hybrid systems introduce additional technical challenges that are not fully captured by standards alone. These include: safety risks, such as thermal runaway, fire, or electrical faults in storage systems. Cybersecurity vulnerabilities in digital control and monitoring systems.



While testing the key components is recommended as part of Quality Review (QR), correct installation of those components, using state of the art techniques, is more critical to building a high-performance power plant. Studies have shown that low plant performance is most likely due to system-level issues rather than individual component failures.

Mitigation strategies include:

- Selecting components with proven track records and appropriate certifications, incorporating lessons learned from operational experience of existing PV and BESS plants
- Designing systems for operational accessibility and maintenance efficiency
- Implementing integrated control and monitoring systems that optimise both PV generation and BESS performance
- Applying rigorous installation quality assurance procedures, including interface testing between PV and BESS
- Conducting safety assessments, including fire risk and emergency response planning for batteries

For more details on specific requirements, see [Chapter 7 Engineering](#), [Chapter 8 Procurement](#) (section 8.6. on *Specific Requirements Per Key Component*) and [Chapter 9 Construction](#).

2.6 Climate risk factors

There are a wide variety of climate risks factors which may impact a solar PV plant over its lifetime. Many of these impacts can lead to major disruptions over a plant, for instance leading to key equipment or infrastructure breakage which cause long period of unavailability. Impacts may also be more diffused in case equipment or plant design has not properly accounted for the prevailing climate conditions for a plant's operation and this can lead to continued losses of efficiency or structural reduction of the plant availability.

Considering the long lifetime of a solar PV plant, project developers should not only consider historical data for climate risk factors impacting their project, but also look to factor in forecasts or model of future climate risks that reflect the changing climate.

Among the typology of different climate risks which may impact a solar PV project, developers should already consider how their projects may be affected at the EPC stage for the following non-exhaustive list of risks:

- **Hail:** Hail is rapidly emerging a crucial risk for the long term profitability and availability of solar PV plants. While this typology of risk has had a minimal impact on project development and operation until the beginning of the current decade. It is also expected that the weight of hail impact will continuously grow as the risk increases along with the rapid growth of installed PV capacity. Project developers, notably in regions of Southern Europe where the hail risk is already well identified and documented, should implement mitigation measures for the impact of the risk at the design, procurement and construction phase of the plant. Project developers in other regions are also encouraged to enquire about the evolution of the hail risk over the operational lifetime of their projects.

- **Snow and ice:** Snow is a climate risk with greatly varying chances of occurrence according to the location of a solar PV plant. It however is a risk with significant potential impact on the plant availability and productivity which project developers can consider and address. Risks associated with snow for a PV plant may be complex, ranging from production losses due to shading/coverage of the module by snow, to module breakage or damages to mounting structures in more extreme events. Snow and ice risks can largely be mitigating through design, procurement, planning and relevant operation and maintenance practices.
- **Flood:** Flood risks in Europe are quite diverse and correspond to a wide array of realities from floods from river beds, flash floods from extreme weather events or even marine submersion. They are among the categories of climate risks which are evolving rapidly in terms of distribution and magnitude as a consequence of climate change. This means that over a solar PV project's lifetime, the nature of the flood risk for the project may evolve significantly. Project should consider current flood risks, which are usually accurately mapped by national, regional or local authorities when initiating a project, but also enquire about potential evolution of the risk at various stages of the EPC process to ensure that proper mitigation measures are implemented. Flood risks may be challenging to factor in, as the nature of the risk may be site specific and additional assessment may be relevant beyond available flood risk mapping.
- **Storms:** Storms include different manifestations of climate risks for solar PV plants, notably including extreme wind loads and lightning in addition of hail or flooding. Storm risks is usually well mapped by local, regional or national weather forecasting services or authorities, and services are available to map out the potential evolution of the storm risk in a changing climate. Specific risks such as extreme wind speeds should be a specific focus of climate risk mitigation during the EPC process, as this risk can largely be addressed in the design and procurement phases of the project development. Lightning also represents a significant risk to PV equipment and infrastructures (such as inverters or BESS systems) and relevant mitigation measures should be taken to protect key infrastructure and equipment.

Storms present a specific challenge of being a composite risk with various potential impacts happening simultaneously or in a short interval, which also requires projects to embed an added layer of resilience in planning for climate risks.

- **Wild fires:** Wildfires are a growing climate and environmental risk across Europe, which can have various impacts on PV plants from reduced plant availability/productivity, to damage to equipment and infrastructure. Some mitigation measures may be taken in the EPC phase to reduce the potential impact of wild fire risk for projects located in wildfire prone areas, which should be coupled with relevant O&M practices.
- **Geophysical:** Geophysical risks which include a wide range of impacts from earthquakes, landslides, soil instability or erosion, may be particularly impactful for a solar PV plant. These risks are location specific and information on the level or risk may be provided by local, regional or national geological surveys.

2.7 Other risk factors

In addition to technical, financial, contractual and regulatory risks, hybrid PV projects face operational, logistical, and digital risks that can impact project performance, safety, and bankability. Key "other" risk factors include:

- **Component availability and supply chain:** delays or shortages of PV modules, inverters, or battery cells can disrupt project schedules and increase costs. Critical materials (e.g., lithium, gallium and cobalt) are particularly vulnerable to global supply chain volatility, and the longer lead times typically required for batteries amplify scheduling risk.

- **Transportation:** both PV and battery components can be damaged during shipping, storage, or on-site handling. Batteries, in particular, are sensitive to mechanical shock, extreme temperatures, and improper packaging, necessitating strict logistics and handling procedures to prevent loss of performance or safety incidents.
- **Delays,** e.g. in shipments, permitting or local approvals: late shipments, customs clearance issues, and extended permitting processes can have cascading effects on project timelines and financial performance. In addition, local testing, certification, or import permits for PV and battery systems may vary significantly, creating additional operational uncertainty.
- **Local certifications, import rules.**
- **Import taxes.**
- **Climate and environmental exposure:** extreme weather events, including heat waves, storms, hail, wind, flooding, or fire, can impact overall system reliability. Site-specific environmental conditions must be considered in planning.
- **ESG and sustainability compliance:** projects are expected to meet evolving requirements for carbon reporting, circular economy practices, and end-of-life battery recycling. Failure to comply with these obligations can lead to regulatory penalties, reputational damage, or restrictions on financing and insurance coverage.
- **Cybersecurity:** Hybrid systems depend on digital control and monitoring. Cybersecurity risks include unauthorised access to control systems, data manipulation, ransomware or malware attacks, and interference with grid compliance.



Conclusion and recommendations

Effective quality and risk management is essential across all phases of hybrid PV + BESS projects. While upfront investments in quality assurance may add approximately 2% to the total project cost, they significantly reduce the likelihood of underperformance, safety incidents, and unplanned corrective expenditures over the system's lifetime. In hybrid systems, inadequate attention to risk can result not only in reduced energy yields but also in accelerated battery degradation, warranty misalignment, safety hazards, or non-compliance with emerging regulatory requirements.

To maximise project success, EPCs and developers should integrate risk management across the entire value chain. This includes selecting components with proven performance records, designing systems for operational accessibility, and implementing robust installation and commissioning practices. For hybrid projects, particular focus should be placed on PV-BESS integration, battery safety, EMS functionality, and cybersecurity. Proactive monitoring and predictive maintenance, informed by digital twins or advanced analytics, can further enhance system reliability and long-term performance.

Financial, contractual, and regulatory considerations are equally critical. Careful financial modelling that accounts for both PV and storage revenues, alignment of warranties across subsystems, and thorough due diligence on partners and suppliers reduces the risk of disputes or underperformance. Compliance with country-specific regulations, permitting requirements, ESG obligations, and evolving storage standards is essential to maintain bankability and avoid operational or legal setbacks. Finally, ongoing performance assessment is crucial. Regular inspections, energy yield verification, and timely corrective actions provide confirmation of a healthy and well-performing system. For hybrid PV + BESS projects, such oversight should also include monitoring of battery capacity, EMS operation, cybersecurity controls, and compliance with regulatory and safety standards. By embedding comprehensive risk and quality management throughout the project lifecycle, developers and EPCs can ensure that hybrid systems deliver on both technical performance and long-term financial expectations, safeguarding the interests of all stakeholders.



**JUNE
23–25
2026**

MESSE MÜNCHEN, GERMANY

The World's Leading Exhibition for the Solar Industry

- **Connecting Solar Business:** International markets, new business models, pioneering technologies and trends
- **Experience innovation up close:** From solar cells and modules to inverters, mounting systems, and PV hybrid systems
- **Join in the growth market:** Keep up with, and benefit from, the PV market's dynamic growth
- **Industry meeting point:** 100,000+ energy experts and 2,800 exhibitors at four parallel exhibitions

Health, Safety, Security and Environment

Health, safety, security, and environment are key priorities for all utility-scale solar PV and hybrid PV + BESS project. The integration of BESS introduces new dimensions of risk and regulatory obligation, requiring a holistic, lifecycle-based approach to HSSE that is embedded from project inception through decommissioning. This chapter outlines the essential elements of HSSE management for EPC contractors, with a focus on the unique challenges and requirements of hybrid projects. For a general overview of the fundamentals of HSSE coordination, please refer to SolarPower Europe's *Lifecycle Quality Guidelines V 1.0*.

The integration of BESS introduces new dimensions of risk and regulatory obligation, requiring a holistic, lifecycle-based approach to HSSE that is embedded from project inception through decommissioning

3.1 Health, Safety and Security

To fully understand site hazards, mitigate them through inherently safe design, and manage any residual safety and operational risks during construction, the following best practices should be carried out across the full lifecycle of a project, and always be underpinned by strong HSSE leadership and personal ownership.

Establishing Leadership, Culture, Communication and Accountabilities: It is important that the EPC service provider (Principal Contractor) has a Health & Safety (H&S) policy statement that summarises its commitment to H&S throughout all levels of the organisation. The EPC service provider's organisational structure, with defined roles and accountability for leadership and service provider's personnel, related to the delivery of safe compliant and reliable operations, further demonstrates this commitment.

3.1.1 Pre-Construction and Design

Pre-construction & Design relates to activities taken to improve asset design that removes construction and operational risk and as such is Inherently Safe, one of the most effective risk mitigations.

Thorough subcontractor selection process (pre-qualification) and final selection informed by historical HSSE performance

Operational HSSE performance requires everyone on site to be equally focused and committed to understanding day-to-day risks where they work, the preventions that have been put in place to minimise the chances of those risks materialising, and the mitigations that have been put in place to keep any impact as low as possible. In industry, when working with partners, contractors that share the same goals tend to develop a safety culture that delivers high HSSE performance. Prior to selecting a contractor, a thorough review of their commitment to HSSE, HSSE performance and systems should be conducted.

Health and Safety Plan/File

The Health and Safety Plan/File is the EPC service provider's working document which sets out in detail how they will manage HSSE on the project and will include answers to any safety issues raised during Pre-Construction design. The purpose of a Health and Safety Plan on a project is to make everyone aware of the scope of the project, how the HSSE of the project affects them, and how the Health and Safety Plan affects others, including non-project related personnel.

The Plan/File details the following:

- Project description
- Residual hazards
- Structural/electrical design information
- Hazardous materials
- Safe O&M procedures and training requirements
- Location of services
- As-built drawings
- How to decommission the plant
- Waste management
- HSSE roles and accountabilities
- Emergency Preparedness & Response Plan
- Cybersecurity & information security plan
- Decommissioning & End-of-Life plan



Identifying and aligning on Environment, Health & Safety legal requirements

The Health & Safety Plan/File and the subsequent implementation needs to comply with local codes and regulations as well as all applicable international standards such as ISO 45001, ISO 14001 and ISO 9001. For hybrid PV + BESS projects, compliance shall also cover applicable PV and battery safety standards (e.g., IEC 62619, IEC 63056, IEC 62933-5-1/-2, NFPA 855, UL 9540A) and, where relevant, the EU Battery Regulation (2023/1542), which sets requirements across the entire lifecycle including safety, sustainability, and end-of life management. In addition, the Plan/File shall address cybersecurity obligations given the increasing safety impact of digital control systems.

It is important that, to meet legal compliance to local law, the EPC service provider maintain a register of compliance obligations and be able to provide details demonstrating their compliance to partners, operators and for external and internal audits.

Safety in design: The industry continues to design and install new technology, seek construction efficiencies, reduce HSSE accidents and improve reliability and quality. It is important that every opportunity to de-risk an operation through Inherently Safe Design principles is taken. The following cross-functional check-ins are valuable formal reviews, and it is recommended that the EPC service provider follow the intent of the following workshops:

- **Project HSSE Kick-off:** A meeting held at the start of the project between the Owner and EPC service provider's project teams to discuss HSSE expectations on the project.
- **Design Review:** To gather designers, clients and other stakeholders and find ways to reduce construction, maintenance, repair, and demolition safety risks associated with design. For PV + BESS systems this includes verifying compliance with fire codes, hazardous materials handling, safe maintenance access, and cybersecurity-by-design principles. This is usually attended by the project team and designers of the Owner, EPC service provider and Technical Advisor. This is conducted sufficiently in advance so any design changes identified can be easily implemented without material, commercial, or scheduling impact on the project.
- **Hazard & Operability study (HAZOP):** HAZOP workshops gather designer, clients, and other stakeholders to identify and mitigate potential remaining hazards and operational issues with the design of equipment and the plant. For hybrid PV + BESS systems, this includes all standard PV considerations, as well as BESS-specific hazards, which should be explicitly categorised and assessed:
 - Electrical hazards: DC/AC shocks, overvoltage, short circuits, and other electrical failures.
 - Mechanical hazards: Collisions, structural failures of racks, containers, or mounting systems.
 - Chemical hazards: Exposure to electrolytes or other toxic components from batteries (e.g., lithium-ion)
 - Other hazards: Fire, explosion, thermal runaway, or uncontrolled energy release.
- **Project Health, Safety, Security, Environment Review (PHSSER):** A pre-mobilisation safety workshop to review site specific requirements and mobilisation details. It is the final Project HSSE cross functional check, ensuring all the design, permitting, Compliance register entries, cybersecurity and data-handling obligations, biodiversity and waste considerations, risk registers, contractors and their interfaces are understood and addressed prior to starting construction.

3.1.2 Construction Phase

The following steps are carried out during construction.

Site-Specific Health and Safety Agreement

The Site-Specific Health and Safety Agreement is an agreement between businesses working on a specific site that determines how H&S will be managed. It identifies which supporting forms are needed and which can be removed. The agreement must cover safety of all areas relevant to the project, including hybrid system interfaces (PV, grid, and BESS).

Safety and Operational Risk Register

This site-specific register is for the EPC service provider to record significant hazards that are involved in their work and cannot be eliminated. The register is a live document that should be kept up to date during the work period. The Site Job/Hazard and Risk Register relates to site-specific hazards and risks only and does not replace a company's overarching H&S hazard register.

Site Briefing Minutes and Toolbox Talks

Site/Briefings and Toolbox Talks provide a means of structuring briefings and meetings in a useful and logical way. The frequency should be based on need, but still at regular intervals. It is an extremely valuable meeting whereby a renewed focus on safe operations, and a discussion on upcoming risks and challenges for the day can be had between team members.

Holding daily Safety Conversations provides an invaluable opportunity to establish and maintain a Safety Culture on site.

Site Traffic Management Plan

The Site Traffic Management Plan is a live and detailed document that addresses site specific risk and is designed to:

- Keep people and vehicles apart
- Minimise vehicle movement including reversing
- Ensure vehicle handling competencies of staff
- Introduce turning and reversing vehicle controls
- Maximise people and plant visibility
- Define signs & Instructions
- Keep hazards away from the plant

It is important that the EPC service provider develops this plan, ensures that changes that occur over time are appropriately updated in the document, it is clearly communicated to all personnel on site and implementation check conducted regularly to ensure implementation.

For hybrid PV + BESS projects, the Site Traffic Management Plan shall explicitly address the transport, delivery, and lifting of battery energy storage systems. Highly integrated BESS containers may exceed standard transport or lifting thresholds (e.g. >40 t or >50 t), requiring oversized vehicles, escort arrangements, reinforced access roads, larger crane exclusion zones, and extended lifting operations. These factors significantly increase interface risks between personnel, vehicles, and plant and must be mitigated through defined delivery routes, controlled lifting zones, weather-dependent lifting criteria, and clear segregation of pedestrian and vehicle movements. Where modular or lower-weight BESS architectures are used, associated reductions in traffic and lifting risk should be reflected in the plan.

Site Security and Access Control

Security is a critical aspect of risk management during the construction phase. Robust entrance protocols including physical barriers, security personnel, and electronic access control systems are essential to ensure the safety of workers, protect assets, and prevent unauthorised access. All personnel and visitors should be registered and tracked as they enter and exit the site, with electronic systems used where possible to maintain accurate records and support incident response. For large-scale parks, security requirements may vary depending on the development stage; particular attention must be paid to projects where certain sections are already commissioned and operational while others remain under construction. In such cases, strict separation between operational and construction zones must be maintained, with differentiated access rights and clear demarcation of boundaries. These measures not only safeguard workers and equipment but also help prevent theft, vandalism, and disruptions to ongoing operations.

Control of Work

An effective Control of Work process provides a work environment that allows high risk tasks to be completed safely and without unplanned loss. It contains:

- Written procedures for control of work
- Roles and accountability
- Training and competency
- Work plan
- Risk assessment of work
- Permit to Work
- Documentation, communication, and approval
- Work monitoring and management
- Safe conditions on completion/interruption of work
- Auditing the control of work process
- Lessons learned
- Obligation and authority to stop unsafe work

Permit to Work

Where proposed work is identified as having a high risk, strict controls are required. The work must be carried out against previously agreed safety procedures and a 'permit-to-work' system.

The Permit to Work is a documented procedure that authorises certain people to carry out specific work (high risk in nature and not captured in a Method Statement) within a specified time frame. It sets out the precautions required to complete the work safely, based on a risk assessment. It describes what work will be done and how it will be done; the latter can be detailed in a 'method statement'.

The permit-to-work requires declarations from the people authorising and carrying out the work. Where necessary it requires a declaration from those involved in shift handover procedures or extensions to the work. Finally, before equipment or machinery is put back into service, it will require a declaration from the permit originator that it is ready for normal use.

Task Analysis/Safe Work Method Statement

The Task Analysis/Safe Work Method Statement (TA/SWMS) register is a job-planning tool for higher-risk activities. "Higher risk" refers to activities such as working in a confined-space, asbestos-related work, working at height, working in an excavation, working next to or over deep water, or working with any hazardous product or material. A principal or main contractor can request a TA/SWMS at any time, for any activity, not just those listed above. The TA/SWMS is written in accordance with and aligned to the Permit to Work process.

Risk Assessment Matrix and Hierarchy of Controls

The Risk Assessment Matrix allows you to assess the risk of a hazardous event occurring while certain tasks are being performed. The risk assessment defines the potential/severity and probability/likelihood of a specific risk so it can be compared across projects and against other risks, be effectively mitigated, tracked over time, and communicated.

The Hierarchy of Controls table takes you through a logical flow of options, from most effective to least effective to guide you in eliminating and minimising hazardous events.

For a template Risk Assessment Matrix, see [Annex D](#).

Hazardous Works Notification

Certain activities are considered high risk and must be made note of before work begins. The Contractor controlling the site or activity must notify the authorities.

Hazardous Products and Substances Register

This register records every product, substance, and material that is brought to or used on the site by the subcontractor. You are required by national laws to record every product, substance, and material used on-site that contains potentially hazardous ingredients. The register must be completed before any work starts on-site and updated as changes occur.

Onsite Training and Competency Register

This register records the training, qualifications, experience, and competencies of your employees working on a particular site. It must be fully completed before any work starts on the site and updated as employees or circumstances change. This register is designed to be used in conjunction with a subcontractor's company-wide training and competency register.

Site Inspection Checklist

Inspection is a vital part of hazard management. An inspection can identify an issue before it causes harm. Inspections range from specific (vehicles) to broad (sites) and differ from one industry or trade to another. An inspection checklist therefore must be customised to meet the specific requirements of a job. Parties need to agree how and when inspections will be carried out. The frequency of these inspections is determined by the Site-Specific Safety Plan (SSSP) Agreement document.

HSSE Performance Monitoring of leading and lagging indicators

The tracking of HSSE performance against key performance indicators may identify emerging trends that require direct focus. It may also identify areas of high performance that others can look to replicate. Key performance indicators (KPIs) can be both lagging indicators of safety performance, built on historical performance that shows that performance has improved or deteriorated, or leading indicators the trends from which may indicate possible future performance change. See examples of Lagging and Leading HSSE KPIs in *Annex E*.

Management of Change

During construction it is not uncommon that conditions change, there are discoveries that compromise the original design or change the level of risk associated to the operation. While a number of these situations have negligible impact some may be material or may compromise some other part of the design.

Changes to design or changes in risk profile should be subject to a Management of Change review that is signed off by the same cross-functional team, Owner and EPC service provider that endorsed the original design and noted on all 'As-Builts'.

Emergency Response Plan

The Emergency Response Plan (ERP) saves lives. It must be in place before any work starts on-site and updated as changes occur. A comprehensive ERP is needed for any work that requires a TA/SWMS or a Permit to Work, such as harness rescue (above or below ground), extraction from a confined space, trench, or excavation collapse, and chemical or fuel spill.

As a general rule, the ERP must be shared with all parties involved or in the vicinity of the construction site of a PV plant. For example in the specific case of C&I rooftops, the ERP plan needs to be shared with the parties operating inside the building as any incident may impact their activity. Additionally, the neighbours and the occupants of the building usually have their own emergency response teams which can be included in the ERP.

For an example ERP, see *Annex C*.

Robotics and Automation for HSSE

Ergonomic Safety: Reasoning with newly outcoming module technologies

Automation and robotic solutions represent a significant advancement in implementing inherently safer design principles during PV plant and BESS construction. By reducing direct human exposure to high-risk activities, these technologies mitigate residual hazards across multiple construction phases.

Automated pile-driving equipment eliminates manual handling of heavy tracker foundations, reducing musculoskeletal injuries and removing personnel from struck-by hazards. Robotic module installation systems, such as semi-autonomous mounting platforms and mechanised clamp systems, minimise working at height whilst preventing repetitive strain injuries associated with installing thousands of modules manually.

RGB and thermal imaging drones provide real-time oversight of construction zones, enabling identification of unsafe working conditions, unauthorised personnel in restricted areas, and potential electrical hazards before energisation. Thermal surveys detect hotspots in temporary electrical installations and verify proper isolation procedures during commissioning activities.

Autonomous material handling vehicles reduce personnel exposure to electrical and mechanical risks during activities. For BESS installations, automated container positioning systems and remote-controlled connection interfaces minimise proximity to high-voltage equipment during commissioning. Drone footage provides

When integrated within the Health and Safety Plan and supported by appropriate Task Analyses and Safe Work Method Statements, these innovations demonstrably reduce both the likelihood and severity of construction-phase incidents. This supports compliance with ISO 45001 requirements whilst delivering measurable improvements in lagging HSSE indicators, including Total Recordable Incident Rate and Lost Time Injury Frequency Rate throughout the project lifecycle.



Cosmic Robotics supports field crews by lifting solar modules into place.

3.1.3 Project Review

Following the construction of the asset the EPC service provider and Owner should jointly hold a Post Construction Workshop. This workshop is to evaluate the effectiveness of the execution of the project against the aims and objectives. It should include H&S management provision, environmental protection, and general management of the overall project. Lessons from this workshop should be fed back into subsequent designs and handed over to O&M teams.

3.1.4 Decommissioning

Prior to commencing any dismantling or demolition works of the PV+BESS plant, a qualified Structural Engineer should undertake an assessment of the risks together with a detailed investigation of the PV plant. The following consideration should be included:

- Identification of residual electrical and thermal energy in PV modules, inverters, and battery storage units, with verification that batteries are safely discharged or isolated.
- Review of O&M manuals, as-built documentation, and any previous modifications, including BESS installations conditions and commissioning records.
- Assessment of structural integrity, including PV mounting systems, racks, foundations, and BESS enclosures.
- Demolition sequencing to avoid uncontrolled structural collapse, energy release, or safety hazards. Consider Partial Demolition, Complete Progressive Demolition, or Manual/Mechanical techniques.
- Recognition of danger points, such as floor loadings, falling debris, fire hazards, chemical exposure from batteries, and the need for secure edge protection.
- Debris management.

BESS-Specific Environmental and Safety Considerations:

- **End-of-life handling and recycling:** Batteries and associated materials shall be disposed of or recycled in compliance with applicable local, national, and EU regulations, including EU Battery Regulation (EU) 2023/1542. The BESS shall be designed to facilitate safe removal and separation of components, with minimal disassembly where practicable. To ensure the availability and robustness of the recycling chain, third-party audits are recommended. Manufacturers and project developers should provide supporting documentation for audit purposes, such as qualifications and permits of downstream recyclers and waste treatment facilities.
- **Hazard mitigation and mitigation:** Electrical, chemical, mechanical, and thermal hazards shall be identified and controlled throughout the BESS lifecycle, including risks related to electrolyte leakage, fire, or exposure to toxic materials. Appropriate engineering controls, operational procedures, trained personnel, and personal protective equipment (PPE) shall be employed.
- **Accessibility and maintainability:** The BESS and associated equipment (including HVAC systems, inverters, and power conversion systems) shall be designed to allow safe access for inspection, maintenance, replacement, and decommissioning without the need for extensive disassembly.

- **Environmental protection during operation and dismantling:** Contaminated materials, including damaged components and contaminated PPE, shall be managed in accordance with environmental permits and best-practice waste management procedures. Measures shall be taken to minimise impacts on soil, groundwater, surface water, and surrounding ecosystems during operation, dismantling, and demolition activities.
- **Noise Control:** Noise emissions from BESS installations, including cooling systems and auxiliary equipment, shall be assessed and controlled in accordance with applicable local and EU noise regulations. Manufacturers should provide evidence demonstrating effective noise mitigation measures over the operational lifecycle.
- **Application of eco-friendly refrigerants:** HVAC and cooling systems associated with BESS shall prioritise the use of eco-friendly refrigerants with low environmental impact. Compliance with relevant EU legislation on fluorinated greenhouse gases (F-gases), including Global Warming Potential (GWP) limits, leakage prevention, and control provisions, shall be demonstrated. Manufacturers should provide documentation confirming compliance and effective control measures.
- **Land use of BESS should be minimised to mitigate their impact on land resources.**

As a general guideline, any dismantling or demolition works should consider local recycling and waste management requirements, based on the relevant local legislation, including hazardous materials from PV modules, BESS units, and contaminated PPE, in accordance with local legislations.



© jeson/AdobeStock

3.2 Environment

Without precaution, the environment hosting the PV + BESS power plant may be affected during the project lifetime. Hence, an effective assessment of the associated impact of the proposed development project is a crucial aspect of any environmental and social impact assessment (ESIA). Since a universal methodology might not apply to every project's environmental and social conditions, different approaches are adapted to suit the environmental context of each site.

There are several basic environmental authorisations including, but not limited to:

- Environmental impact assessment (EIA)
- Endangered/protected species
- Agricultural protection
- Cultural and Historic preservation
- Forestry and landscape protection

Permitting and licensing requirements for solar PV + BESS power plants differ significantly from country to country and even, within different country regions.

All necessary environmental permits, licenses and requirements must be acquired prior to start of construction. Best practices for permitting, including efficient stakeholder consultation and alignment with national and EU legislation, are described in the SolarPower Europe report *EU Renewable Energy Permitting: State of Play*. It is a common practice to hire a specialist environmental consultant to provide advice on:

1. the specific country requirements, laws, and regulations,
2. to consult with the relevant environmental agencies, planning and government authorities, and to determine any additional obligations relevant to the venture. One important aspect to already consider during the planning phase is the situation at the end of the lease term. In addition, equitable purchase/lease of land and water use for cleaning of solar modules should also be considered. The site-specific permitting shall be taken into consideration when moving towards decommissioning, repowering, acquisition to the landowner, etc.

3.2.1 Biodiversity

Biodiversity concerns the variety of living species, including plants, animals, bacteria and fungi on the site.

The SolarPower Europe *Sustainability Best Practices Benchmark* and *O&M Best Practice Guidelines* discuss how to make sure that a high level of biodiversity is maintained during plant operations. Decisions made during site selection, design, and construction are particularly critical for achieving biodiversity objectives. The goal is to maximise synergy between technical systems and ecological systems.

Perhaps the most important one of these decisions concerns the choice of where to build the plant. Several studies (for example *BNE Study*, *ENERPLAN et. al.*) have shown that biodiversity can be significantly improved, if the PV plant is built on a biologically degraded site. This does not necessarily mean, that PV plants should be built on contaminated soil – and the obligation to do so should only be accepted if the resulting risk is carried by the polluter. Furthermore, sites with polluted soil might nevertheless show a high level of biodiversity if industrial activity has been terminated a long time ago.

Other opportunities are agricultural sites with low productivity, because in this case the high potential to increase biodiversity combines well with an acceptable loss of agricultural potential. Occasionally it makes even sense to maintain agricultural activities within the PV + BESS plant. However, a clear decision should be made as to whether the purpose is energy-centric or agriculture-centric.

Construction can temporarily disrupt the existing natural ecosystem. Therefore, after the site has been chosen, an initial ecological survey should create a baseline of species and habitat conditions before construction, making later studies more meaningful. The design of this initial survey should be consistent with subsequent monitoring efforts. Certain design decisions contribute to higher biodiversity of a future plant. Air, land, and water are the main pillars in supporting animal and plant life, so the decisions focus on these points.

Some examples:

- Limiting soil sealing (foundations, tracks inside the plants etc.). For example, soil sealing could be limited to less than 2%
- Roads in the PV plant should be water-bound
- Avoiding terracing or at least limiting it to small problematic areas
- Using the support structure as cable duct wherever possible, and hereby reducing buried cables and earth movements to a minimum
- Avoiding the use of concrete fundaments for piles of the support structure
- Biodiversity can help limit soil erosion (and increase soil fertility by avoiding nutrient run off), pest regulation and keeping vegetation height limited etc
- Avoiding clearing trees and bushes wherever possible
- Creating new hedges (for example at the Northern side of the PV plant, the hedge functions as habitat and visual screen)
- Several studies and best practice guidelines (for example, the BNE study and the Triesdorf biodiversity strategy) underline the importance of respecting minimum row distances
- Vegetation under the panels instead of gravel may increase transpiration (water vapour as a by-product of photosynthesis), which, to some extent, can cool panels
- Fences should allow small animals to pass (for example, presence of spaces of 15 cm between soil and fence). For larger animals passages should be planned, if the overall surface of the plant is bigger than, for example, 10-15 hectares. The width of such passages should be at least 10 metres. Security and biodiversity can here be in a trade-off situation, as animals can trigger motion sensors or cameras
- During construction the integrity of the vegetational and upper soil layer should be maintained wherever possible
- If sowing is nevertheless necessary, seeds should stem from regionally present plants. In any case, spreading of invasive alien species must be avoided
- The use of fertilizers or herbicides must be avoided

- Soil type and solar radiation will impact the type of wildlife and plants. Shadow from the panels impacts plants under or next to as well as can provide a refuge for animals
- Bird and bat boxes might be considered to help create the right balance
- For hybrid sites, ensure BESS containers, fire suppression zones, and access routes are designed to minimise habitat disruption and soil compaction.

Given the specificities of protecting biodiversity, an external ecological consultant should, where possible, be used to suggest strategies that are appropriate for a site's size and location.

