IRENA
International Renewable Energy Agency

BOOSTING SOLAR PV MARKETS:

THE ROLE OF QUALITY INFRASTRUCTURE

About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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Contributing authors

Francisco Boshell, Alessandra Salgado (IRENA) and Paul Raats (DNV GL).

For further information or to provide feedback: publications@irena.org

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Abbreviations

AC	alternating current
ASA	Australian Safety Approval
BIPM	International Bureau of Weights and Measures (Bureau International des Poids et Mesures)
BIS	Bureau of Indian Standards, India
BoS	balance of system
CCS	Conformity Certification Services Pty. Ltd.
CEC	Clean Energy Council, Australia
CIFES	Center for Innovation and Promotion of Sustainable Energy (Centro Nacional para la Innovación y Fomento de las Energías Sustentables), Chile
CORFO	Production Development Corporation (Corporación de Fomento a la Producción), Chile
CPN	cost priority number
CQC	China Quality Certification Centre
c-Si	(poly)crystalline silicon
DC	direct current
EMC	electromagnetic compatibility
EPC	Engineering, Procurement and Construction
ESV	Energy Safe Victoria (Australia)
FiT	feed-in tariff
FSEC	Florida Solar Energy Center
GW	gigawatt
IAM	array incidence loss coefficients
IEC	International Electrotechnical Commission
IECEE	IEC Conformity Assessment for Electrotechnical Equipment and Components
IECRE	IEC System for Certification to Standards Relating to Equipment for Use In Renewable Energy Applications
IRENA	International Renewable Energy Agency (IRENA)
ISO	International Organization for Standardization
JAS-ANZ	Joint Accreditation System of Australia and New Zealand
kWh	kilowatt hour
kWp	kilowatt peak
LCOE	levelised cost of electricity
LID	light induced degradation
m^2	square meter
MCS	Microgeneration Certification Scheme
MNRE	Ministry of New and Renewable Energy, India
m-Si	mono-crystalline
MW	megawatt
NABCEP	North American Board of Certified Energy Practitioners
NEC	National Electrical Code, United States
NMI	National Metrology Institute
NOCT	nominal operating cell temperature
NREA	New and Renewable Energy Authority, Egypt
NSM	National Solar Mission, India
PES	National Strategic Programme on Solar Industry (Programa Estratégico Nacional de Industria Solar), Chile
p-Si	multi- or polycrystalline
PV	photovoltaic
QA	quality assurance
QI	quality infrastructure
QMS	quality management system
REC	Renewable energy certificates
STC	standard test conditions
TBS	Tanzania Bureau of Standards
TC82	Technical Committee for Photovoltaics (International Electrotechnical Commission)
UL	Underwriters Laboratories
W	watt
W/m^2	watt per square meter

Summary for POLICY MAKERS


1

Summary for Policy Makers

The upsurge of solar photovoltaics

By the end of 2016, the global cumulative installed capacity for photovoltaic (PV) power had reached an estimated 290 gigawatts (GW), indicating nearly 50 times the growth in cumulative installed capacity within a decade (see Figure 1.1). The uptrend of new installed capacity is expected to be maintained in the years to come as new markets expand, such as those of Latin America, the Middle East, North Africa and Southern Asia. Projections for total PV installed capacity by 2030 range between 1760 GW and 2500 GW. This can be attributed in large part to a continued decrease in the levelised cost of electricity (LCOE) expected for solar PV.

The decrease in PV system LCOE over the past decade has been driven by substantial PV module cost reductions, although projected reductions in the coming decade will be largely driven by a decrease in Balance of System (BoS) costs. IRENA estimates that global average total installed cost of new utility-scale PV systems could fall from approximately USD 1.8/watt (W) in 2015 to USD 0.8/W in 2025, a 57% reduction within a decade. A breakdown of typical costs over time is depicted in Figure 1.2.

Figure 1.1. Evolution of cumulative installed capacity for photovoltaic

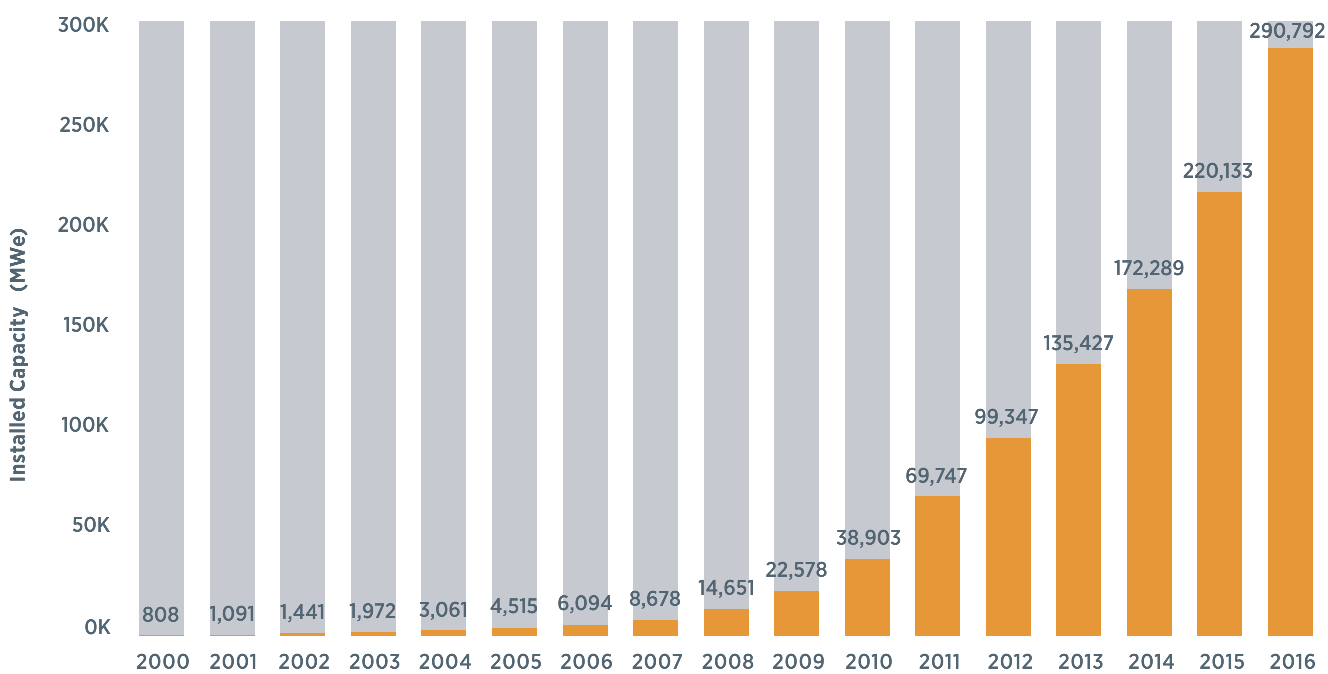
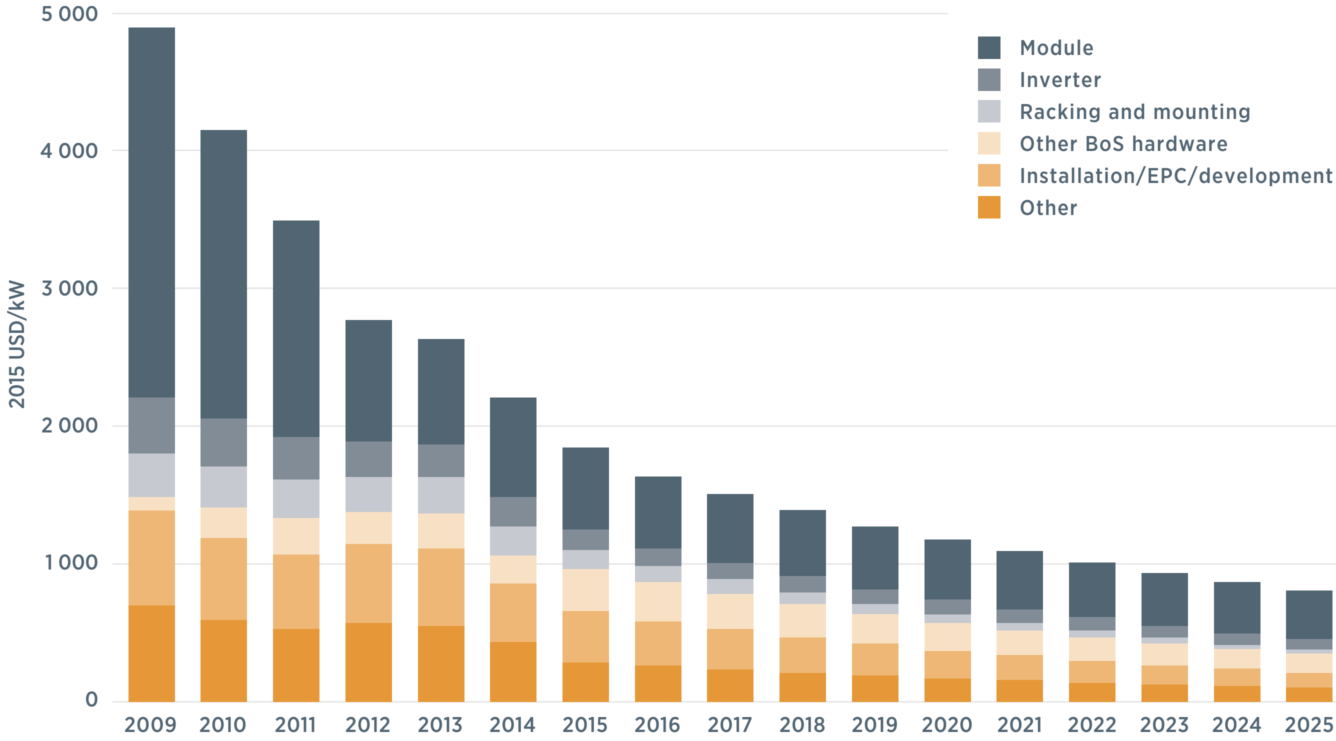


Figure 1.2. System investment cost breakdown for utility-scale photovoltaics: Global weighted average



Technical risk mitigation

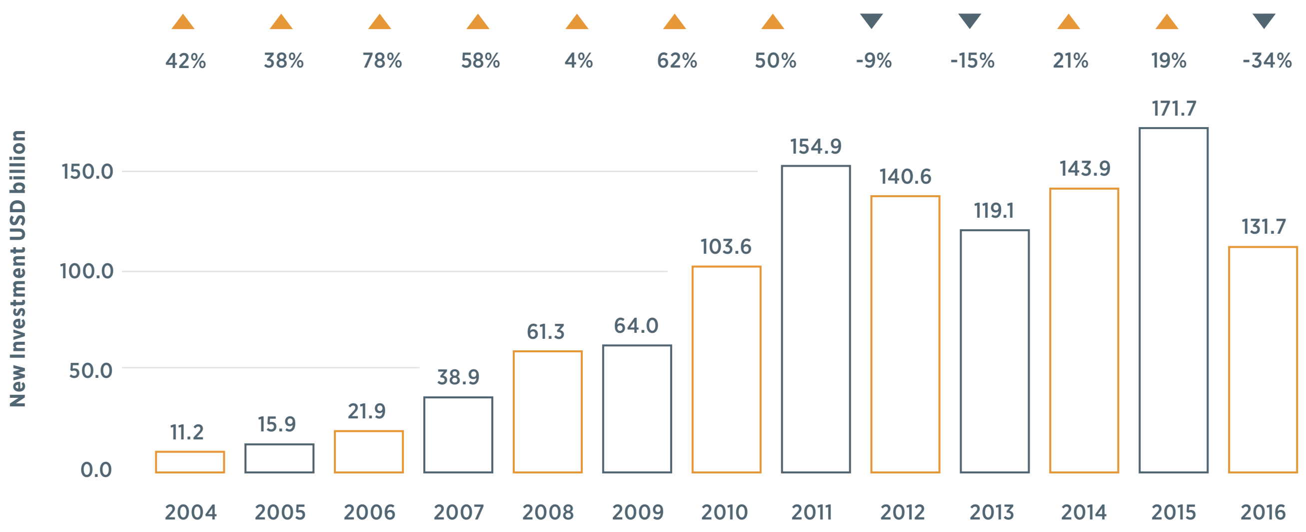
As PV systems reach competitiveness, future market growth will depend on assuring their performance and durability.

The last 5 years, investments in Solar PV overpassed USD 110 billion annually, as reflected in Figure 1.3. 2016 shows lower investments compared to other years, however it was a record year for annual net additions in solar PV technology, this decrease reflects the effect costs reductions are having in this technology. Between 2016 and 2030, investments in PV in the order of USD 2 trillion would be required to achieve the projected approximation of 1500 GW of additional installed capacity. With PV systems rapidly becoming a very competitive power supply option, with trillions of U.S. dollars at stake, more efforts should be made to ensure that these systems deliver as expected throughout their lifetime. Thus, in order to lay the foundation for sustainable market growth, credibility on the technology must be enhanced, and the risk for investors, policy makers and consumers alike must be reduced.

Past results indicate that along the project lifecycle, PV systems observe a failure rate with a 'bathtub' curve. Failure rates are higher at early stages due to technology infancy failures, as are end-of-life stages due to wear (see Figure 1.4). At the early stages of project development, the high risk of failure is commonly borne by the engineering, procurement and construction (EPC) holder and the project developer. These stakeholders are often liable for only a few years, which leads them to focus on ensuring short-term quality. Technology failures may decrease in midlife, leading to higher revenues for lenders and project owners, although the curve – at the end of the lifecycle – will reveal a growing trend in breakdowns due to wear. These risks are ultimately assumed by public entities or communities.

Quality assurance (QA) is crucial in order to reduce electricity costs, since it contributes to ensuring stability for the investors and other stakeholders and it is an essential instrument to protect and accelerate future investments in PV deployment. QA helps to reduce risk by providing the confidence that a product or service will meet expectations which, in turn, lowers capital costs, raises performance, increases module lifespans and, finally, lowers LCOE. As shown in Figure 1.4, QA mechanisms may have a substantial positive impact on changing the failure curve shape.

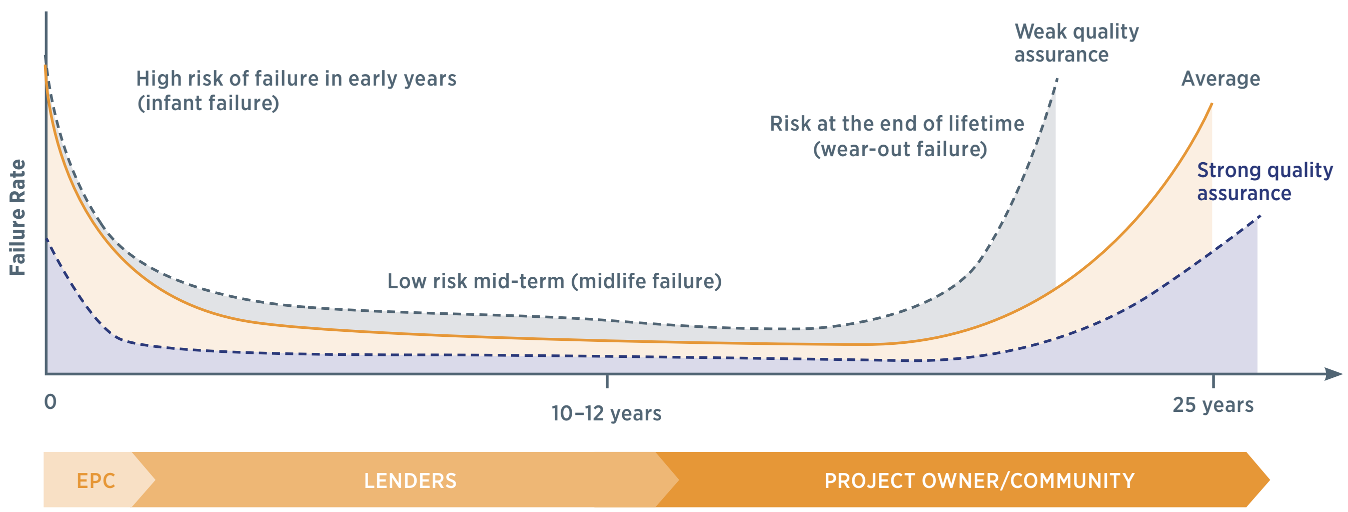
Figure 1.3. Global trends in solar energy investment



Based on: FS – UNEP Centre and Bloomberg New Energy Finance, 2017

Notes: Investment volume adjusts for re-invested equity. Total values include estimates for undisclosed deals. USD = U.S. dollar.

Figure 1.4. Failure curve of solar photovoltaic system



Based on Solar World, 2016

Note: EPC = engineering, procurement and construction.

Bolstering the investment outlook

The implementation of a comprehensive QA framework requires a physical and institutional infrastructure, referred to as quality infrastructure (QI).

QI comprises the entire institutional network and legal framework necessary to regulate, formulate, edit, and implement standards for the common and repeated use of products and services. It also includes the provision of evidence for its fulfilment, including testing, certification, metrology and accreditation.

Within the investment context, QI implementation impacts the key parameters that lie behind the LCOE. Technical risk and the relevant financial rates, the lifetime of the project, and projected energy production are parameters for which QI can significantly reduce uncertainty and enhance performance. A quality-driven environment for emerging technologies and projects can increase investor confidence, enable lower weighted average costs of capital and attract more investments for solar PV technologies.

The importance of quality infrastructure across the value chain

To assure the quality of products will require going beyond the performance role of equipment. It will require the implementation of QI, which will benefit PV systems across the entire value chain.

Quality requires a holistic approach. The implementation of a QA framework covers not only the equipment, but the entire system, including design, installation, operation, maintenance services and disposal. Enacting proper quality schemes, as well as incorporating international practices and stakeholder consultation can impact positively on each of the stages of the technology lifecycle.

A well-developed QI is essential for the sustainable growth of solar PV. At the market level, a national QI that is aligned with international best practices assures quality and safety in the sector. Implementation of QI is effected through the deployment of the elements listed in Figure 1.6.