To produce the best biodiversity results, the ecosystem of a site needs to be considered in its entirety when designing a strategy. This may not be achieved entirely in the first round and the strategy can require updating as the ecosystem is mapped more accurately.

3.3 Electrical Safety During Construction

Establishing robust electrical safety throughout the construction phase requires a comprehensive organisational framework aligned with EN 50110-1 and applicable national regulations.

The construction phase extends from site mobilisation through mechanical completion, commissioning, and energisation until Provisional Acceptance Certificate (PAC) issuance, with critical overlap and cooperation with the O&M service provider during the final stages.

Pre-Construction Electrical Safety Framework

Before commencing any construction activities, the EPC service provider must establish and document the electrical safety management structure as part of the Health and Safety Plan. This includes:

- A clear organisational hierarchy identifying all electrically responsible personnel, including separate appointments for Low Voltage (LV: 50-1000V AC/120-1500V DC) and High Voltage (HV: >1000V AC/>1500V DC) systems. For hybrid plants incorporating PV and BESS, additional consideration must be given to interface risks at DC/AC boundaries and battery system-specific hazards.
- Formal appointment documentation for all qualified electrical personnel, verified against national competency requirements and notified to relevant authorities. These appointments must be reviewed and reconfirmed at the start of each major construction phase and whenever personnel changes occur
- A comprehensive electrical risk register identifying voltage-specific hazards, DC arc flash risks, construction-phase energisation sequences, and interface points between multiple electrical contractors.
- Competency Management and Verification

The EPC service provider must maintain a skills matrix (as detailed in Annex B) mapping required competencies against assigned personnel. All electrical personnel must hold valid certifications appropriate to their scope of work, including country-specific electrical licenses and PV system-specific qualifications. Regular competency verification through documented toolbox talks, pre-work briefings, and practical assessments ensures personnel understand both standard procedures and site-specific electrical hazards. Particular attention must be paid to DC system safety, as many electricians lack experience with high-voltage DC installations typical of modern PV plants.

Electrical Safety Documentation Hierarchy

A structured documentation system must be established and maintained throughout construction:

- Method Statements for all electrical works, submitted minimum two months after contract award
- Task-specific Risk Assessments covering each electrical intervention
- Permit-to-Work system with clear authorisation protocols
- Lock-Out/Tag-Out procedures integrated with work permits
- Switching Logs recording all energisation and isolation activities
- Electrical Test and Commissioning Protocols conforming to IEC 62446

Interface Management and Coordination

Construction electrical safety requires careful coordination across multiple interfaces. The EPC service provider must establish formal coordination mechanisms between electrical subcontractors, civil works teams, and equipment suppliers. Weekly electrical safety coordination meetings chaired by the designated electrical safety manager ensure alignment on upcoming energisation activities, interface risks, and permit requirements.

For hybrid plants, specific protocols must address the interaction between PV DC systems, battery storage DC systems, and AC grid connection equipment. These interface protocols should be documented in the Project HSSE Review conducted pre-mobilisation.

Transition Planning and O&M Cooperation

As detailed in Chapter 11 *Handover to O&M* and aligned with SolarPower Europe's *O&M Best Practice Guidelines*, the EPC service provider must initiate O&M transition planning well before PAC. A sufficiently long transition period of six months is recommended as best practice, during which the EPC service provider is obliged to cooperate with the incoming O&M service provider.

Early engagement includes dedicated HSSE training sessions where the O&M service provider's staff and Asset Owner HSSE coordinator review all electrical safety procedures, identify site-specific hazards, and adapt procedures to align with operational requirements. This is particularly critical where O&M service providers maintain stricter HSSE standards than regional construction regulations. Training must cover both theoretical knowledge from O&M manuals and practical demonstrations of electrical isolation procedures, emergency response protocols, and SCADA system operation. Poor training standards during this transition can result in lower plant performance and increased electrical safety incidents during the operational phase.

Documentation for Operational Handover

Electrical safety documentation compiled throughout construction forms a critical component of as-built documentation delivered at PAC. This includes updated single-line diagrams reflecting any design changes, complete test records, equipment warranties, maintenance reports completed during the warranty period, and the final electrical risk register. This documentation provides the foundation for operational electrical safety procedures detailed in the O&M Best Practice Guidelines Chapter 2 (Health, Safety, Security and Environment).

BATTERY STORAGE EUROPE PLATFORM

A new platform by SolarPower Europe to promote the development and expansion of battery storage in Europe



BATTERY
STORAGE
EUROPE
PLATFORM

Learn more



Personnel and Training

Having the right personnel with the right skills is crucial to the success of any project. This chapter touches briefly on the specific skill sets required by EPC service providers. For a more in-depth view of the skills required across a project's lifecycle we strongly encourage you to refer to SolarPower Europe's *Lifecycle Quality Guidelines v 1.0*, as well as the most recent O&M Best Practice Guidelines, which emphasise workforce upskilling, digitalisation, and sustainability reporting requirements.

The EPC service provider and its personnel should be able to prove that they have all the necessary qualifications to safely and efficiently carry out the work required of them

4.1 Training

The EPC service provider and its personnel should be able to prove that they have all the necessary qualifications to safely and efficiently carry out the work required of them (refer to [Chapter 5.2.2. References and Expertise](#)). Despite the EPC phase being one of the shortest in a project's lifecycle, the range of work and different skills required is large. It includes selecting modules; creating electrical wiring diagrams, which requires an awareness of local site regulations; civil engineering and construction work, which can include earth or mechanical work. Other examples involve supply chain management and logistics, including transportation; restrictions on work and access to sites; management of personnel, including handling local restrictions on travel and accommodation. Increasingly, EPC personnel are expected to also demonstrate knowledge in circular economy principles and sustainable procurement.

The personnel of the EPC service provider typically have the following skill profiles (for a useful skills matrix, see [Annex B](#)):

- **Science, technology, engineering, and mathematics (STEM):** E.g. electrical, or geotechnical, expertise in hybrid systems, battery storage (BESS), grid integration, and sector coupling.
- **Managerial and administrative:** Notably finance, project management, supply chain management, quality assurance, stakeholder engagement, and ESG compliance, including adherence to reporting obligations and due diligence.
- **Technical:** Including doing groundwork, constructing frames, mounting panels, electrical installation, commissioning, and health and safety certifications. Increasingly expected to have knowledge of sustainable construction practices and waste handling.
- **Digital and data-driven:** Use of BIM, digital twins, SCADA/EMS, monitoring platforms, cybersecurity protocols, as well as AI-based predictive analytics.
- **Robotics and automation:** Operation and supervision of robotic construction tools, drones, and automated O&M solutions

EPC personnel should be trained to design and document projects with long-term O&M in mind. This includes ensuring accessibility of equipment for maintenance, compatibility with robotic and automated inspection systems, provision of comprehensive as-built documentation, and integration of monitoring devices that enable predictive maintenance.

Robotics and Automation in EPC

Robotics and automation are rapidly changing how solar PV and hybrid projects are designed, built, and maintained. EPC service providers should ensure that their personnel are trained not only in traditional construction and installation methods but also in the application, supervision, and integration of robotic solutions in line with evolving safety standards.

Robotic applications during the EPC phase can include:

- **Construction and installation:** Robot-assisted pile driving, module installation, automated cable laying, precision welding, and automated earthworks.
- **Operations and Maintenance readiness:** Preparing sites for the future use of robotic cleaning systems, inspection drones, and autonomous monitoring tools by ensuring suitable layouts, access, and docking/charging infrastructure.



BotCrew's Gravion can perform multiple tasks during solar construction.

To maximise the benefits of robotics, EPC personnel should be trained in:

- **Operation and oversight:** Understanding the technical limits and safety requirements of robots and automated equipment, as well as applying appropriate risk assessment methodologies to human-robot collaboration.
- **Data management:** Processing and integrating inspection or performance data from robotic systems into digital platforms (BIM, SCADA, CMMS), in compliance with specific standards.
- **Safety and compliance:** Ensuring that robotic operations meet site-specific HSSE standards and do not introduce new risks.
- **Upskilling and workforce adaptation:** Retraining traditional construction teams to supervise, calibrate, and maintain robotic systems, ensuring that innovation enhances rather than displaces the workforce. EU-funded reskilling programmes or national reskilling programmes should be leverages to build these competencies.

Robotics should be seen as a tool to improve safety, quality, and efficiency, while expanding the technical capabilities of EPC personnel. Integrating these technologies during the EPC phase lays the groundwork for advanced O&M practices, reduces lifecycle costs, and increases plant reliability.



TerraWise's inspection robot autonomously performs quality checks during the construction process.

Transitioning from Project Development to EPC

This chapter addresses the critical transition from project development to the Engineering, Procurement and Construction phase, where early-stage decisions are translated into contractual scope, technical execution, and ultimately project delivery. While many key requirements such as layout definition, preliminary system design, permitting constraints, and grid connection conditions are established before an EPC service provider is appointed, they have a direct and lasting impact on cost, schedule, and performance during construction. This is particularly true for hybrid PV + BESS projects, where battery integration studies, energy management strategy, and early safety planning must be sufficiently developed and documented to avoid design gaps, interface issues, and delays later in the EPC phase. Accordingly, this chapter focuses on three areas that are especially relevant at this handover point: assessing project readiness and quality prior to the Notice to Proceed, selecting a suitable EPC service provider, and ensuring the structured transfer of development documentation to maintain continuity from development into execution.

During this phase, the developer conducts initial engineering activities, including layout definition and preliminary system design

Project requirements are generally set up during the development phase, which precedes the EPC phase. They are mainly regulated under project development agreements executed between the Special Purpose Vehicle (SPV), as the Owner of the project (or the Asset Owner when the SPV has not been established yet), and the local developer responsible for early-stage development activities.

During this phase, the developer conducts initial engineering activities, including layout definition and preliminary system design. In addition to technical activities, the developer is responsible for filing all applications for the necessary authorisations and construction permits with the competent public administrations. For these reasons, the role of the EPC service provider is marginal during early development. This is confirmed by the fact that the layout and other prescriptions to be met are generally outside the EPC service provider's scope of work.

For hybrid PV + BESS projects, the early development phase also includes preliminary battery integration studies, high-level energy management strategy considerations, and initial safety and fire mitigation planning. These additional elements should be documented and included in the information transferred to the EPC service provider to prevent design gaps and delays during the EPC phase.

Therefore, in the present Guidelines, only three points are discussed because they are particularly relevant for the transition from the development to the EPC phase:

- Before the beginning of the construction phase, the different stakeholders especially investors and lenders must assess the quality of the developed project in order to reach a final decision to build the project, sign the relevant contracts, and issue the Notice to Proceed (NTP).
- The financial stakeholders then select an EPC service provider.
- Finally, the project must be handed over to the EPC service provider without losing important information.

5.1 Selection of EPC projects

To select EPC projects and assess their quality, investors and lenders scrutinise a set of criteria, which are often condensed into checklists and internal guidelines (also referred to as "ex-ante KPIs"). The content of these assessment tools strongly depends on stakeholder characteristics such as strategy, experience, and geographic focus. For example, one investor may exclude projects in a certain region, while another may specialise in that region.

The scope and depth of the assessment also depend on project size, as the complexity of the evaluation generally increases with total project cost. In the selection of EPC projects, risk analysis and mitigation play an important role, particularly for hybrid PV + BESS projects, where system integration and operational complexity are higher. For further information, see Chapter 2 *Risk Management*.

5.1.1 Profitability

An important consideration for all stakeholders is the assessment of project profitability. Since the business plan must be realistic and robust, it is essential to ensure that all relevant cost and revenue parameters have been properly considered. At least one yield study, carried out in accordance with industry standards, should underpin expected PV energy production. Technical and legal due diligence studies must confirm that this production can be converted into revenue.

For hybrid PV + BESS projects, the business plan may require adjusted cash-flow models to reflect battery operation, including energy arbitrage, peak-shaving, and ancillary service revenues, where applicable. The quantitative assessment of profitability follows these qualitative verifications. A key KPI for project profitability is the Internal Rate of Return (IRR). According to the IRR methodology, a project can be pursued if the internal rate of return exceeds the minimum required rate of return.

5.1.2 Technical Quality

One of the overarching engineering KPIs for PV projects is the expected Performance Ratio (PR) and associated energy yield, which are key input parameters for the business plan. Multiple parameters determine the expected PR, including component quality, system design, and site conditions. A more detailed list is typically included in technical due diligence or yield studies.

In addition to PV-specific parameters, other aspects are equally important, such as pre-qualification criteria (e.g. manufacturer reputation, component ratings, and compliance with applicable standards) and overall design quality.

For hybrid PV + BESS projects, the technical quality assessment shall also cover:

- Battery technology selection and system design
- Integration between PV and BESS, including EMS/BMS functionality
- Battery lifecycle expectations, including cycle life and calendar life
- Definition of minimum technical benchmarks and standardised verification methods for battery lifecycle predictions
- Mandatory KPIs, such as energy retention rate, capacity fade, and round-trip efficiency, supported by verifiable data
- Safety provisions, including fire detection, mitigation, and emergency response concepts

Clear qualification thresholds for battery manufacturers (e.g. minimum years of commercial operation and reference projects) are recommended as part of the technical quality assessment.

The technical quality of a project depends strongly on procurement decisions. For more information, see Chapter 8 on *Procurement*.

5.2 Selection of EPC Service Provider

The following criteria (also called “ex-ante KPIs”), among others, help to assess EPC service providers: financial stability, expertise, prices, and procurement performance.

5.2.1 Financial Stability

One important factor is the financial stability of the EPC service provider. It is important to get as close as possible to the present-day financial situation of the company. Credit ratings (seen in relation to the country/market the EPC service provider operates in) as well as audited statements from the last 2-3 years are typically the most solid and indisputable financial information. Since accounting definitions can vary from country to country, comparisons might be difficult.

An alternative to this is a bank guarantee where the investor moves the evaluation over to a bank partner. This does not necessarily give a better evaluation of the financial viability than one's own evaluation, but it gives the financial insurance of a bank. This obviously comes with a cost. The mere demand for a bank guarantee can be prohibitive for some projects and can eliminate smaller, competent EPC service providers from participating, even though they are financially solid for their size.

Assessment of the following four areas provides insight into the financial situation of a company: liquidity, solvency, operating efficiency, and profitability.

An important KPI for **liquidity** is the quick ratio (also referred to as acid test). It is defined as the ratio between quickly available or liquid assets and current liabilities. Solvency is a company's ability to meet its debt obligations on an ongoing basis, not just over the short term. The debt-to-equity ratio (D/E) indicates the relative proportion of shareholders' equity and debt used to finance a company's assets. The lower the D/E ratio, the more of a company's operations are being financed by shareholders who do not charge interest, but more importantly, may enable the company to raise debt capital in case needed. On the flipside, a decreasing D/E indicates increasing financial solidity of the company.



A good indicator of a company's **operating efficiency** is reflected by its Return on Sales (ROS, also called EBIT margin):

Return on Sales (ROS) is defined as:

$$ROS = \frac{EBIT}{Revenue} \times 100 \%$$

Where:

- EBIT = Earnings Before Interest and Tax and its Return on Capital Employed (ROCE)

Return on Capital employed (ROCE) is defined as:

$$ROCE = \frac{EBIT}{CE} \times 100 \%$$

Where:

- CE = Capital Employed = Total assets – Current liabilities

However, it is to be noted that EBIT may contain tangible book value and depreciation risks. Therefore, EBIT may be a misleading metric where there have been inappropriate depreciation or book value assumptions. Financial return KPIs based on cash flow (like EBIT) positions may reflect a more reliable evaluation base, though the percentage must naturally be higher.

A good KPI for evaluating a company's **profitability** is its Net Profit Margin (NPM):

Net Profit Margin (NPM) is defined as:

$$NPM = \frac{Net\ profit}{Revenue} \times 100$$

A low NPM means a higher risk of the company running into difficulties quickly if operating cost or competition increases. A larger net margin indicates its higher potential to invest capital into growth (but should be seen in relation to fixed costs).

Apart from the financial stability of the EPC service provider, other means may secure the investor: bank guarantees (e.g., performance bonds), insurance cover solutions, or cash retentions. Bankamp guarantees, in this ex le a performance bond, ensure that the EPC service provider is able to pay for liabilities and warranties that might arise from the EPC contract. To receive this type of bank guarantee, the EPC service provider has to pay a percentage to the bank. The downside is that, besides the cost of the performance bond incurred by the EPC service provider, the impact on their available free liquidity. Small EPC service providers, in particular, often face challenges in accessing bank guarantees. In this case cash retentions may secure the investor, i.e., the last payment only occurs after the Final Acceptance Certificate (FAC) is issued.

5.2.2 References and Expertise

Experience of the EPC service provider in the construction of PV power plants in a particular country, region, grid environment, for a specific installation type (ground-mounted, rooftop), size and technology can play an important role in the selection procedure. The EPC service provider may provide their references in a track record, to document their experience, including relevant PV and, where applicable, BESS experience to demonstrate their capability in managing hybrid systems. EPC staff must hold the necessary training and certifications to execute the project successfully. In cases where subcontractors are engaged, their experience in their specific area of work should also be documented and verified. For hybrid projects, this includes expertise in battery installation, EMS integration, and safety management.

Another sign of expertise is the quality approach of the EPC service provider. Apart from potential verifications at the manufacturer's production site, non-mandatory quality checks during the construction phase are recommended (for more information, see Chapter 8 on *Procurement*). The extent of checks needs to be adapted to the size of the project.

As part of the expertise, it should be made sure that the EPC service provider has a proper quality management procedure in place. For hybrid projects, this system should include procedures covering PV and battery integration, fire and emergency mitigation, cybersecurity, and ongoing operational monitoring to ensure performance throughout the project lifecycle.

5.2.3 Price and Performance of Procurement

Those EPC service providers that are preferred partners of their suppliers get better conditions. This may be a better price, but also better delivery time, secured delivery in case of shortage or favourable warranty conditions and claim solving.

5.3 Handover from Project Developer to EPC Service Provider

At the contracting stage, when selecting or appointing an EPC service provider, the developer should hand over all the important documentation about the project and preliminary works (see *Annex F, Section Basic Design – Development Documentation*). This will be the basis for the scope of work negotiation with the EPC service provider and the share of responsibilities between the Asset Owner and the EPC service provider. The main topics to be discussed by both parties include the site description with its particularities, the permitting process and the associated constraints from legal authorities and the technical specifications from the grid connection side.

5.3.1 Site description (including site surveys and site data)

To ensure the best understanding and the most accurate design of the PV plant, a detailed description of the site and all associated constraints should be delivered to the EPC service provider. To pass on responsibilities to the contractor all preliminary studies, and surveys should be shared to allow identification of requirements, constraints, and the need for extended investigations. Information should include topography, soil conditions, shading analysis, drainage, access roads, and existing infrastructure. The main information to be shared is listed in *Annex F, Section Basic Design – Development Documentation*. If applicable, some documents from the Pre-Construction Documentation should also be considered. For hybrid projects, optional additional information may include preliminary battery locations or EMS interface points, but the primary focus should remain on PV site characteristics to maintain clarity and minimise necessary complexity during handover.

5.3.2 Permitting Process

The developer is typically responsible for obtaining all necessary permits and authorisations, including construction and environmental approvals. EPC contracts should explicitly state that the provider must comply with all permits and maintain their validity throughout construction.

Authorities may impose requirements related to:

- Environmental mitigation (e.g., tree planting, restoring vegetation, exclusion zones for grading works, measures to protect flora and fauna)
- Aesthetic and landscape integration (e.g., cabinet design, structure height, hedges or visual screening)
- Fire and emergency measures
- The EPC provider should understand these obligations to ensure compliance and avoid delays or penalties during construction

5.3.3 Grid Connection Process

During development, the most suitable point of interconnection and the strategy for connecting to the local network are identified, typically in consultation with the network or grid operator. The EPC provider must receive all relevant information to ensure timely grid connection and smooth communication with the operator.

The handover should include:

- Grid connection technical specifications from the network operator
- Network operating conditions applicable during the operation phase
- Any technical requirements arising from a Power Purchase Agreement (PPA), noting that commercial information may remain confidential
- For hybrid projects, any additional requirements related to energy storage, reactive power management, or EMS functionality should be referenced, but the primary focus should remain on the PV plant's grid compliance

Technical Due Diligence

Technical Due Diligence (TDD) is a structured and independent assessment of the technical, operational, and lifecycle risks associated with a solar PV or hybrid PV + battery energy storage (BESS) project. It is typically conducted on behalf of lenders, investors, insurers, or asset owners to support financing, refinancing, acquisition, or portfolio transactions.

Technical due diligence process evaluates whether a given project meets the technical, performance, safety, and risk expectations required for long-term asset viability and financial confidence

While these EPC Best Practice Guidelines focus on how to engineer, procure, construct, and commission high-quality and bankable projects, the technical due diligence process evaluates whether a given project meets the technical, performance, safety, and risk expectations required for long-term asset viability and financial confidence. To support alignment across the value chain, SolarPower Europe has developed the *Technical Due Diligence Best Practice Guidelines* (TDD BPG), which define a harmonised framework for assessing technical risks across the full project lifecycle.

Although technical due diligence is typically performed by independent technical advisors, its findings are largely shaped by decisions taken during EPC delivery. Design choices, equipment selection, construction practices, quality assurance processes, documentation quality, and commissioning outcomes directly influence the risk profile assessed during TDD.



For EPC contractors, understanding the scope and focus of technical due diligence is therefore essential to:

- Anticipate how EPC execution will be evaluated by third parties
- Reduce the likelihood of adverse TDD findings, conditions precedent, or post-COD remedial actions
- Support smoother financing, refinancing, and asset transfer processes
- Strengthen stakeholder confidence in the technical robustness and bankability of the project

Alignment between EPC Best Practice Guidelines and the TDD BPG helps ensure that projects are not only delivered efficiently, but also withstand independent scrutiny throughout their operational life.

The Technical Due Diligence Best Practice Guidelines identify and assess a wide range of risks that are directly influenced by EPC scope, execution, and interfaces. Key EPC-relevant areas include, but are not limited to:

- **Design and engineering robustness.** TDD evaluates whether the plant design is technically sound, compliant with applicable standards and grid codes, and appropriate for site-specific conditions such as climate, geotechnical characteristics, and environmental constraints. Design margins, redundancy, protection concepts, and hybrid system integration (PV-BESS-grid) are assessed from a long-term performance and safety perspective.
- **Failure modes and defect typologies.** The TDD BPG includes structured failure mode and defect typologies across design, procurement, construction, and commissioning phases. These analyses reflect industry experience with recurring technical issues, and are frequently used as reference frameworks by lenders and insurers. EPC contractors should be aware that construction quality, installation practices, and interface management are often reviewed against these failure modes during due diligence.
- **Equipment selection and bankability.** Technical Due Diligence assesses whether selected components (modules, inverters, trackers, transformers, BESS, PCS, EMS) are proven, certified, and suitable for the intended application and duty cycles. Warranty terms, performance guarantees, degradation assumptions, and supplier track records are reviewed in the context of long-term risk exposure. EPC procurement decisions therefore have a direct impact on TDD outcomes.
- **Construction quality and execution controls.** The TDD process evaluates the effectiveness of construction management, quality assurance and quality control (QA/QC) systems, inspection regimes, and defect resolution processes. Evidence of systematic controls, non-conformance management, and corrective actions is critical to demonstrating that construction risks have been adequately managed.
- **Commissioning and performance verification.** Commissioning procedures, test protocols, and acceptance criteria are a key focus of technical due diligence. The TDD BPG clarifies expectations for "bankable commissioning," including functional testing, grid compliance verification, performance baseline establishment, and documentation completeness. Gaps in commissioning evidence frequently result in due diligence findings, even where physical construction is complete.

- **Interfaces, scope gaps, and responsibility allocation.** TDD places particular emphasis on interfaces between EPC contractors, equipment suppliers, integrators, and O&M providers. In hybrid PV + BESS projects, unclear responsibility allocation for system integration, control logic, protection schemes, and long-term performance obligations is a common source of technical and contractual risk identified during due diligence.

Stakeholders involved in EPC delivery are strongly encouraged to consult the SolarPower Europe Technical Due Diligence Best Practice Guidelines (Version 1) for a detailed description of:

- TDD scope and methodology
- Risk categorisation and severity assessment
- Failure mode and defect analyses
- Due diligence deliverables and reporting structure

Using both guideline documents together supports a shared understanding of quality, risk, and bankability expectations across EPC contractors, asset owners, financiers, and insurers, thereby strengthening project outcomes across the full lifecycle.

**SOLAR
POWER
SUMMIT**

SOLAR+

Solar & Storage Securing
Europe

5-6 May 2026

Théâtre National Wallonie-Bruxelles, Brussels



REGISTER NOW TO BENEFIT FROM
OUR SUPER EARLY BIRD PROMOTION

Engineering

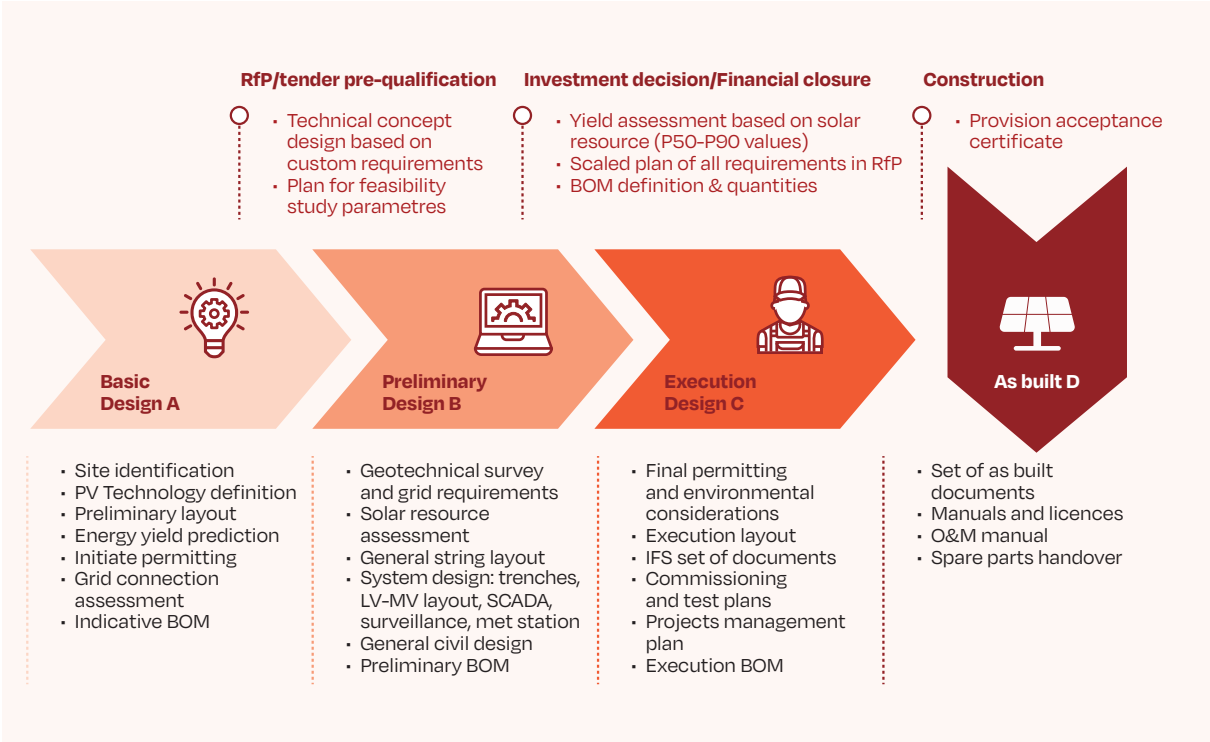
This chapter describes the engineering design and modelling process as a core element of the EPC lifecycle, guiding a project from early technical concept through investment decision, detailed execution design, construction, and final handover. As engineering is inherently iterative, it requires structured input from key stakeholders including developers, investors, grid operators, EPC contractors, and O&M providers to achieve an optimised design that balances performance, reliability, and cost. For hybrid PV + BESS projects, this process must also integrate ESS sizing, coupling architecture, control logic, safety systems, and lifecycle performance considerations from the outset, as storage requirements directly influence electrical design, component selection, and operational constraints. The chapter therefore presents a structured overview of the common engineering stages, milestones, and deliverables, highlighting the importance of early alignment with applicable standards, permitting rules, and stakeholder requirements to ensure quality and continuity throughout the project lifecycle.

For hybrid PV + BESS projects, the engineering process must additionally integrate energy storage system (ESS) sizing, coupling architecture, control logic, safety systems, and lifecycle performance considerations

The engineering design and modelling of a PV plant is a crucial element of the EPC lifecycle, as it guides the whole process of EPC, from conceptualisation to investment decisions and to the actual construction and handover of the solar power plant. It is also a highly iterative process in which inputs from all the main stakeholders (developers, investors, grid operators, EPCs, and O&M providers) are considered, to achieve an optimised design that balances performance, reliability, and cost.

For hybrid PV + BESS projects, the engineering process must additionally integrate energy storage system (ESS) sizing, coupling architecture, control logic, safety systems, and lifecycle performance considerations. Unlike stand-alone PV plants, hybrid systems require a use-case-driven design approach, where grid services, energy shifting, or self-balancing objectives directly influence electrical architecture, component selection, and operational constraints. As such, storage engineering considerations must be embedded throughout all design stages, from basic design through to as-built documentation.

Figure 4
 Overview of Engineering Design Stages, Milestones and Deliverables



As a best practice, all locally applicable standards and permitting rules, and environmental requirements shall be clearly described and considered at the very start of the design process. Later, different stakeholders may have different engineering and design requirements to perform their respective services. Good communication and timely adjustments of the engineering design along the way are strongly recommended to ensure quality throughout the entire process.

In the following chapter, the engineering stage of the project has been divided into four sub-phases, which are considered the common flow for PV and hybrid project development. However, some of these phases (and milestones) may differ from the reader's project due to different companies' business approaches or philosophies, types of project finance, number of stakeholders and project size.

Starting off as a basic technical concept, the engineering design is itself a process that evolves, and is constantly refined as the project development advances. It evolves into a detailed execution design blueprint issued for construction. Once construction and commissioning are completed, a detailed set of 'as built' documents is handed over to the O&M service provider.

7.1 Basic Design

The basic design phase is the foundation of the engineering process. It serves to confirm the technical feasibility of the project, and create the first coherent project documentation set that stakeholders can rely on for permitting, financing, and negotiations with suppliers and contractors. Although the level of detail is less than in subsequent design stages, a robust basic design prevents costly revisions later and helps ensure that all key constraints and opportunities are identified early.

At this stage, the information available about the project site and its conditions is often limited. However, it is essential to gather as much preliminary data as possible to build a reliable picture of the project. Inputs typically include satellite imagery, geotechnical data, GIS data, meteorological databases, public grid maps, and, where possible, preliminary site visits or drone reconnaissance. The outputs should reflect the technical, economic, and environmental feasibility of the project, and should already be adapted to the project's financing and permitting strategy.

7.1.1 Hybrid System Definition and Duty Cycle

Stationary energy storage systems (ESS) integrated with solar PV plants are engineered to fulfil a defined operational role within the electricity system. From an engineering perspective, the first and most critical step is to clearly define the application, operational boundaries, and duty cycle of the storage system, as these parameters directly determine system sizing, architecture, control strategy, and lifecycle performance.