Figure 1.5. Quality in different aspects of the value chain

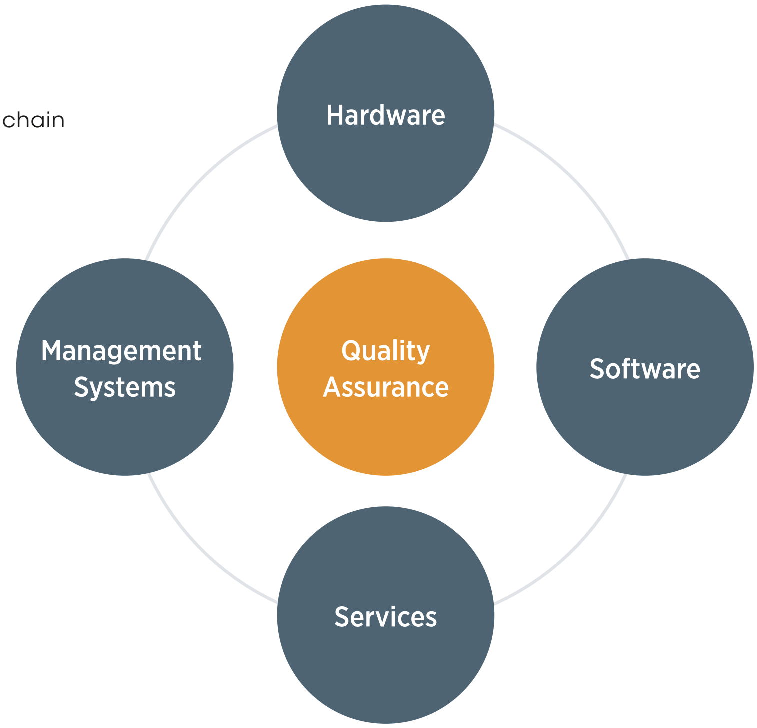
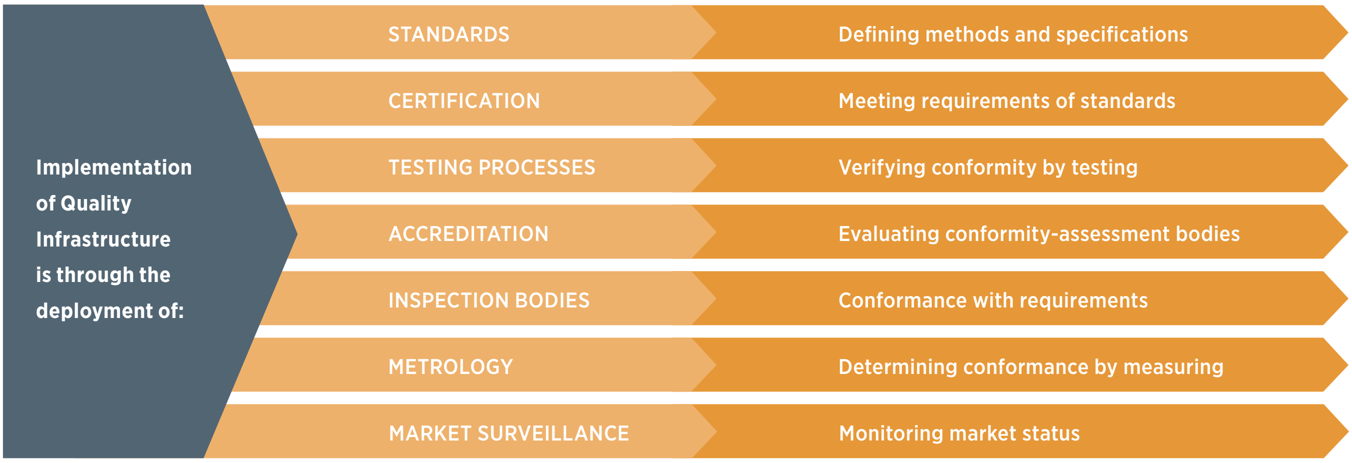


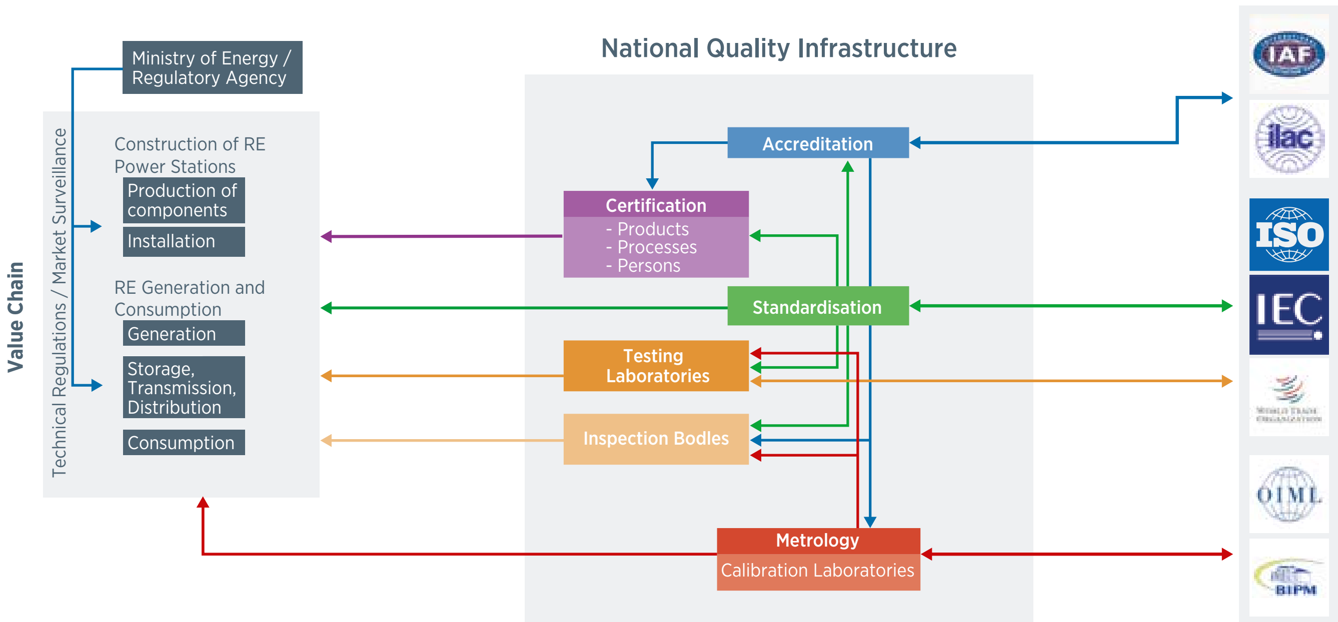
Figure 1.6. Elements of quality infrastructure



Implementing QI in the solar PV market benefits the entire value chain and involve all stakeholders, including governments, financiers, project developers, manufacturers, installers and end users.

Figure 1.7. indicates the elements of a QI, such as described above, and the relevant international institutes that relate to each element.

Figure 1.7. Quality infrastructure framework



Based on The National Metrology Institute of Germany (Physikalisch-Technische Bundesanstalt), 2010

Standardisation

There is a core group of international standards, developed by the International Electrotechnical Commission (IEC) and used broadly on a global scale. In addition, there are country-specific standards that exist, most of which are based on international standards. These measures cover every aspect of the PV value chain, from the system component manufacturing phase through to the end of the technology's life. Specific examples are featured in Figure 1.8.

Figure 1.8. International and country standards applicable to the photovoltaic value chain

System component manufacturing

International – PV Module

IEC 61730 – Photovoltaic (PV) module safety qualification

IEC 61215 – Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval

International – Inverter

IEC 62109 – Safety of power converters for use in photovoltaic power systems

IEC 62093 – Balance-of-system components for photovoltaic systems

The USA – PV Module

UL 1703 – Safety of Safety for Flat-Plate Photovoltaic Modules and Panels

IEC 61215 – Crystaline silicon terrestial photovoltaic (PV) modules – Design qualification and type approval

IEC 61646 – Thin-film terrestrial photovoltaic (PV) modules - Design qualifications and type approval

The USA – Inverter

UL 1741 – Standard for Inverters, Converters, COntrollers and Interconnection Systems Equipment for Use With Distributed Energy Resources

UL 62109 – Standard for Safety of power converters for use in photovoltaic power systems – Part 1: General requirements

* China has developed its own standards

System design and equipment selection

International

IEC 62548 – Photovoltaic (PV) arrays – Design requirements

IEC TS 62738 (Technical Specification) – Design guidelines and recommendations for ground-mounted photovoltaic power plants

IEC 62257 – Recommendations for small renewable energy and hybrid systems for rural electrification – Part 1: General Introduction to IEC 62257 series and rural electrification

IEC 62116 – Utility-interconnected photovoltaic inverters – Test procedure of islanding prevention measures

Australia

AS/NZS 4777 – Grid connection of energy systems via inverters

AS/NZS 3100 – Approval and test specification – General requirements for electrical equipment

China: GB50797-2012 – Code for design of photovoltaic power station

The USA: NEC Article 690 – Solar Photovoltaic (PV) Systems

* Rollout of **national standards** for intallations and certification of installers

Installation and commissioning

International

IEC 62446 – Grid connected photovoltaic systems -- Minimum requirements for system documentation, commissioning tests and inspection

IEC 61724 – Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis

The USA: ASTM E2848 - Standard Test Method for Reporting Photovoltaic Non-Concentrator System Performance

Performance and operation & maintenance (O&M)

International

IEC 61724 – Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis

IEC 62446-2 – Photovoltaic (PV) – Requirements for testing, documentation and maintenance

The USA: Standard Test Method for Reporting Photovoltaic Non-Concentrator System Performance

End-of-Life

International

Decommissioning and waste management options need yet to be properly addressed in international standards.

Directives: like the European Waste Electrical and Electronic Equipment (WEEE) directive, are implemented awaiting transposition into national laws and standards.

Notes: IEC = International Electrotechnical Commission; PV = photovoltaic; NEC = National Electrical Code; AS/NZS = Australian/New Zealand Standard; GB = Chinese Standard.

These are the primary standards most often called upon for project approval or due diligence engineering on behalf of financiers. Further standards that govern manufacturing and testing equipment, sensors, measurements and others provide the QA foundation for product safety and performance. While not specific to PV installations, these standards are relevant and applicable to a variety of other sectors within the electrical industry.

Quality infrastructure development and its different contexts

Successful experience with QI development around the world highlights the benefits of off-grid, distributed generation and utility-scale PV systems.

Table 1.1. lists 11 cases that include developed and developing countries for which the challenges and solutions in developing and implementing QI are indicated. These examples showcase specific measures that relate to the various market development stages. The implementation of QI elements appears highly dependent on country experience and the maturity of the PV market.

Table 1.1. Challenges and solutions for quality infrastructure development

Market	System	Challenges	Solutions
Developing	Utility-scale *(e.g. Egypt, Chile)*	• Lack of lender and developer confidence for ambitious governmental programmes due to political instability	• Creation of an organisation responsible for regulation, monitoring and quality assurance
	Distributed generation *(e.g. China, the Philippines)*	• Lack of quality infrastructure (QI) awareness • QI hampered by unattractive incentive scheme • Market allows for substandard products	• Certification of photovoltaic (PV) installers • Guidelines for testing and certification • Increasing awareness of QI elements for rooftop PV owners
	Off-grid *(e.g. India, Tanzania)*	• Lack of certification process for installers and limited quality assurance for technology, installers and installations	• QI improvements in component testing; adoption of international standards; certification and inspection schemes; inclusion of quality criteria in public programmes; and criteria for commissioning and accreditation of public laboratories
Developed	Utility-scale *(e.g. U.S., Germany)*	• Transmission and distribution capacities require adjustments in line with increasing PV capacity to meet state utility requirements	• Adoption of International Electrotechnical Commission standards in national regulatory frameworks
	Distributed generation *(e.g. Singapore, The Netherlands)*	• Unstructured market surveillance • Lack of national measurement institutes • Private owners are unaware of PV system quality • Installations require high-quality assurance	• Arrangement for mandatory registration of PV installations • Establishment of national solar testing facilities • Provision of information about PV system quality to end users • Adequate skill requirements for installers
	Off-grid *(e.g. Australia)*	• Reducing investor uncertainty through regulatory framework that incorporates quality assurance • Installers not appropriately trained for utility-scale projects • Clean Energy Collective solar component approval process not adequately thorough	• Improved solar component compliance procedure and establishment of a solar retailer code of conduct

The significant effects of quality

The benefits of QI services outweigh their costs. Implementing QI for PV systems may result in significant additional revenue for project owners.

QI implementation and execution measures have an associated cost and require effort. The rationale for implementing a QI, however, is to achieve a positive economic balance by increasing revenues for various actors across the value chain, improving consumer protection, and reducing the carbon footprint.

In the long term, the mitigated costs will outweigh those that relate to the development and implementation of QI. Currently, the costs of reduced quality are partly absorbed by warranty claims and liquidated damages, and these are insufficient to cover all costs of associated quality issues.

Table 1.2. provides an overview of five examples of QI services, as well as the associated costs and expected benefits. These examples were selected based on their capacity to allow for cost benefit analyses.

Table 1.2. Cost/benefit analyses of implementing specific quality infrastructure services

Quality infrastructure service	Cost	Benefit
Development: Solar resource and yield uncertainty		
Energy Production Assessment (EPA) based on measured irradiance data	Measuring local irradiance for at least one year	Reduction of uncertainty in EPA from 8% to 6% leads to an increase in P90 values by 3%. Rewarded through improved loan conditions.
Preconstruction: Prevention of low plant yields		
Batch acceptance testing for wholesale and utility projects	The cost of a batch acceptance test (Typically USD 50 000–55 350 for a 20 megawatt (MW) plant)	A reduction of the degradation rate from 0.75% a year to 0.4–0.6% a year in a project's financial model (Resulting in USD 450 000–1 000 000 of increased revenue over 25 years for a 20 MW plant)
Construction: Performance testing		
Includes independent testing in engineering, procurement and construction contracts on photovoltaic systems performance	The cost of batch testing for a 20 MW plant is USD 276.75–553.50/MW	Photovoltaic module manufacturers deliver modules exceeding contracted performance by 2–3% when batch testing is announced. (Earning an additional EUR 4 000–6 000/MW a year increased generation for a 20 MW plant) (USD 4 428–6 642/MW/year)
Operation and maintenance		
Potential induced degradation (PID) reduction. Inspections to detect, classify and mitigate PID effects	Cost of inspection and corrective actions (for a 6 MW plant in Western Europe: EUR 2 500–4 000/MW) (USD 2 767.5–4 428/MW)	Tackling PID reduces underperformance of 3–5%; however, recovery is not immediate (for the 6 MW plant, EUR 6 000–10 000/MW/year) (USD 6 642–11 070 MW/year)

Quality now and in the near future: Action required

QA is essential to establish the necessary credibility among stakeholders and to enable market growth.

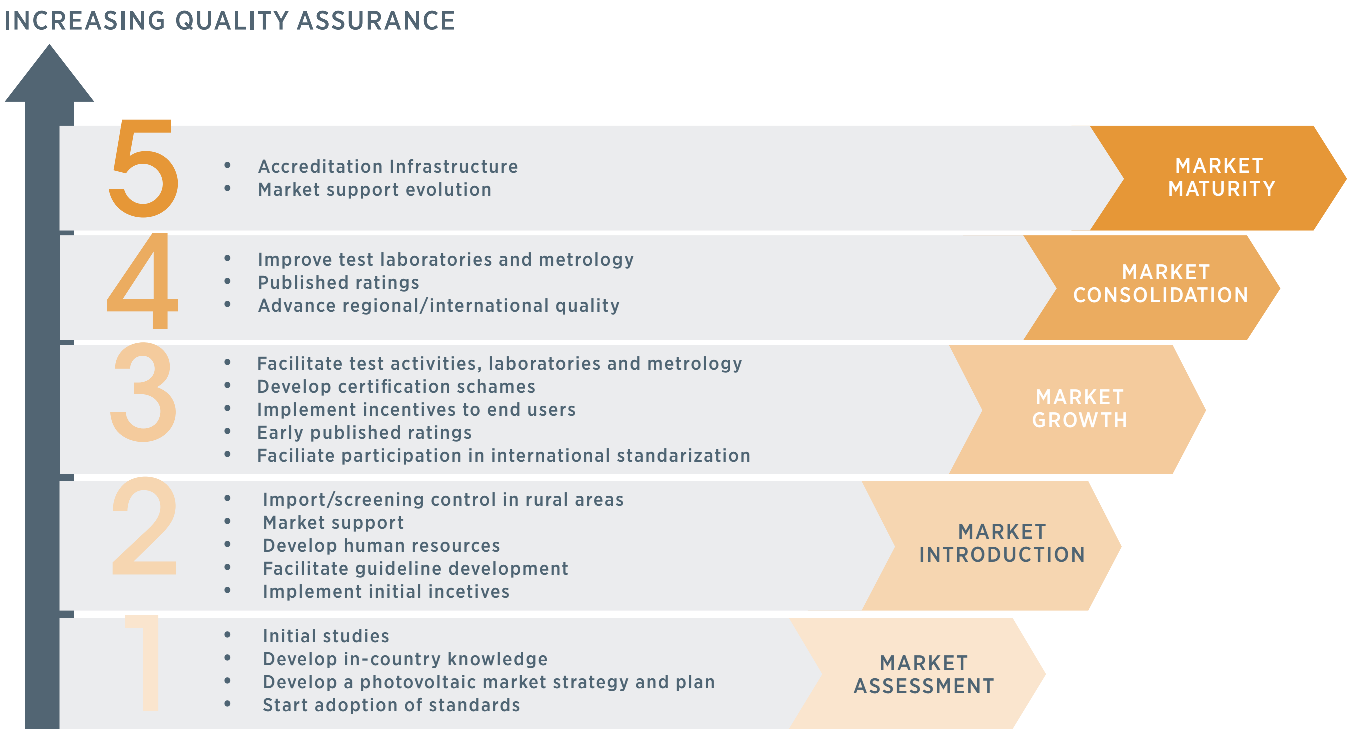
Policy makers can use a staged approach to understand and initiate appropriate measures in developing QI for PV systems. They should bear in mind that quality requirements must be implemented in conjunction with market growth.

QI also acts as a tool to support policies and regulations along the value chain, since it refers to a system that provides the means to appraise conformity with appropriate standards and compliance with relevant regulations. A well-tuned incremental approach can help raise the bar for quality requirements as country capacities and PV markets grow. Well-designed QI requirements are balanced in a way that they do not allow for the deployment of subpar systems; neither are they so stringent that local suppliers and institutions are unnecessarily restricted. Incentives and specific programmes are deployed in most countries to support PV development in line with market growth.

Nevertheless, photovoltaic equipment and applications may sometimes appear to lag in terms of QA schemes that encourage a sustainable and accelerated deployment of this type of technology. Further research on this topic highlights the fact that the cost of implementing testing and certification requirements, the prevailing absence of capacity issues, and the lack of awareness of QI benefits could contribute to the primary challenges of establishing quality schemes.

In order to maintain the balance between market needs, building affordability and QI implementation for solar PV, the approach should be incremental and linked to the level of PV market maturity. Measures at each stage of market development should be sufficiently flexible to allow for various country considerations. The steps proposed in this report will contribute to the effective development of a PV market through QI measures that are successively implemented.