Stationary energy storage systems are commonly categorised based on their point of grid interconnection:

- **Front-of-the-Meter (FTM)** systems are connected on the grid side of the consumer meter and are primarily used to support grid operation, provide market-based services, or enhance the dispatchability of generation assets.
- **Behind-the-Meter (BTM)** systems are connected on the consumer side of the meter, and are typically used to optimise onsite energy consumption, reduce grid import peaks, or manage self-consumption of renewable generation.

In the context of utility-scale solar-plus-storage installations, BTM configurations are generally limited to energy shifting or self-balancing applications, whereas FTM systems enable a broader range of grid and market services.

Common storage applications for solar-plus-storage projects include:

Table 1

Overview of front-of-the-meter (FTM) and behind-the-meter(BTM) applications and definitions

Category	Application/ use case	Definition
FTM	Ancillary services	Provision or absorption of power to balance supply and demand, and thus maintain the frequency of the grid at a reference value or reduce grid constraints: Frequency regulation <ul style="list-style-type: none"> • Replacement for reserve spinning, non-spinning, and supplemental thermal generators • Voltage support • Reactive power compensation • Black start (recovery from a total or partial shutdown of grid)
FTM/BTM	Energy shifting (arbitrage)	EES is charged when market selling prices are low or energy would be clipped for other reasons (high DC/AC ratio at the inverter, maximum power limit for injection into grid, etc.). It is discharged to meet demand, sell at higher prices and/or smooth the production curve. Renewable energy assets coupled with storage essentially become dispatchable generation assets.
FTM/BTM	Self-balancing portfolio optimisation (Virtual power plant)	Balance responsible parties (BRPs) and distribution system operators could use energy storage to reduce imbalance within portfolios to avoid imbalance charges. The BRP does not actively bid on the imbalance market using its load flexibility but uses it within its own portfolio. The combination of several assets at different grid connection points is known as virtual power plant (VPP).
BTM	C&I / Residential energy storage	Energy storage that is used to increase the rate of self-consumption of a PV system from C&I or residential customers or to reduce power consumption at the grid connection point to reduce grid connection costs.

Source:

At the outset of the engineering process, the intended duty cycle of the ESS must be defined. This includes:

- Expected charge and discharge profile
- Number of cycles per day and per year
- Typical depth of discharge
- Annual energy throughput
- Expected operational lifetime and degradation trajectory

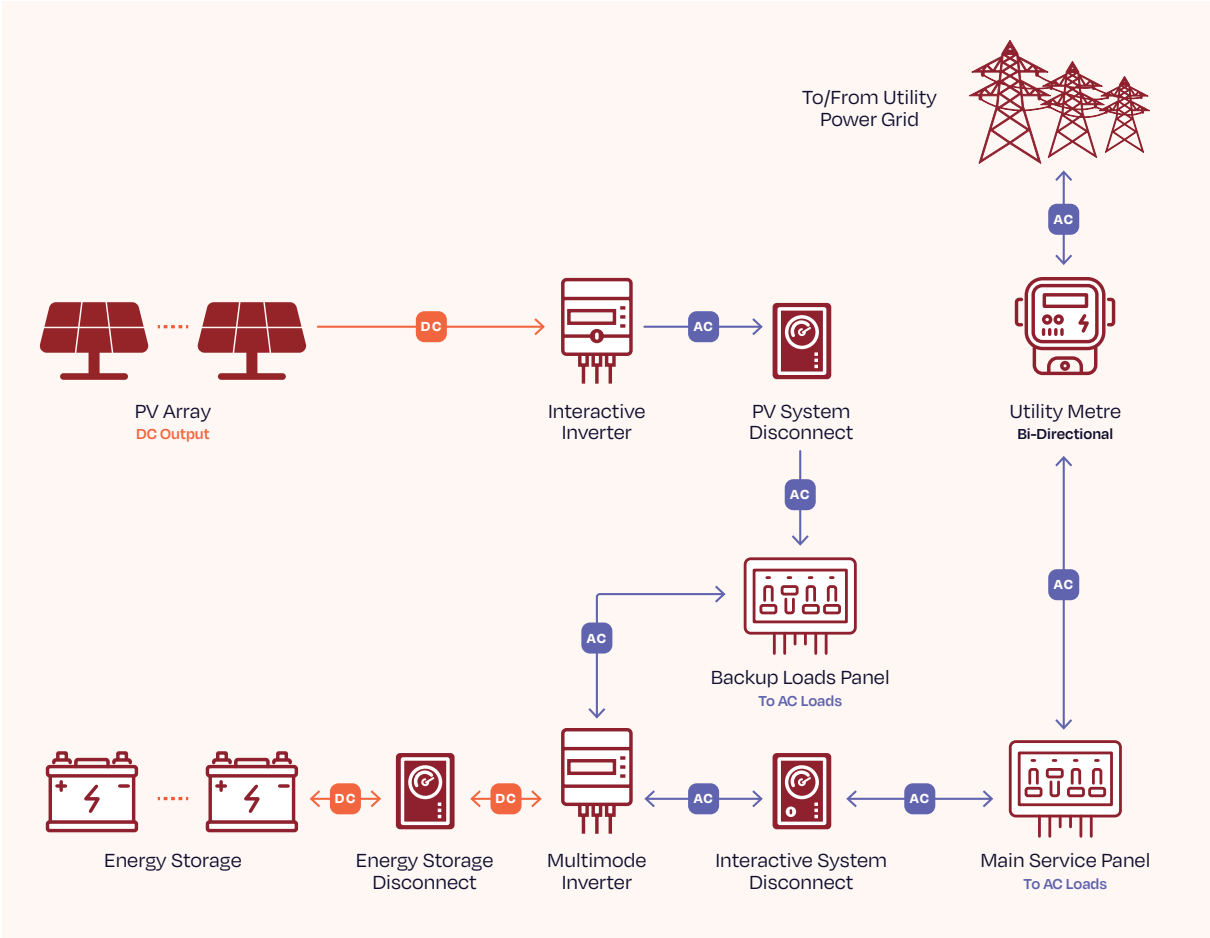
Duty cycle assumptions form the basis for initial power and energy sizing, battery technology selection, degradation modelling, and augmentation strategy. This phase is typically iterative, with commercially available solutions assessed through software-assisted simulations that combine storage performance models with solar PV energy yield assessments. The outcome directly influences capital expenditure, replacement planning, and long-term financial performance.

A key engineering decision in solar-plus-storage projects is the selection of the ESS coupling architecture.

AC-coupled systems: the PV plant and the storage system are connected to the grid via separate inverters. This configuration allows independent dispatch of solar PV and storage assets, and provides high operational flexibility, particularly for ancillary service provision and retrofitting storage to existing solar PV plants.

Figure 5

AC-coupled ESS

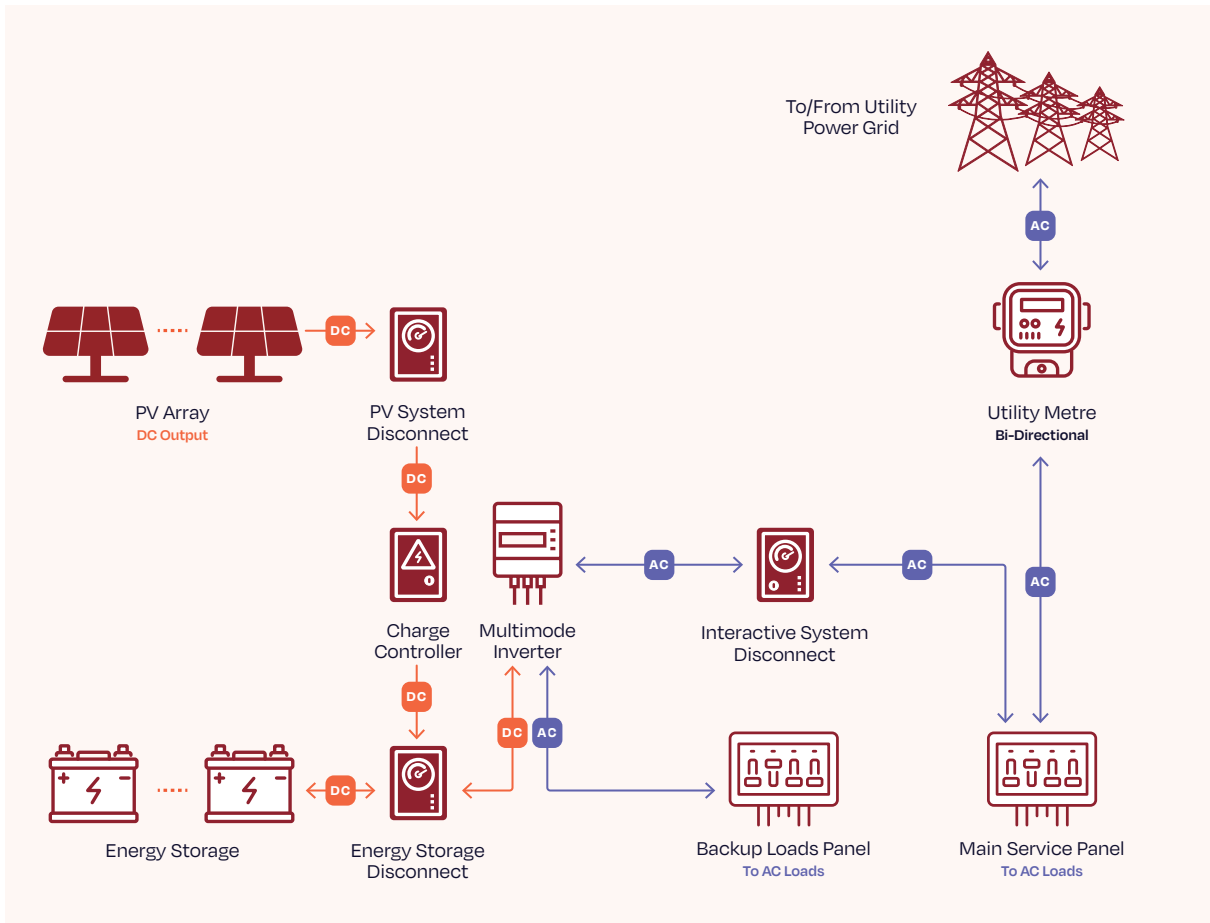


DC-coupled systems: the solar PV array and the storage system share a common DC bus, and are connected through a single inverter. DC-coupled architectures may be configured as:

- Loosely coupled, using bidirectional inverters that allow charging from both the solar PV plant and the grid.
- Tightly coupled, using unidirectional inverters where the battery can only be charged from the solar PV array.

Figure 6

DC-coupled ESS



Each architecture presents trade-offs in terms of efficiency, flexibility, redundancy, and balance-of-plant requirements.

Table 2

Overview of front-of-the-meter (FTM) and behind-the-meter(BTM) applications and definitions

AC-coupled ESS	DC-coupled ESS
<p>Advantages:</p> <ul style="list-style-type: none"> • Higher operational flexibility • AC-coupled systems have the same efficiency when charging the battery from PV or the grid, and discharging is independent of the PV inverter • Faster reaction speed for ancillary service provision of battery system possible • To date, utility-scale systems have relied primarily on AC-coupled structures so more references are available • Easier to install when retrofitting existing PV plants 	<p>Advantages:</p> <ul style="list-style-type: none"> • Higher round trip efficiency when charging from solar • Eliminates the need for one set of inverters, MV switchgear, and other balance of plant costs • Better suited to take advantage of oversizing PV (higher DC/AC ratio) and store otherwise clipped energy
<p>Disadvantages:</p> <ul style="list-style-type: none"> • Lower round-trip efficiency (more conversions are needed) • PV inverter DC-AC, battery inverter AC-DC when charging, DC-AC when discharging) • Cannot take advantage of clipped energy, so it does not make sense to oversize the PV part much 	<p>Disadvantages:</p> <ul style="list-style-type: none"> • Lower operational flexibility • The combined output of the PV and battery is limited by the size of the inverter, and if the inverter has a failure, both the energy storage and the PV generation is lost • More complex design & installation process (with DC coupling, the PV and batteries are paired on each inverter)

Source:

The optimal coupling approach depends on the project's use case, grid code requirements, regulatory framework, retrofit versus greenfield context, and procurement strategy.

7.1.2 Key elements of a basic design

1. Preliminary layout and electrical concept

The basic design should contain an indicative layout of the plant, showing PV module rows, inverter and transformer positions, battery container locations, EMS/control cabinets, access roads, and, where applicable, other site infrastructure. A first single line diagram (SLD) should be developed to illustrate the main electrical connections, including the point of interconnection to the grid. The design should already respect the land boundaries, known easements, and zoning restrictions, leaving buffer zones where necessary.

2. Energy yield estimation

A first simulation of energy yield should be carried out, using long-term solar resource data (e.g., Solargis, PVGIS, or ERA5 datasets), ensuring the dataset is the most recent version available for accurate irradiation and temperature profiles. The simulation should consider:

- Global Horizontal Irradiation (GHI) and Plane of Array (POA) irradiation
- Basic shading assessment from surrounding terrain and structures
- Initial assumptions on system losses (soiling, mismatch, cabling, availability)
- For bifacial modules: ground albedo assumptions
- For hybrid projects: battery dispatch profiles and round-trip efficiency scenarios
- This early modelling provides stakeholders with an order-of-magnitude estimate of annual production and capacity factor, sufficient for prefeasibility financial models.
- Hybrid plant assumption logic and curtailment assumptions
- Battery degradation assumptions and usable capacity evolution
- PV clipping recovery for DC-coupled systems
- Auxiliary consumption of BESS (HVAC, control systems)

3. Grid connection pre-study

The basic design should include an identification of feasible interconnection points, based on discussions with the local grid operator and publicly available data. It should highlight the voltage level, estimated capacity, distance from the site, and likely technical constraints. In hybrid projects, the grid study should also assess the potential role of storage in meeting interconnection requirements, such as peak shaving, grid stability, or flexibility services.

For hybrid projects, the grid connection assessment should also consider dynamic behaviour, including ramp rates, fault ride-through, reactive power capability, and compliance with applicable grid codes for inverter-based resources. Where required by the grid operator, early-stage dynamic or RMS modelling may be necessary to assess the impact of combined solar PV and storage operation.

4. Preliminary Bill of Materials (BOM)

An indicative BOM should be provided, listing the main system components:

- PV modules (technology type, power class, indicative manufacturer)
- Inverters (PV and/or BESS inverters, DC/AC ratio assumptions)
- Mounting system / tracker for PV, racks or containers for batteries
- Transformers, switchgear, and electrical protection for PV + BESS
- Battery system (chemistry, size, architecture) and EMS/control equipment for storage and hybrid operation

While supplier names are optional at this stage, it is best practice to check that the shortlisted technologies are bankable, compliant with local standards, and supported by credible warranty conditions.

5. Site and permitting considerations

The basic design must reflect early knowledge of site constraints and permitting requirements. This includes:

- Topography and hydrology (slopes, floodplains, drainage requirements)
- Environmental restrictions (protected areas, biodiversity corridors, land use)
- Land ownership boundaries and right-of-way considerations
- Local building and safety codes, including fire protection and emergency response for both PV and battery systems
- Preliminary stakeholder mapping (local communities, municipalities, landowners)
- Noise emission limits, HVAC requirements, and thermal zoning considerations for battery containers

When integrating site specific considerations into the design of the project, EPC service providers should notably look to consider the mitigation of risks that the project may be subject to due to its location. These notably include climate risks which differ from site to site in their specific nature and capacity to mitigate them. Projects should consider how design choices help to reduce the impact of such risk, for instance in hail prone areas considering tracker mounting systems has been proven to significantly improve project resilience to hail in regions with high prevalence of this risk.



© catocala/AdobeStock

6. Maintainability and operational design requirements

Even at the concept stage, maintainability should be designed into the project:

- Access spacing between module rows for vegetation management and cleaning
- Safe working distances from fences and obstacles
- Drainage systems to prevent erosion and flooding
- Walkways for rooftop projects
- Cable management that minimises risks of water ingress, animal damage, and excessive OPEX
- Monitoring SCADA and EMS for PV and storage, designed for error detection, remote troubleshooting, and hybrid operation
- Battery container spacing and access for firefighting
- Provision for battery augmentation and replacement
- Segregation of HV, LV, and communication systems
- Design of HVAC redundancy and thermal zoning
- Cybersecurity considerations for EMS and remote control

Digitalisation and documentation

Best practice in 2026 is to develop the basic design within a digital workflow, creating a preliminary digital twin of the asset. Tools such as PV information modelling (PViM), drone photogrammetry, and GIS databases can generate a more accurate site representation and facilitate stakeholder engagement. Documentation produced in this phase should be sufficient to initiate permitting, trigger early technical due diligence, and serve as a basis for tendering in competitive procurement or auctions.

7.1.3 Outputs of the Basic Design

By the end of the basic design stage, the following deliverables should be available:

- Indicative plant layout with installed capacity (Wp and MWac)
- Preliminary single line diagram
- Preliminary energy yield report with key assumptions
- Initial grid connection assessment (technical feasibility, indicative costs)
- Indicative bill of materials for main components
- Site constraint map with environmental, permitting, and land-use overlays
- Maintainability and safety design considerations
- Documentation package suitable for permitting initiation and financial pre-feasibility analysis

7.2 Preliminary Design

A detailed basic design usually provides sufficient basis for taking an investment decision or arranging finance. However, depending on the stakeholders involved, clearing that milestone may require more precise site topography measurements as well as regulatory and financial closure aspects to be accounted for in a preliminary design concept. A key element of preliminary designs is a topographical survey. A ground-based site survey should be enhanced through a full topographical survey using a drone, which can produce site orthomosaics, Digital Elevation Models (DEM), and Point Cloud maps. Using a drone to collect the terrain and shading scene (both near and horizon) is vital in ensuring an optimal array design for a given area of land. If an EPC service provider is contemplating using bi-facial modules, then an albedo estimate can also be made from the drone photogrammetry.

Computer Aided Design (CAD) based software will ingest these 3D models to produce the topographical layouts of the PV plants where all elements are in their true geographical locations, to an extremely high level of accuracy and precision.

In any situation, the present section, and the *Annex F, Preliminary Design* are an indicative guideline for the phase's steps and documentation.

At the preliminary design stage for hybrid projects, the ESS architecture (AC- or DC-coupled), container layout, inverter configuration, and EMS functional description shall be defined with sufficient detail to support permitting, safety assessments, and preliminary grid compliance studies. Noise emission studies and preliminary fire risk assessments should be carried out where required by local regulations or insurers.



The preliminary design shall be part of the Pre-Construction Documentation, where the layout shall propose:

- PV Array sections
- Inverter Stations
- Mounting systems or trackers
- Substation
- Communication systems
- Monitoring systems¹
- Cable routes (DC, MV, HV)
- Access roads and crane pads
- Laydown areas
- Meteorological stations
- Site tracks
- Manholes and drainage systems
- Construction area
- Permanent and temporary buildings
- Fencing and perimeter security

The preliminary design shall include a preliminary bill of materials (preliminary BOM in Figure 4) for budgeting purposes. The bill of materials gives quite a precise indication of quantities, so that (binding or non-binding) term sheets can be collected from suppliers and contractors.

The topographical survey and layouts of PV plants can be used as a 3D model to generate a preliminary digital twin of a PV plant, intended as a tool to visualise the asset. The information related to the choice and selection of components are part of the PV Information Modelling can also be visualised within the digital twin.

In projects where a turnkey EPC contract is signed, the design is only approved by the Asset Owner or the developer, and the EPC service provider is responsible for providing all the contracts and suppliers.

If an EPC service provider has already been involved in the design phase, the set of documentation shall include the projects' buildings, amenities, preliminary studies, quality and testing plans, as well as the method statement, in addition to the layout and equipment specification.

At this stage, the Owner/Developer shall also agree with the EPC service provider on the Project Management Plan, including the project reporting, EHS, quality, changing plans and document register.

A detailed overview of the documentation of this stage can be found at [Annex F, Preliminary Design](#).

7.3 Execution Design

As the preliminary design is changed and/or approved by the Owner, the EPC service provider shall move to the execution design stage, incorporating all the relevant construction blueprints and working instructions. Once the design is finalised, it shall provide all the information necessary to request a grid connection, as well as all the necessary parameters for a grid impact analysis (if required).

A fully detailed specification of equipment and bill of materials (including the spare parts) shall be produced. As part of the execution design, the construction plans would have the final reports of calculations and assessments for all electrical and civil structures.

Factory acceptance plans shall be defined for major equipment. In addition, commissioning and testing procedures shall be provided to the Owner/developer for verification and approval.

For hybrid plants, the execution design shall include detailed EMS and control architecture documentation, including operational modes, interlocks, fail-safe behaviour, communication protocols, and cybersecurity measures. Fire detection, suppression, and emergency response interfaces shall be fully engineered in accordance with applicable standards (e.g. IEC 62933, UL 9540A, NFPA 855). Battery degradation models, augmentation plans, and performance guarantees shall be aligned with the final design and contractual framework.

It is recommended that a list of companies, major machinery, number of personal involved in the construction phase and quality assurance measures planned be included in project management plans. A method statement shall be clearly defined for each project phase.

A detailed overview of the documentation of the execution stage shall be found at [Annex F, Execution Design](#).

For large assets drone-based construction monitoring is recommended during construction. This data provides an excellent risk management tool and helps ensure the integrity of construction vs design plans by capturing any deviations or design changes as they occur.



7.4 As-built Design

After the PV plant is accepted by the Asset Owner or the developer via the Provisional Acceptance Certificate (PAC) (see also section [10.4.3 Provisional Acceptance Certificate](#)), the project enters the handover stage. This is the phase of the project where the EPC service provider shall deliver all the design documentation that details how the PV plant has been built (as-built design documentation). This is important to emphasise, because during the construction phase some of the execution design may change due to unexpected events, mistakes on the design, terrain, or underground difficulties.

A dimensionally and geospatially accurate 'as-built' model of the asset can be generated from the drone-captured construction monitoring data, which can be used to update the digital twin. If construction monitoring has not been undertaken, then a single photogrammetry flight can produce an as-built record of the visible array layout. It is also possible to generate a 3D model of the new asset for onward yield modelling and verification by using more enhanced photogrammetry approaches. Such data capture and modelling can be valuable as part of the handover documentation from the EPC service provider to the Asset Owner and the O&M service provider.

For hybrid systems, the as-built documentation shall include final EMS configuration files, control logic descriptions, protection settings, battery serialisation, and a baseline performance and degradation reference state. This information is critical for long-term O&M, warranty management, and performance verification.

A detailed overview of the as-built documentation can be found in [Annex F, As-built Design](#) (consider also IEC standard 62446).

In addition to the as-built design, the EPC service provider should also organise other handover documentation, such as the O&M manuals, for the Asset Owner and the O&M service provider. For more information, see [Chapter 11 Handover to O&M](#).



Procurement

The Procurement phase covers purchasing components such as PV modules and inverters, mounting structures, battery energy storage systems (BESS) and associated equipment (BMS, EMS, PCS/inverters for storage, HVAC, fire detection/suppression), as well as identifying and mitigating risks. It involves supplier selection and onboarding, and conducting inspections and tests to qualify materials to be used in construction throughout the procurement process. This chapter will help stakeholders to identify risks in the procurement process of components (such as PV modules, inverters, and BESS) and to mitigate them through suitable inspection, testing and qualification mechanisms for individual projects. The procedures shall be underlined with definitions of acceptance level and criteria.

Responsible procurement requires consideration of supplier performance across technical, financial, legal, and ESG dimensions, including human rights compliance, environmental management, and traceability of key materials

8.1 General Procurement Guidelines

This section addresses general guidelines applicable to the procurement of any component of a system and provides guidance on how to integrate quality and responsible sourcing practices aspects into the procurement process. In addition to technical and performance requirements, procurement should integrate environmental, social, and governance (ESG) due diligence, in line with the OECD Due Diligence Guidance and the Solar Stewardship Initiative (SSI) ESG and Supply Chain Traceability Standards. It is recommended to apply the general requirements, where relevant, to subcontracted activities such as engineering, construction, or quality management activities. Responsible procurement requires consideration of supplier performance across technical, financial, legal, and ESG dimensions, including human rights compliance, environmental management, and traceability of key materials. This section follows the different steps of procurement, from supplier onboarding to inspection and tests until completion of the procurement process. The guidelines are independent from the procurement process itself and remain applicable whether the EPC service provider decides to work through recurring orders, single purpose contracts or project-based procurement. By integrating ESG requirements alongside technical ones, EPCs ensure resilience, regulatory compliance, and long-term trust with clients and stakeholders.

8.1.1 Site-specific Resilience for Hybrid Systems

Procurement decisions for hybrid PV + BESS projects must explicitly reflect local environmental, regulatory, and operational risks, as system requirements are inherently site-specific. Components and materials including PV modules, inverters, mounting structures, batteries, BMS/EMS, and safety systems should be specified and selected to withstand relevant stressors such as high or low temperatures, humidity, wind or snow loads, corrosivity, flooding, seismic activity, and fire hazards.

As part of supplier selection and technical due diligence, EPC contractors should require documented evidence of compliance with applicable standards and certifications, as well as proven performance under relevant operating conditions (e.g. IEC/EN standards for PV, IEC 62933, UL 9540/9540A, NFPA 855 for energy storage systems, and compliance with the EU Battery Regulation 2023/1542, where applicable).

In addition to technical conformity, procurement requirements should ensure that warranties, performance guarantees, and after-sales support are aligned with the hybrid system's intended duty cycle, dispatch strategy, and environmental conditions. Failure to align technical specifications with site-specific risks at the procurement stage may result in reduced system availability, accelerated degradation, and increased lifecycle costs, with limited contractual recourse during operation.

8.1.2 Use of Third Parties

Engaging credible third parties in the procurement process can significantly improve both the technical quality of products and the integrity of ESG performance claims. Involving third parties in the procurement process can lead to the delivery of better products as they can bring quality expertise and objectivity to the judgement of products and suppliers. The contractual agreement on the Quality Monitoring measures, be it by third-party or other means, often leads to more quality awareness on the supplier's side and to more stringent application of quality standards. A contractual agreement should address the scope of the responsibility assigned to the third party and their authority to make decisions on quality. In general, involving third parties in the procurement process is best practice but not an outright necessity.

Third party technical assessments vary significantly in terms of thoroughness, accurateness, completeness, reliability, validity, and transparency. A good guide to identifying a credible third-party service provider may be the proof of an accreditation according to ISO 17020, ISO 17025 or acceptance by IECRE, for technical quality. Beyond technical accreditations, buyers should also consider whether suppliers have been independently verified under credible ESG and human rights schemes. Examples include the Responsible Business Alliance (RBA) Validated Assessment Program, SA8000 certification, or sector-specific International Responsible Business Conduct Agreements. While these do not replace the SSI ESG and Traceability Standards, they can provide complementary assurance of labour, environmental, and governance practices, particularly in upstream tiers of the supply chain. Independent, third-party ESG verification is essential because it reduces the risk of self-declaration, strengthens comparability across suppliers, and provides buyers with credible evidence for regulatory compliance and investor due diligence. Integrating such verification into procurement helps ensure that commitments to responsible sourcing are not only policy statements but are demonstrated in practice through external audits and transparent reporting.



8.2 Integration of Quality Management into the Procurement Process

Regardless of the procurement process they have defined, the EPC service provider is ultimately responsible for providing the required quality level for the activities and components provided by its suppliers. The EPC service provider must ensure that the quality of the components and services procured from external sources fulfil their internal quality standards, and that risks related to procurement activities are identified and mitigated.

Therefore, the EPC service provider shall define and deploy the appropriate procedures for:

- The selection, evaluation and monitoring of its suppliers
- The monitoring it intends to apply on the products and services procured from external sources, such as quality requirements and evaluation criteria, products release procedures, auditing processes

The EPC service provider may elect a wide array of service providers for delivering the quality verification of components and services. Overall, companies may check compliance of product, production processes, transport and other factors which impact the reliability and lifetime performances of PV equipment. Ongoing efforts from the solar PV sector aim to address a trust gap in the quality of equipment, which represent up to 80% of a project final CAPEX, and their impact on project production, availability and profitability. To compensate for the gaps between existing quality validation procedures and observed degradation or reliability of equipment, standardisation bodies including IECRE, IEC are bringing forward adapted testing procedures and quality evaluation frameworks.

8.3 Management of Suppliers

8.3.1 Selection of Suppliers

Prior to signing a contract with a supplier, the EPC service provider should determine the ability of the supplier to consistently deliver products and services that can meet the requirements in sufficient quantities. Alongside this, suppliers' performance on technical, financial, legal, environmental, social, and governance (ESG) standards should be assessed. This assessment should also include the supplier's ability to demonstrate traceability of high-risk inputs such as metallurgical-grade silicon, polysilicon, ingots, wafers and other high-risk raw materials such as copper, cobalt and nickel. EPCs are encouraged to require suppliers to align with the SSI Supply Chain Traceability Standard, which defines a segregated chain of custody model and progressively moves toward full traceability across the solar value chain.

This requires cooperation from suppliers along all these lines. There is a severe risk of reputational damage linked to a lack of supply chain transparency. For example, failure to identify links to forced labour or environmental harm in upstream tiers may expose EPCs and their clients to legal and financial risks. For more information on building sustainable and transparent supply chains, please refer to SolarPower Europe's Sustainability Best Practices Benchmark. Buyers are also encouraged to consult the [Solar Stewardship Initiative \(SSI\) Buyer's Guide](#), [ESG Standard](#), and [Supply Chain Traceability Standard](#) for sector-specific due diligence guidance.

When selecting a supplier, TIER-ratings give an overview of the track record of the manufacturer, but only provide limited information on the quality of a product. Therefore, selecting products just on their TIER rating is insufficient. Consequently, the selection must be based on product testing accompanied by factory audits and a documentation review. This review should include disclosure of whether supplier sites are undergoing independent ESG and traceability assessments, for example through SSI-approved Assessment Bodies.

A technical rating of products can be based on accessible product data and quality assurance information provided by the manufacturer. It can be used as preselection criteria as a part of an overall quality review process for PV power plants. The rating or scoring system of suppliers should start before the sourcing phase. A rating may be based on a questionnaire, which should include the product-related data as well as quality assurance information, including:

- Technical Specifications
- Bill of Materials
- Certificates
- Warranties
- Any beyond standard quality assurance/quality control measures (e. g. extended reliability test programmes)
- Manuals, labels, and data sheets
- Quality management in the production
- ESG and human rights policies (e.g. forced labour prevention, grievance mechanisms, remediation commitments)
- Evidence of compliance with international frameworks (e.g. OECD Due Diligence Guidance, UN Guiding Principles on Business and Human Rights, ILO conventions)

BESS specific notes

In supplier questionnaires and evaluations, include: battery chemistry and configuration, EMS/BMS capabilities, grid code compliance evidence (unit certification, not prototype), safety case and fire mitigation design (UL 9540A test reports, NFPA 855 conformity), cybersecurity posture (if SCADA/EMS connectivity applies), and local regulatory compliance (e.g., EU Battery Regulation).

8.3.2 Qualification of Suppliers

While all products are usually qualified and manufactured under a valid quality management system, variations in production lines, bills of material, and general fluctuations in quality are still common in the solar industry. Quality measures should be monitored during manufacturing and shipping to get a full assessment of the quality of the procured goods. In addition, monitoring should explicitly include ESG performance. Contracts should stipulate that major non-conformances with ESG standards (such as the use of forced labour, child labour, or severe environmental breaches) are valid grounds for corrective action, suspension, or rejection of deliveries, not only technical failures.