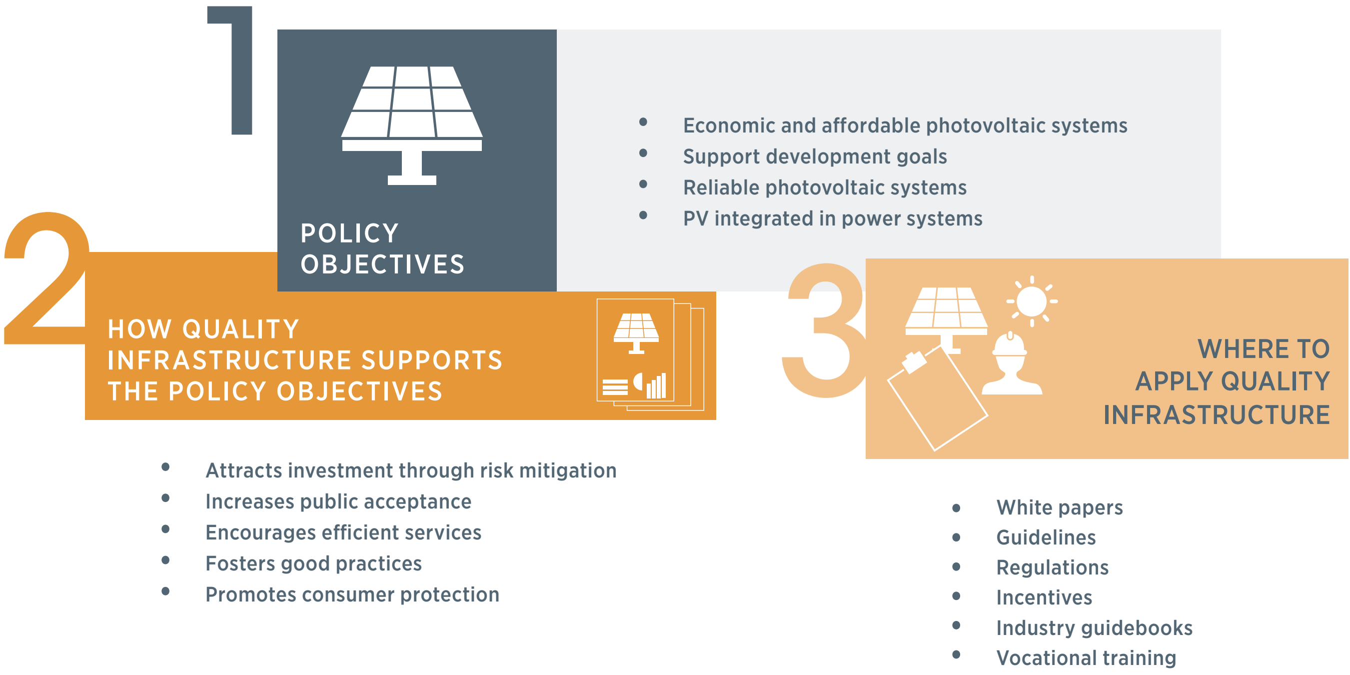
Figure 1.9. Steps in quality infrastructure development linked to market maturity indication



Making the work of policy makers and regulators easier with quality infrastructure

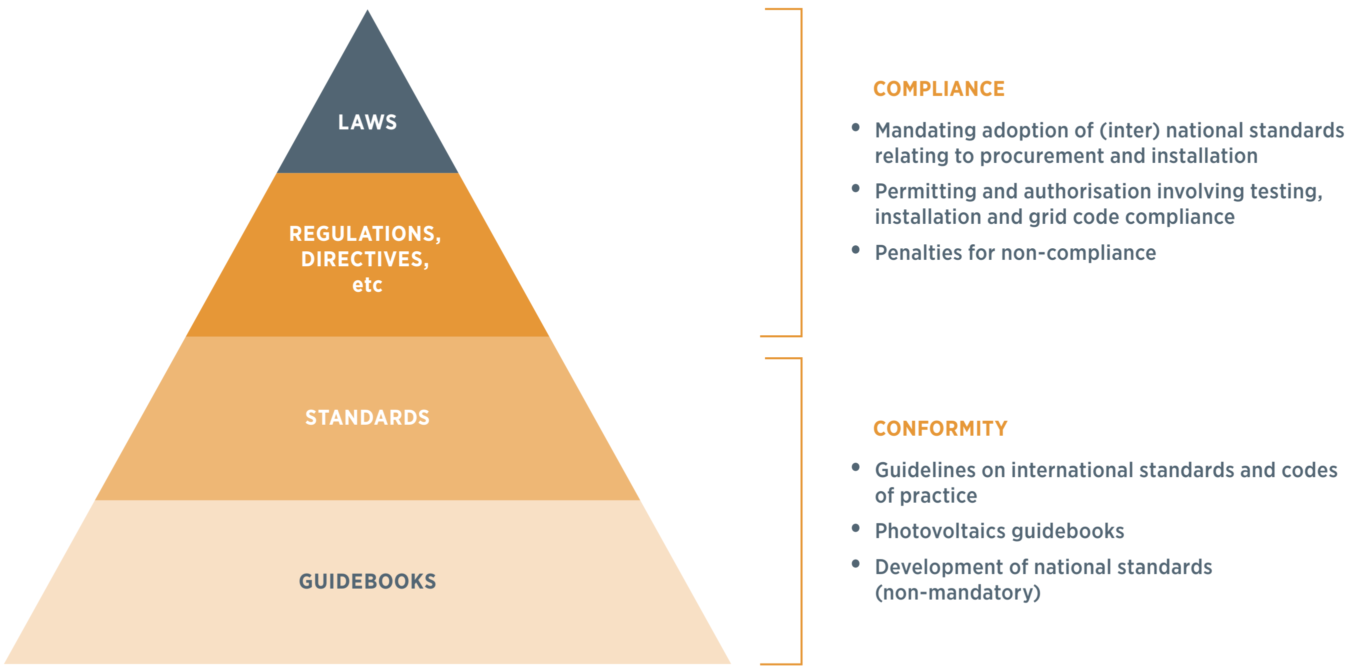
QI is essential to enable the achievement of renewable energy (RE) policy objectives more effectively. It also facilitates the efforts of relevant key decision makers.

Figure 1.10. Contributing to policy objectives through the implementation of quality infrastructure



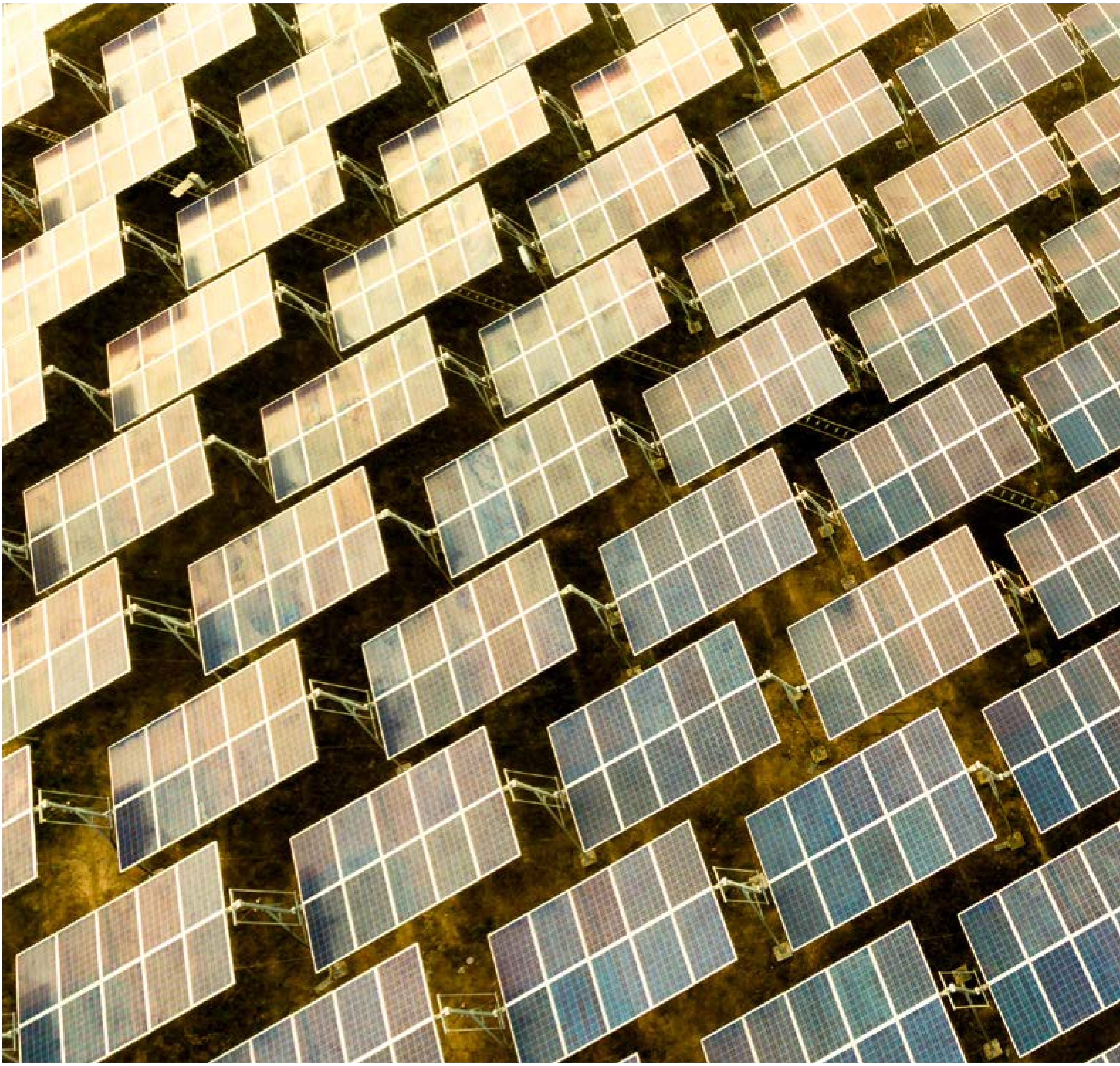
Policy makers require instruments that help them reconcile two key macro objectives in the energy sector: i) providing citizens with affordable and reliable energy supply; and ii) fostering sustainable economic growth through deployment of clean and modern technology. QI bridges these two objectives, ensuring that suitable energy technologies promoted by governments deliver as required to effectively fuel economic growth and well-being. However, the importance placed by policy makers on ensuring the quality of renewable energy systems deployed in the country seems to be small in comparison to other factors, such as technology affordability. It is worth noting that focusing on QI may also lead to lower life-cycle costs.

Figure 1.11. Different levels of public policy



The work of policy makers can be eased by using standards, testing and certification in conjunction with policies and regulations. This report illustrates how policy makers can benefit from QI requirements through voluntary and legislative actions including guidebooks, laws, technical regulations, decrees and other actions outlined by a statutory body.

PV markets that achieve a level of maturity reflect lower equipment costs, with quality assurance playing a key role in the mitigation of technology risk and improving equipment performance. Thus, putting QI in place encourages further deployment of solar technologies.



Overview of

PHOTOVOLTAIC SYSTEMS


2

Overview of Photovoltaic Systems

This section examines PV systems technology and markets. PV is currently the third most used RE technology worldwide, following its wide commercialisation during the last decade. Its main application is the generation of electricity for residential and commercial purposes, where the demand is driven by carbon dioxide reduction targets, increasing energy needs, goals for sustainable energy production objectives and accessible low-cost solutions.

2.1 Technology

Photovoltaics refers to the effect of converting solar irradiation into direct current (DC) electricity. Different types of semiconducting materials are used, processed into solar cells and interconnected to compose a solar panel (or module). The main application of generated electricity in PV modules is for grid-connected power generation, following its conversion into alternating current (AC) electricity by means of an inverter and the use of transformers and substations to connect to the grid.

In utility-scale PV systems, the PV modules are mounted in supporting structures that anchor them to the ground. Fixed structures, as well as mechanical equipment (i.e. trackers) that follow the sun's position throughout the day are commonly installed. The PV modules are electrically connected in a series to strings so as to increase the voltage up to the operational range of the inverter. Several strings are connected in parallel-forming arrays that are attached to the inverters. Additional electrical equipment is needed to connect the PV system to the grid and to control and monitor its performance.

More information about PV technology is reported in the IRENA-ETSAP technology brief on solar photovoltaics (IRENA and IEA-ETSAP, 2013).

2.2 System components

The following sections provide a technical overview of the various components that compose a PV system. The QI for non-PV-specific equipment, such as transformers and switchgear, is not assessed in depth. A breakdown of components, specifically in relation to QI, is provided in table 21, indicating which supplies are included in the scope of this report.

Table 2.1. Breakdown of the components of a photovoltaic system

Components of a Photovoltaic System	In the Scope of This Report
Modules	Yes
Support structures	Yes
Cables and connectors	Yes
Direct current combiner box	Yes
Inverters	Yes
Transformer	No
Switchgear	No
Medium and high voltage equipment	No
Monitoring system	Yes
Meteorological system	Yes
Safety system	No

Panels: Overview of technologies

PV modules are composed of solar cells that form the basic building blocks that collect the sun's light. They are, in fact, large area semiconductor diodes that, due to their photovoltaic effect, convert energy from light (photon energy) into DC electricity.

Solar panels have improved substantially in terms of their efficiency and power output over the last few decades. Various technologies are now available, with the most common being (poly)crystalline silicon panels. Crystalline silicon (c-Si) technologies are mainly represented by mono-crystalline (m-Si) and multi- or polycrystalline (p-Si) technologies. On average, p-Si cells are slightly less efficient than m-Si cells and are less expensive.

A crystalline panel consists of multiple cells that have been manufactured from wafers and are electrically interconnected, forming a module. The cells and the electrical interconnection are encapsulated in a highly transparent plastic layer. This layer is sandwiched between a high, transparent front cover, which is commonly glass, and a reflective back layer to increase slightly its efficiency. The electrical contacts are led to the module terminals (i.e. junction box) and an aluminium frame mechanically supports the module and allows for mounting. For aesthetic reasons, some manufacturers do not use aluminium frames, in which case the module's back layer is often glass to increase the mechanical strength of the module.

Since the 1990s, there has been increased development of thin film processes for the manufacture of solar cells and, more recently, with a significant improved performance. In these processes, photoactive semiconductors are applied in thin layers to a low-cost substrate (in most cases, glass). Thin-film modules can be made of a flexible or rigid variant, depending on the material used to encapsulate the cells. These modules are generally less efficient, despite their production cost being lower.

Another type of PV module is based on the multi-junction solar cell, a combination of a crystalline and a thin-film layer with an intrinsic layer (i.e. insulation) in between. In comparison to crystalline solar cells, the multi-junction cells are distinguished by greater energy yields at higher temperatures due to their lower temperature coefficient and the fact that they have a higher efficiency.

When applications differ from the conventional solar power plant or rooftop development, alternative photovoltaic technologies can be utilised. These can be high efficiency modules used in aerospace applications; concentrated photovoltaics used to enhance incoming irradiation with optics; and dye-sensitised solar cells, representing other technologies in the area of PV.

In terms of standardisation, PV modules normally comply with specific IEC standards. The organisation's Technical Committee for photovoltaics (TC82) is responsible for developing the standards that relate to solar PV energy systems. Qualification testing of crystalline, thin-film and concentrating modules are covered by international standards such as IEC 61215, IEC 61646 and IEC 62108, respectively.

Panel support structure

The structures that support the PV modules can either be fixed or moving structures (i.e. trackers). Selection will depend on the system purpose, location and financing.

For the typical case of a ground-mounted solar plant, a galvanised steel or aluminium racking system is used to hold the modules in an optimal position so as to absorb the most radiation over the year. The mounting (or racking) system either held in place by a pole, driven in the ground or on a concrete base. For flat rooftop developments, the frames can be held in place by ballast – in most cases a couple of cinder blocks − or it can be fixed to the roof.

Trackers are used to increase the solar resource on the PV panel's surface, and therefore the electrical energy output of the system. Single axis tracking is performed around either a horizontal or vertical axis, with the use of an electrical or hydraulic system. The system is geared to move synchronously with the sun and is normally operated under feed-forward control through specific algorithms in order to follow the sun's path. By using such systems, the energy yield can typically be increased by about one-quarter for single axis trackers and one-third for double axis trackers compared with fixed systems. Dual-axis tracking is less used as it requires more sophisticated equipment and maintenance, increasing the cost.

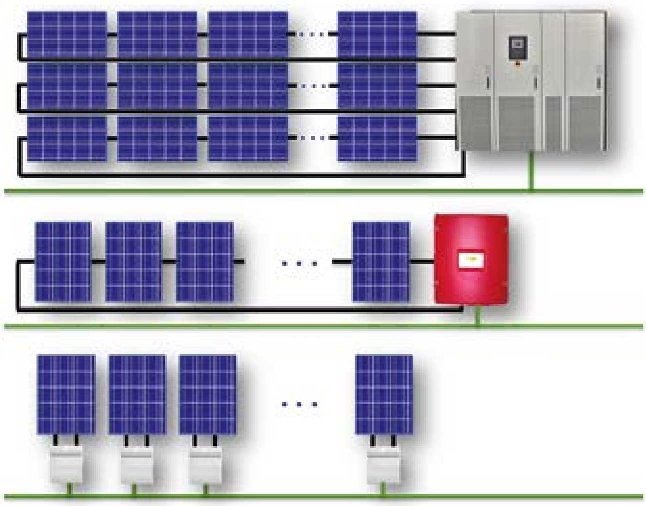
With regard to standardisation, Specification IEC/TS 62727 for solar trackers provides for parameter guidelines to be specified and measurements methods for tracking systems. Steel-based mechanical structures generally comply with ISO 1461 of the International Organization for Standardization (ISO) for hot-dip galvanised coatings.

Inverters: Functionality and applications

Inverters are the power electronic devices that are connected to the PV array on the DC side and to the electrical grid on the AC side. They essentially convert the DC electricity produced by the array into the AC electricity required by the grid in order to be transmitted over longer distances. The electronics of these systems allow for high efficiencies in partial and peak loads and feed the alternating current into the grid with a synchronous frequency. There are three types of inverters, as follows:

- central inverters
- string inverters
- micro inverters.

Figure 2.1. Inverter connection methods for central, string and micro inverters



Utility-scale PV systems often use central inverters. While central inverters offer lower DC watt unit costs and fewer component connections, they have higher installation, DC wiring and combiner costs. When selecting inverter types, a further aspect to consider is the mismatch losses between strings that could result from different levels of shading.

String inverters are smaller and, as the name suggests, they convert the power of one or a few strings. String inverters allow for more system design flexibility and thus are popular in case of complex shading situations, such as for rooftop systems. The use of string inverters recently has become a viable option in utility-scale projects. Some advantages are the efficient replacement of broken inverters, restricted downtime periods and limited manpower. They are also a good solution in areas where the inverter supplier is unable to provide a fast response in the event of a failure that requires a repair, such as islands.

A micro-inverter converts the DC current from a single PV module to AC current. Their output can be combined and connected to the grid. Its main advantage is the optimisation of the maximum power-point tracking of the module and the independence from each module that reduce the losses due to mismatching, shading and soiling. Conversely, their upfront and maintenance costs are much higher as they are harder to access when installed on a roof. Power optimisers can be used in lieu of micro-inverters so as to optimise power in shading situations.

In terms of standardisation, IEC 62109 and UL 1741 apply to the safety of inverters in PV systems; IEC 61000 applies to electromagnetic compatibility (EMC); IEC 61727 applies to the requirements of utility PV systems to the grid; and IEC 62116, which provides a test procedure of islanding prevention measures. Moreover, inverters have to comply with the prevailing national grid codes.

Batteries: General description

Batteries are most commonly used for storage applications in stand-alone systems that are independent of the grid and more prevalent in rural areas (i.e. off-grid applications). Cost reduction, however, is expected to encourage battery use for storage in grid-connected power plants, mostly with distributed generation. Different types of batteries are available, with lead-acid batteries the most widely used in PV systems due to their low price. Other types can offer higher storage density or lower self-discharge as lithium-ion, nickel–cadmium and nickel-metal hydride types, although they are more expensive. For use in a PV plant, batteries can be installed as quick storage to comply with the ramp-rate limitation imposed by the utility, as a base load production and as a means to shift the production. Usually, the batteries are charged and discharged in daily cycles. The lifetime of a lead-acid storage battery tends to be between five and ten years.