It is recommended that one carries out quality review measures for production supervision that are in line with international conformity assessment standards. Alternatively, onsite assessments, and product testing should be done before signing a contract with a supplier. In addition, supplier qualification should require evidence of ESG due diligence, including site-level risk assessments, public reporting, and independent verification by credible third-party schemes (such as SSI, RBA, or SA8000).

Where suppliers source from high-risk regions, EPCs should request proof of mitigation measures or disengagement strategies in line with SSI Principles and global best practice. Suppliers should be required to show evidence of functioning traceability systems, such as documentation of upstream material flows. This ensures that key inputs are sourced responsibly and can be traced back to certified production sites. Such documentation helps EPC to prepare for compliance with regulations such as the EU Forced Labour Ban (from 2027).

Documentation review

A general document review, submitted by the supplier, should contain:

- Product certificates and associated reports (all relevant market access documents)
- Factory certificates (management system, laboratory accreditations)
- Warranty condition
- Review of recalls / claim handling

Factory inspection

Before production starts, a pre-production factory inspection is recommended. The aim is to identify issues in the manufacturing and quality assurance processes that can have a negative impact on the quality of the components. The inspection should consist of verification and evaluation of the following processes and procedures:

- Incoming inspections and preparation of materials – warehouse
- Production process assessment
- Electrical safety tests
- Outgoing performance / output power verification
- Evaluation of equipment and procedures for quality control tests (such as solar simulators, visual inspection tools, electroluminescence (EL), insulation test)
- Quality assurance/control (storage and handling of materials, production areas, staff training, claim handling)
- Handling of test and calibration equipment
- Documentation of process data
- Process for handling faulty products
- Conditioning of the finished product
- Review and comment on the warranty claim list
- Product traceability

Product qualification testing

While type approval and safety certification are the minimum requirements to market any product, series production might show fluctuations in production quality based on production lines or material variations.

It is therefore recommended to fix a particular bill of materials and factories / production lines in the purchasing agreements and pre-test products accordingly. The product qualification testing shall be based on standards and be product / component specific. Depending on the size of the project, extensive factory inspections may be performed, as well as a conformity testing, to ensure that the components arriving on site have been manufactured using the correct bill of materials, and the manufacturing process has delivered the specified quality requirements. Further details are listed in *section 8.6 Specific requirements per key component*.

8.4 Supply Review

When large quantities are procured with a specific deadline, it is important to assess the supplier's ability to meet it by checking material supply as well as actual production capacity.

8.4.1 Pre-production Review

Prior to production, it is advisable to assess the factory's readiness to supply the products ordered within the agreed lead-time and at the right quality level.

Focus shall be put on:

- The availability of agreed components (bill of materials)
- The status of maintenance and calibration of the production and testing equipment
- The communication of specific quality requirements of the project and availability of related documentation
- The qualification of the production manager to apply the specific quality requirements



8.4.2 During Production Inspections

During production inspections are performed after production of the components for the PV project (e.g., modules) has started.

The inspection shall focus on the following topics:

- Verification of production on the agreed manufacturing lines
- Use of material in accordance with the agreed bill of materials
- Quality Monitoring during the manufacturing process
- Verification (spot-check basis) through in-line tests
- Verification of performance determination test on a spot-check basis
- Verification that contractually agreed specifications are met

Sampling plans and the acceptance criteria for required verification tests and inspections shall be agreed upon in advance. Any production inspection process is a compromise between cost and thoroughness. Ideally, manufacturers should be monitored closely enough to ensure that no significant unobserved material deviation from the agreed features goes unnoticed.

8.5 Delivery

8.5.1 Post-production Monitoring

Contractually agreed upon monitoring for post-production (before dispatch, after receipt, during construction) is an important tool for assessing the consistency of quality and thus the degree of fulfilment of the contract. Sound statistical sampling at this early stage of the project helps avoid long-term failures. For example, if the components have already been installed and show early faults, the cost of handling complaints and, if necessary, subsequent replacement is more expensive. Comprehensive testing would add significant costs to the project thus a standard like ISO 2859 should be applied. The case to be considered in testing should be agreed with the component suppliers in the contracts. The level of a batch conformity should also be agreed with the component supplier in the contracts as this may influence the financial risk assessment and thus affect the overall cost of funding. Typically testing will be in the production line, but should be witnessed and verified through sample third party testing. Typically General Inspection Level I (visual and electric properties) and Special Inspection Level 2 (insulation and dimension checks) with AQL Major 1.5 and Minor 2.5 is used for sample size definition.

8.5.2 Pre-shipment Inspection

Pre-shipment inspections are carried out on a sample basis and used to release finished goods for shipment if they meet the agreed requirements. The inspections include:

- Visual inspection
- Power verification
- Electric insulation
- Label verification
- Verification of packaging and fit for shipping

8.5.3 Pre-shipment testing, Factory Acceptance Testing

Critical tests that determine the conformity to agreed ratings as well as quick quality monitoring tests are performed on random samples taken from packages ready for shipment. It is important to agree on pass/fail criteria and clear criteria for shipment rejection. Testing / inspection can be done at the factory site (Factory Acceptance Testing, FAT) or at a warehouse, depending on access and availability of testing equipment.

A FAT shall include the following aspects:

- Assessment of quality standards of production line / manufacturing site
- Verifying the quality system in place in the production line, considering procedures, compliance of all staff and processes, traceability, and problem mitigation
- Mechanical specifications of the product
- Electrical specification of the product
- Documentation, including manuals, SLDs and warranty
- Service and support quality
- Data management and display

8.5.4 Post-shipment Inspection

Post shipment inspections are performed to check whether the received goods hold all necessary documentation and import papers / certifications (e. g. Certificate of Conformity). Furthermore, the post-shipment inspection shall document any transportation damages to enable claims based on such damages. Again, a prior agreement on acceptance criteria is of major importance.



8.6 Specific Requirements Per Key Component

Generally, spelling out solid requirements for key components is one of the most mission critical items. The importance of this topic can hardly be underestimated when it comes to the long term technical and financial success of a PV project. Going into great detail is outside the scope of this document and therefore, the following subchapters only give an outline. One of the biggest challenges comes from time pressure during the construction phase combined with manufacturing or delivery problems that may occur during the project execution. An additional challenge is related to reviewing quality, as the variety of testing and inspection services offered in the market is quite wide when it comes to reliability, accuracy, validity, viability etc.

There is no principal reason behind underperforming PV assets. System faults occur the most frequently, but individual components can also have defects. It is absolutely crucial for EPC service providers to ensure the quality and reliability of all the components that they use.

8.6.1 Modules

Modules are the core of the final system and represent a significant share of project CAPEX, making corrective maintenance measures essential. During the planning phase, it is critical to verify that modules are, at least theoretically, capable of operating in the intended environment for the expected lifetime and with the assumed durability. A common misconception is that passing IEC 61215 / IEC 61730 type and safety approval tests guarantees this capability. While these standards have significantly reduced early failures in the field, they remain design qualification standards only. They assess known failure mechanisms under moderate climate assumptions and do not address all risks. Failure modes often overlooked include backsheet defects, Potential-Induced Degradation (PID), Light and elevated Temperature Induced Degradation (LeTID), Ultraviolet-Induced Degradation (UVID), and micro-cracks. These issues can lead to reduced energy yield, hot spots, and accelerated degradation. The standards provide no insight into long-term durability or the quality of the specific modules installed only the general suitability of the product family.

Recent reliability assessments highlight several critical risks:

- Degradation and Power Loss (LID, LeTID, PID, UVID): Often caused by manufacturing defects or environmental exposure, leading to financial losses. Current controls such as SCADA monitoring are insufficient; extended stress testing per IEC 63209 and manufacturer-provided mitigation data are recommended.
- Micro-cracks and Cell Cracks: Resulting from mechanical stress during transport, installation, or operation, these can cause hot spots and higher degradation. Preventive measures include stricter handling procedures, post-installation imaging (IEC 62446-2); and optimised clamping design.
- Delamination: Typically linked to poor encapsulation or UV degradation, increasing moisture ingress and safety risks. Controls should include verification of encapsulant specifications (e.g., POE), gel content and peel strength testing, and improved lamination process QC.

Incorporating these considerations into procurement and quality assurance processes such as enforcing IEC 63209 extended testing, requiring proof of LID/LeTID mitigation, and implementing stricter PSI protocols (EL and flash testing per VDE AR 90038-2) is essential to reduce long-term reliability risks. Beyond addressing these specific risks through procurement and QA measures, it is equally important to verify whether modules will operate under conditions represented by the tests they have undergone or account for increased quality risk if field conditions fall outside the test standard's scope."

Ideally one should verify whether the modules will operate at conditions represented by the tests they have undergone or account for an increased quality risk if conditions in the field are expected to be out of the test standard's scope, this is especially relevant in light of evolving weather impact and climate risks as described in section 2.6 of this document. An example of modules potentially operating outside tested specification could be building integrated mounting or systems in arid climate zones, as such systems may run much hotter than they have been tested for. IEC TS 63126 Guidelines for qualifying PV modules, components, and materials for operation at high temperatures gives guidance on testing modules and components for high temperatures. As some standards also allow variants of test conditions based on manufacturer's definition, reviewing the testing protocol alongside the certificate is recommended.

The evolution of the risk related to impact such as hail or wind should also lead EPC service provider to consider the relevance of equipment complying with standards that go beyond minimal requirements for hail resistance in the climate zone of the project, also taking into account probable future risks. For instance developers in regions of Southern Europe with an already documented risk for large hail impact on PV installations could consider the IEC TS 63397:2022 Qualifying guidelines for increased hail resistance of PV modules at the procurement stage.

Integrating testing requirements for PV modules in the procurement conditions allows for claims against underperformance as well as identifying design deficiencies. PV modules from one system supplied by various production sites or batches may require separate assessment.



© jeson/AdobeStock

There are three groups of quality tests described:

1. Performance characterisation testing
2. Qualification testing
3. Module Reliability Tests (Stress Tests, Accelerated Aging Tests)

Performance characterisation testing mainly addresses the electric performance of the PV modules and the condition of the cell interconnection circuit (cell cracks or interrupts). Regarding the power warranty, the performance of the entire delivery can be deduced from a random sample according to ISO 2859-1. As budget and timing is usually critical, mostly General Inspection Level based on the total number of modules per production batch is applied. As an alternative, a combination of a smaller sample size (e.g., 50 per batch) and the manufacturer's flash list will allow a robust product verification if the measurements have been carried out with a sufficiently low uncertainty and the service provider has an appropriate quality system. It is advisable to combine power measurement with electroluminescence imaging for crack detection. The performance at low irradiance is something needed for the energy yield calculation, but samples size can be small (e.g., S 1). In the absence of third party verified PAN files it is advisable to base PAN files on independent measurements as simulations based solely on data sheet information may lead to high uncertainties in energy yield simulation.

Product qualification tests are typically destructive or longer-term tests and sample sizes are kept smaller. It is important to perform tests on modules that represent the material combinations (bill of materials) of the module type. The tests shall check the functioning manufacturing processes, the production control and are helpful in determining general workmanship. Some suitable qualification tests are defined in the standard IEC 61215-2, which is the basis for type approval and design qualification of PV modules. The sampling method is typically Special Inspection Level S 1 to S 3 acc. to ISO 2859-1 with consideration of all bills of materials and potentially different production lines to be represented. Induced degradation tests (such as PID and LeTID) are screening tests and are suggested if sufficient proof of resistance to such degradation is not provided. Here sampling rate could be reduced to two modules per bill of materials to minimise testing cost.

Product reliability tests shall evaluate the long-term behaviour with a focus on module performance but also on electrical safety. Several test sequences for investigating a module's resistance to environmental conditions, such as measuring degradation induced by exposure to high levels of UV, strong temperature changes, high temperatures combined with high relative humidity and mechanical stress both from wind forces and snow loads are described in IEC TS 63209 Photovoltaic modules - Extended-stress testing - Part 1: Modules. Depending on the application and the project region the stress level may vary. The suggested sample size is two modules per test and bill of materials. In particular polymeric material degradation has caused major reliability concerns in the recent years. Here the technical specification, issued in 2021, provides a combination of damp heat testing, UV testing and thermal stress in its sequence three that is designed to screen for long-term backsheet failures.

On the specific topic of UVID, which emerges as a major risk for long term reliability of plants if not well measured and mitigated, it may be relevant for developers to look at testing and validation of product reliability that exceed the requirements of IEC 61215. Various testing lab may readily provide such services.

Table 3

Types of quality tests for PV modules

Performance characterisation testing	Sampling rate acc. to ISO 2859-1
Maximum power determination at Standard Test Conditions (STC)	G I
Efficiency loss at low irradiance	S 1
Electroluminescence inspection	G I
Qualification testing	
Visual Inspection	S 3
Insulation test under wetting (wet leakage test)	S 3
Degree of ethylene-vinyl acetate (EVA) cross linking	S 1
Adhesion strength EVA/backsheet	S 1
Power loss due to light induced degradation (LID)*	S 1
Power loss due to power induced degradation (PID)**	2 modules per BOM and test
Power loss due to light and elevated temperature induced degradation (LeTID)	2 modules per BOM and test
Reliability testing	
Design suitability (extended stress testing i.e. damp heat, thermal cycling, humidity freeze, UV exposure, mechanical load), relevant for all BOM used	2 modules per BOM and test
<p>Example:</p> <p>Sampling for a 50 MW PV Plant with 400 Wp modules and two different BOMs. Total number of modules: 125,000.</p> <p>Performance characterisation testing:</p> <ul style="list-style-type: none"> G I level would lead to a sample size of 200 modules <p>Qualification testing:</p> <ul style="list-style-type: none"> S 1 level would lead to a sample size of 8 modules; considering 1/2 of the modules are of each of the 2 BOMs, sampling rate S 1 for 62,500 modules comes to the same sampling rate. Hence 8 modules would be chosen per BOM S 3 level would lead to a sample size of 32 modules; considering 1/2 of the modules are of each of the 2 BOMs, sampling rate S 3 for 62,500 modules comes to the same sampling rate. Hence 32 modules would be chosen per BOM <p>Induced degradation and reliability testing:</p> <ul style="list-style-type: none"> 2 modules per BOM per test would mean 4 modules per chosen test sequence are to be selected <p>Testing can mostly be organised pre-shipment at a test centre close to production. Sampling should always be random or organised by an independent third party. Post-shipment testing can make sense, if pre-shipment was not possible, timelines did not allow it, or transportation damages are to be assessed.</p>	

*Can be less considered for n-type technology.

**Can be less considered for systems that have anti-PID solutions.

8.6.2 Inverters

The inverter is one of the most complex components in a PV power plant and includes multi-functional power electronics for optimising the power output. This element is the interface with the grid and reads and communicates operational data to the monitoring system. A fault with the inverter leads to an immediate decrease in power output, which grows in proportion to the size of the inverter. Owners should not simply rely on data sheets but invest in quality review services, conducted by experienced technical advisors. In a quality assurance process, the key steps of design, manufacturing, installation, and commissioning are independently evaluated, to prevent potential issues that could decrease performance across the inverter's lifecycle. In 2026, these reviews should explicitly include verification of mandated grid support functions (e.g., volt var, freq watt, ride through) and certification pathways aligned with EU Network Code RfG as these functions are now essential for grid connection and bankability.

The key risk mitigation steps are a factory audit, the review of a manufacturer's factory-out inspection and the commissioning, which are presented in sections 8.4. SUPPLY REVIEW. and 8.5. DELIVERY. In addition, reliability qualification per IEC 62093 (accelerated environmental and functional testing of inverters) is recommended at the audit stage to surface design or process weaknesses before deployment.

Aside from the general comments above, key areas for potential issues with inverters include:

- Adaptation to voltage and power design
- Isolation issues
- Blocked air vents, filters etc.
- Derating characteristic of inverters, high temperature shut off
- Rating or spacing not suitable for location (e. g. high altitude)
- Grid code compliance
- Unavailable required national certification
- Inverter metrology
- Interference with radio signals etc. (electromagnetic compliance and adaptability)
- Optimisers
- Local transportation including unloading opportunities
- Local service

Inverters need to be chosen depending on system topology. There is no formal assessment available currently, but a risk assessment when choosing a system topology considering performance, maintainability, impact of failures, likelihood of failure and reparability. As an example, a central inverter may have a higher efficiency, be cheaper to install, but in case of a failure takes down the system and will take weeks to repair, while spare string inverters could be stocked, and any failure could be corrected in a short time. The evaluation of risks will depend on design objectives, but it should be documented for later verification and any future process improvements.

When planning a system, it is critical to match the operating characteristics of the inverter (efficiency, load-related derating, voltage window) to the real operating conditions.

Sufficient diligence needs to be exercised when it comes to:

- Specific requirements for inverters, e.g., compliance with (EU) 2016/631 for Europe (NC RfG)
- Performance characterisation testing (INV File generation for energy yield simulations)
- Product qualification testing, including factory audits and type/functional tests; applying IEC 62093 accelerated stress protocols (power cycling, thermal/humidity extremes with active monitoring) for design verification.
- Product reliability testing according to appropriate standards

8.6.3 Mounting Structure (fixed tilt)

Racking systems hold valuable modules in place and ensure stability of the installation of the PV system. Mounting components consist of various metal parts with different coatings or materials, such as aluminium, alloy, stainless steel, or galvanised steel. Corrosion can occur due to the constant and long-term exposure of these materials to each other, to soil conditions and to environmental stresses, such as rain and moisture and other atmospheric pollutants like chlorides in marine environments or sulphur dioxide and nitrous oxides in industrial locations. As corrosion intensifies over time, serious structural failures in racking and mounting components can result in instability in the PV system and cause it to malfunction.

Above ground atmospheric corrosivity can be assessed relatively easy and is not different from other industrial applications. The determination of the corrosivity of the soil is more challenging given the high number of soil parameters defining its corrosivity (DIN50929-3: Corrosion likelihood of metallic materials when subject to corrosion from the outside – buried and underwater pipelines and structural components), and PV farm specific aspects to be considered:

- Presence of large (copper) earthing grid (possibly including galvanic corrosion of the mounting structure)
- Physicochemical variations of soil over PV site, inducing local high corrosion rates of interconnected mounting structures
- Presence of leakage/stray currents from PV/BESS installations or other electrical infrastructure nearby (e.g. cathodic protection infrastructure, HV installations,...)

It lays at hand that quality of mounting systems plays a tremendous role in each step from manufacturing to installation, maintenance, and recycling.

As lifespans of solar PV systems can reach up to 30 years, racking manufacturers must target a similar life span for the racking materials. The following norms and guidelines are of great significance and should be adhered to during the project development and during the construction stage:

- The manufacturing process of mounting systems should be in accordance with Eurocodes 1991 1-1 - 1-6 Actions on Structures. Note that the second-generation Eurocodes are being implemented in 2026, introducing enhanced robustness and harmonisation requirements for structural design. The norm includes guidance on the actions to be performed on structures designed for use in buildings and other civil engineering works.

- In addition, to prevent corrosion of the mounting structure, manufacturers should comply with the standards EN ISO 1461:2022 (“Specifications and test methods on hot dip galvanised coatings on fabricated iron and steel articles”) and EN 10346 (“Continuously hot-dip coated steel flat products for cold forming – Technical delivery conditions”). Supplementary guidance from EN ISO 14713 1/ 2 should be considered for corrosion protection design. These standards underline the importance of corrosion-free purlins, aluminium mounting brackets and bolts and focus on the chemical composition and mechanical characteristics of the components for racking systems in general. Information on coating thickness (e.g, zinc-coated steel, anodised aluminium, or zinc-magnesium coatings for harsh environments) can be determined by measurements in testing labs or on site.
- A third standard, the “Execution of steel structures and aluminium structures - Part 1: Requirements for conformity assessment of structural components” (DIN EN 1090-1), assures the quality of steel components, aluminium components, and kits in the manufacturing process.
- For highly corrosive soils (according to DIN 50929-3 Type III), galvanised steel coatings might be insufficient to reach a 30 years lifetime; in this exceptional case, supplementary corrosion prevention methods could be considered; for instance: paints systems, cathodic protection, concrete encasing or footing, or use of low corrosive backfill. Note that these methods will have a large impact on the project costs and should only be considered if deemed essential to reach the project lifetime.
- The material quality should be verified on documentation basis (alloy, etc.). Spot checks of the anti-corrosion coating thickness can be performed in factory or onsite. Further the dimensions and tolerances of the delivered parts shall be verified against the available documentation.

8.6.4 Mounting Structure (trackers)

Tracker systems offer a significant additional complexity to a PV power plant system as it entails moving parts being added to an otherwise static system. When considering tracking, be it single axis or dual axis tracking, in addition to the previous section, the following points should be considered:

Tracker system selection

- Structural calculation according to applicable standards in the country of the project and international codes like ASCE or Eurocodes. This calculation should consider the specific conditions known or foreseen for the soil conditions. It is highly recommended to check whether the tracker system has undergone wind tunnel testing, and in addition, CFD (computer fluid dynamics) modelling to simulate wind situations. This is particularly important for resonant frequency conditions that can occur at wind angles of attack that can hardly be simulated in a wind tunnel. Note that catastrophic failure at resonant frequencies does not necessarily require high wind speeds.
- Certification of the PV tracker against relevant standards like IEC 62817, UL 3703 or UL 2703. Specific confirmation that the components used in the trackers to be supplied are listed in those certificates.
- Accelerated lifetime tests beyond those associated with the certifications mentioned above. Due to the dynamic load conditions, the mounting structure materials could ‘age’ more rapidly, in particular in corrosive environments.
- Justification in the form of studies, wind tunnel measurements or tracker measurements showing that all the aero-elastic stabilities are properly added to the structural calculation mentioned above. Particularly, the following instabilities should be considered as a minimum: flutter/ galloping, torsional divergence, buffeting, vortex-induced vibrations, and aero-elastic deflection. Justification of the values used for the damping ration and natural frequency should be provided.

Tracker system reception and installation. Once on site, the delivered equipment should be verified by collecting a sample of each element of the structure which is then measured and verified against the specifications. Certificates for the steel and galvanisation are provided directly from the manufacturer's sub-suppliers with site measurements of dimensions and thickness.

It is recommended that the installation process should be overseen by a representative of the manufacturer and the following recommendations should be a general checklist for this stage, being part of the project commissioning stage.

1. Torque verification according to manufacturer specifications
2. Tolerances in installation are within the levels accepted by the manufacturer
3. Piles driving are tested (pull-out) showing minimum recommendation by the manufacturer
4. Tracker Control Units (TCUs) and Network Control Units (NCUs) are installed and connected with configuration approved by the manufacturer and Owner's engineer
5. Meteorological stations are commissioned according to manufacturer recommendations and testing to see whether the stowing strategy is working.

Special care should be taken if material is galvanised (or painted). To maintain the corrosion protection, the coating must not be damaged by scratching or any machining.



8.6.5 Cabling (including connectors and cable management systems)

Proper cabling and connections must be ensured. The list of partially serious problems is virtually endless but here are a few examples:

- Cabling specification
 - Cable cross-sections are undersized
 - Cross sections of safety fuses are undersized
 - Cables sheathing is made of inferior material not capable of weathering (e.g., low UV light resistance, low permeability)
 - Cable wire material is inferior (e.g., not compliant with strand construction class 5 or 6 as per IEC 62930:2017 or not compliant with stranding class B or higher as per UL: ZKLA or PV-wire requirements)
- String / combiner boxes
- Non-matching or “compliant” or “compatible” connectors
 - Connections have a too small contact surface or are not suitable for the specific current (and voltage) application
 - Materials used between different manufacturers can be slightly different causing contact corrosion
 - Metal contact size not fitting with the cable conductor cross section
 - Seal gasket not fitting with the PV cable outer diameter
- Fuses (e. g. power rating/wire diameter, housing, temperature derating)
- Earthing, potential bonding
- Cable ties insufficiently resistant to UV radiation
- Metallic cable ties can have sharp edge and damage the cable sheath (in accordance with IEC 60364-7-712)
- Excessive spacing between cable attachment points

Various standards refer to proper cabling and connection practices, such as IEC 62930:2017 resp. EN 50618 (Electric cables for PV systems), IEC 62790 (junction boxes for PV modules), IEC 62275 (Cable ties for electrical installation), IEC 60364-7-712 (LV electrical installations – Requirement for solar PV), IEC 62852 for DC connectors and IEC 62738 (Design guidelines). There are also other international and national standards and codes related to cabling and connectors. In addition to the pertinent standards, the IECRE offers a conformity assessment system referring to most relevant standards, like IECRE OD-401 and OD-403.

Qualification requirements may depend on the application. For example, when cables are planned to be laid underground, they must be qualified and tested for this application. Having systems close to the coast or on floating systems, will bring additional requirements like resistance to salt laden atmospheres.

When defining system components, it is also important to check compatibility of components and their interfaces. For example, a connector on a module might mate to a connector on a string cable, but its connection with the “mating” connector of another make may not be approved. Warranties may exclude such cross connection, so caution should be taken.

8.6.6 Transformers

The power transformer testing (Factory Acceptance Test) should be performed once the assembly is completed at the manufacturing facility. The power transformer procurement process should include a design review and quality control of the manufacturing process. Factory Acceptance Tests are done at the factory to make sure that applicable standards are met, to assure high quality products, considering IEC 60076-1, 2, 3, 10, 18.

The following table summarises the tests to be performed for the transformers to be provided.

Table 4

Tests to be performed for transformers

	Test description	Testing requirement
Routine tests	Measurement of ratio and check of vector group	To be conducted on all transformers supplied
	Measurement of DC winding resistance	
	Measurement of No loss and current	
	Measurement of load loss and impedance	
	Measurement of Insulation resistance of windings to earth and between windings	
	Separate source voltage withstand test on HV and LV windings	
	Pressure test on assembled transformer	
	Paint thickness test	
	Visual Inspection and dimensional checks	
	Functional test on auxiliary circuits	
Type tests	Measurement of Acoustic Noise level of the transformer	To be conducted on one transformer of each design
	Impulse voltage withstand tests-Chopped and plain wave impulse tests	
	Temperature rise test	
Special tests	Induced Voltage test with PD measurement (IVPD) prior to impulse tests	
	Induced Voltage test with PD measurement (IVPD) after the impulse tests- long duration 1 hour	
	Induced Voltage with PD measurement for 60 minutes	
	Induced Voltage with PD measurement for 5 minutes	
	Measurement of Sweep Frequency Response Analysis	
	Dissolved Gas Analysis of Transformer Oil prior to and post dielectric tests and all tests	
	Chemical Analysis of Transformer Oil	

8.6.7 Battery Energy Storage Systems (BESS) and Associated Equipment

In hybrid PV + BESS projects, electrochemical storage systems particularly lithium-ion and, increasingly, redox-flow batteries are currently the most relevant technologies from an EPC procurement and system-integration perspective due to their technical maturity, scalability, and compatibility with utility-scale PV systems.

This section defines the procurement-specific requirements for BESS and associated equipment forming part of hybrid facilities, focusing on the technical scope definition, compliance, integration, guarantees, safety, and supplier documentation.

Scope and Technical Specifications

The procurement scope shall clearly define the required BESS configuration and operating conditions, including:

- **Battery technology and architecture**, including chemistry (e.g. LFP, NMC, redox-flow), module and rack design, and containerised or modular solutions;
- **Rated power and energy capacity** (MW/MWh), including initial capacity and assumptions on oversizing and future augmentation;
- **Intended application and duty cycle**, reflecting the primary use case (e.g. energy shifting, ancillary services, self-balancing), expected number of cycles, depth of discharge (DoD), state-of-charge (SOC) window, and lifetime assumptions;
- **Operating regimes and environmental constraints**, including temperature range, humidity, altitude, corrosion category, and noise emission limits;
- **Energy Management System (EMS) and Battery Management System (BMS)** functionality, including control philosophy, dispatch logic, data resolution, and interface requirements;
- **Grid services capability**, including frequency and voltage control, reactive power provision, ramp-rate control, and black-start functionality, where applicable.

The technical specification shall be aligned with the hybrid PV + BESS plant design and grid connection requirements, including the selected coupling topology (AC or DC).

Certification and Regulatory Compliance

The EPC should ensure that suppliers provide evidence that the proposed BESS and associated equipment comply with all applicable international, European, and national standards, including but not limited to:

- IEC 62933 series (safety, performance, and environmental aspects of electrical energy storage systems);
- UL 9540 (system-level safety) and UL 9540A (thermal runaway propagation test method), where applicable;
- NFPA 855 (installation and fire protection requirements), where referenced by local authorities;
- EU Battery Regulation (EU) 2023/1542 and relevant national implementing legislation.

Power Conversion Systems (PCS), inverters, and transformers shall hold unit-level (type) certification suitable for grid connection, not prototype or pre-certification only. Compliance documentation shall be submitted as part of the tender.

Integration, Communication & Cybersecurity

The procurement scope should define interoperability requirements between the BESS and:

- PV inverters and plant controllers;
- SCADA systems;
- External stakeholders such as TSOs, DSOs, and energy traders.

Requirements shall include:

- Communication protocols and data models;
- Cybersecurity hardening measures;
- Data ownership, access rights, and long-term availability.

Responsibility for system integration, testing, and interface management shall be clearly allocated to avoid scope gaps.



Performance and Product Guarantees

Suppliers shall provide both product guarantees and performance guarantees, including:

- Product warranty periods (typically 2 years plus 12 months, or equivalent);
- Performance guarantees covering capacity retention at defined duty cycles over 10–15 years, including clear definitions of:
 - Measurement and verification methods;
 - Operating assumptions and exclusions;
 - Remedies in case of underperformance (e.g. augmentation, replacement, liquidated damages).

Guarantees shall be consistent with the declared battery lifetime, degradation assumptions, and use profile.

Safety and Emergency Preparedness

The procurement documentation shall require a comprehensive safety concept, including:

- Fire detection and suppression systems;
- Ventilation and gas management;
- Emergency shut-down and isolation procedures;
- Hazardous materials registers and Safety Data Sheets (SDS);
- Alignment of the Emergency Response Plan (ERP) with local emergency services;
- Training and familiarisation programmes for first responders.

The BESS design shall allow safe access for inspection, maintenance, and module replacement, and facilitate separation of battery components from HVAC, PCS, and other auxiliary systems.

Supplier Qualification and Documentation

As part of the procurement process, suppliers shall demonstrate:

- Proven experience with utility-scale BESS projects of comparable size and application;
- Availability of certified equipment (not prototypes);
- Capability to meet delivery schedules and manage supply-chain constraints.

The tender submission shall include comprehensive documentation, such as:

- Technical datasheets and drawings;
- Certifications and test reports;
- Operation and maintenance manuals;
- Safety documentation and ERP;
- Manufacturing and delivery schedules.

BECOME A MEMBER OF SOLARPOWER EUROPE

SolarPower Europe is the leading European solar association. Join our solar community today to unlock a world of shining benefits for your organisation.



Industry Influence

Help us shape the solar policy framework in Europe, by joining forces with industry leaders.



Networking Opportunities

Connect with 300+ members from across the entire solar value chain. Join exclusive networking opportunities at our events.



Expert Knowledge

Get access to the latest solar best practices, comprehensive market intelligence, weekly policy update, quarterly market updates webinars and knowledge exchange within our workstreams.



Visibility and Promotion

Be visible in front of an engaged solar audience of 25K+ monthly unique visitors on our website, 85K+ followers on social media, 27K+ newsletter subscribers, and more.



Amazing Discounts

Get exclusive member discounts for SolarPower Europe and partner events, advertising on partner media outlets, sponsorship opportunities and more.



Join SolarPower Europe today

www.solarpowereurope.org/membership



Construction

This chapter describes the main activities, concerns, and requirements to be met during the construction phase of a PV plant, including hybrid PV + battery energy storage (BESS) systems. During this phase, the solar power plant and, where applicable, the energy storage system are installed in accordance with supplier-provided installation manuals and technical specifications to ensure the correct storage, handling, assembly, and commissioning of all key components. These include mounting structures, PV modules, inverters, transformers, cabling, monitoring systems and sensors, battery containers, power conversion systems, and other balance-of-system equipment. The construction phase is critical not only for the physical assembly of the plant but also for ensuring long-term performance, operational reliability, and safety of both the PV and storage assets.

In addition to standard PV plant construction, hybrid projects require specific attention to battery logistics, container foundations, thermal zoning, HVAC systems, fire detection and suppression, emergency access, and EMS integration

A well-structured schedule and meticulous preparation of construction activities are essential and should preferably follow established project management practices. This includes a clear definition of objectives, responsibilities, activities (who does what?), timelines, milestones (when?), cost allocations, and quality assurance measures. Effective communication, reporting, and documentation flows between the Asset Owner, EPC service provider, subcontractors, and other stakeholders are crucial to encourage accountability, promptly identify and mitigate construction defects, uphold high standards, and facilitate performance monitoring throughout the execution phase.

In addition to standard PV plant construction, hybrid projects require specific attention to battery logistics, container foundations, thermal zoning, HVAC systems, fire detection and suppression, emergency access, and EMS integration. These considerations are necessary to ensure safe installation, compliance with applicable standards (such as IEC 62933 and UL 9540A), and seamless integration of PV and BESS systems into the grid and plant operations.

The overall construction activity can be divided into two main phases: firstly, the **preparatory phase**, covering early planning, site surveys, permits, and mobilisation; and secondly, the **implementation phase**, including site preparation, civil, mechanical, and electrical works, testing, and commissioning necessary to bring the plant into operation.

9.1 Construction Preparatory Phase

The construction preparatory phase includes the planning and preparatory activities that ensure the smooth realisation of the PV plant. The Asset Owner and the EPC service provider define the project organisation and objectives, structure the main parts of the project in a work-breakdown structure (WBS), and develop a time schedule with clearly defined work packages, responsibilities, interdependencies, durations, and resources. This schedule serves as the reference for monitoring progress from both physical and cost perspectives and must be regularly updated.

For hybrid PV + BESS projects, particular attention shall be given to the logistical requirements associated with battery system weight and form factor. Some BESS solutions are delivered as highly integrated containers exceeding 40 tonnes, and in some cases 50 tonnes, which can significantly increase requirements for transport permits, reinforced access roads, crane capacity, lifting plans, and onsite safety measures. These constraints must be assessed early during the preparatory phase and reflected in site layout, crane pad design, foundation sizing, and construction scheduling. Where feasible, more modular BESS architectures with lower individual unit weights (e.g. below 40 t or 20 t) can reduce logistical complexity, increase installation flexibility, and mitigate construction risk, particularly on constrained or remote sites.

9.1.1 Site Survey

The site survey verifies that the execution design (see [Chapter 7 Engineering](#)) is feasible onsite and identifies any physical or geographical constraints that could conflict with the planned layout. As a best practice, updated topographical surveys should be performed using drones equipped with LiDAR or photogrammetry to validate terrain, shading, and site access with high precision. Survey results should be cross-checked against the latest CAD drawings to confirm alignment between design intent and actual site conditions. CAD-based layout verification helps detect conflicts such as pile positioning, cable routing, and access paths early, reducing redesign risks and avoiding costly delays.

The survey also establishes the current status of the site and supports planning of preliminary activities necessary to prepare for mobilisation of personnel, equipment, and materials. While full mobilisation usually occurs after contracts enter into force (e.g., following a notice to proceed), some early or preliminary works may begin sooner as part of the project strategy. Incorporating CAD updates into this stage ensures that any adjustments from the survey are reflected in the execution design before procurement and construction commence.

Key topics to be investigated during the site survey include:

- **Mapping of the construction site:** Allotments, boundaries, topography, and elevation profiles. As a best practice, mapping should be performed using drones equipped with Real-Time Kinematic (RTK) positioning to achieve centimeter-level accuracy for geospatial data. This ensures precise alignment with CAD drawings and minimises layout errors.
- **Temporary facilities and storage areas:** Layout of laydown zones, warehouses, and onsite logistics.
- **Identification of interferences and obstacles:** Geolocated obstacles, underground utilities, and areas requiring mitigation. Drone surveys are recommended to provide precise geospatial data.
- **Assessment of critical elements and risks:** Technical hazards, unexploded ordnance, hazardous waste, archaeological discoveries, or environmental constraints.
- **Transportation facilities and access routes:** Evaluation of routes for delivery of PV and BESS components, including heavy containers (~30 tonnes).
- **Foundation and structural checks:** Execution of pull-out tests for mounting structures and assessment of ground conditions for battery container foundations.

For hybrid PV + BESS projects, the survey additionally evaluates:

- **Battery container siting:** Ensuring sufficient space for crane pads, fire brigade access, emergency egress, and maintenance operations.
- **Container types and foundations:** Standard ISO containers, skid-mounted PCS units, or compact module blocks in outdoor housings. Foundations can include plinths, stripes, or special water-retention systems in sensitive areas. Drainage must be considered to prevent flooding.
- **Installation and commissioning logistics:** Space for crane operations, personnel access, and staging areas for pre-assembled modules. For example, installing a ~12 m (40 ft) container with pre-installed modules typically requires 2–3 person-days.
- **Fire safety and regulatory compliance:** Containers must allow access for emergency services, and local fire and safety regulations must be considered, including relevant certifications (e.g., UL 9540A, IEC 62933).

This survey provides the foundation for safe, efficient, and compliant construction of both PV and storage components and ensures that preliminary planning and mobilisation proceed without delays.

9.1.2 Stakeholder Management

The primary tool for understanding the context in which the project is implemented is to identify and understand the stakeholders involved in, or affected by, the project. This allows one to become aware of their expectations and to determine the effective, potential, or perceived impact that the project can have on them identifying methods for involving them.

The identification of the stakeholders and their needs and expectations requires suitable knowledge of the relationships that exist between the different actors that are present and active in a given context. For this purpose, all subjects that could influence or be influenced by the project must be considered.

It is important that the identification of the stakeholders is not limited to local and administrative authorities but should also consider people and organisations that are relevant for local communities, as they represent their interests and identity. For hybrid PV + BESS projects, additional attention should be given to emergency services and environmental authorities due to fire safety and site-specific environmental or water-safety requirements related to battery installations. Early engagement of first responders and consultation with environmental authorities is crucial to ensure smooth coordination, avoid delays, and mitigate operational restrictions associated with storage deployment.



9.1.3 Construction Plan Preparation

Construction Planning aims at planning all construction activities properly and guaranteeing that resources are available and scheduled consistently with activities. This avoids any unplanned stops.

After definition of the project scope of work, the project management team structures the project by organising the activities in a hierarchical structure, the **Work Breakdown Structure (WBS)**. Only the activities identified with the WBS shall be within the project scope and, therefore, can be planned and controlled. As only an up-to-date WBS is helpful, the level of detailedness should be considered and not all subjects might be included. There is only one WBS per project. To support effective planning, coordination, and communication during the construction phase, mock-up tables and templates may be used to illustrate the expected structure, level of detail, and information content of construction-related documentation. These mock-up tables are provided for guidance and alignment purposes only and do not represent final or project-specific data.

Mock-up tables may be used, for example, to define the structure of work package descriptions, construction schedules, interface matrices, inspection and test plans, logistics plans, or material tracking registers. Their use helps ensure consistency between the Asset Owner, EPC service provider, and subcontractors, and reduces the risk of misunderstandings or omissions during execution. Final project documentation shall be developed, validated, and approved prior to construction in accordance with contractual requirements and applicable standards.

A well-defined WBS:

- Provides complete definition of the project scope at different levels
- Allocates tasks and responsibilities
- Defines a numbering system, which is used as reference in project plans, reports, and technical documentation
- Provides an input to integrate cost and schedule data
- Ensures the alignment with the contracting execution strategy
- Facilitates the roll up of cost, progress, and schedule performance information for reporting purposes

All parties (the Asset Owner, the EPC service provider and other service providers) involved in the project should comply with the WBS and related coding system. Clear and effective communication between the Asset Owner, the EPC service provider and other service providers (and in general, all third parties involved in the project), and constant monitoring of the construction work progress according to the WBS, are key to ensuring full alignment on scope of work, objectives, deliverables, and timing.

WBS's lowest hierarchical items are the work packages (WP). By defining each WP in detail and considering dependencies, the **project plan** is created. Each WP should contain at least the following information:

- Name
- Unique number/code
- Version and status information
- Description of content and results to be obtained

- Prerequisites and dependencies (deliverables required etc.)
- Projected duration
- Resource requirements (people, material, tools, vehicles, etc.)
- Person responsible for the WP

A detailed schedule with milestones and dependencies is essential for timely completion. The project plan should be continuously updated and linked to digital planning tools, including BIM, digital twins, and construction monitoring platforms. These tools enable real-time progress tracking, remote monitoring via drones or IoT sensors, and more effective coordination between teams.

Subordinate plans derived from the central project plan include mobilisation, safety, quality, environmental management, and logistics. Typical documents include:

- **Construction site organisation chart:** showing subcontractors, roles, expected personnel, and working hours
- **List of vehicles and equipment:** including certifications, maintenance records, and suitability for tasks
- **Logistic plan:** detailing delivery schedules, laydown areas, internal transport routes, crane positioning, and sequencing of heavy component handling

Work plan and mobilisation plan guarantee in-time arrival and accommodation of construction site personnel and assembly materials. They also ensure that the different elements of the construction phase are properly coordinated.

Construction site organisation shall also anticipate the impact of weather conditions and seasonal constraints on project implementation. These considerations fall in different categories:

- **Weather related scheduling risks and contingency planning:** Construction plans should incorporate buffers and alternative work sequences to accommodate heavy rainfall, storms, heat waves or high-wind periods that may halt civil or lifting activities. Seasonal weather patterns and short-term forecasts should be integrated into the schedule to reduce delays and minimise rework.
- **Worker health, safety, and productivity under extreme temperatures:** Exposure to heatwaves or cold spells requires adapted working hours, appropriate PPE, and enforced rest and hydration protocols to maintain safe working conditions. Clear stop-work criteria should be defined to prevent heat stress, cold-related incidents, or reduced task quality.
- **Protection of construction equipment and sensitive components:** PV modules, inverters, cabling, and BESS units should be stored and handled in weather-protected areas to avoid moisture ingress, thermal stress, or damage from wind and hail. Temporary coverings, controlled storage environments, and post-event inspections help ensure that components remain within their specified installation conditions.
- **Site accessibility and soil stability under weather extremes:** Heavy rainfall, snow, or flooding may reduce soil bearing capacity, obstruct access routes, and compromise safe operation of machinery such as cranes or pile drivers. The construction plan should include temporary access reinforcement and erosion-control measures to maintain safe and continuous site operations.
- **Integration of climate risk data into construction sequencing:** Historical and forward looking climate information should be used to anticipate high risk periods and adjust installation sequences accordingly. Activities most vulnerable to weather impacts, such as foundation works or heavy lifts, should be scheduled to minimise exposure to extreme events.

Physical progress should be tracked through progress curves and KPIs, integrated with real-time monitoring tools where possible. Specific calculation rules and weighting criteria should be defined for all activity types (see Chapter 12.1 – Project Performance KPIs).

The construction plan should also define processes and procedures for interfacing with engineering, quality, and EHS teams. All proposed changes by the EPC or subcontractors must be reviewed and approved by engineering (change management). Activities should be verified in accordance with quality plans, EHS procedures, and BESS-specific safety standards, ensuring compliance with cost, schedule, and regulatory requirements.

9.1.4 Check and Finalisation of Works Permits

Country-specific legislation and regulations around HSSE and construction activities are continuously evolving. It is critical to be sure that all works, administrative permits, and authorisations have been obtained to avoid breach of any legal provision. Such a breach could result in severe consequences, both in terms of personal and administrative sanctions and in downtime and delay in the execution of the activities.

A useful tool to ensure full compliance is the prescription and authorisation checklist which should identify all the relevant legislation and regulations applicable to the specific project and location. It also lists all requisites necessary to start the construction activities (authorisations, particular training requirements for certain works, such as works at height, land lease agreements, etc).

9.1.5 Activation of External Suppliers (services and materials)

Once all preliminary activities have been assessed and completed, the construction activities are ready to start. All subcontractors and suppliers must be activated according to the specific clauses of the relevant contracts and based on the scheduled activities. The scope of this phase is to ensure that all resources are present at the site in a timely manner to avoid any downtime and delay.



9.1.6 Soil Protection and Erosion Control

Construction activities shall be planned and executed in a manner that minimises soil disturbance, compaction, erosion, and contamination. Soil protection measures are particularly important during site preparation, earthworks, and civil works, and shall be proportionate to site sensitivity and local environmental requirements.

Measures may include limiting the extent of soil stripping, segregating and storing topsoil for later reinstatement, controlling vehicle movement to designated routes, and implementing erosion and sediment control measures such as temporary drainage, silt fences, or retention basins. Construction activities shall avoid unnecessary soil sealing and shall comply with applicable environmental permits and land-use conditions.

Soil protection requirements shall be reflected in the construction plan, environmental management plan, and contractor method statements, and shall be monitored throughout the construction phase.

9.1.7 Waste Management

A construction waste management approach shall be established prior to the start of construction works, in accordance with applicable legislation and project-specific environmental requirements. The objective is to minimise waste generation, maximise reuse and recycling, and ensure the safe and compliant handling, storage, and disposal of all waste streams.

Typical waste streams during PV and hybrid PV + BESS construction include packaging materials, scrap metal, surplus cables, damaged PV modules, civil works spoil, hazardous waste (e.g. oils, chemicals, batteries), and general site waste.

Waste shall be segregated on site where practicable, stored in designated and clearly labelled areas, and removed by licensed contractors. Hazardous waste shall be handled in accordance with relevant regulations, including specific requirements for batteries and electrical equipment. Waste management procedures shall be included in contractor documentation and monitored throughout construction.

9.1.8 Special Site-specific Requirements (e.g. sheep grazing protection)

In locations where construction activities take place on land used for livestock grazing, such as sheep farming, specific protective measures shall be implemented to ensure the safety of animals and personnel and to prevent damage to construction works and installed equipment. Measures may include the installation of temporary or permanent fencing to restrict animal access to active construction zones. Where grazing is intended to continue during or after construction, fencing and layout design shall be compatible with livestock movement and maintenance access.

Additional precautions may include protection of exposed cables and foundations, avoidance of hazardous materials accessible to animals, clear signage, and coordination with landowners or farmers regarding construction schedules and grazing patterns.

9.2 Construction Implementation Phase

Construction site activities must be supervised by the EPC service provider's Construction Manager. They should coordinate with the Asset Owner's Construction Manager and the Construction Supervisor on the monitoring and control of subcontractors. Throughout construction, drone construction monitoring flights should be carried out periodically to monitor, record and report on construction progress and quality. The data from these scans can also provide valuable support to H&S, stock management, and adherence to local planning and environmental regulations. For HSSE-related best practices, refer to [Chapter 3 Health, Safety, Security, and the Environment](#).

9.2.1 Construction Site Organisation

Construction site organisation refers to the preparation of the site for the start of civil, mechanical, and electrical works.

The effective mobilisation of the EPC service provider and related subcontractors usually takes place approximately 60 days from the signature of the contract. However, preliminary site preparation and executive engineering may begin immediately after signing.

In the mobilisation phase, contractors will begin to mobilise direct and indirect labour, equipment and means so that all planned activities can start as scheduled.

Site preparation main activities are:

- Opening of the construction site
- Archaeological survey may be requested by local authorities depending on the historical interest of the site
- Removal of vegetation removal and the superficial part of soil where foreseen (this kind of activity should be minimal in accordance with a positive biodiversity strategy)
- Staking and alignment of PV and BESS structures, including battery container foundations
- Visual mitigation works planned
- Preparation of dedicated laydown areas for PV modules, mechanical components, and battery containers

9.2.2 Civil Works

Civil works cover excavation for cable ducts, foundations, MV overhead line supports, preparation of areas for inverters, DC boxes, distribution stations, road construction, and general earthworks.

All civil activities must be carefully planned to minimise interference and overlap with electro-mechanical works, which can pose safety challenges if not properly coordinated. For hybrid PV + BESS projects, civil works also include foundations for battery containers (plinths, stripes, or special water-retention foundations where required) and crane pads or access areas for container delivery and installation.

Biodiversity and environmental considerations (see [section 3.2.1 - add title](#)) must be respected to reduce impacts. Where avoidance is not possible, restoration or compensation measures should be implemented. Clear guidelines and personnel awareness are essential to ensure compliance and minimise damage during construction.

9.2.3 Electro-mechanical Works

Mechanical activities mainly consist of:

- Withdrawal of materials from the Contractor warehouse
- Assembly of metal structures
- Installation of PV equipment / panels
- Package or cabin assembly, including PCS and battery containers for hybrid plants.
- Installation of HVAC, ventilation, and fire suppression systems inside BESS containers.
- Tests and inspections of mechanical assemblies and structural integrity.

Electrical activities mainly consist of:

- Laying ground network (equipotential bonding)
- Laying DC (LV) solar cabling and related components for connecting PV module strings to inverters, using tools certified or qualified by the manufacturer for PV cable-connectors assembly.
- Laying MV cables from transformer stations to the distribution station
- Laying LV auxiliary cables for PV and BESS systems.
- Cabin and field connections
- Tests and inspections



9.2.4 Ancillary Works

Ancillary works are activities that are not directly connected with the assembly of the “electric generation plant”. They refer in general to security (fencing, CCTV, lighting, ...), vegetation care, internal roads, signposting, and so on and so forth.

These works, even if not prioritised, must not be underestimated because they could delay the handover of the entire plant.

9.2.5 Grid Connection

Utility scale PV plants need to be connected to the network, usually managed by the Transmission System Operator (TSO). Connection complexity depends on the distance between the plant and the substation, its conditions and the technical solution identified for the connections. These works are the final stage of the construction activities and normally require the involvement of the TSO, which should be scheduled well in advance.

9.2.6 Checks and Functional Tests

Once the plant is completely built and connected to the grid, one must test that it works properly. It is important that tests are carried out according to a detailed procedure agreed between the EPC service provider and the Asset Owner.

To this end, the EPC service provider must send the Asset Owner a detailed plan of execution of all the work necessary to reach Start-up (Start-up Plan), before the start of the Mechanical Completion and Pre-Commissioning activities of the plant.

The plan should include the following minimum requirements:

- Definition of a start-up team
- Definition of the project functional units and related sub-units
- Definition of the plant sections that can be put into production in sequence
- Definition of the schedule and procedures for carrying out the preparatory tests for the start-up for each functional unit and plant section
- Description of how to perform the Mechanical Completion and Pre-Commissioning tests on the functional units
- Description of the execution of the Commissioning tests on the functional units and on the entire system

9.2.7 Mechanical Completion

When the plant is completely built and connected to the grid, after a visual inspection, the Asset Owner issues the Mechanical Completion Certificate (MCC).

The aim of the visual inspection is to verify:

- That all components and materials are present and in accordance with the project documentation
- The compliance of the completed project with the project documentation, the Technical Specification, and the current legislation
- The electro-mechanical completion of the plant
- That all components are free of visible damages that could compromise the safety of the components and personnel
- That the components have been installed correctly
- The correct identification and labelling of all components such as inverters, DC boxes, cables, support structure rows, switches, communication devices, monitoring elements, etc.
- The correct execution of the connections
- An aerial survey or digital verification (e.g., drones, 3D scanning, digital twin) confirms the plant layout matches the approved design.

9.2.8 Training of Asset Owner and O&M Service Provider

As soon as the plant is ready for operation, after MCC has been issued, the EPC service provider should arrange for a specific training for the Asset Owner and the O&M service provider's personnel (that could be a third-party or the O&M division of the EPC service provider). This training can transfer the knowledge and philosophy with which the plant has been designed and constructed.

Training is important as it allow the O&M service provider's staff to familiarise themselves with the plant and its operations. Poor training standards can result in lower performance of the plant, due to delays in detecting system malfunction signals, resulting in longer downtime as faults are resolved. This is also an opportunity for the O&M service provider to give feedback to the construction (and engineering) team, especially if both belong to the same company.

The Asset Owner's personnel should also receive training. This will help avoid misunderstandings between the Owner and O&M service provider and make their collaboration more efficient and effective.

A comprehensive and detailed as-built documentation ([Annex E](#)), manuals and procedures ([Annex C Documentation Set Accompanying the Solar PV Plant](#) of the [O&M Best Practice Guidelines](#)) should be part of the training activities. For more information on the handover to a specialised O&M service provider, please refer to [Chapter 11 Handover to O&M](#).

System Commissioning

System commissioning represents one of the most critical phases in delivering a solar PV plant to commercial operation. This chapter establishes the procedures, quality gates, and deliverables required to transition from completed construction to a fully operational asset. The commissioning process requires that the installation meets design specifications, complies with grid codes, and performs according to contracted parameters. This chapter applies to utility-scale and commercial installations. For residential systems, the same principles apply but should be scaled appropriately to the installation size and complexity.

For hybrid PV and BESS installations, commissioning requires parallel workstreams for the photovoltaic and battery storage systems, with integration testing validating combined operation, control system coordination, and grid services functionality

10.1 General Process

10.1.1 Commissioning Overview

Commissioning serves three fundamental objectives: validating that all systems function safely and correctly, establishing performance baselines for warranty enforcement, and enabling formal handover to operations. The process mitigates risks including undetected installation defects, safety hazards from improper wiring or configuration, performance shortfalls that trigger liquidated damages, and delayed grid connection approvals.

The commissioning phase typically spans 4-12 weeks depending on plant capacity 4-6 weeks for plants under 20 MWp, extending to 8-12 weeks for installations exceeding 100 MWp. Key stakeholders include the EPC Contractor (execution lead), Asset Owner (acceptance authority), Technical Advisor (independent verification), Grid Operator/TSO/DSO (grid connection approval), OEM Representatives (equipment validation), and the O&M Service Provider (operational readiness). Commissioning proceeds through two distinct phases. Cold Commissioning encompasses all testing performed with energised subsystems but without current flowing to the grid validating installation quality and safety prerequisites. Hot Commissioning follows with current-carrying tests, grid synchronisation, and operational data validation through SCADA, monitoring and alarm systems.

For hybrid PV and BESS installations, commissioning requires parallel workstreams for the photovoltaic and battery storage systems, with integration testing validating combined operation, control system coordination, and grid services functionality. BESS-specific commissioning procedures are detailed in Annex G.

The Commissioning Report serves as the unique vehicle carrying all test results, measurements, and certifications through the process. This document accumulates evidence from each phase and forms the basis for acceptance decisions at each gateway, culminating in Provisional Acceptance Certificate (PAC) issuance.

10.1.2 Preparation and Planning

Commissioning preparation establishes the procedural framework, resource allocation, and stakeholder alignment required for efficient execution. Poor preparation risks schedule delays, incomplete testing, disputed results, and costly rework. Preparation begins during final engineering and construction closeout, typically 4-8 weeks before mechanical completion. Agreement on the commissioning protocol following final engineering represents a critical milestone.

The EPC Contractor develops and submits the commissioning protocol detailing test sequences, acceptance criteria, witness requirements, and documentation templates. The Asset Owner and Technical Advisor review and approve this protocol at Gateway 1. Parallel activities include confirming OEM representative availability, scheduling grid operator witnesses for synchronisation tests, mobilising O&M personnel for shadowing and training, and establishing data infrastructure for result capture.

The Commissioning Report structure should be defined during preparation, establishing templates for measurement files, test certificates, and defect registers. Integration with digital systems requires confirming readiness of the 3D model, time-series data model, Asset Performance Management (APM) platform, and Computerised Maintenance Management System (CMMS). Gateway 1 approval of the commissioning protocol by Asset Owner and Technical Advisor marks successful preparation completion.

10.1.3 Stakeholder Coordination and Roles

Clear role definition prevents gaps in test coverage, ensures appropriate witness attendance, and establishes accountability for acceptance decisions. Inadequate coordination risks incomplete testing, delayed approvals, and long-term disputes over defect responsibility. Coordination requirements span the entire commissioning phase with intensity varying by activity.

Commissioning requires a multidisciplinary team combining electrical, controls, digital, and safety competencies. The EPC Commissioning Team includes the Commissioning Manager (overall coordination and quality), Lead Electrical Engineer (DC/AC testing, protection systems), Digital Systems Specialist (OT, IT, Modbus, IEC 104, Digital Twin setup), and Safety Responsible (preferably with electrical background). External stakeholders include OEM Representatives (inverter, tracker, and BESS manufacturers for equipment-specific validation), Technical Advisor (independent verification and approval recommendations), Grid Operator (synchronisation approval and grid code compliance verification), and O&M Service Provider (operational readiness and knowledge transfer).



For hybrid installations, BESS OEM representatives and battery management system specialists must be integrated into the coordination framework. The stakeholder responsibility matrix in Annex G details specific accountabilities by commissioning phase. Success requires all witnesses confirmed and scheduled with no gateway delays due to stakeholder availability.

Figure 7

Stakeholder Responsibility Matrix Overview

This matrix defines stakeholder accountabilities across the seven commissioning gateways. Effective coordination between all parties is essential to prevent delays and ensure quality outcomes.

Gateway	Cold Commissioning		Hot Commissioning		Defects Liability Period (DLP)	
	EPC Contractor	Technical Advisor	Asset Owner	Grid Operator	OEM Reps	O&M Provider
1. Validate Plan Commissioning protocol	Execute	Review	Approve	-	Input	Input
2. Approve Schedule Coordination Agreement	Execute	Review	Approve	Witness	Review	Review
3. Validate Cold Cold Commissioning Complete	Execute	Witness	Witness	-	Sign-off	Shadow
4. Validate Hot Hot Commissioning complete	Execute	Witness	Witness	Witness	Sign-off	Shadow
4b. Grid Approval Grid Operator Sign-off	Support	Review	Coordinate	Approve	Support	Prepare
5. Validate Baseline Performance Analysis	Execute	Approve	Accept	-	-	Monitor
6. PAC Issuance Provisional Acceptance	Request	Recommend	Issue	-	-	Confirm
7. FAC Issuance Final Acceptance	Support	Review	Issue	-	Warranty	Execute

Role Indicators

- Primary responsibility for delivery
- Final decision authority
- Technical review & feedback
- On-site verification
- Equipment-specific approval
- Assistance & coordination
- Requirements & specifications

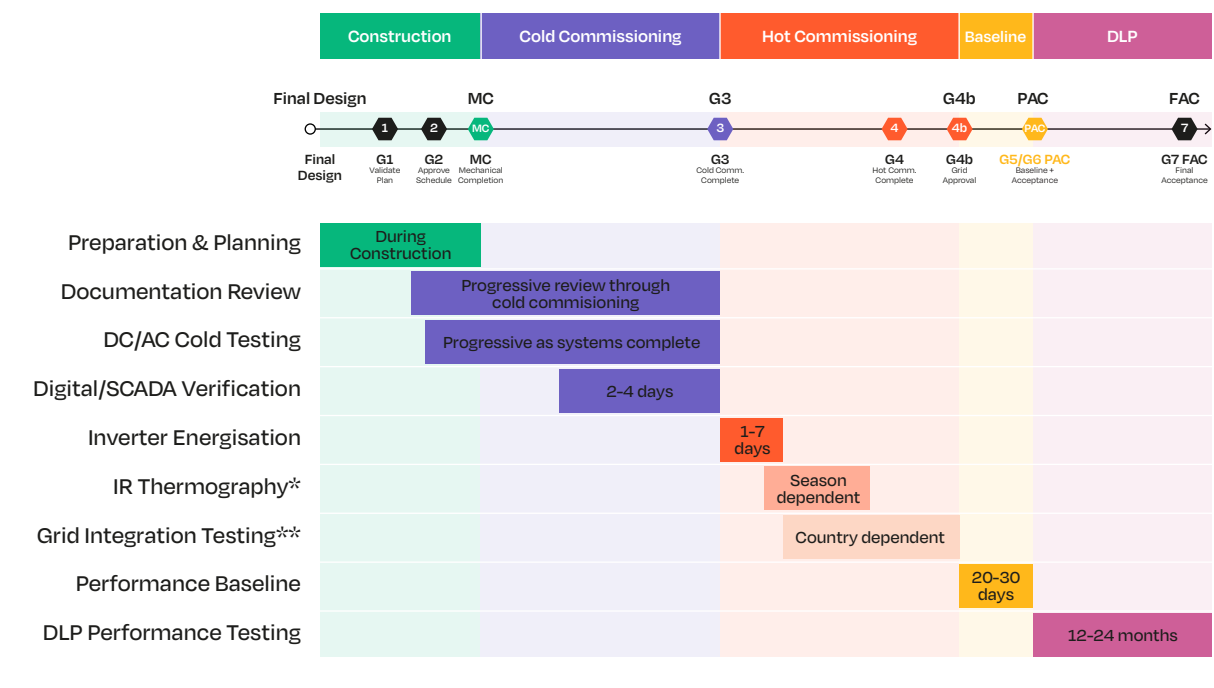
10.1.4 Quality Gates and Hold Points

The gateway system establishes formal decision points preventing progression until prerequisites are satisfied, mitigating risks of accumulated defects, unsafe energisation, and acceptance of non-compliant systems. Gateway reviews typically require 1-3 days depending on complexity.

Commissioning proceeds through seven gateways, with Gates 1-5 covered in this chapter and Gates 6-7 addressed in Chapter 11 (Handover to O&M), which includes the defects liability period operational responsibility.

Figure 8

Commissioning Process Timeline with Activities & Gateways



*IR Thermography (IEC 62446-3):

- **Season dependent:** Requires minimum 600 W/m² stable irradiance conditions
- If IEC conditions not achievable during commissioning window (e.g., winter commissioning), relative thermography is performed and full IEC-compliant survey scheduled at earliest suitable date

**Grid Integration Testing:

- **Country dependent:** Requirements and duration vary significantly by market (TSO/DSO regulations, witness requirements, grid code compliance tests)
- Allow 3-6 month buffer for grid operator coordination in markets with lengthy approval processes

Baseline Period:

Starts after Grid Approval (G4b). Minimum 20-30 days of valid measurement data required. Duration may extend until representative PR is obtained

Key Principles: (1) Cold commissioning activities (documentation review, DC/AC testing) begin during construction as subsystems are completed. (2) MC marks end of construction; cold commissioning continues to G3. (3) Performance Baseline begins after Grid Approval (G4b) and must demonstrate acceptable PR before PAC. (4) Commissioning concludes at PAC; all post-PAC activities are warranty period testing. (5) Durations are indicative and vary by plant size, complexity, and country requirements.