In terms of standardisation, IEC 62509 includes developing performance. It also relates to the functioning of photovoltaic battery charge controllers.

Utility meters: Presentation of the grid connection point

In order to monitor the quantity of the energy injected and consumed, and to calculate the revenues of the PV system, a utility meter is used, generally installed at the grid interconnection point. Depending on the period when the electricity is transmitted, different tariffs will apply and accompanying revenues will be generated.

Other balance-of-system components

BoS refers to all components, excluding the solar modules and, sometimes, the inverter. The other BoS components are mainly DC combiner boxes, step-up transformers, switchgear, cabling, safety systems and monitoring.

In order to guarantee expected revenues and act immediately in case of malfunction, a monitoring system is installed in commercial PV systems. Production is commonly measured at the plant, inverter or combiner box level. Global horizontal or in-plane irradiance, measured with either pyranometers or reference cells, allows for the comparison of expected and real production, triggering operational and/or maintenance actions if necessary. When measuring irradiation, ISO 9060 shall be used.

Residential rooftop systems (distributed generation) now also comprise of a monitoring system, given that their owners wish to observe the installation's performance. Monitoring of residential (and sometimes commercial) systems is not always effected systematically, causing systems to underperform for long periods of time. IEC 61724 on Photovoltaic System Performance Monitoring provides guidelines for sensors, measurement data exchange and analysis.

2.3 Types of photovoltaic systems

There are three main types of PV systems, based on their application. Their implementation depends significantly on prevailing policies and the requirements of users.

Off-grid applications

Off-grid (or stand-alone) applications are typically used where there is no electric grid or when the cost of connecting to the grid is high. Off-grid applications tend to be smaller in scale than other system types, often used for small-scale projects in remote locations and rural areas or as solutions in developing countries. Off-grid PV systems are also designed for residential households willing to disconnect from the grid depending on prevailing policies. Currently, they are implemented in remote activities such as mining in countries such as Australia. Obviously, an important element is the design of the electricity storage system, since the entire system has to provide the required energy during low-light and night periods. The storage system consists of the batteries and a charge controller that prevents the batteries from being overloaded and deeply discharged.

Stand-alone PV installations can be formed into mini-grid systems with multiple systems interconnected. They also can be integrated with other power generation sources, such as diesel generators. These hybrid systems offer the advantage of a reduction in diesel consumption and are commonly used on islands or in rural areas.

Specific IEC standards have been developed for stand-alone systems. Among them is the IEC 62257 series that offers recommendations for small RE and hybrid systems for rural electrification.

Distributed generation

Generated by numerous smaller plants over a wider region, distributed generation allows for a contribution from a multitude of grid-connected generators, enhancing the flexibility and reducing the intermittency of the power plant. This type of arrangement is represented by rooftop PV systems, placed on private households and commercial and industrial buildings. The main driver for its development is the reduction of the energy that is required by a building and taken from the grid. Residential rooftop PV systems are of little kilowatt power and are connected to the internal grid of the house or building. These systems usually use string inverters of small capacity with a little lower conversion efficiency compared to central inverters. Storage systems of small capacity tend to become more popular for this type of PV systems.

Utility-scale photovoltaic systems

The most commonly noticeable form of solar power is the large, grid-connected power plant. The energy generated is not intended to be self-consumed but delivered completely to the grid. Utility-scale PV systems are typically ground-mounted systems. Erecting such a solar plant requires a significant amount of collaboration with the utility, the grid authority and the government to ensure compliance with technical standards, environmental and safety standards and contractual agreements.

Utility-scale PV systems are the largest of all PV systems. They usually comprise high-capacity central inverters, allowing high overall efficiency and cost-effectiveness. The output is stepped up through transformers to reach the voltage level of the grid connection point or to the intermediate AC voltage of the plant. So-called medium-voltage stations, which integrate inverters and transformers in a containerised solution, are frequently used as they facilitate installation and modularity.

The plants are generally connected to the medium- or high-voltage grid through switchgear or an internal substation that concentrates all the transformer outputs into a centralised control. These PV plants are often secured by fences, closed-circuit television and security personnel to avoid vandalism and robbery, depending on the assurance requirements. Maintenance and operation of the assets are done by special teams that are able to be on site or which are remote, but are able to monitor constantly – among other tasks – the performance of the plant.

2.4 Global market status

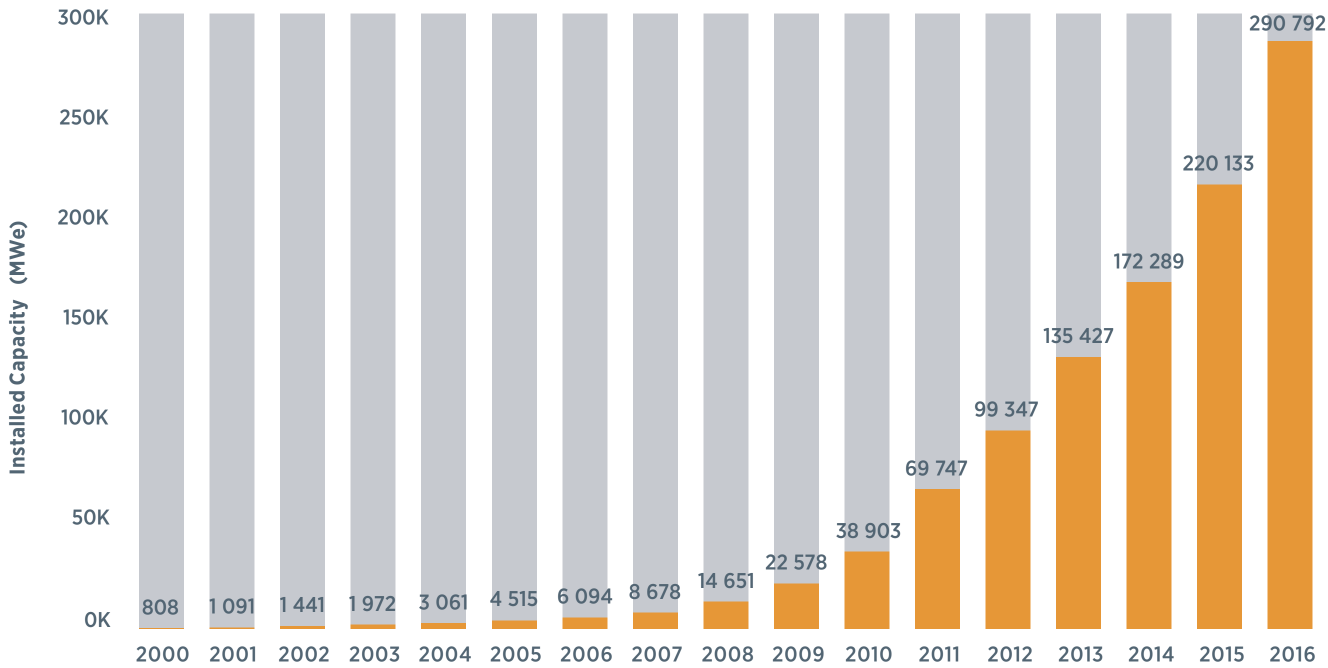
Market development and future trends

Over the last decade, PV has been the fastest growing energy source. The significant incentives provided by governments – either through feed-in tariffs or tax breaks – together with technology maturity, economies of scale and associated rapid cost reductions, have supported the industry to compete with conventional power systems and other renewable energies.

At the end of 2016, the global accumulated capacity of PV power was estimated to be at least 290 GW. The uptrend in new installed capacity is expected to continue throughout the following years as new markets develop. Figure 2.2. illustrates the cumulative PV capacity at the end of 2016.

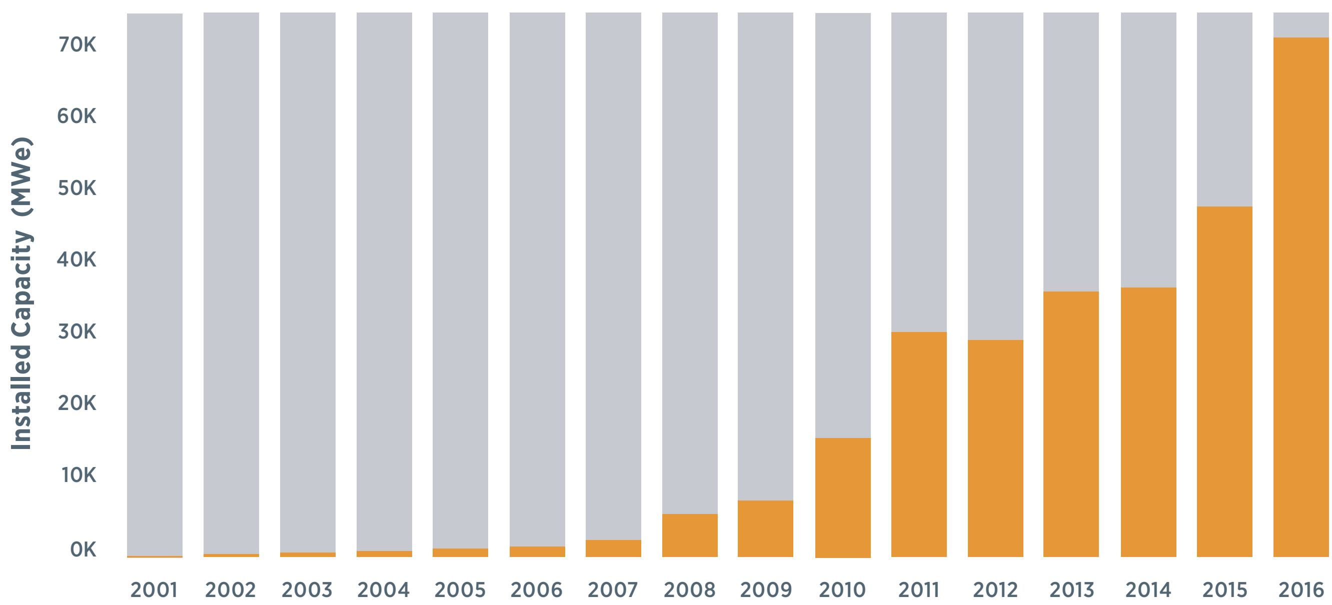
Germany led the market in terms of cumulative installation until 2015 when China overtook it with 43.2 GW (PV Magazine, 2017), which accounts for approximately 20% of global installed capacity. The major developments of PV installations in 2015 took place in China, India, Japan, the United Kingdom and the United States. Future developments of PV installations are expected to be centred in China, India, and the United States, as well as in the Gulf and Asia Pacific regions, while the contribution from Europe will continue to decrease. shows the cumulative installed PV capacity in countries with capacities over 2 GW. With respect to QI, this can indicate in which countries good QI for PV can be found.

Figure 2.2. Evolution of cumulative installed capacity



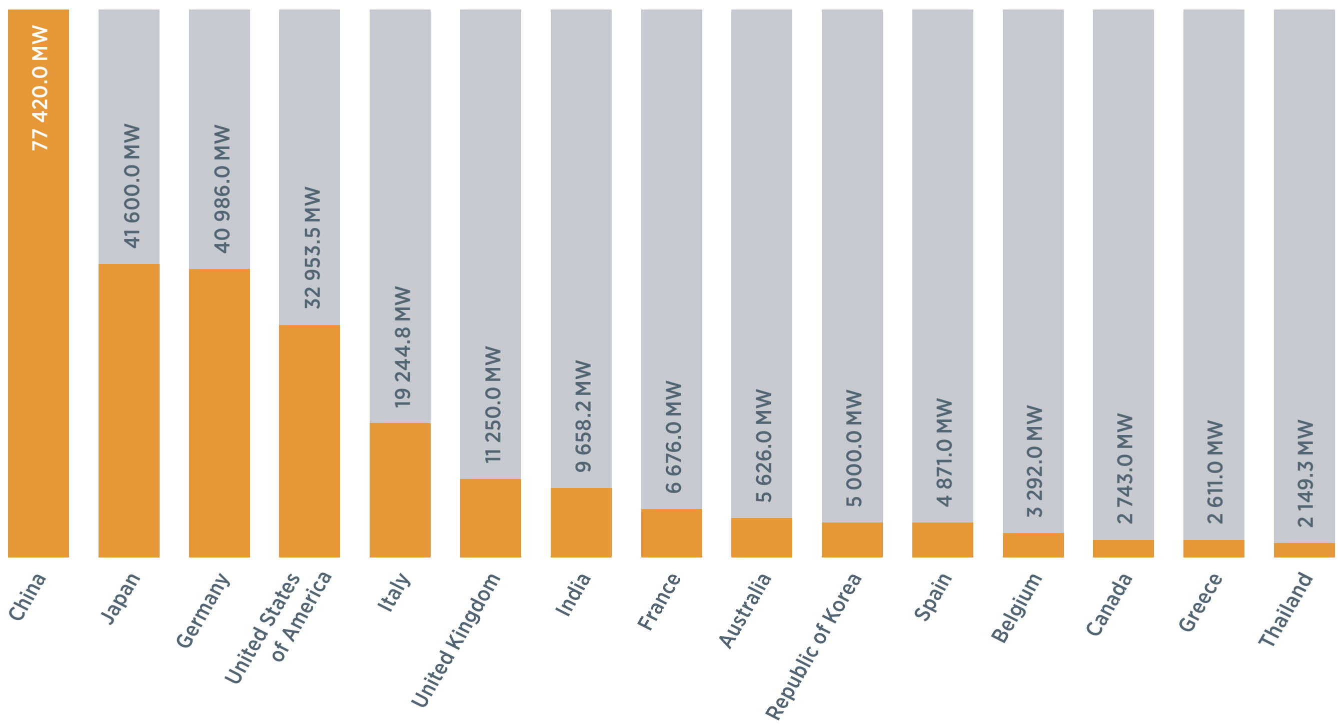
Note: MWe = megawatt electric.

Figure 2.3. Evolution of net annual additional capacity



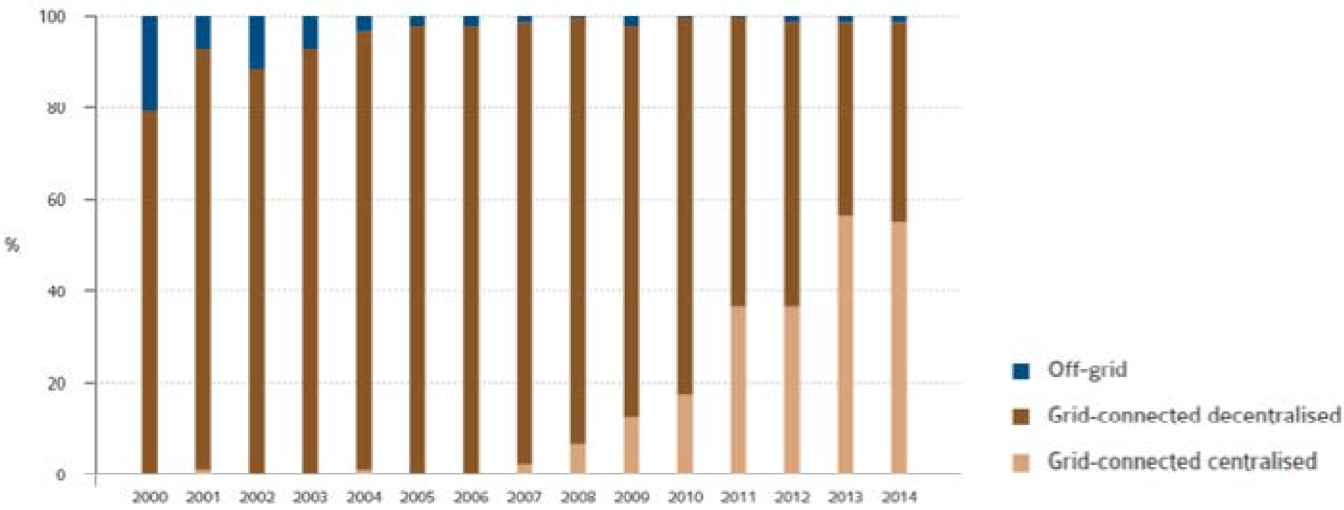
Note: MWe = megawatt electric.

Figure 2.4. Top 15 countries ranked to their solar PV power capacity, installed in 2016



The utility-scale segment dominates the share of installed capacity, and less than 1% is dedicated to off-grid applications (IEA-PVPS, 2015) as shown in Figure 2.5. According to the IEA-PVPS report, this trend is expected to be maintained as the new installed capacity is mainly provided from countries with major development in utility-scale projects.

Figure 2.5. Photovoltaic installation types and their worldwide market shares



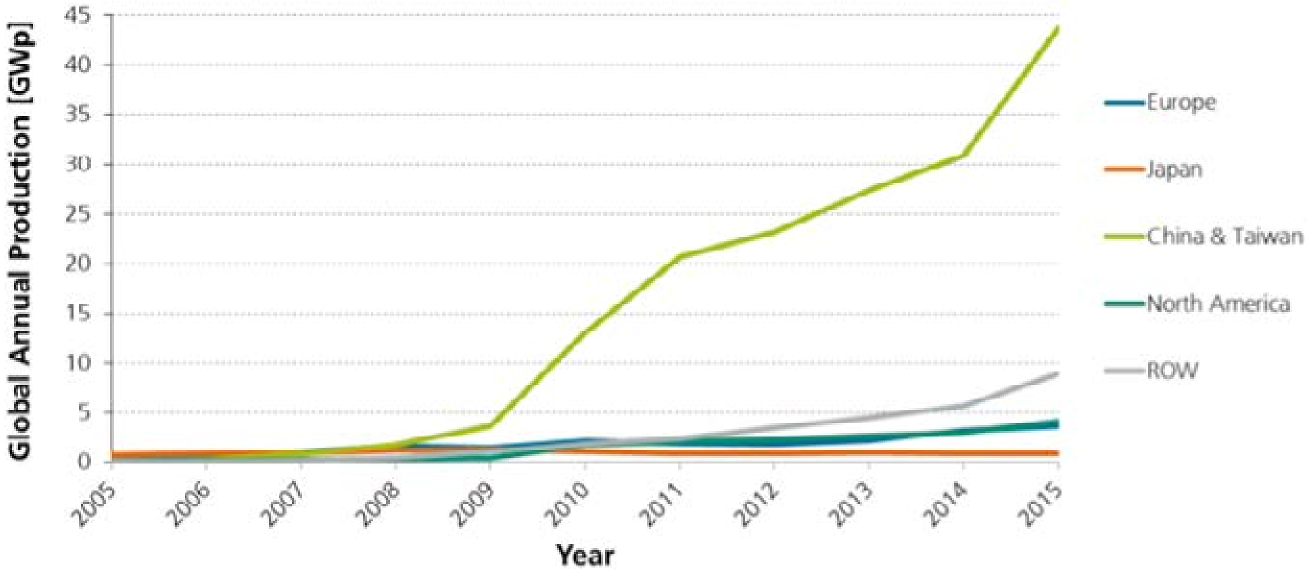
Source: IEA-PVPS, 2015

PV module production, on the one hand, shifted from Europe and the United States to China in approximately 2008, and China has since largely dominated the world market. On the other hand, Japan has been able to maintain its capacity as a result of its internal market absorption. New countries, particularly within the Asia Pacific region, now are adding new manufacturing capacity based on changes in their regulatory frameworks. The main manufacturing capacity is concentrated in countries that participate in the IEC Technical Committee 82 (solar photovoltaic energy systems).