Legend

- Construction / Preparation
- Cold Commissioning (no current)
- Gateway
- Hot Commissioning (current flowing)
- Season dependant*
- Country dependant**
- Performance Baseline (20-30 days)
- Defects liability period
- PAC Milestone

- **Gateway 1 – Validate Commissioning Procedures:** Triggered at final engineering completion, the EPC Contractor submits the Commissioning Protocol for review. Asset Owner and Technical Advisor approve the procedures, confirming alignment with contractual requirements and industry standards.
- **Gateway 2 – Approve Commissioning Schedule:** Triggered at construction completion, all stakeholders review and approve the detailed commissioning schedule including witness requirements, resource allocation, and critical path activities.
- **Gateway 3 – Validate Cold Commissioning Results:** Triggered upon completion of all non-current-carrying tests. Asset Owner, Technical Advisor, OEM Representatives, and Grid Operator (where required for synchronisation authorisation) review cold commissioning results. This gateway includes Grid Operator approval for synchronisation, which varies significantly by European jurisdiction—refer to Annex H for country-specific requirements.
- **Gateway 4 – Validate Hot Commissioning:** Triggered upon completion of all current-carrying tests and grid integration. Asset Owner, Technical Advisor, and Grid Operator validate hot commissioning results including performance measurements, SCADA data quality, and grid compliance verification. This gateway includes Grid Operator approval for commercial feed-in.
- **Gateway 5 – Validate PAC Performance Analysis:** Triggered upon completion of performance baseline establishment. Asset Owner and Technical Advisor review the performance baseline report, and confirm readiness for PAC issuance.

Each gateway requires unanimous approval from designated authorities. Conditional approvals must specify remediation requirements and timeline. Detailed gateway criteria and checklists are provided in [Annex G](#).

10.2 Cold Commissioning

10.2.1 Overview and Safety Prerequisites

Cold commissioning validates installation quality through tests performed with energised subsystems but without current flowing through the generation path to the grid. This phase identifies defects safely before full energisation, mitigating risks of arc flash incidents, equipment damage from installation errors, and undetected connection faults. Duration varies from 1–4 weeks depending on plant size.

The EPC Contractor executes testing with OEM Representatives witnessing equipment-specific procedures. The Technical Advisor conducts independent verification of critical tests. Grid Operator engagement is required where synchronisation authorisation depends on cold commissioning completion.

Cold commissioning proceeds sequentially: documentation verification, visual inspection, electrical continuity and insulation testing, plant control systems verification, and digital infrastructure validation. All results are recorded in the Commissioning Report as measurement files with traceability to tested components.

Safety prerequisites must be verified before any energisation: completion of site safety induction for all personnel, availability and inspection of appropriate PPE, posting of emergency procedures and contact information, verification of first aid equipment and trained personnel, implementation of site access controls, and completion of arc flash hazard analysis. Safety prerequisite verification forms part of Gateway 2 approval. For hybrid PV and BESS installations, additional safety protocols apply for battery systems including thermal runaway prevention measures and emergency response procedures specific to battery chemistry. Gateway 3 prerequisites as defined in Annex G establish the success criteria.

10.2.2 Documentation and As-Built Verification

Documentation verification confirms that the installation matches design intent and provides the foundation for systematic testing, typically requiring 2-5 days. Discrepancies identified at this stage prevent wasted testing effort and establish the as-built baseline for operational maintenance.

Required verification includes confirmation that as-built single-line diagrams reflect installed configuration, equipment datasheets match installed components (model numbers, ratings, firmware versions), warranty certificates are available for major components, OEM installation certificates confirm proper installation procedures followed, network topology diagrams (OT and IT) reflect actual deployment, and cybersecurity documentation (network segmentation, access control) is complete per IEC 62443-3-3.

String schedules must verify physical labelling consistency, combiner box assignments, and inverter input mappings. DC cable documentation should confirm cable types, cross-sections, and routing match design calculations. AC cable verification confirms cable sizing for rated capacity plus any future expansion provisions.

10.2.3 Visual Inspection

Visual inspection identifies installation defects, physical damage, and safety hazards before energisation, typically requiring 3-7 days depending on plant size. Inspection follows IEC 62446-1:2016 Section 7.2 *Requirements with additional PV-specific considerations*.

Module-level inspection covers mechanical damage (cracks, chips, delamination), proper mounting and grounding connections, junction box condition and cable management, absence of shading from construction materials or vegetation, and label legibility including serial numbers. DC cabling inspection verifies proper cable routing and support, connector condition and tightness (where accessible), proper polarity marking, absence of mechanical stress or UV exposure, and grounding conductor continuity.

Combiner box inspection confirms proper ventilation and drainage, busbar and fuse condition, surge protection device installation, door seals and gasket condition, and internal cable management. Inverter station inspection verifies equipment installation per manufacturer requirements, AC and DC cable terminations, including correct bending radius and stress relief, cooling system operation (fans, filters), protection device settings, and housekeeping (cleanliness, no stored materials).

Substation inspection (if within EPC scope) includes transformer installation and oil level, switchgear and protection relays, battery backup systems, ventilation systems, fire suppression systems, as well as standard-compliant signage and earthing/grounding verification. All inspection findings are documented with photographs and component traceability. Critical defects preventing safe energisation must be resolved before Gateway 2 approval.

10.2.4 Electrical Testing

Electrical testing validates installation integrity before energisation, covering continuity, insulation resistance, polarity, and grounding effectiveness. Testing follows IEC 62446-1:2016 procedures with country-specific amendments per national electrical codes. Duration typically requires 1-2 weeks.

String testing includes open-circuit voltage measurement (VOC) at standard conditions with acceptance within +/-5% of calculated value based on irradiance and temperature, short-circuit current measurement (ISC) at $\geq 700 \text{ W/m}^2$ irradiance with acceptance within +/-10% of expected value and $\leq 5\%$ variation between strings in same array, insulation resistance measurement ($\geq 1 \text{ M}\Omega$ required, $\geq 10 \text{ M}\Omega$ typical for new installations), and polarity verification confirming consistent positive/negative across all DC infrastructure.

Grounding system testing verifies earth continuity across all metallic frames and structures, ground resistance measurement (typically $\leq 10 \Omega$ for TN systems, $\leq 4 \Omega$ for TT systems, subject to local codes), bonding conductor sizing per IEC 60364-4-41, and equipotential bonding verification between electrical and non-electrical metallic structures. AC testing includes insulation testing of AC cables and switchgear (acceptance criteria per voltage level and equipment class), protection device coordination verification, phase sequence and rotation verification, and voltage unbalance measurement ($< 2\%$ recommended).

For hybrid PV and BESS systems, battery system electrical testing includes cell voltage uniformity ($< 30 \text{ mV}$ variation typical), isolation monitoring, DC bus voltage verification, and battery management system communication verification. Detailed test procedures, measurement equipment specifications, and acceptance criteria are provided in [Annex H Detailed Commissioning Test Procedures](#).



10.2.5 Plant Control Systems Verification

Plant control systems verification confirms SCADA functionality, protection relay configuration, and communications infrastructure before hot commissioning. This testing occurs with systems powered but without current flowing to the grid. Duration typically requires 3-5 days.

SCADA hardware verification includes server redundancy testing, network switch functionality, uninterruptible power supply (UPS) operation, and historian database configuration. Communication testing validates all protocol implementations (Modbus TCP, IEC 61850, IEC 60870-5-104, DNP3 as applicable), device addressing and polling configuration, data point mapping accuracy, and communication reliability ($\geq 99.5\%$ availability over 24-hour test period).

Protection relay testing verifies correct settings per grid code requirements, coordination between protection stages, communication with SCADA, and alarm generation and escalation. Meteorological station verification confirms sensor calibration certificates (irradiance, temperature, wind speed), data logging configuration, and SCADA integration.

For tracker systems, control verification includes tracker controller communication, position feedback accuracy, backtracking algorithm validation (without motors energised), and emergency stow command functionality. Software updates also need to be done and verified to ensure the correct operational settings are in. Remote access verification confirms VPN functionality and access controls, remote desktop capability for troubleshooting, and cybersecurity controls per [Annex H Section H.8](#).

10.2.6 Digital Infrastructure Validation

Digital infrastructure validation ensures network security, data quality, and operational technology readiness before live operations. This represents a distinct discipline often overlooked in traditional commissioning approaches. Duration typically requires 2-4 days.

Network segmentation validation confirms physical or logical separation between OT (operational technology) and IT (information technology) networks, firewall rules implementation per IEC 62443-3-3, DMZ (demilitarised zone) configuration for SCADA remote access, and network access control lists restricting unauthorised devices. For installations requiring NIS2 Directive compliance, additional security validation may be necessary refer to [Annex H Section H.8.2](#).

Data quality validation includes time synchronisation verification across all devices (NTP configuration, <100 ms maximum deviation), data point validation confirming correct scaling and engineering units, alarm threshold configuration, and historian data retention policies. Cybersecurity validation covers default password changes on all network devices, user access control implementation with role-based permissions, security patch status on all networked systems, and antivirus/endpoint protection deployment per IT security policy.

Digital twin readiness (where applicable) requires 3D model upload and validation, asset hierarchy configuration in APM platform, time-series data model implementation, and initial KPI calculation verification. Gateway 3 approval requires successful completion of all digital infrastructure validation with documented evidence.

10.3 Hot Commissioning

10.3.1 Overview and Safety Gate

Hot commissioning validates equipment performance and grid integration through tests with current flowing from PV arrays to the grid. This phase confirms the plant operates safely and meets contractual performance obligations. Duration varies from 2–4 weeks depending on plant complexity.

The EPC Contractor executes testing with mandatory OEM Representative attendance for inverter energisation and Grid Operator witness for synchronisation. The Technical Advisor conducts independent verification of critical performance measurements.

Safety gate approval is mandatory before any inverter energisation. The safety gate verifies all cold commissioning tests passed, all critical defects resolved, safety equipment confirmed functional (emergency stops, disconnects, fire suppression), hot work permits issued as required, and designated safety personnel onsite during initial energisation. Detailed safety gate checklist is provided in [Annex G](#).

10.3.2 DC Systems Energisation and Testing

DC systems testing validates PV array performance under actual generation conditions, typically requiring 5–10 days spread across multiple weather conditions. Testing follows IEC 62446-1:2016 Section 7.4 with additional verification for modern system architectures.

Initial inverter energisation occurs with OEM Representative present, following manufacturer-specific startup procedures. One inverter can be energised first as a pilot, with monitoring for 2–4 hours before proceeding with additional units. Startup monitoring includes DC voltage and current profiles, AC voltage and frequency, inverter alarm/fault logs, and thermal performance during initial operation.

String performance testing includes I-V curve measurements on minimum 10% or as defined in the EPC contract of strings (20% recommended) using dedicated I-V tracer or inverter-based curve scanning where supported. Acceptance criteria require measured VOC and ISC within +/-5% and +/-10% respectively of values predicted from irradiance and temperature, with curve fill factor >75% indicating healthy string performance. Any strings failing initial testing require investigation before plant-wide acceptance.

MPPT tracking verification confirms inverter power tracking performance, response time to irradiance changes, and absence of oscillation in steady-state conditions. Power quality measurement validates voltage unbalance <2%, total harmonic distortion (THD) <5% per EN 50160, and reactive power capability per grid code requirements.

Thermographic inspection per IEC 62446-3:2017 is mandatory during hot commissioning, covering 100% of modules, DC cabling, combiner boxes, and inverters. **Where irradiance conditions permit** (minimum 600 W/m² within 2 hours of solar noon), full quantitative thermographic inspection shall be completed during commissioning. **Where seasonal or geographic conditions prevent adequate irradiance levels**, qualitative thermographic inspection of all DC and AC components shall be performed during commissioning to identify gross defects, with quantitative thermographic baseline inspection scheduled at the earliest date when irradiance conditions are met—this must occur prior to Final Acceptance Certificate issuance. Acceptance criteria follow IEC classification: zero Class A defects (temperature difference >20°C), <0.5% Class B defects (ΔT 10–20°C), and <2% Class C defects (ΔT <10°C). The thermographic baseline report serves as reference for future inspections during the Defects Liability Period.

For BESS systems (if applicable), DC systems testing includes charge/discharge cycling, thermal management system validation, and battery management system alarm testing. Detailed BESS commissioning procedures are provided in [Annex H Section H.4](#).

10.3.3 Grid Integration and Synchronisation

Grid integration validates compliance with grid codes and authorises commercial export. Testing follows national grid codes which vary significantly across Europe refer to Annex H for country-specific requirements. The Grid Operator typically witnesses synchronisation testing, with approval required before commercial operation.

Grid code compliance testing covers voltage and frequency operating ranges per EN 50549-1 or national grid code, active power control response (ramp rates, curtailment signals), reactive power/power factor control capability, fault ride-through capability per grid voltage level, and anti-islanding protection verification. Synchronisation testing validates automatic synchronisation logic, synchroscope operation (where applicable), breaker closing coordination, and stable operation post-synchronisation.

Grid protection relay testing confirms overcurrent protection coordination, under/over voltage protection, under/over frequency protection, vector shift protection (where required), and loss of mains protection. Communication with the Grid Operator typically requires IEC 60870-5-104, IEC 61850, or DNP3 protocol validation including remote active power setpoint control, reactive power/power factor control, and status indication visibility.

For installations with Power Purchase Agreements (PPAs), additional testing may include scheduled dispatch verification, telemetry data provision per PPA requirements, and day-ahead/intra-day scheduling coordination. Gateway 4 approval requires Grid Operator sign-off on synchronisation test results and authorisation for commercial feed-in.

10.3.4 Digital Systems Commissioning

Digital systems commissioning validates SCADA performance, data quality, and cybersecurity controls under operational conditions. This represents the operational technology complement to the network infrastructure validation performed during cold commissioning. Duration typically requires 3-5 days with systems under load.

SCADA operational testing includes alarm generation and acknowledgment workflow, historical data trending and analysis tools, report generation capability, user interface responsiveness under high data loads, and mobile/remote access functionality. Data quality validation verifies energy meter data accuracy (typically +/-1% of reading per IEC 62053-22), meteorological data consistency (irradiance sensor comparison if multiple sensors installed), inverter performance data completeness ($\geq 99\%$ over 24-hour test), and data synchronisation across distributed systems.

Cybersecurity operational validation includes penetration testing per IEC 62443-4-2 (if required by contract), security event logging and monitoring, backup and disaster recovery procedures, and incident response readiness. For critical infrastructure subject to NIS2 Directive requirements, additional cybersecurity verification may be necessary as detailed in [Annex H Section H.8.3](#).

APM platform commissioning (where applicable) validates KPI calculations (Performance Ratio, availability, energy yield), alarm management and escalation rules, maintenance work order generation, and integration with CMMS. Digital twin commissioning includes 3D visualisation accuracy, real-time data overlay validation, asset hierarchy navigation, and documentation linkage.

The deliverable from digital systems commissioning is a digital systems Commissioning Report documenting SCADA acceptance test results, data quality certification, cybersecurity validation summary, and APM/Digital Twin readiness confirmation. This report forms part of the overall Commissioning Report package.

10.4 COD, PAC, and Performance Baseline

10.4.1 Commercial Operation Date (COD)

Commercial Operation Date (COD) marks the transition from construction to revenue generation. Achieving COD triggers contractual milestones including payment releases, PPA activation, and performance guarantee periods. Delays risk financial penalties and stakeholder disputes.

COD prerequisites typically include Grid Operator approval for commercial feed-in, completion of all critical commissioning tests, PPA conditions satisfaction (if applicable), regulatory permits and approvals, and meter installation and verification. COD achievement typically follows shortly after Gateway 4 approval.

COD may precede PAC where contracts separate commercial operation from formal acceptance. The relationship between COD, PAC, and performance guarantee commencement should be clearly defined in the EPC contract.

10.4.2 Performance Baseline Establishment

Performance baseline establishment creates the reference dataset against which warranty performance is measured. Without a properly established baseline, performance disputes during the Defects Liability Period become difficult to resolve, risking warranty enforcement challenges, disputed PR calculations, and ambiguous degradation assessment.

Minimum 5 days of compliant measurement are required; best practice is 7-10 days to capture operational variability. Data from days with equipment issues, grid curtailment, or unusual weather conditions are excluded. Weather station calibration should be verified before the baseline period.



© 106882997/Shutterstock.com

Energy performance measurement follows Performance Ratio (PR) calculation per IEC 61724-1:2021 methodology with temperature correction per O&M Best Practice Guidelines (SPE, v6.0). Weather normalisation methodology must be documented for future comparison. Acceptance criteria require measured PR within +/-3% of expected PR accounting for soiling, temperature, and system losses.

Equipment performance baseline includes I-V curve measurements on minimum 10% sample (20% best practice) establishing string-level baseline for degradation tracking, plus inverter efficiency curve validation at multiple operating points. SCADA data completeness $\geq 99\%$ over the baseline period must be confirmed with data quality issues resolved before baseline acceptance.

The Performance Baseline Report documents PR calculation methodology and results, I-V curve database, and data quality certification. Detailed PR calculation formulas, data curation procedures, recommended measurement intervals, and exclusion criteria are provided in Annex I.

10.4.3 Provisional Acceptance Certificate (PAC)

The Provisional Acceptance Certificate marks the formal conclusion of commissioning and commencement of the Defects Liability Period. PAC issuance transfers operational responsibility to the O&M Service Provider while maintaining EPC warranty obligations a critical transition point in the asset lifecycle. PAC issuance typically follows 1-2 weeks after performance baseline completion.

Technical prerequisites require all commissioning tests completed and passed, Grid Operator approvals obtained, Performance Baseline Report approved, and punch list items closed or acceptable remediation plan agreed (remaining value typically <2-5% of contract price).

Documentation prerequisites require the as-built documentation package complete (refer to Annex F of EPC Guidelines), O&M manuals delivered, warranty documentation compiled, and training records complete.

O&M readiness prerequisites require O&M personnel trained on all systems, spare parts inventory stocked per contract requirements, maintenance procedures documented, remote access verified operational, and O&M team granted system access.

Digital handover prerequisites require SCADA access credentials transferred, network documentation delivered, cybersecurity configuration documented, and monitoring platform handover complete.

Upon PAC issuance, the Defects Liability Period (typically 24 months) commences. During this period, the EPC Contractor maintains performance warranty obligations while the O&M Service Provider assumes operational responsibility. The transition should be managed per [Chapter 11 Handover to O&M](#) and aligned with the SolarPower Europe [O&M](#) and [Asset Management Best Practice Guidelines](#).

PAC conditions, checklist, and certificate template are provided in Annex I.

10.4.4 PAC Gateway (Gateway 5)

Gateway 5 validates all PAC prerequisites and authorises formal acceptance. This final commissioning gateway ensures comprehensive verification before asset handover, typically requiring 2-3 days for Asset Owner and Technical Advisor final verification.

The review confirms completion of all commissioning activities (Gates 1-4 passed), Performance Baseline Report approval, documentation package completeness, O&M readiness verification, punch list status acceptance, and financial prerequisites (bonds, guarantees, any applicable LDs).

Following Gateway 5 approval, the Asset Owner issues the PAC, formally concluding commissioning and commencing the Defects Liability Period covered in [Chapter 11](#).

BATTERY STORAGE EUROPE PLATFORM

A new platform by SolarPower Europe to promote the development and expansion of battery storage in Europe



ABOUT THE PLATFORM

MEMBERS LIST

JOIN NOW



BATTERY
STORAGE
EUROPE
PLATFORM

Learn more



Handover to O&M

This chapter defines effective handover to Operations and Maintenance (O&M) as a structured, progressive process that begins during EPC contracting and runs in parallel with the commissioning gateway system described in Chapter 10 and Annex G, rather than a single event at Provisional Acceptance Certificate (PAC). By aligning O&M engagement activities with each commissioning milestone, the approach enables early operational input, continuous quality assurance, and timely knowledge transfer, ensuring the O&M service provider is fully prepared to assume responsibility at PAC. The chapter therefore introduces a gradual engagement model supported by an O&M Independent Audit framework at both PAC and Final Acceptance Certificate (FAC), covering documentation, monitoring data, digital infrastructure, and onsite readiness to reduce operational risk, prevent handover gaps, and support long-term asset performance.

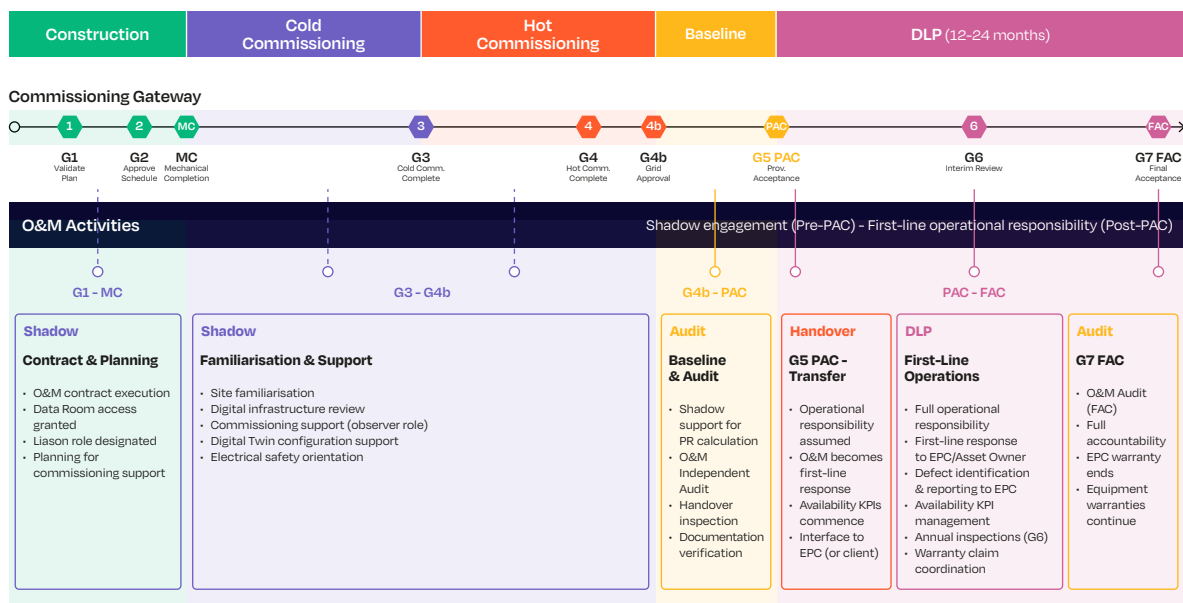
O&M contracting should occur alongside or shortly after EPC contract execution

Effective handover to O&M is not a single event at Provisional Acceptance Certificate (PAC) issuance, but rather a progressive process that begins during EPC contracting and runs parallel to the commissioning gateway system established in Chapter 10 and Annex G. This gradual engagement model ensures that O&M service providers are fully prepared to assume operational responsibility when contractual obligations commence at PAC, while providing continuous quality assurance throughout the commissioning process.

Figure 9 illustrates how O&M handover activities operate as a shadow process aligned to the commissioning gateways. Each commissioning milestone triggers corresponding O&M engagement activities, building capability and knowledge transfer progressively rather than through a compressed handover period.

Figure 9

Handover Process as Shadow Process to Commissioning Gates



Progressive Shadow Engagement

O&M involvement begins at G1 with contract execution and Data Room access. During commissioning, O&M observes, familiarises, and supports—building knowledge for operational handover without bearing direct commissioning responsibility.

O&M Independent Audits

Formal operational readiness assessments at PAC (G5) and FAC (G7). Scope includes documentation, monitoring data quality, Digital Twin verification, and physical inspection. Audit independence varies with EPC-O&M integration model.

DLP – KPI Responsibility Split

O&M assumes: Availability KPIs, operational control, first-line response.
EPC retains: Performance warranties, defect rectification obligations. Technical Asset Manager coordinates between parties.

Note – EPC - O&M Integration: The independence of the O&M audit depends on the relationship between EPC and O&M providers. **Common practice** is for the EPC contractor's O&M division (or a designated partner) to assume operational responsibility during the DLP. This arrangement simplifies coordination for defect resolution and performance warranty management, as the EPC retains closer oversight. Where a fully independent third-party O&M provider is contracted, the audit process and handover inspection carry greater weight in protecting both parties' interests.

Legend

- O&M Independent Audit Point
- O&M Shadow Activities (Pre-PAC)
- O&M First-Line Operations (Post-PAC)

11.1 Gradual Engagement Model

O&M contracting should occur alongside or shortly after EPC contract execution. Early engagement enables the O&M service provider to plan resource allocation, participate in commissioning planning discussions, and provide operational perspective during engineering reviews where feasible. Two primary models exist: EPC-led O&M through an internal division or designated partner (best practice during the Defects Liability Period), or third-party O&M contracted directly by the Asset Owner. Regardless of model, early engagement establishes the foundation for effective knowledge transfer.

During commissioning execution, the O&M service provider participates as an observer and consultant rather than bearing direct commissioning responsibility. This role provides an additional quality assurance perspective an independent set of eyes validating that systems are installed, tested, and documented to standards that support long-term operational excellence. The O&M team works alongside the Asset Owner's Technical Advisor, progressively familiarising themselves with plant systems, identifying potential operational concerns, and validating that commissioning outputs meet the requirements for effective O&M per the O&M Best Practice Guidelines (SPE, v6.0).

Documentation and system access transfer occurs progressively as commissioning gates are passed. Rather than receiving a complete documentation package at PAC, the O&M team receives and reviews deliverables as each subsystem is validated DC systems documentation following cold commissioning completion (Gateway 2), digital infrastructure documentation following hot commissioning readiness (Gateway 3), and so forth. This progressive approach allows early identification of documentation gaps and ensures the O&M team has sufficient time to review and raise queries before formal acceptance.

The O&M Independent Audit at PAC (Gateway 5) and FAC (Gateway 7) serves as the formal operational readiness assessment within this gradual engagement model, detailed in Section 11.2.



© Rawpixels stock/Shutterstock.com

11.2 O&M Independent Audit

The O&M Independent Audit is a targeted assessment of operational readiness, conducted from the O&M service provider's perspective before assuming responsibility. This audit does not replace the EPC contractor's quality assurance and quality control (QA/QC) processes, technical due diligence (TDD), or the commissioning verification activities defined in Chapter 10. Rather, it provides an O&M-focused evaluation ensuring that the plant configuration, documentation, data systems, and physical condition support effective long-term operations.

The audit serves risk management objectives for both parties. For the O&M service provider, it reduces the risk of inheriting undisclosed operational constraints, documentation gaps, or data quality issues that would burden day-to-day operations. For the EPC contractor, early identification of O&M-relevant concerns enables remediation before PAC, avoiding unexpected post-handover costs and disputes that increase OPEX exposure during the Defects Liability Period.

Two audit points align with the commissioning gateway system: the PAC Audit before Gateway 5 (PAC issuance) confirming operational readiness, and the FAC Audit before Gateway 7 (FAC issuance) confirming the plant remains fit for continued operation after the warranty period. Audit findings inform acceptance decisions, punch list negotiations, and the O&M provider's risk assessment for assuming operational responsibility.

11.2.1 Documentation Audit

The documentation audit verifies that handover documentation is complete, accessible, and sufficient for O&M purposes. This assessment reviews documentation against the requirements specified in [Annex F](#) and [Annex C](#) of the SolarPower Europe *O&M Best Practice Guidelines v.6.0*, with particular attention to documents essential for maintenance planning, troubleshooting, and regulatory compliance.

At PAC, key documents reviewed include as-built drawings, commissioning records (Commissioning Report, test certificates, measurement files), Performance Baseline Report per Annex I methodology, warranty documentation with claim procedures, and O&M manuals for all major equipment. Format verification confirms that technical drawings are provided in both editable format (.dwg) and signed PDF, that documents are searchable and logically organised, and that data files are compatible with O&M systems.

Gaps identified are recorded with remediation requirements and timelines. Documentation deficiencies that would impair O&M effectiveness are flagged for resolution, informing punch list negotiations where appropriate. At FAC, the audit additionally verifies that DLP operational records have been maintained and are available for transfer, including maintenance reports, production data, and equipment replacement records.

11.2.2 Monitoring Data Audit

The monitoring data audit validates that SCADA and monitoring systems provide data of sufficient quality and accessibility to support O&M performance management. Verification criteria align with Chapter 9 of the SolarPower Europe *O&M Best Practice Guidelines v.6.0*, including data completeness ($\geq 99\%$ over the baseline period), timestamp accuracy, signal validity, and absence of systematic gaps that would impair performance calculations or fault diagnosis.

Historical data integrity for the commissioning period is verified to ensure the Performance Baseline Report rests on reliable measurements and that trending analysis can be performed from commercial operation date. Data export capabilities are tested to confirm that historical and real-time data can be extracted in formats required for O&M analytics and reporting platforms.

Where data quality falls below thresholds required for effective O&M, specific gaps are documented with remediation requirements. At FAC, the audit extends to DLP period data, verifying continuity and quality throughout the warranty period.

11.2.3 Digital Twin Verification

Where digital twin technology has been implemented, the audit verifies that the model is accurate and operationally useful. The 3D geospatial model is compared against as-built documentation to confirm accurate representation of plant layout and equipment positions. Asset hierarchy and equipment relationships are validated against the physical configuration to ensure the digital twin supports maintenance planning and fault localisation.

Sensor associations and data point mapping are verified to confirm that time-series data flows correctly to the digital twin platform. Data ingestion pipelines are tested with live operational data. Discrepancies between the model and physical reality are documented for remediation to ensure the digital twin delivers operational value.

11.2.4 Punch List Audit

The audit includes review of the EPC punch list from an operational perspective, assessing how outstanding items may affect O&M activities. This is not a re-verification of EPC work quality that remains the responsibility of the Asset Owner's Technical Advisor and EPC QA/QC processes but rather an evaluation of operational implications.

Closed items are reviewed for any residual operational concerns. Outstanding items are assessed for impact on maintenance access, monitoring capability, safety procedures, or availability performance. Items presenting operational constraints are flagged, and remediation timelines are evaluated for acceptability from an O&M planning perspective.

The punch list audit findings contribute to the O&M provider's risk assessment and inform negotiations regarding acceptance conditions.

11.2.5 Onsite Independent Inspection

The onsite inspection provides direct observation of plant condition from an O&M operational perspective. This inspection complements rather than duplicates the commissioning inspections performed under Chapter 10, focusing on aspects relevant to ongoing operations and maintenance.

Health and safety verification confirms that the plant configuration supports safe O&M activities, including access provisions for routine maintenance, safety signage visibility, emergency equipment accessibility, and compliance with operational safety requirements.

Visual inspection identifies any conditions that may affect O&M activities access constraints, housekeeping issues, labelling adequacy, or physical conditions that could complicate maintenance execution. Sample verification of accessible components provides confidence that the plant condition aligns with documentation. Inspections reference the criteria in IEC 62446-1:2016 and IEC 62446-3:2017 where applicable, adapted to the O&M operational readiness context.

11.2.6 Audit Deliverables

Each O&M Independent Audit produces an audit report documenting findings across all components. The report includes verification status for each element, identified concerns with severity classification from an operational impact perspective, recommended remediation where applicable, and an overall assessment of operational readiness.

At PAC, the O&M Independent Audit Report accompanies the O&M acceptance signature, documenting the basis for assuming operational responsibility and any outstanding concerns or accepted risks. At FAC, the report confirms that the plant remains fit for continued operation and that DLP period issues have been adequately addressed.

The audit report is an O&M internal document informing the provider's acceptance decision; it does not constitute certification of EPC work quality or replace Technical Advisor assessments.

11.3 O&M During Defects Liability Period

The Defects Liability Period (DLP) spans from PAC to FAC, typically 12–24 months. During this period, the plant operates commercially while performance warranties remain in effect. Clear delineation of responsibilities between EPC contractor and O&M service provider is essential.

11.3.1 DLP O&M Models and Coordination

Best practice recommends O&M during DLP is performed by the EPC contractor's internal division or designated partner, ensuring continuity of knowledge and clear accountability for defect resolution. Alternatively, a third-party O&M provider may assume operational responsibility at PAC, with clear contractual boundaries defining EPC warranty responsibility versus O&M operational accountability.

Regardless of model, the O&M service provider should designate a Technical Asset Manager or O&M Manager to serve as the primary liaison with the EPC contractor and Asset Owner. This designated contact ensures smooth coordination for defect notification, access arrangements, warranty claims, and performance reporting throughout the DLP. Regular coordination meetings typically monthly maintain alignment on operational issues, defect resolution progress, and FAC preparation.

Annual inspections during DLP align with Gateway 6 (Interim Review) per Annex G, tracking plant condition and verifying defect rectification.

11.3.2 KPI Responsibility Split

Clear KPI allocation prevents disputes during DLP:

O&M responsibility - Availability KPIs (per *O&M Best Practice Guidelines v6.0*, Chapter 10):

- Technical Availability / Uptime
- Contractual Availability
- Service response metrics (Acknowledgement, Intervention, Response, Resolution Times)

EPC responsibility - Performance Warranty KPIs:

- Performance Ratio (PR) per Annex I methodology
- Energy yield guarantees
- Equipment performance warranties (coordinated with manufacturers)

This split recognises that O&M controls operational factors affecting availability while EPC is accountable for design and construction quality affecting energy performance.

11.3.3 O&M Supporting FAC Achievement

The O&M team supports FAC achievement through ongoing operations, defect identification, and providing operational data for performance warranty validation. FAC remains an EPC contractual obligation; O&M's role is to identify issues and report them for EPC rectification.

The O&M Independent Audit at FAC (Gateway 7), per [Section 11.2](#), confirms from an operational perspective that the plant remains fit for continued operation, helping protect O&M from latent operational constraints that should have been addressed under EPC warranty.

11.4 Documentation and Knowledge Transfer

A complete documentation package is fundamental to effective O&M. Documentation transfer should be progressive, enabling O&M familiarisation throughout commissioning rather than concentrated at PAC.

11.4.1 Progressive Transfer via Data Room

A dedicated data room, i.e. a digital shared document repository should be established, where O&M has ready access from early commissioning. Documents are uploaded progressively as they become available, with version control ensuring O&M can track updates. Documents should not be held back pending completion of later commissioning phases; preliminary versions transfer as available, with updates following validation.

The EPC contractor retains responsibility for documentation accuracy and completeness until FAC. The O&M service provider is responsible for reviewing documentation progressively and informing EPC of any material updates, corrections, or additions required to support operational needs. This shared responsibility ensures documentation evolves to reflect operational realities identified during early engagement.

The complete package, verified against Annex F requirements, must be finalised at PAC. The O&M Independent Audit ([Section 11.2](#)) confirms sufficiency for operational purposes.

11.4.2 Documentation Package Requirements

Documentation requirements are defined in [Annex F](#) (EPC Guidelines) and [Annex C](#) (*O&M Best Practice Guidelines v6.0*). Key components include as-built drawings in editable (.dwg) and signed PDF formats, equipment datasheets and O&M manuals, and warranty documentation.

Commissioning documentation from Chapter 10 includes the Commissioning Report, Performance Baseline Report per Annex I, thermography and I-V curve databases, and SCADA configuration documentation. Format requirements emphasise searchability and logical organisation aligned with plant systems.



11.4.3 DLP Operational Records

Operational records generated during DLP support FAC validation and ongoing asset management. Required records include maintenance reports, production data (minimum 15-minute resolution), irradiation measurements, force majeure documentation, and equipment replacement records with warranty claims.

These records transfer at FAC or, for third-party O&M assuming responsibility post-FAC, per [Section 11.7](#).

11.5 Digital Infrastructure Handover

Modern solar plants depend on digital infrastructure for monitoring, control, performance management, and cybersecurity. Effective handover of these systems requires specific attention beyond traditional documentation transfer, ensuring the O&M service provider can operate, maintain, and secure digital systems from day one of operational responsibility.

11.5.1 SCADA and Monitoring Systems

SCADA system handover encompasses access credentials, configuration documentation, and historical data. User accounts with appropriate role-based permissions must be established for O&M personnel before PAC, with secure credential transfer following cybersecurity best practices. Configuration documentation includes the complete data point register mapping all monitored signals, alarm threshold settings and notification routing, control setpoint configurations, and communication protocol parameters.

Historical data from the commissioning period transfers to the O&M service provider, establishing continuity for performance trending and enabling comparison against the Performance Baseline Report. Data export procedures should be tested during the O&M Independent Audit to confirm that data can be extracted in formats compatible with O&M analytics platforms.

Integration with O&M service provider systems requires attention to interoperability. Per Chapter 9 of the O&M Best Practice Guidelines (SPE, v6.0), data silos should be avoided through use of standardised protocols (Modbus, IEC 60870-5-104, IEC 61850) and open interfaces enabling data exchange between SCADA, monitoring platforms, and service management systems.

The Monitoring Data Audit component of the O&M Independent Audit ([Section 11.2.2](#)) verifies data quality and accessibility before acceptance.

11.5.2 Cybersecurity Handover

Cybersecurity handover follows the baseline established during commissioning per [Chapter 10](#) and [Annex H](#) procedures. Network topology documentation including all IP addresses, VLAN configurations, and firewall rules transfers to the O&M provider. This documentation enables the O&M team to maintain network security, troubleshoot connectivity issues, and implement updates as required.

Access credentials for all network devices, security appliances, and management interfaces transfer through secure channels. Default credentials must have been changed during commissioning; the handover confirms that unique, strong credentials are in place and documented. VPN configurations for remote access are handed over with associated certificates and authentication procedures.

Incident response procedures established during commissioning transfer to O&M, defining escalation paths, containment procedures, and recovery processes. The O&M provider assumes responsibility for ongoing vulnerability management, patch maintenance, and security monitoring per Chapter 9.7 of the SolarPower Europe *O&M Best Practice Guidelines*.

11.5.3 Communication and Remote Access

Communication system handover addresses both technical configuration and contractual arrangements. Internet service provider contracts, mobile network agreements, and any third-party communication services require transfer or novation to the O&M provider or Asset Owner as appropriate.

Proprietary PLC code presents particular challenges. Where EPC contractors have developed custom control logic, arrangements for code access and documentation should be established during EPC contracting. Options include full code transfer with documentation, ongoing support agreements with the original developer, or replacement with O&M provider systems where code access cannot be secured.

Due to the complexity of digital infrastructure migration, a transition period of up to six months is recommended for complex systems. During this period, the outgoing party (EPC contractor or their O&M division) should provide cooperative support to the incoming O&M provider, with cooperation obligations defined in the EPC contract.

11.6 Operational Readiness and Inspection

Operational readiness verification is a two-way process. The EPC contractor must confirm that the O&M service provider has the capacity and capability to fulfil contractual obligations during DLP and beyond. Equally, the O&M provider must demonstrate organisational readiness and validate that the plant configuration supports effective operations. This mutual verification protects both parties and the Asset Owner.

11.6.1 EPC Assessment of O&M Readiness

The EPC contractor has a legitimate interest in confirming that the incoming O&M provider can fulfil contractual duties, as O&M performance directly affects warranty claims, defect identification, and FAC achievement. Before PAC, EPC should verify that O&M has:

- Designated personnel available (control room operators, field technicians, management)
- Documented operational procedures aligned with the Site Operating Plan
- Established communication protocols with Asset Owner and grid operator
- Completed site-specific training per [Section 11.8](#)
- Adequate spare parts inventory per SPE *O&M Best Practice Guidelines* Chapter 8

This EPC verification is not a gatekeeping exercise but ensures smooth DLP operations and reduces disputes arising from inadequate O&M capacity.

11.6.2 O&M Internal Readiness Planning

The O&M service provider must plan and execute actions to achieve operational capacity aligned with plant requirements. A key input to this planning is the O&M Independent Audit ([Section 11.2](#)), which clarifies the operational needs and realities of the specific plant equipment types, system complexity, access constraints, monitoring requirements, and site-specific considerations.

These operational realities must translate into appropriate O&M capacity: personnel skills matching installed equipment (inverter types, tracker systems, BESS where applicable), tooling and test equipment, spare parts strategy, and subcontractor arrangements for specialised activities (HV maintenance, vegetation management). The audit findings inform resource planning and identify any capability gaps requiring development before PAC.

11.6.3 Handover Inspection Scope

The onsite handover inspection verifies plant condition from an operational perspective. Inspection planning should be agreed in advance, with a schedule defining activities and personnel requirements.

Key inspection elements include health and safety verification (access provisions, signage, emergency equipment, electrical safety compliance), as-built consistency checking against documentation, and assessment of whether plant configuration supports O&M contractual commitments (access for maintenance, spare parts storage, monitoring functionality).

Additional technical inspections may include aerial thermography per IEC 62446-3:2017 and sample I-V curve measurements, documented in the handover report.

11.6.4 Handover Report and Acceptance

The handover inspection produces a report documenting plant condition at O&M assumption, including findings by system, photographs, documentation verification status, and operational readiness assessment.

The punch list captures identified issues with severity classification, remediation actions, and timelines. Critical items affecting safety or operability should be resolved before PAC; minor items may be accepted with documented commitments.

At PAC, the O&M service provider signs handover acceptance confirming assumption of availability KPI responsibility. This signature is accompanied by the O&M Independent Audit Report ([Section 11.2](#)), documenting the basis for acceptance and confirming that O&M capacity aligns with plant operational requirements.



11.7 Post-FAC Handover to Third-Party O&M

Where the EPC contractor's O&M division has operated during DLP and a different provider is contracted for long-term operations post-FAC, an additional handover process is required. This involves transfer between two O&M organisations rather than from EPC to O&M.

11.7.1 When Third-Party Handover Applies

This section applies when operational responsibility transfers between O&M organisations following FAC. Common scenarios include Asset Owner contracting a specialised provider after DLP, asset sale to a new owner, or expiry of the initial O&M contract.

The recommended transition period is three to six months for documentation transfer, system access migration, and knowledge transfer. Compressed timelines risk operational disruption and loss of institutional knowledge.

11.7.2 Third-Party Handover Requirements

The incoming O&M provider should conduct an independent assessment following the audit methodology in [Section 11.2](#), adapted for post-FAC context.

Documentation transfer encompasses EPC handover materials plus DLP operational records maintenance histories, performance reports, defect logs, and modifications. The provider should verify completeness against Annex C of the O&M Best Practice Guidelines.

System access migration transfers SCADA credentials, monitoring accounts, and network access. Security best practice requires credential rotation during transfer. VPN and remote access requires reconfiguration for incoming personnel.

Contract transfer addresses third-party agreements (vegetation management, cleaning, HV maintenance, security). Subcontracts require novation or replacement. Grid operator relationships should transfer with introductions to relevant contacts.

Site familiarisation through walkthrough with outgoing personnel captures undocumented operational knowledge site-specific procedures, equipment quirks, historical issues, and stakeholder relationships.

11.7.3 Continuity Considerations

Best practice favours continuity with the same O&M organisation post-FAC, avoiding knowledge loss inherent in provider changes. Where change is necessary, an overlap period with both providers present enables direct knowledge transfer.

Reference the O&M Best Practice Guidelines (SPE, v6.0) for guidance on assuming operational responsibility and meeting contractual obligations.

11.8 Training and Capacity Building

Comprehensive training requirements are addressed in Chapter 5 of the SolarPower Europe [O&M Best Practice Guidelines v6.0](#). This section addresses handover-specific training obligations.

11.8.1 Handover-Specific Training

The EPC contractor provides training for systems, equipment brands, or practices not already within the O&M provider's competency. Where the plant includes equipment types new to the O&M team, such as unfamiliar inverter brands, tracker systems, or BESS configurations the EPC contractor arranges manufacturer training or provides competency transfer before PAC.

Training gaps are identified during the O&M readiness assessment ([Section 11.6.2](#)) and addressed through targeted sessions. Training records documenting attendance and competency verification form part of handover documentation.

11.8.2 Asset Owner Coordination

The O&M service provider works closely with the Asset Owner's representative, typically a Technical Asset Manager throughout handover and ongoing operations. Training and familiarisation activities should include Asset Owner personnel where they have operational involvement or oversight responsibilities.

Reporting requirements and communication protocols are established during handover, defining format, frequency, and content of performance reports, escalation paths for significant issues, and arrangements for periodic review meetings. During DLP, regular coordination meetings between O&M, EPC, and Asset Owner ensure alignment on defect resolution, performance tracking, and FAC preparation.

11.9 Final Acceptance and Warranty Transition

The Final Acceptance Certificate (FAC) marks the conclusion of EPC Defects Liability Period obligations and transition to long-term operations. FAC prerequisites and O&M's supporting role during DLP are addressed in [Sections 11.2](#) and [11.3](#). This section addresses the FAC audit and subsequent warranty transition.

11.9.1 FAC Audit

The O&M Independent Audit at FAC (Gateway 7) follows the methodology established in [Section 11.2](#), with scope extended to cover the DLP period. The FAC audit confirms from an operational perspective that the plant remains fit for continued operation without EPC warranty support.

11.9.2 Post-FAC Warranty Transition

Upon FAC issuance, the EPC contractor's DLP warranty obligations end performance guarantees, workmanship warranty, and defect rectification obligations conclude. Final retention payments are released per contractual terms.

Equipment warranties continue beyond FAC. Module performance warranties typically extend 25-30 years, inverter warranties 5-10 years, and BESS warranties 10-15 years. These warranties are held by the Asset Owner, with the O&M provider managing claims on their behalf.

The O&M service provider assumes full operational accountability without EPC warranty backstop. Performance responsibility aligns with O&M contractual guarantees typically availability-based per the SolarPower Europe *O&M Best Practice Guidelines* Chapter 10.

Where a third-party O&M provider assumes responsibility post-FAC, the handover process in [Section 11.7](#) applies. Reference the *O&M Best Practice Guidelines* (SPE, v6.0) and Asset Management Best Practice Guidelines for long-term operational management following FAC.

Key Performance Indicators

This chapter introduces the key performance indicator (KPI) framework relevant to EPC projects, recognising that KPI requirements evolve across the project lifecycle and differ by stakeholder perspective. While standard project management KPIs remain essential for tracking time, budget, and quality, hybrid PV + BESS projects require additional indicators to reflect the increased technical complexity, safety-critical systems, and integration interfaces introduced by storage. Accordingly, the chapter groups EPC-related KPIs into ex-ante KPIs used for project and contractor selection, project performance KPIs used to monitor delivery during construction, and ex-post KPIs used to assess outcomes after completion highlighting the need, where applicable, to distinguish between PV-only, BESS-specific, and combined system-level performance.

For hybrid PV + battery energy storage (BESS) projects, the KPI framework must reflect the increased technical complexity, safety-critical elements, and system interfaces introduced by storage integration

There are different types of Key Performance Indicators (KPIs) relevant to EPC, depending on project phase and relevant stakeholders. For hybrid PV + battery energy storage (BESS) projects, the KPI framework must reflect the increased technical complexity, safety-critical elements, and system interfaces introduced by storage integration. While the fundamental project management principles remain unchanged, additional KPIs are required to capture BESS-specific readiness, integration quality, and safety performance. Where applicable, KPIs should therefore distinguish between PV-only aspects, BESS-specific aspects, and system-level performance across the combined plant. KPIs related to EPC can be grouped into three categories:

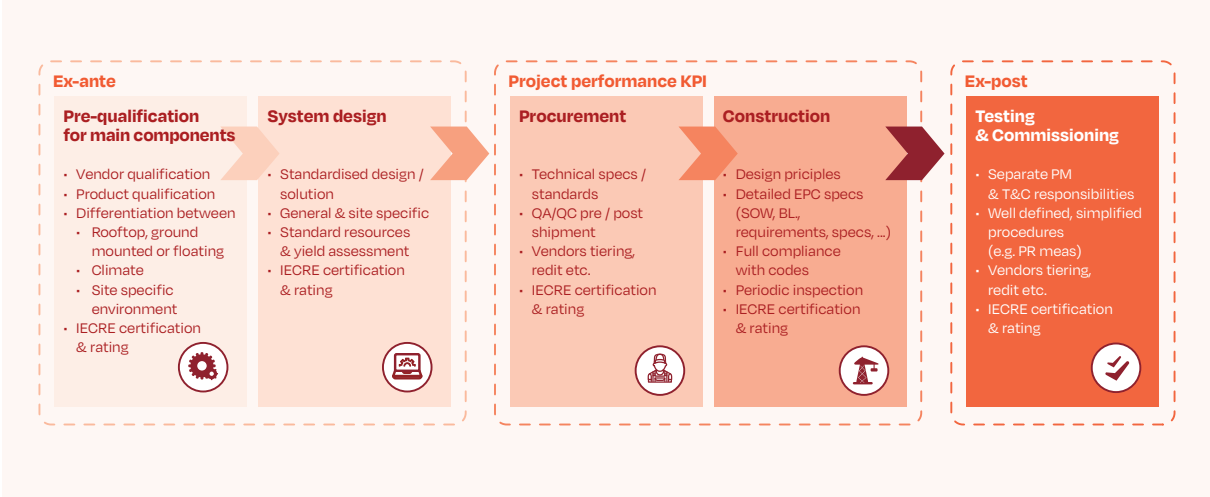
- **Ex-ante KPIs** allow the (future) Asset Owner (or project developer) to decide whether to invest in a project that is being developed and trust a particular EPC service provider. They also help lenders to assess projects for financing. These aspects are important during the transition from the development to the construction phase and are considered in Section 5.1. *Selection of EPC projects* and Section 5.2. *Selection of EPC provider*
- **Project performance KPIs** help all stakeholders to track project progress, and EPC service providers to optimise their processes
- **Ex-post KPIs** deliver a final assessment on a built project. For EPC service providers these KPIs may also be helpful when presenting their references to potential new clients



The number of criteria to be looked at depends on the value of the project: big projects need to be examined in more detail.

Figure 10

Key Performance Indicators in different project phases relevant for EPC



Source: S G.Agostinelli, Technical Risk Mitigation framework for Solar Portfolios, IFC/World Bank Group, 2017

12.1.1 Project Performance KPIs

During the construction phase, the performance of the project should be tracked closely. There are available project management standards for this, such as ISO 21500, or publications of associations like the German Association for Project Management (GPM), or the Project Management Institute (PMI). In principle, project management tracks deadlines, budget, and quality, to achieve planned results.

There exist multiple KPIs for project performance. Here we focus on those which track the three essential elements of the 'project management triangle': (1) time, (2) budget, (3) quality. To achieve customer satisfaction, the planned goals concerning these elements have to be respected. The sections below discuss KPIs related to these aspects in more detail.

For hybrid projects, project performance KPIs should be structured in a way that allows differentiated tracking of PV construction works, BESS installation works, and system integration activities. Experience shows that delays or quality issues in one subsystem can have disproportionate impacts during commissioning if not identified early. Separate tracking improves transparency and enables timely corrective actions, particularly during the transition from construction to commissioning.

12.1.2 Deviation in Time

Milestones are used in project management to mark specific points along the project timeline. These points may signal anchors such as project start and end date, or the need for external review, input, and budget checks. Therefore, one important KPI concerning time is the Deviation in Time expressed as percentage of milestones missed:

Deviation in Time

$$\Delta T(i) = \frac{\#M_a(i)}{\#M_p(i)} \times 100\%$$

Where:

- $\Delta T(i)$ = Deviation in Time, expressed as a percentage (%).
- $\#M_a(i)$ = Number of Milestones achieved at the point of time i .
- $\#M_p(i)$ = Number of Milestones that should have been achieved at the point of time i according to the plan.

The value of this KPI increases if the granularity of milestones becomes finer and milestones are well distributed over the whole construction phase.

On the contractual side, Liquidated Damages may be linked to Deviation in Time – see Section 13.5. [Limitation of Liability and Liquidated Damages](#).

Since the importance of different milestones may differ, another KPI should be introduced: the number of Critical Milestones Missed (CMM). A critical milestone is one that must not be missed, because of its significance to the project. Examples include the date of receipt of construction permits or of grid connection. In a normal project CMM should be 0. Additional KPIs may include Deviation of Planned Hours of Work.

In hybrid PV + BESS projects, additional critical milestones typically relate to storage-specific activities and integration readiness, such as delivery and installation of battery containers, completion of fire safety systems, availability of grid-compliant control logic, and successful completion of integrated commissioning tests. These milestones should be explicitly identified as critical, as delays at these stages often impact grid connection, acceptance, and Commercial Operation Date.

12.1.3 Deviation in Budget

At defined moments in the project, usually at milestones and after (or even before) purchase of important components (like modules) or services, current accumulated costs $C_{ca}(i)$ should be compared to costs according to the business plan $C_{pa}(i)$. The resulting KPI Deviation in Budget can be defined as:

Deviation in Budget

$$\Delta B(i) = \frac{C_{ca}(i)}{C_{pa}(i)} \times 100\%$$

Where:

- $\Delta B(i)$ = Deviation in Budget, expressed as a percentage (%).
- $C_{ca}(i)$ = Current accumulated costs at the point of time i .
- $C_{pa}(i)$ = Planned accumulated costs according to the business plan at the point of time i

In this case the value of the KPI depends again on the choice of the measurement points i , their granularity and distribution over the period of the project.

For hybrid projects, budget deviation KPIs should ensure clear attribution of costs to PV systems, BESS systems, and integration scope. This separation is important to enable meaningful analysis of cost drivers, avoid misinterpretation of overruns, and support subsequent technical and financial due diligence. Particular attention should be paid to storage-related logistics, heavy lifting operations, safety systems, and integration engineering, which may introduce cost variability compared to PV-only projects.

12.1.4 Deviation in Quality

Quality KPIs measure the quality of construction as well as the construction process and are therefore quite technical. A general KPI for quality tracking is the Deviation in Quality, which can be defined as:

Deviation in Quality

$$\Delta Q(i) = \left(1 - \frac{\#NC(i)}{\#QC(i)} \right) \times 100\%$$

Where:

- $\Delta Q(i)$ = Deviation in Quality, expressed as a percentage (%).
- $\#NC(i)$ = Number of detected non-conformities at the point of time i .
- $\#QC(i)$ = Total number of quality checks at the point of time i .

The value of this KPI depends on the definition of quality checks, their number, and distribution over the project period. Non-conformities may include:

- Deviations from execution plans
- Construction defects
- Deviations from norms, standards, grid code, and industrial best practice (the documents to be considered should be listed in the tender document)
- Deviations from permits

Tracking certain quality aspects separately, like conformity with HSSE protocols, is recommended. In this case we would count non-conformities in HSSE and only compare it to the number of all HSSE checks.

Since the importance of different quality aspects may differ, it is best practice to assign a weighting factor for each conformity check.

Other aspects of project quality may be examined, for example:

- The number of change requests (indicates the quality of project development and preparation)
- KPIs describing the quality of communication between the stakeholders (surveys)
- The completeness of required documents for the O&M phase (see Annex C of the SolarPower Europe *O&M Best Practice Guidelines*)

This list should be completed according to the necessities of the specific project. It is also important to establish feedback loops to create an atmosphere where continuous improvement can flourish.

12.1.5 Ex-post KPIs

Ex-post KPIs are the KPIs that help evaluate EPC projects after the construction phase.

12.1.6 Performance Ratio

The Performance Ratio (PR) remains a widely adopted KPI for evaluating PV plant performance, valued for its simplicity, standardization, and effectiveness in identifying underperformance. However, PR exhibits methodological limitations in scenarios involving midday power curtailment whether due to grid operator constraints or plant-level commercial strategies and in systems affected by derating from elevated DC/AC ratios, where its interpretative validity is substantially reduced. In such cases, alternative indicators such as the Energy Performance Index should be considered (see SolarPower Europe *O&M Best Practice Guidelines*, Chapter 10). Furthermore, in bifacial photovoltaic systems, the reliability of PR is diminished by the difficulty of accurately quantifying rear-side irradiance, which is influenced by site-dependent factors including ground albedo and mounting structure geometry. This increases uncertainty in the reference yield and further limits PR's utility as a performance indicator. For detailed explanations and formulas, refer to section 10.3.4 *Temperature-Corrected Performance Ratio* and Chapter 10 *Key Performance Indicators* of the SolarPower Europe *O&M Best Practice Guidelines*.

12.1.7 Overall Project Performance

KPIs regarding overall project performance are, in most cases, identical to the Project performance KPIs described in section 12.1., with i being the concluding milestone of the project.

12.1.8 Warranty KPIs

Additional ex-post KPIs after FAC measure the handling of warranty claims by the EPC service provider, for example:

- Number of broken components / Total number of components
- Number of broken components replaced in warranty procedure / Total number of broken components

Contractual Framework

This chapter describes key contractual clauses and contractual concepts which are often seen in the market for a 'full-wrap' EPC contract, under which the EPC service provider undertakes to build and deliver the plant in compliance with the agreed time-schedule. The EPC service provider also manages the supply of the necessary equipment, and all the necessary ancillary works and activities. For other approaches such as 'split contracts,' see the box on *Split EPC contracts*.

The EPC contract is one of the most important elements of a solar project and it has a major impact on project financing and bankability

Under a standard EPC contract, the service provider will typically have to meet a precise deadline to reach the Commercial Operation Date (COD). Setting this deadline right is particularly crucial when the plant is willing to apply for feed-in tariffs (considering that, quite often, this is dependent on reaching COD within a certain date) or has to meet contractual deadlines within the terms of a corporate power purchase agreement (which might result in liquidated damages being payable to the off-takers of the Power Purchase Agreement in case such agreed deadlines are not met).

By executing a full wrap EPC contract, the owner of a plant aims to reduce the risks derived from hiring several contractors in the construction phase. The owner of the plant also strengthens their position by creating a single point of liability with the service provider, who will be liable and accountable for the timely and accurate execution of all the construction works carried out onsite, even when executed by sub-contractors (if allowed by the EPC contract). In this respect, all the relevant legal guarantees (e.g., time to complete the works, or performance related guarantees) associated with the execution of construction works will be issued by a sole entity, which will take full responsibility for the EPC contract. This results in one creditworthiness check rather than several and is especially useful when a parent company guarantee is chosen over bank guarantees.



© Tsvetan/AdobeStock

Split EPC Contracts

The EPC contract may be construed either as a full-wrap contract or a split contract. In the latter case, the supply and installation of the components are carried out by different service providers. In this case, the Asset Owner (SPV) enters into different contracts for the supply and installation of the components. The choice of executing a full-wrap or a split EPC contract is up to the Asset Owner, who must evaluate how to allocate the risks associated with the individual activities. The Asset Owner's choice should comply, as much as possible, with the Lenders' requests and interests, who tend to prefer a single reference point for the construction of the project. As previously stated, the contract structures are one of the bankability criteria to be respected to ensure that the SPV receives the necessary funds for covering the construction and operating costs. Also, a mix between the two contracts is possible. For example, the SPV could choose to buy the modules directly, as they are the most expensive component. This solution is often referred to as 'EPC light.'

A split contract is mainly chosen when the Asset Owner has the necessary in-house resources, skills, and personnel to deal with some of the tasks that would otherwise be outsourced through a full wrap contract. Outsourcing some activities to contractors located in other jurisdictions and shifting profits to other countries may have advantages in terms of tax optimisation and cost savings.

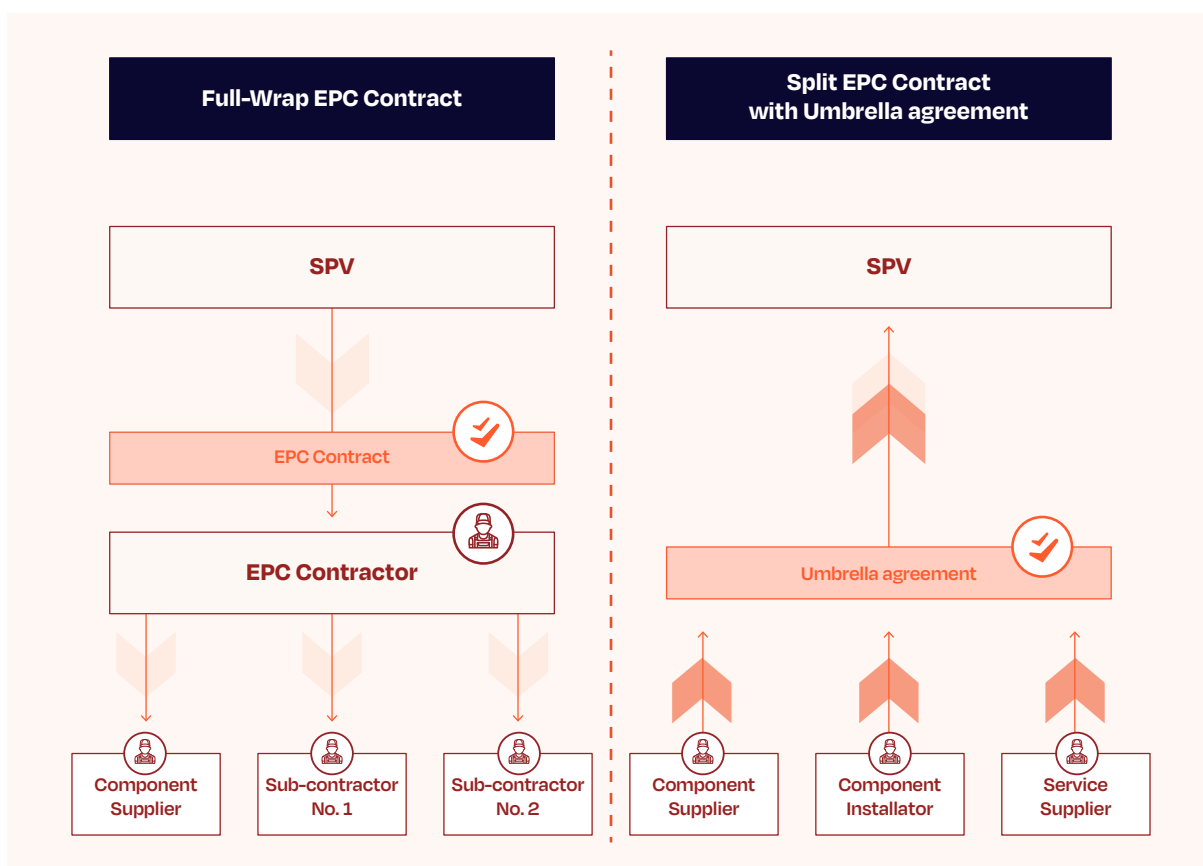
To maintain the single point of liability and efficiently coordinate the different processes, a third agreement is usually executed between all service providers to determine how the risks and the liabilities must be allocated. This is referred to as an 'umbrella agreement' and ensures that no derogation from the overall turnkey covenant concept occurs, and the bankability criteria are respected. Moreover, it should be noted that an umbrella agreement is frequently used in conjunction with parent company guarantees, which ensures the service providers perform all their obligations.

To avoid disputes in the case of a split contract and an umbrella agreement, the following areas should be covered:

1. **Scope of work:** It is important that no gaps arise between the scopes of work in each single agreement, as it is not unusual that technical inconsistencies may occur between different agreements. Such mismatches may be mitigated by defining the project specification in the main contract (usually the installation agreement) and by defining the other scopes of work by reference to it. Thereby the main contractor shall remain responsible for all the further activities
2. **Testing and commissioning:** (mismatch in responsibilities) The main contractor must wrap the completion risk and assume the risk of performing all the testing activities and the economic burden of the related Liquidated Damages
3. **Cross-contract claims:** It needs to be agreed when contractors should be entitled to claim against the SPV for time extensions or cost revision if other contractors default
4. **Caps on liabilities:** The SPV should not be negatively impacted by the sub-division of any liability caps in the splitting process. It may be possible to retain an overall liability cap for each contract on the understanding that the different contractors are not jointly and severally liable
5. **Termination:** The termination of one of the contracts should not have an impact on the other agreements and should not lead to chain resolutions

For a turnkey approach a full-wrap contract is the preferred option due to the single point of liability principle. Lenders frequently prefer to have one financially robust party to take full responsibility in respect to all aspects of the construction works regarding time, budget, costs, and technical and performance requirements.