Figure 2.6. shows the PV module manufacturing trend during the last ten years.

Solar PV system prices depend on many factors such as the country, type of system and system size. The cost of PV systems, however, has been fast declining on a global basis within the last few years due to substantial module cost reductions. Figure 2.7. shows the decline of PV module prices for each type of technology.

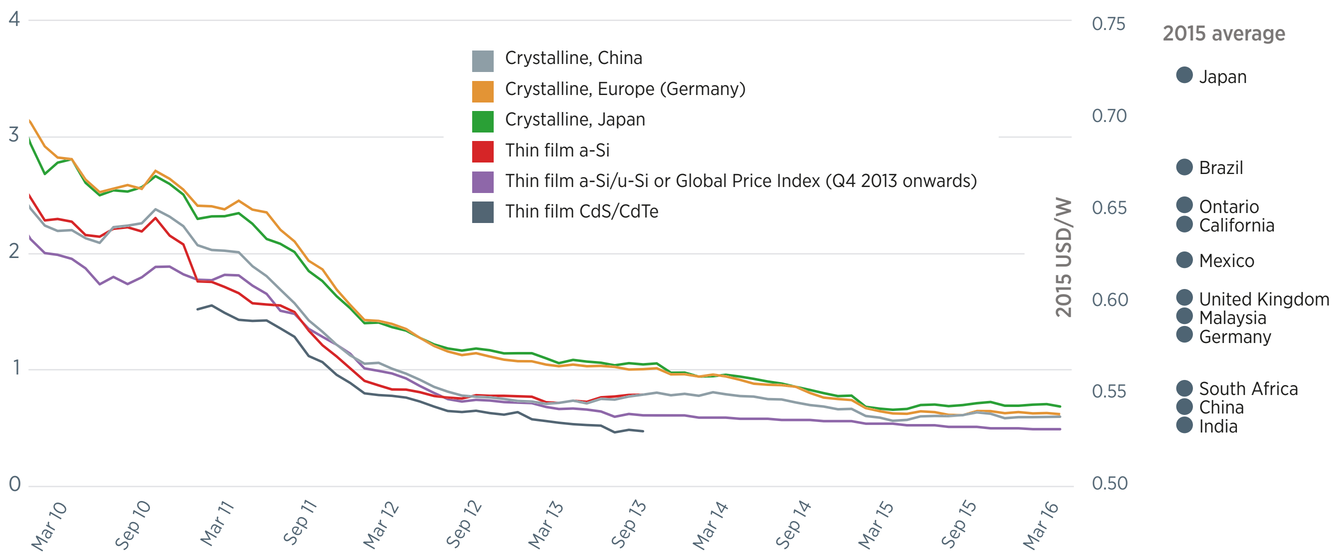
Figure 2.6. Photovoltaic module manufacturing by region



Source: Fraunhofer ISE, 2016

Notes: GWp = gigawatt peak; ROW =Rest of the World

Figure 2.7. Global photovoltaic module price trends, 2009–2016



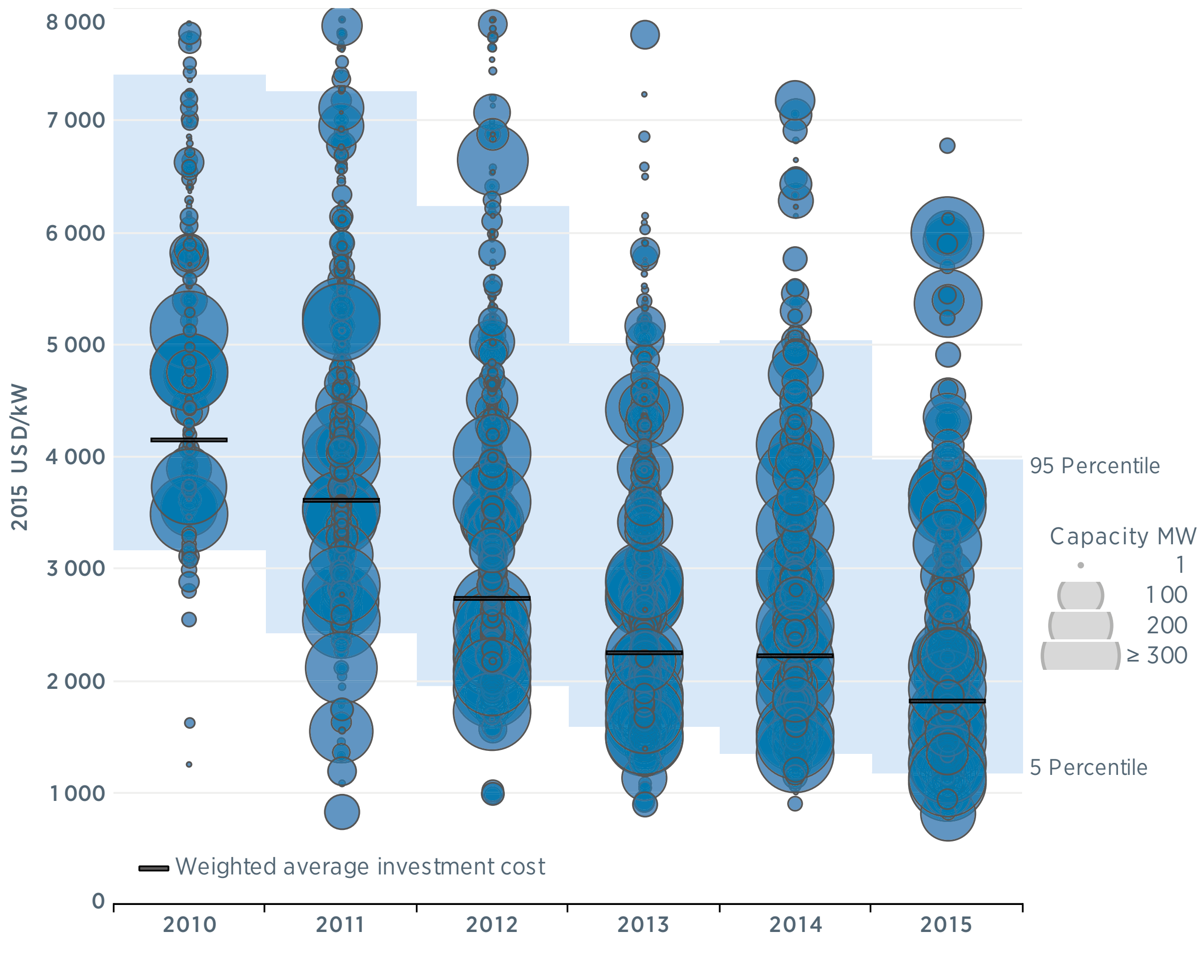
Source: IRENA, 2016c

Notes: a-Si = amorphous silicion; CdS/CdTe = cadium sulphide /cadium telluride; USD = U.S. dollars; W = watt.

This decline in PV system cost is illustrated in Figure 2.8. whereby the industry has established more cost-effective methods of operating. The light blue bands indicate 90% of the system costs within industry and they show a steady decline over the past six years.

IRENA estimates that the global average of the total installed cost of utility-scale PV systems could fall from approximately USD 1.8/W in 2015 to USD 0.8/W in 2025, a 57% reduction in ten years. Considering the level of uncertainty around cost drivers, the decrease could be anywhere between 43% and 65% from 2015 levels. The majority (approximately 70%) of the cost reductions are expected to originate from lower BoS costs. For virtually its entire history, the solar PV market's cost reductions have been driven by module cost declines – given the learning rates of 18–22% – and BoS cost reductions. With module prices in the range of USD 0.5/W and USD 0.7/W, cost reductions from modules in the future will contribute less than in the past to total installed cost reduction potentials, even with the very rapid growth in solar PV deployment. Globally, the opportunities for PV system cost reductions in the next decade will originate from continuous BoS cost reductions, where PV module costs will continue to decrease and a reduction of cost of capital will be crucial.

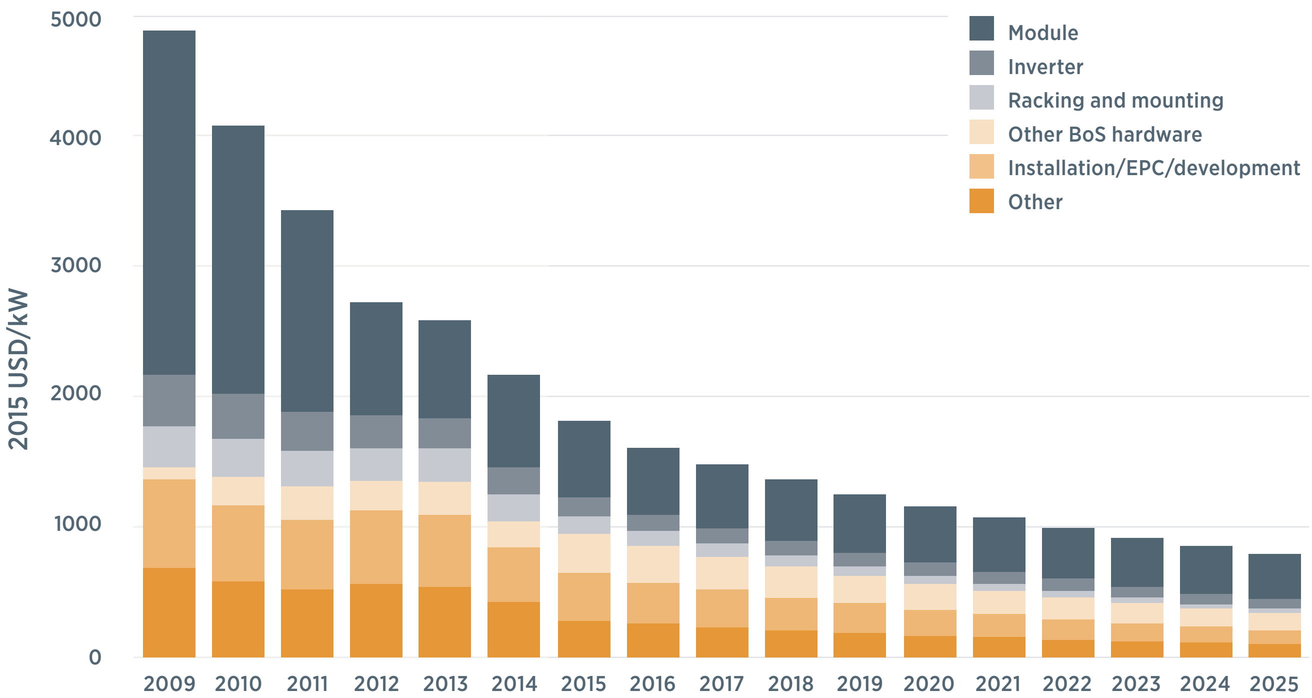
Figure 2.8. Total installed photovoltaic system cost and weighted averages for utility-scale systems, 2010–2015



Source: IRENA, 2016c

Notes: USD = U.S. dollar; kW = kilowatt; MW = megawatt.

Figure 2.9. System cost breakdown for utility-scale photovoltaic: Global weighted average



Source: IRENA, 2016c

Notes: USD = U.S. dollar; kW = kilowatt; BoS = balance of system; EPC = engineering, procurement and construction.

Solar photovoltaic in the power generation mix

Currently, 1.2% of total electricity generation is attributable to PV (REN21, 2016), albeit a small but growing player. Countries with more PV energy production in their energy mix include Germany, Greece and Italy with over 7% (IEA-PVPS, 2016).

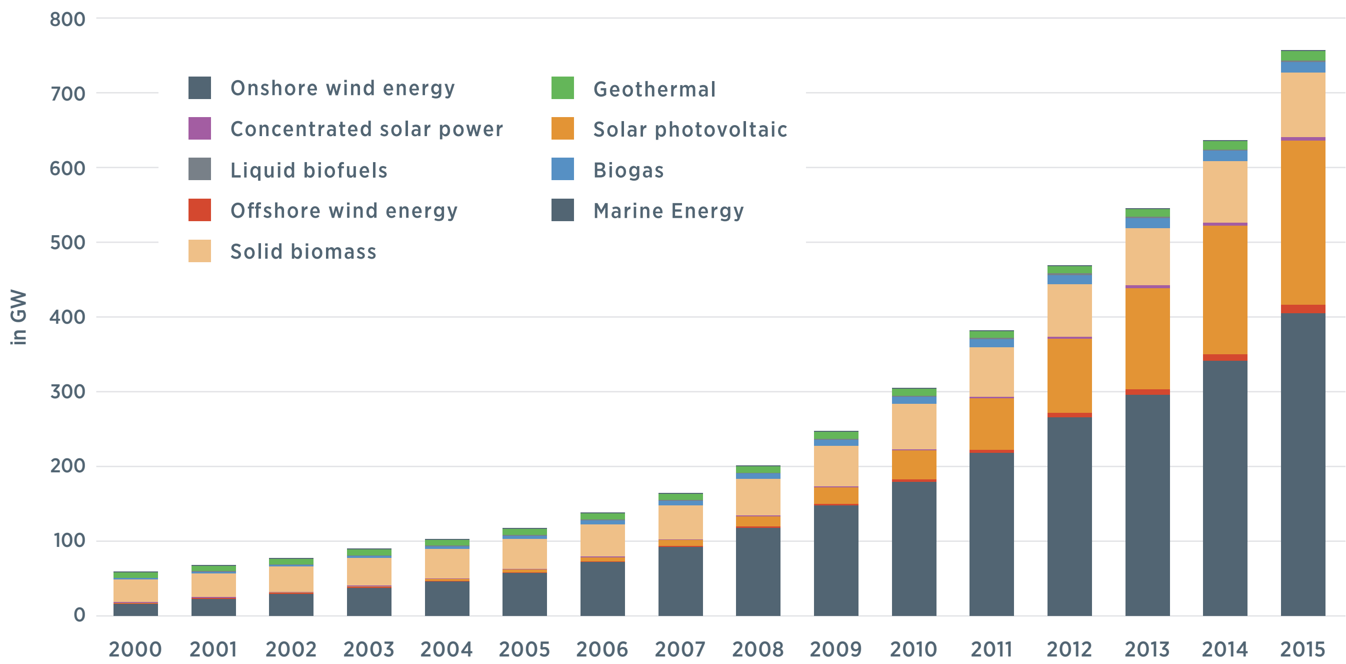
The number of PV installations is increasing year by year and PV solar accounts for the second largest installed capacity for renewable electricity production following that of wind. This is shown in Figure 2.10. and it excludes hydropower.

Solar PV contributed less than 2% to global electricity production in 2015. IRENA estimates that solar PV capacity could reach between 1 760 GW and 2 500 GW by 2030, accounting for between 8% and 13% of global power generation (IEA-PVPS, 2016).

Figure 2.11. shows the change in LCOE for different RE technologies from 2010 to 2015, where solar PV has undergone the most significant cost reduction in the weighted average of its LCOE over this period.

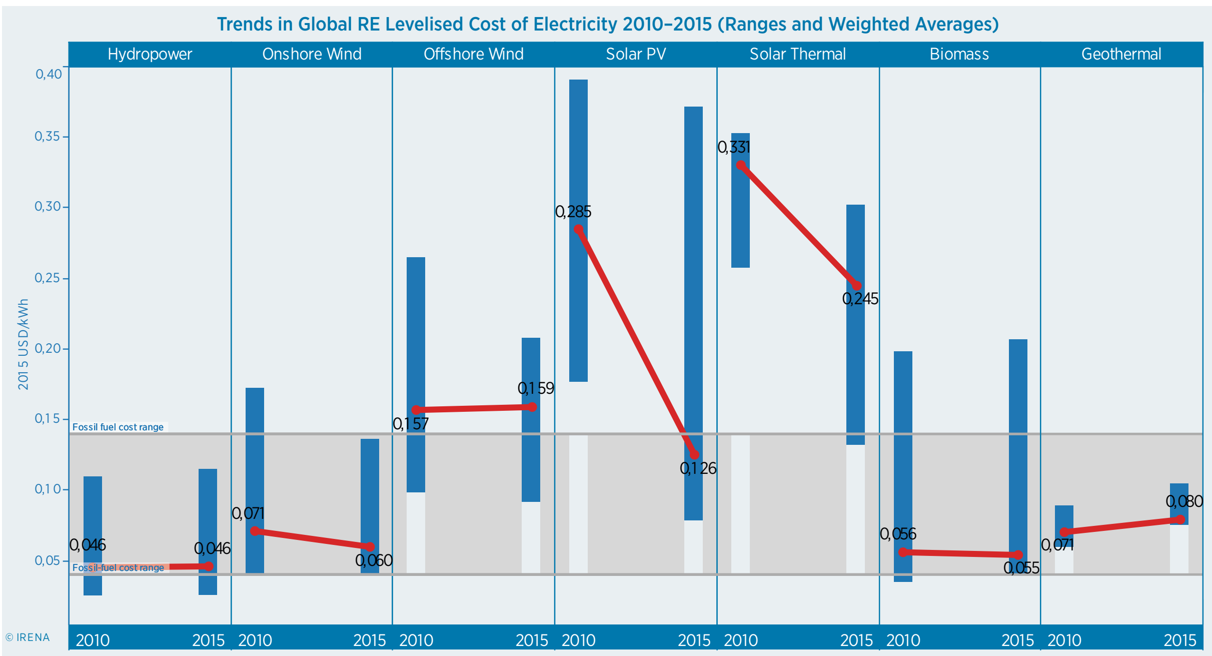
The global weighted average LCOE for PV could decline from USD 0.13/kilowatt hour (kWh) in 2015 to USD 0.055/kWh by 2025 (a 59% decline). By 2025, the LCOE cost ranges for individual utility-scale solar PV projects could fall to between USD 0.03/kWh to USD 0.12/kWh, 68% and 60% lower than in 2015, respectively (IRENA, 2016c) A large factor influencing the LCOE is the weighted average cost of capital, since financing is – and will be – an important element in PV projects. Quality improvements relating to this topic remain relevant. For example, no standard method for calculating LCOE exists at present.

Figure 2.10. Installed renewable power capacity



Source: IRENA, 2016b

Figure 2.11. Levelised cost of global electricity from renewables



Source: IRENA, 2016b

Note: RE = renewable energy.

Quality Infrastructure:

ESSENTIAL INFORMATION

3

Quality Infrastructure: Essential Information

The solar PV market is rapidly growing as a result of the drop in the cost of PV generated electricity and the global demand for solar PV power plants. This development is supported by advances in solar technology and manufacturing, with diffusion on a worldwide basis directly linked to the technology's advantages as a power generation source in terms of its modularity, distributed nature and the reliability of its output.

The global market, however, is hampered by underperforming, unreliable and failing products that create barriers to the development and enhancement of this renewable technology. TÜV Rheinland reports that 30% of nearly 100 analysed projects indicates serious defects and a large number of issues (TÜV Rheinland, 2015).