Full-wrap contract vs split EPC contract with Umbrella agreement



13.1 Interface between EPC contract and regulatory framework

The EPC service provider's activities are also defined by the applicable regulatory requirements and permits obtained by the developer.

The construction of a PV plant requires a myriad of permits and approvals from public authorities and other regulated bodies. In this respect, the EPC service provider is responsible for obtaining and maintaining all permits and approvals which are strictly necessary for the construction activity (and if applicable, any short term O&M performed by the EPC), for the project (e.g., filing design amendments or other requests to the competent authority). Project related permits, licences and approvals, e.g. the construction permits (zoning permits, nihil obstat from public authorities, environmental impact assessment decree) are usually procured for the Asset Owner by developers in the pre-construction phase and the Asset Owner must make sure that such authorisations will remain in full force for the entire EPC contract's term. The termination of one of them may constitute a termination event under the EPC contract. Even if the plant's Basic Design is not included under the scope of work of the EPC contract, the EPC service provider is obliged to faithfully comply with it, as it has been validated by the public authorities during the authorisation process. As many European countries' grid requirements are strictly defined, the contractor has limited flexibility for altering the design and specifics of the PV power plant. Moreover, during the construction phase, the EPC service provider is also responsible for satisfying any conditions, listed under the permits, upon which the entry into the operation of the PV plant is conditional.

An example of the interaction between an EPC service provider and public bodies occurs at the end of the construction phase, when the PV plant is connected to the grid. Here, the EPC service provider is liable to the SPV and the grid operator for respecting the requirements detailed under the grid rules and concerning the technical requirements with which the PV plant must comply (i.e. voltage, reactive power to be injected into the grid).

It is not unusual that the construction of part of the infrastructure network (i.e., the segment that connects the power plant to the primary cabin) is outsourced to the EPC service provider. When this is the case, the service provider must also coordinate activities with the grid operator during the testing process.

13.2 Contractual Risk Allocation

The EPC contract is one of the most important elements of a solar project and it has a major impact on project financing and bankability. The EPC contract has mandatory principles and contains certain provisions which ensure the bankability of the entire transaction. The presence of these characteristics in the contractual framework makes it possible to carry out a risk allocation (both cost and technical risk allocation) between the EPC service provider(s) and the Asset Owner (or SPV). An appropriate and clear risk allocation, with a single point of reference, are the fundamental expectations of most Lenders. This makes it possible to shift the economic risk related to increasing costs directly onto the Asset Owner. The less well defined the risk allocation of a project is, the more equity support will be demanded from the Asset Owner (investor).

For achieving a balance between the Lenders' demands, and the Asset Owner's interests, the key clauses regarding timing, cost and quality of the works should be aligned to market standards bearing in mind that different Lenders often have different requirements. In this regard, important main drivers are:

- **Single point of liability:** The EPC service provider should be the only one responsible for the Engineering, Procurement, Construction and Commissioning of the PV plant. This allows a total shift of the technical risk from the Asset Owner (SPV) towards the EPC service provider who must face any claims that may arise in connection with the construction of the PV plant, and as such a thorough and detailed description, as exhaustive as possible, in order to avoid ambiguities and potential disputes of the scope of the works is required. This principle is considered a key element as it represents the first tool for the lenders in assessing the creditworthiness of the entire project. However, with regards to the main components the Asset Owner (SPV) may enter into different agreements for the procurement and installation or the EPC service provider might assign all its (warranty) rights regarding the main components directly to the Asset Owner (SPV) to allow direct claims of the Asset Owner towards the component suppliers.
- **Fixed price provision excluding or limiting price adjustments:** This element prevents small technical variations, or small alterations to the design leading to a revision of the price. It allows Lenders to easily assess and define all the costs in the banking base case and the Asset Owner to transfer most of the construction cost risk to the EPC service provider.
- **Fixed completion date:** provision which excludes any request for time extension.
- **Pre-agreed construction standards and criteria:** This requirement assigns the responsibility for achieving minimum standards on parameters like PR and peak power to the EPC service provider. It also makes the EPC Service provider responsible for ensuring compliance with the relevant grid regulatory framework. If a plant fails to meet the minimum guaranteed performance, the Asset Owner is usually granted the right to claim for a pre-defined financial compensation and to request the immediate rectifications of defects and other deficiencies which lead to such underperformance. If such underperformance is not rectified within a reasonable period of time the Asset Owner may have the right to reject the plant and get compensation for the suffered damages. However, performance risk shifting is mitigated through the insertion of a cap on the service provider's maximum liability for payment of liquidated damages (performance LDs).

- **Commercial risk shifting (procurement, inventory, and warranty of components):** As the EPC service provider is the key point of contact for others involved in the construction phase, it is sometimes seen that they may provide a warranty on quality of electromechanical systems, in addition to the product warranty granted by the relevant component producer under national law.
- **Issuance of securities:** The kind of securities usually provided by the EPC service provider very much depends on its creditworthiness. The securities can take the form of advance payment bonds, performance bonds and warranty bonds, of 5-10 % of the contract price, to be delivered by the EPC service provider to secure the relevant payments of the relevant LDs or the performance of the relevant works.

In addition to the points above, the EPC service provider's duty to rectify the constructed works are not generally included in all EPC contracts but limited to agreements executed to build large-scale plants. As EPC contracts tend to be tailored to the size of the project, often smaller plants are not expected to fulfil the same performance guarantees as bigger projects.

13.3 Price and Payment

As for the payment, the EPC contracts typically provide for a payment schedule running in parallel with the construction milestones agreed between the parties.

It is not unusual to have a down-payment of around 10% of the full price, paid upon the execution of the contract (or upon satisfaction of specific conditions required for the contract to take effect). Afterwards, payments tend to be tranches of the full price, paid when relevant milestones have been met. Parties may also agree – in case there is no performance or warranty bond – to postpone the payment of the last 5% of the price until after completion of the works, and the expiry of the warranty period (usually 24 months after the PAC is issued) or until a Warranty Bond is provided by the EPC service provider.

EPC contracts are usually drafted including a fixed price clause which binds the parties to the total price agreed under the contracts. However, occasionally external factors, outside of anyone's control can have a pronounced effect on a project. In these cases, a flexible approach to allocating responsibility for resolving issues should be taken, with the stakeholder most able to handle the issue taking the lead.



However, parties may negotiate specific cases and scenarios when a change in the price is allowed. In certain cases, the Asset Owner may retain the right to withdraw from the contract.

Events justifying a revision of price are generally limited to unforeseeable changes in conditions such as relevant and applicable changes in legislation, or natural events which make the execution of the works particularly burdensome on the service provider.

Every provision that could have an impact on the fixed price of the contract should always be carefully drafted and evaluated from a bankability perspective. This is because banks prefer stability in the price throughout the entire contract. Therefore, there should only be a very limited set of cases which can ideally be objectively assessed where a price adjustment is justifiable for solid reason or project specifics.

In case of delays in the execution of the works or technical defects in the operation, the Asset Owner may have the right to call for a reduction of the price and, under certain conditions, liquidated damages, provided under the contract.

In case of disputes over the payments, parties shall firstly meet to try and amicably settle the dispute. If a technical issue is the basis for a payment dispute, the parties may agree that a technical third-party – agreed before in the contract negotiations – should make a judgement regarding the technical issue. It should be noted that in the price determination, any review mechanism is generally excluded between the parties. Therefore, even in the event of an increase in the cost of materials, labour, or other unforeseeable factors, the agreed price shall not be subject to any change and no other arrangement in the payment mechanism may be adopted.

13.4 Bonds and Guarantees

Depending on the creditworthiness of the EPC service provider, the EPC contract may provide for the issuance of some of the following bonds on the service provider's side to secure its obligations under the EPC:

- **Advance Payment Bond:** This is generally issued upon payment of the down-payment or as a condition for making such a payment if required by the Asset Owner. The Advance Payment Bond will usually cover 10-15% of the price
- **Performance Bond:** This is sometimes required by the Asset Owner and generally issued upon release of the Advance Payment Bond or issued directly upon execution of the EPC contract if no advance payment is provided and there is no issuing of an Advance Payment Bond. The Performance Bond will usually cover 10-15% of the price and will remain in full force until the PAC has been issued and the delivery of the Warranty Bond
- **Warranty Bond:** This is generally issued upon release of the Performance Bond (if required by the Asset Owner) and issuance of the PAC. The Warranty Bond will usually cover 5% of the price and will remain in full force and effect until the expiry of the 24-month EPC warranty period, usually ended by the FAC being issued

All the guarantees above are typically issued as irrevocable, autonomous guarantees by a bank, or another acceptable financial institution and/or a parent company of the EPC service provider, each with an appropriate credit ranking. Sometimes banks require that such bonds are exercisable upon first demand.

- **Asset Owner's parent company guarantee:** The EPC service provider may ask for the issuance of a guarantee securing all the Owner's payment obligations throughout the contract. This is usually done through the issuance of a parent company guarantee, provided that such parent company is sufficiently creditworthy. The Asset Owner's parent company guarantee is generally issued upon execution of the EPC contract and will be in place for the entire duration of the EPC phase, usually covering around 60-80% of the price, depending also on whether or not a down payment is foreseen in the EPC contract.

13.5 Limitation of Liability and Liquidated Damages

Under the EPC contract it is common to set general limitations on the liability applying to both parties. The EPC service provider's liability should not exceed 100% of the total price agreed under the EPC contract, with exclusion of any limitation for willful misconduct or gross negligence.

Liability for indirect damages or losses, and punitive or consequential damages is usually excluded for both parties. Under standard EPC contracts, the service provider also is usually liable for payment of specific LDs or compensations provided to remedy the damages suffered by the Asset Owner for specific violations of the contract.

Standard Liquidated Damages (LDs) are the following:

- **Delays Liquidated Damages:** These are often calculated on the basis of an agreed formula or as a fixed amount due per each day/week of delay on the deadline set for reaching the COD. The amount should be linked to the potential loss of revenue suffered by the Asset Owner
- **Technical Delay Liquidate Damages:** These are generally linked to a failure to meet certain technical thresholds for productivity, power curve or PR, agreed between the parties, during the 24-month warranty period

The LDs/compensation aim to reflect the anticipated loss of revenue or increase in operating costs (or both) resulting from failure to achieve the required performance over the life of the project, or in the agreed deadline.

It is worth noting that the EPC contract will state a maximum amount payable as liquidated damages/compensation for each category (which is usually a percentage of the price comprises between 5-15%, that in extraordinary cases may reach even higher amounts for the single category price). Should the agreed cap amount be reached, the Asset Owner should have the option to terminate the contract, after having granted the EPC service provider the right to reasonably increase such specific LD/compensation cap to avoid the termination of the EPC contract and to ask for full repayment of the accrued liquidated damages.



13.6 Termination, Withdrawal and Force Majeure

Termination clauses are very sensitive and are typically negotiated over a long period between the parties. Generally, the EPC service provider has very limited contractual termination rights, which are predominantly linked to failure of payments that are not remedied within the relevant cure period.

If a bank is financing the project, a direct agreement will likely be put in place between the bank, the EPC service provider and the Asset Owner. Under the direct agreement, the EPC service provider's termination right will be further limited. This is because the EPC service provider will have to inform the bank in advance about its intention to terminate the agreement and the bank will have the right to cure the issue.

At the same time, the Asset Owner will typically have no right to terminate for convenience but the right to terminate the EPC contract for any material failure by the EPC service provider in meeting its obligations including deadlines, payments of liquidated damages and quality standards. Typically, there is a right for the EPC service provider to cure any breach within a reasonable cure period before the Asset Owner can terminate the EPC agreement.

In case of termination for violations of the relevant obligations, the non-defaulting party will be entitled to claim for damages within the limits set forth under the contract. Another case that may lead to the termination of an EPC contract is the occurrence of a **force majeure** event. This can be a natural event (or any other event) which is out of the affected party's control and has a negative impact on the fulfilment of the affected party's obligations.

The EPC contract generally provides a sample and non-exhaustive list of force majeure events. Each party shall have a duty to mitigate the impacts of force majeure events, to minimise the suspension time and restart the performance of services as quickly as possible. However, if the force majeure clause is triggered, the affected party is exempted from any obligation and liability due to its default for the period during which the force majeure event actually prevents the affected party from fulfilling its contractual obligations. To invoke this mechanism the affected party has to inform the other of the forecasted restart day and the measures to be adopted to preserve the balance of obligations originally set forth under the contract. To protect the interests of each party, both may have the right to terminate the contract should the force majeure last for a period longer than a determined threshold (generally 90 consecutive days or 180 days in aggregate), or it jeopardises the performance of the relevant obligations.

Recent global supply chain disruptions, geopolitical events, and regulatory interventions have highlighted the importance of clearly defined force majeure provisions and mitigation obligations, particularly for projects relying on globally sourced components such as batteries and power electronics.

Another sensitive clause is the right to withdraw an EPC contract. Like termination events, withdrawal events are few and well-defined. They generally occur when a force majeure event lasts more than the agreed maximum period, or one of the parties is subject to insolvency proceedings or other similar procedures (depending on the crisis, these can range from difficulty in meeting obligations to the bankruptcy of the service provider or Owner). Other withdrawal events may occur if a change in the applicable law leads to the introduction of further compliance requirements, or other unforeseeable charges, so burdensome that they affect the contractual relationship. In these cases, the affected party must notify the other party in writing, indicating the date of effective withdrawal, and the description of the withdrawal event. This is to give the other party the necessary time to find a reliable replacement.

13.7 Ownership, Expiration of Warranties and Transfer of Risk

The Asset Owner acquires full title of ownership over the components to be installed (except the mounting system, panels, and inverters) usually upon PAC and full payment of the invoices for such components.

For the main components (PV modules, mounting system, transformers and inverters), the timing of transfer of warranty rights and guarantees against the suppliers is usually the issuance of the PAC, as they must be installed and tested by the EPC service provider, unless the EPC service provider grants an own warranty for the components for an initial warranty period of usually 2 years following PAC. Until the PAC issuance date, the EPC service provider retains full title on the main components by virtue of its role as installer and operator of the plant and until the Asset Owner fully pays the invoices for such components.

As the EPC service provider is the only responsible subject for the operation of the plant until the PAC, they also retain the risk of loss. The Asset Owner can also accept the risk of loss and damage from commissioning of the PV plant onwards, as from that date it gets the revenues of the PV plant and pays the OPEX.

After PAC, the equipment warranties remain with EPC provider until FAC is reached, at which point the warranties are assigned to the Asset Owner. However, it is also seen that module warranties and claims are already assigned to the Asset Owner upon PAC, i.e. the Asset Owner benefits from direct claims against the module supplier/manufacturer instead of against the EPC service provider.

13.8 Assignment and Set-off

In general, the EPC contract should exclude each party from reassigning the contract without the prior consent of the other party. The rationale for this is maintaining the same set up as on the date of execution. This principle is based on the Owner's interest in having a solid and reliable counterpart for the construction of the plant. The same key concept is the rationale applicable to the limitation of subcontracting. To the extent the EPC contract allows for the services to be subcontracted, the EPC service provider shall remain fully responsible for the services performed by its subcontractors.

Since solar power plants are increasingly financed through non-recourse financing schemes, the EPC service provider cannot set-off its claims and assign its rights against the Asset Owner. On the other hand, the Owner is always entitled to assign the receivables arising from the EPC contract in favour of lenders.

Where battery warranties extend beyond the EPC warranty period or are subject to operational conditions such as cycling limits, these assumptions should be transparently disclosed and aligned with the project's technical due diligence to avoid inconsistencies between contractual and financial models.

Annex A

List of Applicable Standards

Annex Table A

List of Applicable Standards.

Standard	Description
Cyber Resilience Act	
DIN EN 1090-1	Execution of steel and aluminium structures – Requirements for conformity assessment
DIN EN 50461	Solar cells – Test methods – Part 1: Measurement of pull strength of soldered contacts
EN 10346	Continuously hot-dip coated steel flat products for cold forming
EN 50380	Datasheet and nameplate information for photovoltaic modules
EN ISO 1461	Hot dip galvanised coatings on fabricated iron and steel articles
EU Battery Regulation 2023/1542	Sustainability, performance, and recycling of batteries
IEC 60044-8	Instrument transformers – Part 8: Electronic current transformers
IEC 60076 series	Power transformers
IEC 60228	Conductors of insulated cables
IEC 60364 series	Low-voltage electrical installations
• IEC 60364-4-41	Protection against electric shock
• IEC 60364-4-43	Protection against overcurrent
• IEC 60364-5-52	Wiring systems
• IEC 60364-5-54	Earthing arrangements and protective conductors
• IEC 60364-7-704	Construction and demolition site installations
• IEC 60364-7-712	Photovoltaic (PV) power supply systems
• IEC 60364-8-1	Energy Efficiency
• IEC 60364-8-82	Prosumer's low-voltage electrical installations
IEC 60730	Automatic electrical controls for household and similar use
IEC 60891	Photovoltaic devices – Procedures for temperature and irradiance corrections
IEC 60904 series	Photovoltaic devices
• IEC 60904-1	Measurement of photovoltaic current-voltage characteristics
• IEC TS 60904-1-2:2019	Measurement of current-voltage characteristics of bifacial PV devices
• IEC 60904-3	Measurement principles for terrestrial PV solar devices with reference spectral irradiance data
• IEC 60904-7	Computation of spectral mismatch error
• IEC 60904-8	Measurement of spectral response of a PV device
IEC 61000 series	Electromagnetic compatibility (EMC)
IEC 61215 series	Terrestrial PV modules – Design qualification and type approval for crystalline silicon
IEC 61701:2020	PV modules - Salt mist corrosion testing
IEC 61716:2013	PV modules - Ammonia corrosion testing

List of Applicable Standards.

Standard	Description
IEC 61724-1	PV system performance monitoring - Guidelines for measurement, exchange and analysis of data
IEC 61727	PV systems – Characteristics of the utility interface
IEC 61730 series	PV module safety qualification
IEC 61850 series	Communication networks and systems for power utility automation
IEC 61853 series	PV module performance testing and energy rating
IEC 61936-1	Power installations exceeding 1 kV _{AC}
IEC 61960	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Performance measurement
IEC 62093	Design qualification of balance-of-system (BOS) components
IEC 62109 series	Safety of power converters for use in PV power systems (including IEC 62109-3 for arc fault detection)
IEC 62271 series	High-voltage switchgear and control gear
IEC 62443	OT security for the development process of components, component security and system security, as well as operational security for O&M
IEC 62446 series	PV systems – Requirements for testing, documentation, commissioning, and maintenance
IEC 62477	Safety requirements for power electronic converter systems
IEC 62548	PV arrays – Design requirements
IEC 62619	BESS-specific safety
IEC 62716:2013	PV modules - Ammonia corrosion testing
IEC 62782:2016	PV modules – Cyclic (dynamic) mechanical load testing
IEC 62788-1-5:2019	Encapsulants – Test method for determining the peel strength of encapsulants to a rigid substrate
IEC 62788-1-6:2017	Encapsulants – Methods for determining gel content and dissolution rate of EVA encapsulant
IEC 62788-7-3:2022	Abrasion of materials and coatings
IEC 62790	Junction boxes for PV modules – Safety requirements and tests
IEC 62804 series	Test methods for the detection of potential-induced degradation (PID)
IEC 62817	Design qualification of PV mounting systems (trackers)
IEC 62852	Connectors for DC-application in PV systems – Safety requirements and tests
IEC 62909 series	Bi-directional grid connected power converters
IEC 62910	Test procedure of Low Voltage Ride-Through (LVRT) measurement for utility-interconnected PV inverter
IEC 62915 TS	PV Modules – Retesting for type approval, design and safety qualification

List of Applicable Standards.

Standard	Description
IEC 62930	Electric cables for PV systems (EN 50618)
IEC 62933 series	Safety, performance, and environmental aspects of electrical energy storage systems
IEC 62933-5-1/-2	
IEC 62938	Non-uniform snow load testing for PV modules
IEC 62941	Quality system for PV module manufacturing
IEC 62979	PV module bypass diode thermal runaway test
IEC 63056	BESS-specific safety (battery pack)
IEC 63126 TR	Guidelines for qualifying PV modules, components and materials for operation at high temperatures
IEC 63202-1:2019	Measurement of light-induced degradation of crystalline silicon photovoltaic cells
IEC TS 63202-4:2022	Measurement of Light and Elevated Temperature Induced Degradation (LETID)
IEC 63209 series • IEC TS 63209-1:2021 • IEC TS 63209-2:2022	Extended-stress testing for PV modules (risk analysis and reliability) IEC TS 63209-1:2021: Extended-stress testing – Part 1: Modules IEC TS 63209-2:2022: Extended-stress testing – Part 2: Polymeric component materials
IEC 63225 TR	Incompatibility of connectors for DC-application in PV systems
IEC 63279 TR	Sequential and combined accelerated stress testing for de-risking PV modules
IEC TS 63342:2022	Extended testing for Light and elevated Temperature Induced Degradation (LETID)
IECRE 02	Basic Rules
IECRE OD-300-X series	e.g., OD-300-1 for PV Sector Scheme
IECRE OD-302-X	PV Project Certification
ISO 14001	Environmental management systems Requirements with guidance for use
ISO 14040/14044	Life Cycle Assessment Principles and Framework / Requirements and Guidelines
ISO 17020	Conformity assessment Requirements for the operation of various types of bodies performing inspection
ISO 17025	General requirements for the competence of testing and calibration laboratories
ISO 22095:2020	Chain of Custody
ISO 27001/27002	Information security management
ISO 2859-1:1999	Sampling procedures for inspection by attributes – Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection

List of Applicable Standards.

Standard	Description
ISO 9001	Quality management systems Requirements
NIS2 Directive	NIS2 Directive: EU-wide requirements for information security
NFPA 855:2026	NFPA 855:2026: Standard for the Installation of Stationary Energy Storage Systems
Solar Stewardship Initiative (SSI) Standards	Solar Stewardship Initiative (SSI) Standards: ESG and supply chain traceability
UL 1703	UL 1703: Standard for Flat-Plate Photovoltaic Modules and Panels
UL 1973	UL 1973: Standard for Batteries for Use in Stationary Applications
UL 9540A	UL 9540A: Standard for Energy Storage Systems and Equipment
Low Voltage Directive (2014/35/EU)	
EMC Directive (2014/30/EU)	

Annex B – Skills Matrix, Personnel and Training

Annex Table B

Skills Matrix, Personnel and Training

Job families	Tasks	Required certification	Required skills	Function										
				Project management	Materials Management	Authorities	Electrical	Mechanical	Inspection	Monitoring	Health and Safety	Mechanical engineer	Geographical – Geotechnical	
Site assessment	Risk Assessment - health and safety	Certification (postgrad) of Occupational Health & Safety (or national equivalent)	Hazard identification; permit to work; ERP awareness									X		
	Risk Assessment - mechanical	Chartered/registered Structural engineer (as per national rules)	Structural risk appraisal; temporary works; lifting/exclusion zones	X									X	
	Related partly solar specific regulations (heritage protection, building authority)		Knowledge of Solar Specific regulations and permitting criteria; Stakeholder management; basic environmental constraints	X		X								
Authorisation	Communication with Electricity Provider	Certified electric engineer (country specific)	Knowledge about actual grid standards and regulation, managerial and communication skills Understanding of evolving EU grid codes, flexibility markets, grid connection process; stakeholder communication	X		X	X							
	Create and submit authorisation documentation	License for designing renewable energy structures (country specific)	Knowledge of legal formatting and regulatory terminologies			X								
Electrical	Grid Compliance & Flexibility Engineer: translate grid code; protection/telemetry; plan/witness tests; flexibility participation readiness	National electrical licence where required; HV authorisation if applicable	Training on Grid Connection Codes; Flexibility in energy systems; Systems thinking (hybrid PV+BESS); Smart asset/digital monitoring (signals & QA)				X		X	X				

Skills Matrix, Personnel and Training

Job families	Tasks	Required certification	Required skills	Function										
				Project management	Materials Management	Authorities	Electrical	Mechanical	Inspection	Monitoring	Health and Safety	Mechanical engineer	Geographical - Geotechnical	
Procurement	Purchasing PV modules, Frames, Inverters, electrical materials etc. Manage Supplier		Knowledge of PV systems Supply-chain management Supplier due diligence	X	X									
	Sustainability & ESG Compliance Officer: supplier ESG due diligence & traceability (SSI); embed EU GPP in RfPs; manage ESG evidence; support GRI inputs	ISO 14001/9001 awareness accepted	ESG & Sustainable Finance; Circular economy awareness; Environmental management; GRI; EU GPP toolkit; stakeholder comms SSI traceability evidence packs OECD Due Diligence awareness	X	X	X								
Logistics, Organisation	Managing transportation of personnel, materials and tools	Oversize/heavy haulage permits as required	Route planning; inventory control; site logistics		X									
	On site organisation planning		Scheduling; resource allocation; laydown & crane pad planning				X	X				X		
	Supply Chain Resilience Manager: risk mapping; dual sourcing; oversize/heavy transports (e.g., BESS containers); lift permits & crane pads	Lift planning/permitting training (where required)	ESG & Sustainable Finance (supplier lens); EU GPP awareness; contingency planning; schedule integration Lift plan sign-off and daily lift briefings	X	X							X		
Construction	PV Module installation	Certified electrician	Basic knowledge about the installed product (e.g. handling, general safety guidelines, installation etc.; see also recommendations by module manufacturer/installation manual, thermography, power measurements) Should have some level of inspection skills (during installation) to ensure PV module quality and identify potential defects.				X	X	X		X			

Skills Matrix, Personnel and Training

Job families	Tasks	Required certification	Required skills	Function											
				Project management	Materials Management	Authorities	Electrical	Mechanical	Inspection	Monitoring	Health and Safety	Mechanical engineer	Geographical - Geotechnical		
Construction	Inverter installation	Certified electrician	Power Electronics (e.g. experience with specific product and type of inverter); OEM procedures; ventilation & derating				X								
	Electric - General	Certified electrician	Other relevant skills (e.g. Specific Inspection & Test training, relevant accredited courses etc.) Grid compliance for PV-BESS systems, knowledge of power quality, ancillary services integration				X								
	Data & Communications	Certified electrician	Termination of specific communication cabling, monitoring/SCADA, satellite/broadband system AI-enabled data analytics and predictive maintenance							X					
	Mounting	Company or country relevant requirements (e.g. working at height, Certified industrial alpinist, asbestos awareness, use of specific equipment, construction/ installation certificate etc.)	Basic knowledge about the installed product (e.g. handling, general safety guidelines, installation etc.; see also recommendations by supplier/installation manual), technical experience; mechanical installation; torque & tolerances					X				X			
	Preparatory works if needed (e.g. earthwork, roof works etc)	Specific job-related certification (country specific)	Earthworks; roofing; site prep	X								X	X	X	
	Technical Lead - Electrical (Responsible for all electrical works and guides electric installers.)	Licensed/chartered electrician	Advanced knowledge and experience in solar system's electric works. Managerial skills, experience in supervision and coordination of teams				X					X			

Skills Matrix, Personnel and Training

Job families	Tasks	Required certification	Required skills	Function										
				Project management	Materials Management	Authorities	Electrical	Mechanical	Inspection	Monitoring	Health and Safety	Mechanical engineer	Geographical - Geotechnical	
Construction	Technical Lead - Mechanical (Responsible for all mechanical works (mounting) and guides installers.)	National license/certification	Advanced knowledge and experience in mounting solar systems. Managerial skills, experience in supervision and coordination of teams					X				X		
	Automation & Robotics Engineer: plan/supervise robotic tools (pile drivers, handlers, drones); safety assessments; acceptance tests; basic troubleshooting	OEM/vendor training as applicable	Automation & robotics (safe collaboration & troubleshooting); Systems thinking; data hand off to monitoring					X	X	X	X			
	Mechanical - Structural		Structural integrity testing , ensuring correct geometrical dimension					X	X				X	
Health & Safety	High Voltage (HV) Substation Access	Certified HV technician	Knowledge and appropriate usage of PPE; safe access; switching awareness										X	
	Electrical Inspection - (Touch protection, tests etc)	Licensed electrician. Touch protection certification (if applicable)	Accuracy, advanced knowledge about related standards. Experience in measuring process				X		X					
	Risk Assessment	Certification of Occupational Health & Safety	Identifying existing and potential health hazards in the workplace (Risk Matrix); hierarchy of controls; documentation										X	
	Occupational Health & Safety training course	Certification of Occupational Health & Safety First Aid at Work											X	
	Managing contractors		Contractor control; inductions; toolbox talks	X									X	

Skills Matrix, Personnel and Training

Job families	Tasks	Required certification	Required skills	Function										
				Project management	Materials Management	Authorities	Electrical	Mechanical	Inspection	Monitoring	Health and Safety	Mechanical engineer	Geographical - Geotechnical	
Health & Safety	Battery (BESS) emergency response readiness	ERP drills recorded)	UL 9540A test awareness; thermal-runaway basics; container HVAC & gas handling; fire detection/suppression procedures									X		
	Other task, company or country relevant requirements (e.g. working at height, asbestos awareness, use of specific equipment, construction/installation certificate etc)		Site specific H&S competencies					X				X		
Environment	Environmental management during works	Environmental Management certificate/ training	Environmental controls; sustainability; noise; water; soil	X	X									
	Environmental Engineer: implement EIA/ biodiversity; noise/water/soil; environmental monitoring; regulator liaison	Environmental management training or national credential	Environmental management; Circular economy awareness; stakeholder engagement			X						X		X
Monitoring and metering	Installing monitoring system (WIFI, SCADA, Connection, Settings)	Knowledge of using monitoring tools (Vendor) – SCADA Certification	Monitoring tool training. Other relevant skills (e.g. data handling tool)								X			
	Digital Monitoring Specialist: dashboards; tag lists/time sync; data QA; PR/availability; performance reports	SCADA/monitoring vendor training (if available)	Smart asset/digital monitoring; KPI methods; data quality controls; basic grid signal awareness Time synchronisation configured (NTP/PTP); data completeness ≥99% over baseline period Tag list coverage & scaling verified against SLD and telemetry register						X	X				

Skills Matrix, Personnel and Training

Job families	Tasks	Required certification	Required skills	Function										
				Project management	Materials Management	Authorities	Electrical	Mechanical	Inspection	Monitoring	Health and Safety	Mechanical engineer	Geographical - Geotechnical	
Monitoring and metering	Cybersecurity Engineer (OT/SCADA): network segmentation; access control; backups; incident response; cyber drills; vendor patching	CISSP (optional/pro track); IEC 62443/OT security training (vendor) 62443/OT security training (vendor)	Cybersecurity for critical infrastructure (OT/SCADA); secure remote access; credential mgmt.; logging; incident playbooks								X	X		
	Meter accreditation and calibration	Electricity providers authorised personnel only					X				X			
Warranty services	Handling Equipment and assets Properly during construction as well as ensure warranty conditions are kept		Manufacturer warranty terms; evidence & record keeping	X								X		

SolarPower Europe
Solar | Storage | Flexibility