In order to support the development of the solar market, it is essential to create market awareness and confidence. The implementation of a QA is therefore paramount, since QA is part of a quality management system that provides the confidence that quality requirements will be fulfilled. At the market level, a national QI, according to international best practices, is required to assure quality and safety in the sector (ISO, 2015; IRENA, 2015). QI is implemented through the employment of:

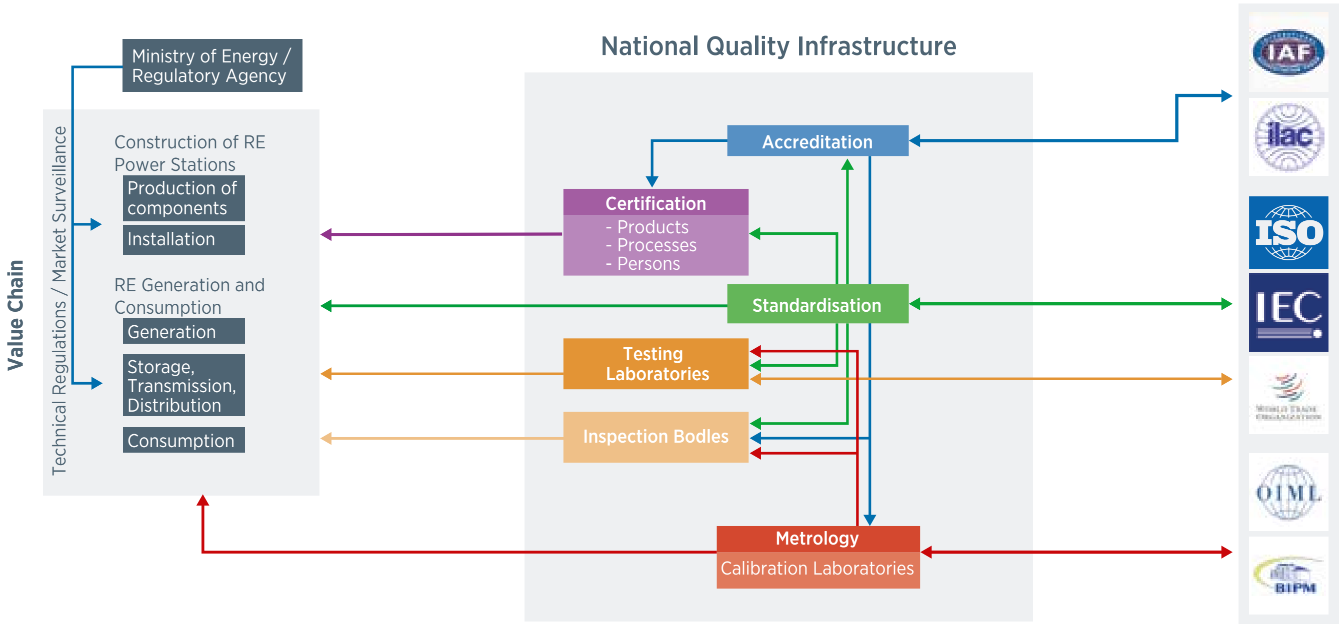
- standards: harmonising the market by defining methods and equivalent specifications;
- certifications: assessing that a product, service, organisational management system and/or individual's qualification corresponds to the requirements of a standard;
- testing processes: verifying the conformity of the object of the test to established quality, performance, safety, and reliability standards;
- accreditation: independent evaluation of conformity by assessment bodies against recognised standards to ensure impartiality and competence to carry out specific QI services, such as tests, calibrations, inspections and certifications;
- inspection bodies: private organisations or government authorities that examine the design of products, services, procedures, and/or installations and evaluate their conformity with requirements that exist in the form of laws, technical regulations, standards and specifications;
- metrology: determining conformity to specifications or technical requirement through measurements; and
- market surveillance: monitoring the market status to ensure that trading processes are conducted in a compliant manner.

According to IRENA, QI is defined as the total institutional network (public or private) and the legal framework that (IRENA, 2015):

- regulates, formulates, edits and implements standards for the common and repeated use of products and services;
- provides evidence of its fulfilment (i.e. relevant mixture of measurements, accreditation, tests, certification and inspections).

A graphic representation of QI is produced by The National Metrology Institute of Germany (Physikalisch-Technische Bundesanstalt) and is shown in Figure 3.1. It illustrates the elements described above and how these are linked.

Figure 3.1. Elements of quality infrastructure



Based on data from The National Metrology Institute of Germany (Physikalisch Technische Bundesanstalt). IRENA, 2015

Notes: IAF = International Accreditation Forum; ILAC = International Laboratory Accreditation Cooperation; ISO = International Organization for Standardization; IEC = International Electrotechnical Commission; WTO = World Trade Organization OIML = International Organization of Legal Metrology, RE = Renewable energy, BIPM: Bureau International des Poids et Mesures.

QI should be considered an interconnected system that relates to the international organisations through, for example, inter-comparisons, proficiency tests and partnerships with international organisations.

Should QI services not be in place (e.g. not be internationally recognised and fulfilling the demand of industry, among others), this will result in:

- higher costs and longer turnaround times, as services have to be bought from other countries;
- national absence of QA; and
- dearth of awareness and information.

Who benefits from the implementation of QI in the solar PV market?

Implementing QI will benefit the entire solar PV market chain and involves all the actors of the solar market. A well-de QI is essential for the sustainable growth of the PV industry.

This section provides a detailed description of QI. Where applicable, a comparison of the three types of PV systems is provided.

3.1 International standards

A comprehensive list of international standards is provided in Appendix A. These are also available online at http://inspire.irena.org/Pages/standards/start.aspx, IRENA's web platform named INSPIRE. The list presents the recommended international standards that are suitable for utility-scale PV systems at the national level. Most of those standards can be applied also to the three PV systems.

A core group of international standards extracted from Appendix A, as well as country-specific standards, are shown in Table 3.1. These are the most relevant in terms of the components, installation and operation of a PV system and are the primary standards most often called upon for project approvals or engineering due diligence on behalf of financiers. Other standards, listed herein, governing the manufacture and testing of equipment, sensors, among others, provide the basis for product safety and performance. Appendix A also includes those standards that relate to equipment on the AC side of a PV installation, such as switchgear and transformers, relevant although not specific to PV installations. These are applicable to a variety of other sectors in the electrical industry.

Table 3.1. International and national standards

Country	Photo-voltaic Module	Inverter	Design and Installation	Comm-issioning	Perform-ance and Operations	Grid-Code-Related	Off-Grid Specific	Utility-Scale Specific
International/ IEC	IEC 61730 and IEC 61215, or IEC 61646 as applicable	IEC 62109-1, IEC 62109-2, IEC 62093 (Qualification)	IEC 62548[1] (Primary) and IEC 60364 series	IEC 62446	IEC 61724 Future IEC 62446-2 (2017)	Country specific, but grid function testing per IEC 62116, IEC 62910	IEC 62257 Series for off-grid and rural electrifica-tion	Future IEC 62738 (2016)
Australia	Same as IEC	AS/NZS 4777, AS/NZS 3100	AS/NZS 5033	Same as IEC	Same as IEC	AS/NZS 4777	AS 4509	
China[2]	National standards and IEC		GB 50797-2012	Same as IEC	Same as IEC			
United States	UL 1703 UL 61215/ IEC 61646	UL 1741, UL 62109	National Electrical Code (NEC) Article 690	Not specified; multiple industry-group recom-mended practices	ASTM E2848, multiple industry-recom-mended practices	IEEE 1547 and regional/ state require-ments	N/A	Future NEC Article 691 (2017)

1 This is a technical specification, often published at the development stage or when insufficient consensus for approval is available of international standards.

2 A list of more than 40 major PV standards has been created in China at the national level (Section 0 and 6.1).

The table highlights the key relevant categories of standards. Those of the IEC are the most comprehensive and are summarised below:

PV modules

- IEC 61215: Design qualification
- IEC 61730: Module safety
- IEC 61646: Thin-film terrestrial photovoltaic modules
- A number of other, as well as new, standards address potential induced degradation, corrosion protection and performance degradation, among others.

PV inverters

- IEC 62109-1 and IEC 62109-2: Safety
- IEC 62093: Design qualification
- New standards are under development for micro-inverter safety and qualification, as well as for arc-fault and earth-fault detection. Inverter efficiency measurement standards are being updated (IEC 61683) and finalised (IEC 62891, based on EN 50530).

System design and installation

- IEC 62548: PV system design
- IEC 60364-7-712: Low-voltage installation of PV systems.

PV system commissioning

- IEC 62446: Commissioning, documentation and inspection

PV system performance and operations

- IEC 61724: Monitoring – two new standards are under development as part of the IEC 61724 series, covering a capacity test and energy test procedure.
- An addendum to IEC 62446 is being drafted to cover PV system maintenance.

Grid-code related

- Grid codes are country- and region-specific, although grid functional testing, such as anti-islanding (IEC 62116) or low-voltage ride through (IEC 62910), are often cited. IRENA's report, Scaling up variable renewable power: The role of grid codes (IRENA, 2016d), provides details on how to design and implement grid connection codes for RE systems.

Off-grid specific

- IEC 62257 is an extensive series covering all aspects of PV-based rural electrification; it is used extensively in developing countries; and
- there are multiple standards that cover small off-grid system components, such as battery charge controllers.

Utility-scale plant specific

- A future technical specification (IEC 62738) will address the design of large power plants, contrasting those of residential/commercial projects which are covered under IEC 62548.

These categories with their relevant standards represent the same core group that is highlighted by the evolving IEC IECRE Conformity Assessment programme, formally designated as the IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications (IECRE)."

Gaps in international standards

Despite the comprehensiveness of the IEC standards, there remain areas in the photovoltaics domain for which standards are missing, as per the following examples:

- Flash test power, provided by module manufacturers, usually does not match the "real" module power that is measured in independent laboratories; that is, while IEC standards and their accompanying certification are based on flash test power values, no standard is yet in place for the assurance of real values in practice.[3]

3 At the time this report was drafted, IEC Technical Specification 62941 was published to fill this gap. Compliance with the specification will be verified through factory audits and certification under the IECRE system.

- Complying with IEC standards to ensure a minimum bar of module robustness does not sufficiently demonstrate PV module reliability in terms of time. IEC 61215 provides the minimum baseline that is accepted by the industry as a module assessment, with the application of environmental stress tests. The scope of standard, however, accounts only for so-called infant mortality and leaves aside a number of common potential causes of failure. Module degradation over time, which can substantially impact the performance of a PV project, is excluded.

- Soiling of PV modules leads to the reduced electricity production- a loss factor among others to be considered during system operation. Considerable values that significantly depend on site and geographic location are taken into account, for which IEC standards do not provide detailed guidance.

Moreover, while PV components are produced for the global market, standards do not take into consideration relevant environmental conditions, such as sand abrasion in deserts and corrosion in coastal areas, among others. Conversely, a hail test – required by IEC 61215 – is irrelevant to particular geographic areas.

Given that testing is perceived as relatively weak compared to international standards, banks and other financial intermediaries now demand more stringent testing. Also, given the time it takes to develop a standard, the absence of specific standards is no surprise. The process – which can be complex and requires multiple iterations involving many stakeholders – is outpaced by an evolving and competitive PV industry. As such they do not always reflect the current status of technology.

3.2 Testing methods

The services of testing laboratories should be accredited by an internationally recognised entity in order to ensure the reliability of tests so that they are internationally and commercially recognised. To achieve the accreditation (which is voluntary), the implementation of a management system according to ISO 17025 is required. As part of the requirements, laboratories must have calibrated equipment usually provided by metrological laboratories. They must regularly participate in round-robin testing and trial runs.

This section details the methods and the equipment necessary for the testing of PV systems and their components, based on IEC and Underwriters Laboratories (UL) standards. It also includes some that extend beyond such standards.

Module testing

IEC standard test protocols for modules focus on the aspects of quality and safety, requiring only a single set of samples to be tested once, usually at the beginning of a product model's life. This section refers to standards IEC 61215:2005 and UL 1703 as examples in describing the testing of PV modules.

IEC 61215:2005 is entitled "Crystalline silicon terrestrial photovoltaic (PV) Modules – Design qualification and type approval". In 2016, a new edition of IEC 61215 was released, covering crystalline as well as thin-film modules. The majority of PV modules currently on the market are certified, according to the 2005 version of IEC 61215. The UL 1703 standard is entitled "Standard for Safety for Flat-Plate Photovoltaic Modules and Panels", focusing on the product safety of PV modules. UL standards are developed for the U.S. market, where they parallel the use of IEC standards.

Table 3.2. represents a list of selected equipment used in the laboratory to test PV modules according to IEC 61215 and UL 1703 standards. Appendix B provides a list of tests with associated equipment.

Table 3.2. Typical equipment for photovoltaic module test labs

Equipment	Test	Description
Ambient temperature measurement	**IEC 61215** 10.3 Insulation test; 10.5 Measurement of nominal operating cell temperature (NOCT); 10.9 Hotspot endurance test **UL1703** 19 Temperature test	An ambient temperature sensor with a time constant equal to or less than that of the module(s) installed in a shaded enclosure with good ventilation near the wind sensors
Balance	**IEC 61215** 10.17 Hail test	A balance for determining the mass of an ice ball to an accuracy of ± 2%.
Irradiance meter	**IEC 61215** 10.8 Outdoor exposure test; 4.10 ultraviolet (UV) preconditioning test (IEC 61215-2:2016); 4.19.3 Hotspot endurance test (IEC 61215-2:2016)	A device capable of measuring solar irradiation, with an uncertainty of less than ± 5%.
Pyranometer	**IEC 61215** 10.5 Measurement of NOCT **UL1703** 19 Temperature test	A pyranometer, mounted in the plane of the module(s) and within 0,3 m of the test array.
Reference cell for measuring the light source	**IEC 61215** 10.2 Maximum power determination; 10.4 Measurement of temperature coefficients; 10.6 Performance at standard test conditions (STC) and NOCT; 10.7 Performance at low irradiance **UL1703** 20 Voltage and current measurements test	A photovoltaic reference device having a known short-circuit current versus irradiance characteristic, determined by calibrating against an absolute radiometer in accordance with IEC 60904-2 or IEC 60904-6.
UV light sensor	**IEC 61215** 10.10 UV preconditioning test	Instrumentation capable of measuring the irradiation of UV light produced by the UV light source at the test plane of the module(s), within wavelength ranges of 280–320 nanometers and 320–385 nanometers with an uncertainly of ±15%.
Velocity meter	**IEC 61215** 10.17 Hail test	An instrument for measuring the velocity of the ice ball to an accuracy of ± 2%. The velocity sensor shall be no more than 1 meter from the surface of the test module.
Continuity tester	**IEC 61215** 10.12 Humidity-freeze test; 10.16 Mechanical load test **UL1703** 41 Mechanical loading test	Instrumentation to monitor the electrical continuity of the module during the test.
Resistance measurement	**IEC 61215** 10.15 Wet leakage current test **UL1703** 27 Wet insulation-resistance test	Instrument to measure insulation resistance.
Steady-state light source	**IEC 61215** 10.9 Hot-spot endurance test	Radiant source 1: Steady-state solar simulator or natural sunlight capable of an irradiance of not less than 700 watts per square meter (W/m²) with a non-uniformity of not more than ±2% and a temporal stability within ±5%; or: radiant source 2: Class C steady-state solar simulator (or better) or natural sunlight with an irradiance of 1 000 ± 10% W/m².
UV light source	**IEC 61215** 10.10 UV preconditioning test	A UV light source capable of producing UV irradiation with an irradiance uniformity of ±15 % over the test plane of the module(s), with no appreciable irradiance at wavelengths below 280 nanometers, and capable of providing the necessary irradiation in the different spectral regions of interest as defined in 10.10.3.
Thermal test chamber	**IEC 61215** 10.11 Thermal cycling test **UL1703** 35 Temperature cycling test	A climatic chamber with automatic temperature control, a means for circulating the air inside and minimising condensation on the module during the test; capable of subjecting one or more modules to the thermal cycle.
Test fixture	**IEC 61215** 10.16 Mechanical load test **UL1703** 41 Mechanical loading test	A rigid test base which enables the modules to be mounted front-side up or front-side down. The test base shall enable the module to deflect freely during the load application.
Power supply	**IEC 61215** 10.15 Wet leakage current test **UL1703** 21 Leakage current test; 27 Wet insulation-resistance test; 40 Arcing test	Direct current voltage source, with current limitation, capable of applying 500 volts or the maximum rated system voltage of the module, whichever is more.
Light filters	**IEC 61215** 10.7 Performance at low irradiance	Equipment necessary to change the irradiance to 200 W/m² without affecting the relative spectral irradiance distribution and the spatial uniformity in accordance with IEC 60904-10.
Chemical fume hood	**UL1703** 38 Metallic coating thickness test	Metallic coating thickness test requires the chemical etching of metal samples using concentrated sulphuric acid (H2SO4).

Note: Descriptions are extracted from original standards. These standards can be accessed through the IEC library: https://webstore.iec.ch/home.

Standards post-2016

As discussed in the previous section a new version of IEC 61215 was released in the first half of 2016. Part 1 of this standard includes the general test requirements, Part 1-x describes the specifics for each PV technology and Part 2 defines the test procedures. This standard covers flat plate module materials, such as c-Si and thin-film modules, and replaces IEC 61646 which covers thin-film terrestrial PV modules.

A new version of IEC 61730, "Photovoltaic (PV) module safety qualification" ("Part 1: Requirements for construction" and "Part 2: Requirements for testing') was released in 2016. It includes the fundamental construction requirements for PV modules in order to provide safe electrical and mechanical operation (IEC, 2016a). The new version contains new requirements, test methods and sequences.

Also in 2016, IEC technical specification 62941:2016(E) was issued, strengthening the performance and reliability of certified PV modules (IEC, 2016b). It includes best practices for product design, manufacturing processes and the selection and control of materials used in the manufacturing of PV modules, in compliance with IEC 61215, IEC 61646 or IEC 62108.

Balance-of-system component testing

PV BoS components range from module wiring connectors to multi-megawatt DC-AC inverters, requiring a wide range of electrical and mechanical testing equipment for certification. Table 33 lists the tests and equipment needed, categorised by component, while Appendix C lists a subset of EMC test equipment, applicable for multiple BoS components.

Due to the multiple functions of inverters, they undergo the most rigid evaluation, including: the processing of significant amounts of power from aggregated PV panels; incorporating the DC and AC interface and protective gear; and meeting the performance and power quality requirements of the utility grid.

The inverter tests listed below represent those that relate to safety, qualification (or design verification), performance, anti-islanding, low-voltage ride through and EMC immunity and emissions.

There is a common subset of equipment applicable to many of the component test standards, due to common objectives:

- electrical testing that requires DC power supplies to simulate power from PV panels and AC power supplies for simulating the utility grid;
- power supplies for electrical withstand (integrity from voltage and current spikes);
- load banks, resistive or complex, for controlling device loading;
- environmental chambers to test the components at controlled temperatures and at various humidity levels and temperature cycles;
- devices to test mechanical and environmental durability, such as impact testing, water and solid body ingress, corrosion, sonic pressure and radiant heat lamps, among others; and
- a full range of electrical transducers and other monitoring devices.

Many pilot arrangements require a major investment, particularly in relation to the testing of large components. Environmental chambers may be as small as a kitchen oven or as large as a spacious room, depending on the equipment undergoing evaluation. In many tests, the equipment undergoes electrical operation while in the environmental chamber, which require the chamber to accommodate the electrical supply and loading cables that enter and exit the enclosure. DC power supplies and dynamic grid simulators also range in size to accommodate the equipment under test.

Tests that involve an accurate simulation of a PV array under dynamic conditions call for specialised DC supplies that are sophisticated relative to standard variable current/voltage supplies. Similarly, tests that require simulation of dynamic AC grid conditions involve back-to-back supplies with highly controlled impedance networks. The latter is becoming more essential for inverters with advanced grid functions, such as low-voltage ride through capability which requires control of a simulated AC grid, where voltage on one or more phases will drop to recommended levels over a full range (0–90%) for precisely controlled time intervals.

EMC testing involves some of the most elaborate and customised equipment, as summarised in Appendix C. In addition to the standards listed therein, IEC continues to work on developing standards dedicated to PV inverter EMC testing, with a more targeted guidance for the test rig requirements and options for EMC testing.

Table 3.3. Methods and equipment for photovoltaic system and component testing

Test	Equipment	Description
General		
Qualification test to IEC 62093	Environmental chambers	Enclosures for controlled testing of temperature, humidity
	Vibration table	Simulator with control of vibration amplitude, frequency, acceleration
	UV chamber	Enclosure for exposing equipment to controlled UV light
	Power supplies	Devices for controlling voltage and current input or output to electrical components
Inverters		
Safety tests to IEC 62109-1 and IEC 62109-2 & UL 1741 (U.S.)	PV simulator	Power supply capable of simulating current-voltage characteristics of a PV array
	Grid and load simulator	AC grid connection or simulated grid supply, and load simulators for off-grid tests
	Residual current test circuits	Resistive/capacitive circuits for validating detection of residual currents
	Environmental chambers	Enclosures for controlled testing of temperature, humidity
	Sound and sonic pressure meter	Device for measuring sound intensity (volume) and sonic pressure
	UV chamber	Enclosure for exposing equipment to controlled UV light
	Access probe	Device for determining physical access to live parts
Anti-islanding tests to IEC 62116 and IEEE 1547 (US)	PV simulator	Power supply capable of simulating current-voltage characteristics of a PV array
	Grid and load simulator	AC grid connection or simulated grid supply, and load banks to simulate electrical island
Low-Voltage Ride-Through tests to IEC 62910	PV simulator	Power supply capable of simulating current-voltage characteristics of a PV array
	Grid simulator	AC grid simulator capable of simulating full range of single and three phase voltage (collapse) with programmed durations.
Efficiency tests to IEC 61683 and IEC 62894	PV simulator/DC supply	Power supply capable of simulating current-voltage characteristics of a PV array
	AC Grid connection or simulator	AC grid connection or simulated grid supply
	Complex load banks	Controlled resistive and reactive loads, non-linear loads
	Transducers	High accuracy voltage and current measurement devices, DC and AC
PV charge controller		
Performance to IEC 62509	Environmental chambers	Environmental chamber is required for nearly every test in 62509 so that operational tests can be performed with the charge controller in controlled steady state temperatures.
	PV simulator/DC supply	Power supply capable of simulating current-voltage characteristics of a PV array is preferred. A controlled dc source (voltage and current) in combination with a series resistor is an acceptable alternative.
	Battery simulator/DC supply	Power supply with independent voltage and current control.
	Resistive load bank	Variable resistive load to provide controlled loads to the simulated battery and charge controller.
Combiner Boxes		
Safety and design verification to UL 1741 and IEC 61439-2	Environmental chamber	Enclosures for controlled testing of temperature, humidity.
	DC power supplies and DC voltage hi-pot tester	Controlled dc voltage and current supply for steady state testing as well as dc high pot voltage tests for validating insulating properties of components.
	DC power supply with high current capability	Supply for performing short-circuit current withstand capability tests on power components (busbars, switches, etc.)
	Radiant heat lamps	Radiant lamps are used to simulate the effects of solar radiation on various sides of the enclosure during the assembly heat-rise tests. [This test is new and will be included in the next edition of the standard.]
	Salt-mister	Salt-mist spray device used for corrosion testing of metallic parts and assemblies
	Miscellaneous environmental related test equipment	Test equipment used for mechanical impact tests (e.g. controlled hammer), controlled water and particulate sources for water and solid body ingress tests (IP ratings), etc.
	EMC test equipment	Appendix C
	Transducers	High accuracy voltage and current measurement devices, DC and AC
PV disconnect switches		
Safety to IEC 60947-3 or UL 98B	Environmental chamber	Enclosures for controlled testing of temperature, humidity.
	DC power supplies and DC voltage hi-pot tester	Controlled dc voltage and current supply for steady state testing as well as dc high pot voltage tests for validating insulating properties of components.
	Miscellaneous endurance related test equipment	Test equipment used for mechanical operations of switch (on/off), contact opening, mold stress relief, IP ratings, etc..

Test	Equipment	Description
PV Connectors		
Safety to IEC 62852 and UL 6703	Access probe for shock protection test	IEC test finger in accordance with IEC 60529.
	Corrosion test equipment	Flowing mixed gas corrosion according to test 11g of IEC 60512. Sulphur dioxide test with general condensation of moisture according to ISO 6988.
	Environmental chamber	Enclosures for controlled testing of temperature, humidity.
	Miscellaneous environmental related test equipment	Test equipment used for mechanical stresses (e.g. forced insertion and withdrawal, swing load tests) controlled water and particulate sources for water and solid body ingress tests (IP ratings), etc.
	DC power supplies and DC voltage hi-pot tester	Controlled dc voltage and current supply for steady state testing as well as dc high pot voltage tests for validating insulating properties of components.

There are relatively few variations in the type of equipment used in U.S., IEC and regional standards. The standards themselves may differ in terms of safety or performance thresholds, while the testing equipment categories are fairly uniform. Table 3.2. reflects this point by including the same equipment for parallel UL and IEC standards.

Other test programmes and protocols

Other test programmes and protocols are employed to support the PV market, extending beyond IEC product standards. UL, for example, has developed a Component Recognition programme that covers the major components in PV modules (e.g. connectors, junction box). Material properties are evaluated and assessed following specific test methods, with the results published on the UL certification website. Manufacturers are able to access the information, and source components and materials that meet North American requirements. Use of UL recognised parts greatly simplifies and accelerates the process of achieving complete module product certification, based on those standards. In addition, UL has developed a Follow-Up Services programme that monitors the consistency of material properties over time, together with production facility inspections and periodic re-testing of samples. There are other certification bodies that also operate such test programmes, such as TÜV.

In the United States, DNV GL offers a product qualification programme for PV modules and inverters (Table 34) that offers extensive PV module and inverter testing, extending beyond minimal IEC standards. Each product is submitted to a performance and reliability testing and characterisation under various conditions. Participation in the programme is funded by manufacturers and solar market stakeholders such as investors, financial intermediaries, developers, international partnership programmes and EPC contractors, who are able to access the results and reports free of charge.

Table 3.4. Tests required under the product qualification programme

PV Modules	PV Inverters
• Testing per bill of material • Extended reliability testing • Performance testing – PAN files – Array incidence loss coefficients (IAM) – Light induced degradation (LID) – Nominal operating cell temperature (NOCT)	• Reliability testing • Envelope characterisation • Transient response • Low-light performance • Efficiency • Arc/ground fault • Micro, string, and utility scale

This type of programme can be used for various purposes, such as the following:

- evaluation of a PV module or inverter;
- benchmark of long-term performance for the various manufacturers;
- preparation of an approved vendor list for products that demonstrate compliance to specific requirements; and/or
- testing of different equipment to define the selected bill of material of a specific project.

Business models for new test laboratories

Establishing a complete external PV test laboratory requires a high upfront investment. Such a laboratory should have sufficient order intake to enable it to operate viably. This will enable new test laboratories to overcome the challenges that prevent them from starting business in commercial and self-sustaining ways.

Nascent commercial test laboratories and PV test activities, nevertheless, are being deployed worldwide either (i) incrementally, by building on existing business activities such as those of national universities, test institutes and engineering consultancies, or (ii) as a means of addressing specific quality issues in the downstream part of the PV supply chain (PV system level), which requires lower upfront investments.

Building upon existing business activities and focusing on the downstream part of the PV supply chain are key elements for viable business models. New test laboratories that have survived the competitive PV market have applied such a business model.

3.3 Certification process

Certification is a formal verification by a conformity assessment body to assess and verify that a product, service, organisational management system or the qualification of an individual corresponds to the requirements of a standard. A certificate attesting conformity to the standard is issued based on the success of the assessment.

Certification can be granted by independent and informally accredited bodies, although accredited bodies offer the advantages of demonstrating consistency across processes and standards organisations. They are also subject to evaluations that assess their own conformity to accreditation standards.

Certification will only be recognised internationally if the certifying body is recognised by an internationally recognised accreditation agency. An accredited certification body may be accredited to its specific scope, such as:

- quality management system, according to ISO/IEC 17021
- products, processes and services, according to ISO/IEC 17065
- inspections, according to ISO/IEC 17020
- testing laboratories, according to ISO/IEC 17025
- persons, according to ISO/IEC 17024.

Table 3.5. Time and cost requirements for photovoltaic component certification in the United States

	PV modules	Inverters* Central	Inverters* String/Micro	Combiner Box	Support Structure
Standard	IEC 61215	IEC 62109	IEC 62109	IEC 61439-2	UL 2703
Time	45–60 days	5–7 months	4–6 months	3–5 months	5–8 months
Cost	USD 50 000– USD 60 000	USD 80 000– USD 110 000	USD 40 000– USD 70 000	USD 40 000– USD 80 000	USD 50 000– USD 100 000
	Regionally centered	Regionally centered	Regionally centered	Local/ manufacturer centered	Regionally centered

* Substantial variation exists between inverters due to variables such as the following:

- the manufacturer has gone through the process only once;
- the number of tests, if any, that can be performed at the manufacturer's facility;
- the number of iterations to modify issues; and
- the relevant extra travel.

In the case of the solar PV market, there are various certification processes, namely:

- PV component certification (e.g. PV modules, inverters, transformers, cables, junction box, supporting structure);
- PV system certification (e.g. building integrated PV systems, stand-alone PV system);
- PV grid code compliance certification; and
- PV installer certification.

Photovoltaic component certification

To certify PV components according to the relevant standards outlined in Section 3.1, specific tests are required. Standards can be international or national, or specific to a particular market or country (see Section 3.1).

The certification process of the solar PV components involves, directly or indirectly, the manufacturers who are to demonstrate the quality of their products and fulfilment the standard requirements regarding safety, performance and resistance. The process is time and cost consuming for the manufacturer and can vary from country to country. Often, laboratory efforts to become certified are undertaken on a regional basis with manufacturer components being sent to a neighbouring state or country.

For internationally recognised product certification, it is essential to use the testing services of an internationally recognised accreditation body.

Examples of solar PV component certification

Australia

Australia has developed a Renewable Energy Target programme that encourages investments in RE projects. As part of this programme, the Clean Energy Council is responsible for maintaining the list of compliant inverters and power conversion equipment that are approved for installation (CEC, 2016a) (see Section 6.1).

Within the programme is a list of accredited bodies responsible for the delivery of Certificates of Suitability for the equipment, evidencing compliance with the safety standards for usage in Australia. The list forms part of the Joint Accreditation System of Australia and New Zealand (JAS-ANZ) and includes but is not limited to the following:

- Australian Safety Approval (ASA) (JAS-ANZ)
- Conformity Certification Services Pty. Ltd. (CCS) (JAS-ANZ)
- Electrical Safety Office (Queensland)
- Energy Safe Victoria (ESV)
- ITACS Pty. Ltd.(JAS-ANZ)
- NSW Fair Trading
- SAA Approvals (JAS-ANZ)
- SGS Systems (JAS-ANZ)
- TÜV Rheinland Australia Pty. Ltd.

The following equipment must be tested for certification by the above accredited bodies:

- stand-alone inverter (with or without charging function);
- multi-mode inverter (inverter able to work in on-grid and stand-alone mode); and
- power conversion equipment (similar to DC/DC converters or charge controllers).

Germany

TÜV Rheinland is one of the world's most recognised testing service providers, operating globally with test laboratories in multiple countries. TÜV Rheinland's PV laboratory is accredited and listed as a certification test laboratory by the worldwide certification system of the IEC Conformity Assessment for Electrotechnical Equipment and Components (IECEE) in the PV category. TÜV Rheinland LGA Products GmbH is qualified as a national certification body.

Japan

The JET PVm certification scheme is managed by Japan Electrical Safety & Environment Technologies Laboratories, and the mark relates to c-Si and thin-film PV modules. Products must have passed various performance and safety tests, based on IEC harmonised Japanese Industrial Standards and on the inspection of the quality management system of the manufacturing location. (Japan Electrical Safety & Environment Technologies Laboratories, 2014).

United States

UL is an independent body that specialises in the testing, inspection, certification, auditing and validation of products and systems relevant to sustainability, RE and nanotechnology. Present in 46 countries, UL is part of nationally recognised testing laboratories in the United States.

UL Listed mark

UL Listing implies that UL has tested representative samples of the product and determined that it meets UL requirements. These requirements are based primarily on UL's published and nationally recognised Standards for Safety within the United States (UL, 2016).

UL Classified mark

UL Classified signifies that UL has tested and evaluated samples of a product with respect to certain properties. UL classifies products to: applicable UL requirements, standards for safety and/or standards of other national and international organisations. The UL Classification mark must be accompanied by a statement that indicates the specific scope of the classification and a control number (UL, 2016).

PV system certification

There are few standard protocols for certifying complete PV systems. Mandatory system-level approvals are generally provided by local authorities for their jurisdictions, and voluntarily by independent engineering firms with the relevant PV expertise for financiers. Despite the IEA having published the International guideline for the certification of PV system components and grid-connected systems in 2002, there are few standards for this purpose. The Association of Electrical Engineering, Electronics and Information Technology (Verband der Elektrotechnik, Elektronik und Informationstechnik, VDE), together with Fraunhofer and TÜV Rheinland, have developed comprehensive programmes for the complete evaluation and certification of PV plants, also having issued a limited number of certifications for plants in Europe and the United States. DNV GL also issued a Service Specification for the certification of PV power plants in May 2015 (DNV GL, 2015). It is anticipated that the IECRE conformity assessment programme under development will ultimately be a more broadly accepted certification process for complete PV systems on the basis of a standard or set of criteria.

The certification process of a complete solar PV system generally consists of a detailed design review, verification, inspection and testing of the completed system. The verification consists of analysing available technical documentation of solar PV components and checking their conformity against specific requirements in the location of the power plant (e.g. datasheets; certifications/other statements of conformity, validity and compliance; compliance with other specific requirements for the PV plant).

The inspection entails a visit to the power plant by a third party to ensure that the installation has taken place in accordance with best practice standards or other specific (typically local) requirement. According to the size of the plant, a sample of the PV plant components or the entire PV plant is inspected. A report is issued following inspection, highlighting the minor and major non-conformity issues that need to be addressed.

Testing also may be a part of solar PV system certification. It takes place on site and consists of verifying that the assembled components are functioning as expected so that installation takes place free of error.

Example of photovoltaic systems certification

Florida

States within the United States may have additional certification requirements for components or systems. As part of the Solar Energy Standards Act of 1976, solar energy systems manufactured or sold within the State of Florida, since 1980, are to be certified by the Florida Solar Energy Center (FSEC). The FSEC website states (University of Central Florida, 2016):

The FSEC standards program has been designed to meet the intent of the legislation while also helping the Florida solar industry to develop quality products, aiding building departments in product approval, and instilling confidence in the consumer who chooses to use solar energy in their residence or business.

The publication, Procedures for photovoltaic system design review and approval: FSEC Standard 203–10, January 2010 (FSEC, 2010), describes the process of certifying grid-connected PV and stand-alone systems, based on an evaluation of the entire design, including safety and code compliance, single components, interaction between components and completeness of technical documentation.

The systems covered by this certification process are the following:

- grid-connected PV systems without battery storage
- grid-connected PV systems with battery storage
- stand-alone systems
- PV-powered water pumping systems
- PV-powered lighting systems
- remote residential PV systems.

Photovoltaic grid code compliance certification

The certification process for the PV grid code compliance consists of verifying that the PV power plant complies with national, regional or utility-specific requirements for grid connection. The process takes place during several stages of PV plant development. During certification, the local/national grid code is analysed and the PV system design is audited in order to assess compliance in terms of safety and conformity. A certificate is issued by a conformity-assessment body.

Example of photovoltaic grid code compliance certification

Germany

In Germany, for each RE generation system connected to the grid, it is mandatory to provide a grid code compliance certificate, issued by an accredited certification body. The certification process generally consists of two key steps:

- Generation unit certification, referred to as a Type Approval for grid code compliance, consists of verifying the conformity of a PV inverter with the national grid code. The type certificate is carried out once for each type of solar PV inverter.

- Generation system certification, known as the Project Certificate for grid code compliance at a given site, is undertaken for the entire PV plant (e.g. switchgears, transformers). The Project Certificate is based on pre-construction data only, and a conformity statement is subsequently delivered following an on-site inspection the PV plant is commissioned. The conformity statement (issued by an expert) assesses that the equipment and system are compliant with the certificate (issued by an accredited body).

According to the level of voltage systems connected, various grid codes apply:

- At low-voltage range, the VDE-AR-N-4105 applies. In Germany, the PV systems connected to the low-voltage distribution network represent approximately 14 GW of total nominal power (VDE, 2016). No certification is required for this sort of project.

- At medium-voltage range, the BDEW (Bundesverband der Energie- und Wasserwirtschaft e.V.) medium voltage guideline 2008 applies. Later, this is replaced by VDE-R-N-4110.

- At high-voltage range, Transmission Code 2007 is indicated, and for 110 kilovolts, the VDE-AR-N-4120 applies. Later, the VDE-AR-N-4130 will apply for > 220 kilovolts.

The certification process relates to an analysis of the requirements specified in the grid code. These relate to the behaviour of the unit or the PV plant during normal operation and in case of disturbances originating from the grid.

International Certification Schemes

Two international certification schemes are relevant to PV, namely the IECEE Certification Body (CB) and IECRE.

IECRE System

The IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications (IECRE System) aims to facilitate international trade in equipment and services for use in RE sectors, while maintaining the required level of safety. In order to achieve this, it (IECREE,2017) :

- operates a single, global certification system;
- aims for acceptance by local/national authorities or other bodies requiring and benefiting from certification; and
- makes use of high-quality international standards and allows for continuous improvement.

The IECRE system is set up to evaluate the many aspects of RE systems (PV, solar thermal, wind and marine), including:

- site condition evaluation
- design evaluation
- equipment evaluation

- structural and electrical design evaluation
- installation and commissioning surveillance
- plant output measurements
- operation and maintenance surveillance.

IECEE CB Scheme

The IECEE CB Scheme is an international system for the mutual acceptance of test reports and certificates relating to the safety of electrical and electronic components, equipment and products. It is a multilateral agreement among participating countries and certification organisations. A manufacturer that makes use of a CB test certificate, issued by one of the accepted National Certification Bodies is able to obtain certification marks of the latter within their scope of adherence in the countries with such accepted bodies. (IECEE, 2016b)

The scheme is essentially based on the use of IEC standards. If some members' national standards are not yet completely harmonised with IEC or national standards, special national conditions and regulatory requirements are permitted subject to formally declaring and detailing them to the IECEE Secretariat for further publication. The CB Scheme makes use of CB Test Certificates to attest that product samples have successfully passed the test conditions and are in compliance with the requirements of the relevant IEC standard (s). When applicable, the CB Test Certificate and its associated Test Report can also include declared national differences, special national conditions and the regulatory requirements of various member countries.

The main objective of the scheme is to facilitate trade by promoting harmonisation of national standards with international standards, as well as cooperation among accepted national certification bodies worldwide in order to bring product manufacturers a step closer to the ideal concept of „one product, one test, one mark, where applicable".

Photovoltaics are included in the IECEE CB scheme. An overview of IEC Standards covered by the scheme is shown in Appendix D.

Figure 3.2. Examples of poor installation work

Left: Cables should be supported and combined correctly.

Right: Irradiance sensors should be installed in the same plane and without shading.

Source: PVCROPS, 2013

3.4 Installer certification

The quality of an installed PV system does not depend only on the quality of the selected products. Moreover, system design and installation are large parts in which system quality or the lack thereof is realised.

Figure 3.2. shows two examples of poor installation workmanship. To assure the quality of solar PV installations, countries may implement installer certification or licensing programmes. Although there are examples, there is a global lack of installer certification and training programmes. Illustrative examples emanate from Europe, such as the Netherlands – where PV penetration is still relatively low but the PV rooftop potential is significant – and from Australia.

European countries have to comply with EU Directive 2009/28/EC. Article 14 (Information and Training) states:

3. Member States shall ensure that certification schemes or equivalent qualification schemes become or are available by31 December 2012 for installers of small-scale biomass boilers and stoves, solar photovoltaic and solar thermal systems, shallow geothermal systems and heat pumps. Those schemes may take into account existing schemes and structures as appropriate, and shall be based on the criteria laid down in Annex IV. Each Member State shall recognise certification awarded by other Member States in accordance with those criteria.

4. Member States shall make available to the public information on certification schemes or equivalent qualification schemes as referred to in paragraph 3. Member States may also make available the list of installers who are qualified or certified in accordance with the provisions referred to in paragraph 3.

The Netherlands

As a result of European legislation, the Dutch PV sector has developed Zonnekeur, an installer's authentication mark or certification. The foundation, DEPK (Duurzame Energie Prestatie Keur, or "Sustainable Energy Performance Authentication") certifies and administers the installer's authentication; DEPK is a non-accredited body. The authentication mark (keurmerk in Dutch) refers to the company, not to its installations. A Zonnekeur certification has an impact on 4 levels the installing company: capacities of the individual, management and later the delivery and verification of the certificate (Zonnekeur, 2013).

Figure 3.3. Zonnekeur

Source: Zonnekeur, 2013

United Kingdom

The Microgeneration Certification Scheme (MCS) is an industry-led and nationally recognised quality assurance scheme, supported by the Department of Energy and Climate Change (DECC). MCS itself, launched in 2008, is a BS EN ISO/IEC 17065:2012 scheme. MCS certifies installation companies to ensure the micro-generation products have been installed and commissioned to the highest standard for the consumer. The certification is based on a set of installer standards and product scheme requirements. (MCS, 2016)

MCS is also an eligibility requirement for the Government's financial incentives, which include the Feed-in Tariff and the Renewable Heat Incentive. It is a mark of quality and demonstrates compliance to industry standards that companies strive to meet. It highlights to consumers that companies are able to consistently install or manufacture to the highest quality every time. (MCS, 2016)

Figure 3.4. Microgeneration Certification Scheme for quality assurance

Source: MCS, 2016

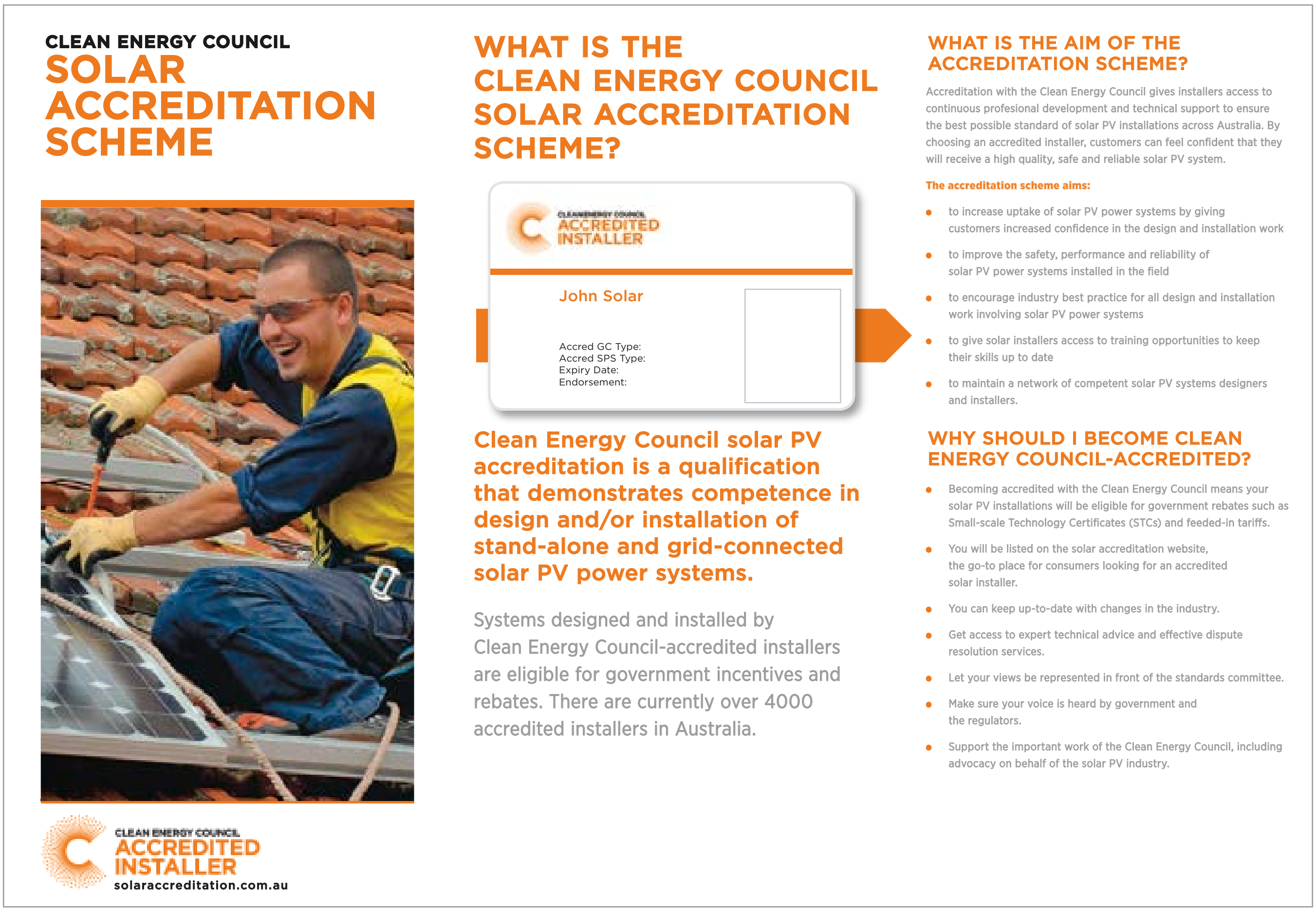
Australia

In Australia, quality mechanism such as accreditation, allows installers (and equipment retailers) to achieve high quality. The relevant website states (Clean Energy Council Accredited Installer, 2014):

Becoming accredited with the Clean Energy Council means your solar PV installations will be eligible for government rebates such as Small-scale Technology Certificates and feed-in tariffs.

To become solar PV accredited, installers must complete training courses and demonstrate their electrical licence, working at heights certification and public liability insurance. Subsequently, a case study is to be submitted regarding one installation performed in order to demonstrate competency in the design and installation of solar systems. Once approved, the accreditation is valid for two years, after is possible to apply for the renewal.

Figure 3.5. Clean Energy Council solar accreditation



Source: Clean Energy Council Accredited Installer, 2014

United States

Licensing requirements are determined at the individual state level in the United States. As of 2015, only 12 states and Puerto Rico required specialty licenses covering PV. These specialty licenses typically fall under the more general electrical or plumbing licenses. Most other states require only the general electrical or plumbing licenses. There are, however, cases where if the state does not have a specialty license requirement, additional licensing or certification may be required at the local city level or for eligibility for state financial incentive programmes (NABCEP, 2017)

Figure 3.6. North American Board of Certified Energy Practitioners

NABCEP™

Raising Standards. Promoting Confidence.

Source: NABCEP, 2017

Note: NABCEP® is a registered trademark owned by the North American Board of Certified Energy Practitioners®, (NABCEP®).

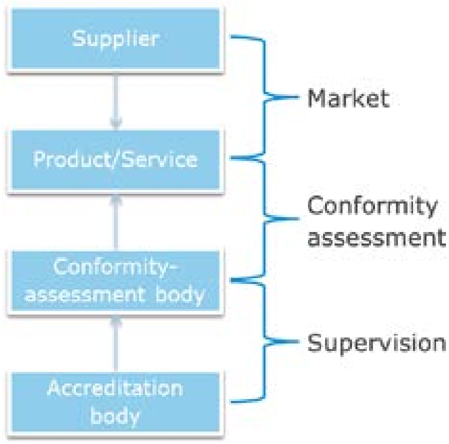
The most commonly cited certification programme is conducted by the North American Board of Certified Energy Practitioners (NABCEP). NABCEP is a nationally-recognised, independent and voluntary certification programme for PV and solar-thermal system installers. To become NABCEP-certified, installers must complete training courses, document appropriate training and experience, pass an exam, sign a code of ethics, and take continuing education courses for re-certification every three years. NABCEP also offers the (i) Associate Program for those beginning a career in the RE industry; (ii) PV Technical Sales Certification for sales persons, application engineers, financial or performance analysts, or site assessors; and (iii) Company Accreditation programme for businesses involved in residential RE installations.

3.5 Accreditation processes

Accreditation (literally, means "giving confidence) (RVA, 2016) is an independent evaluation of conformity-assessment bodies based on recognised standards. The aim is to provide competent and impartial supervision of activities such as testing, calibration, inspection and certification.

Conformity-assessment bodies that certify third parties based on official standards are, themselves, formally accredited. An accreditation body guarantees trust through expert, impartial and independent supervision (see Figure 3.7.).

Figure 3.7. Stakeholders and steps in technology accreditation



By obtaining a statement of conformity from a laboratory or an organisation that inspects, certifies or verifies their products, processes and services, suppliers are better able to access the market. The statement is issued in the form of a certificate or report. Such organisations are referred to as conformity assessment bodies and the impartial and independent statement is of most value to a supplier. An accreditation body therefore checks whether a conformity-assessment body is competent and if the results are positive it becomes an accredited body.

Accreditation bodies apply international standards (e.g. ISO/IEC 17025 or ISO/IEC 17065) when assessing conformity-assessment bodies. These standards mainly focus on their expertise, impartiality, independence and quality improvement culture. Organisations that meet the standards receive formal accreditation (renewable every five years), allowing them to apply the accreditation mark of the accreditation body.

Accreditation bodies exist in many countries and, once their competence has been evaluated by their own peers, agreement is made to boost the cross-border entry of products and services. The technical barriers that restrict international trade are thus removed. Such bodies are recognised internationally for their testing and certification methods only if they, themselves, are accredited by an internationally recognised accreditation body. In Europe, for example, governance takes place at the European Co-operation for Accreditation, an association of national accreditation bodies (RVA, 2016; IECEE, 2016b)

3.6 Metrology

Metrology should be a key characteristic in QI, given its impact in the PV sector. It allows manufacturers to undertake research and development (R&D) and controls, as well as manage yield, resulting in more efficient commercial solar modules at lower cost. In mature markets, such as those of Germany and the United States, quality improvements can take place in metrology so that the entire sector's quality level rises.

In IRENA's publication, ***Quality infrastructure for renewable energy technologies: Guidelines for policy makers*** (2015), metrology is distinguished as follows:

- Scientific metrology describes and disseminates the measurement units;
- Industrial metrology utilises calibrations to guarantee measurement instruments, used in production and in tests; and
- Legal metrology utilises verification to secure the accuracy of measurements in those cases that influence the transparency of economic transactions, health and security.

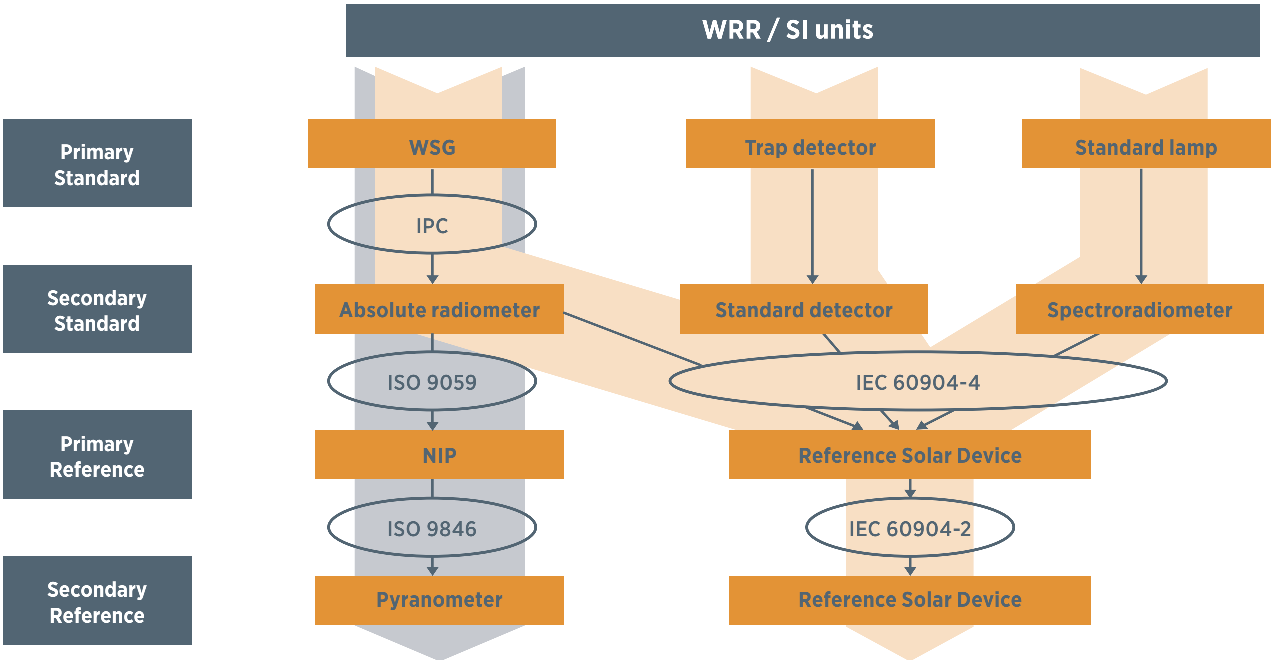
Meanwhile, the hierarchy of national metrology consists of:

- A national metrology institute (NMI) that represents the highest level of measurement standards and technical competence;
- Secondary calibration laboratories that receive the traceability of their secondary measurement standards from the NMI; and
- Industrial calibration laboratories that receive the traceability from the secondary calibration laboratories.

Primary NMIs place their traceability directly on the International System of Units, whereas for secondary NMIs, it is assured by calibrations in one of the primary NMIs. The quality management systems of NMIs are peer-reviewed by regional metrology organisations, International Bureau of Weights and Measures (Bureau International des Poids et Mesures, or BIPM) or International Laboratory Accreditation Cooperation. NMIs are usually a public institute, funded by government.

Considering the metrology requirements relating to PV technology, emphasis is placed on the calibration of measurement devices in the manufacturing process and systems. There are two categories of PV irradiance measurement devices, which include reference cells (reference solar devices) and pyranometers. Furthermore, measurements of humidity, wind speed, and temperature, among others, is necessary for instance to calibrate test equipment. As in the case of metrology institutes, PV measurement devices also depend on a chain of traceability which demonstrates alignment with international standards. The traceability chains of reference cells and pyranometers, however, differ as reflected in Figure 3.8. Pyranometers rely on the World Radiometric Reference, a standard of measurement that represents the unit of irradiance. It is determined by a group of absolute cavity radiometers known as the World Standard Group, located at the World Radiation Center in Davos, Switzerland. Traceability of reference cells can be obtained either by trap detectors, standard lamps or calibrating, based on the World Radiometric Reference. The difference in the measurement devices, and their calibration and traceability chains, make this specific field of metrology somewhat opaque in the PV sector, allowing for future improvement.

Figure 3.8. Traceability chain for solar reference cells and pyranometer



Based on World Standard Group

Notes: Blue = Solar reference cells; green = pyranometer.

WSG = World Standard Group; ISO = International Organization for Standardization; NIP = Normal Incidence Pyrheliometer; IEC = International Electrotechnical Commission.

3.7 Quality infrastructure for each type of photovoltaic system

Based on compliance with international standards, testing methods and certification, PV components have no significant variances. Nor are there fundamental QI distinctions whether or not these components are jointly mounted on a roof or in a field, or connected or not to a grid.

The QI of a PV system requires various stakeholders in addition to those laboratories involved at the component level. At the system level, these include installers, inspection bodies and system suppliers, whose role is essential.

- The distributed generation segment of the market is served by installers from the housing utility sector, therefore is vital to strengthen their knowledge regarding standards for PV system certification and good practices of installation.

- Utility-scale PV systems are mostly constructed and supplied today by industrial system suppliers with PV experience (EPC contractors). QA is often included in their practices, with owners and financing entities applying QI measures through third-party services during the project's development life cycle, operation and periods of maintenance.

- Large off-grid systems of more than a few hundred kW that resemble utility-scale PV systems, smaller off-grid systems for consumer application, however, relate to a separate PV segment in terms of QI. Compared to a PV system, small off-grid systems are those consumer goods that have their QI branded and maintained by retail companies.

Finally, distributed generation and utility-scale PV systems must comply with national, regional or specific grid-code requirements for connection to the electricity grid. Off-grid PV systems are exempt from such requirements.

Quality Infrastructure for Solar Photovoltaic Systems:

COSTS AND BENEFITS

4

Quality Infrastructure for Solar Photovoltaic Systems: Costs and Benefits

Implementing and executing QI measures in PV systems requires effort and implies high upfront costs, but the rationale for implementing a quality infrastructure is that, in the future, costs due to quality issues are avoided. In the long term the mitigated costs will outrun the costs for developing and implementing the quality infrastructure. Currently, the cost of low quality is partially covered by warranty claims and liquidated damages, but these aspects usually do not cover all costs related to low quality, although some warranty issues may remain inconclusive (so no payments done) and liquidated damages may be limited in value. This results to owner's also bearing a part of the costs of low quality.

The outcome of a cost/benefit analysis may vary in different parts of the value chain. Performance guarantees of PV modules usually last over a period of 25 years, although project developers and EPC contractors often are liable for only a few years, driving them to focus on short-term quality aspects.

Developed and developing countries alike have identified the key gaps and challenges of QI development and implementation for PV systems. These include the following:

- Americas: Chile and the United States
- Middle East and Africa: Egypt and the United Republic of Tanzania
- Europe: Germany and the Netherlands
- Asia and Pacific: Australia, China, India, Indonesia and the Philippines.

4.1 Technical risks and impact on energy yield

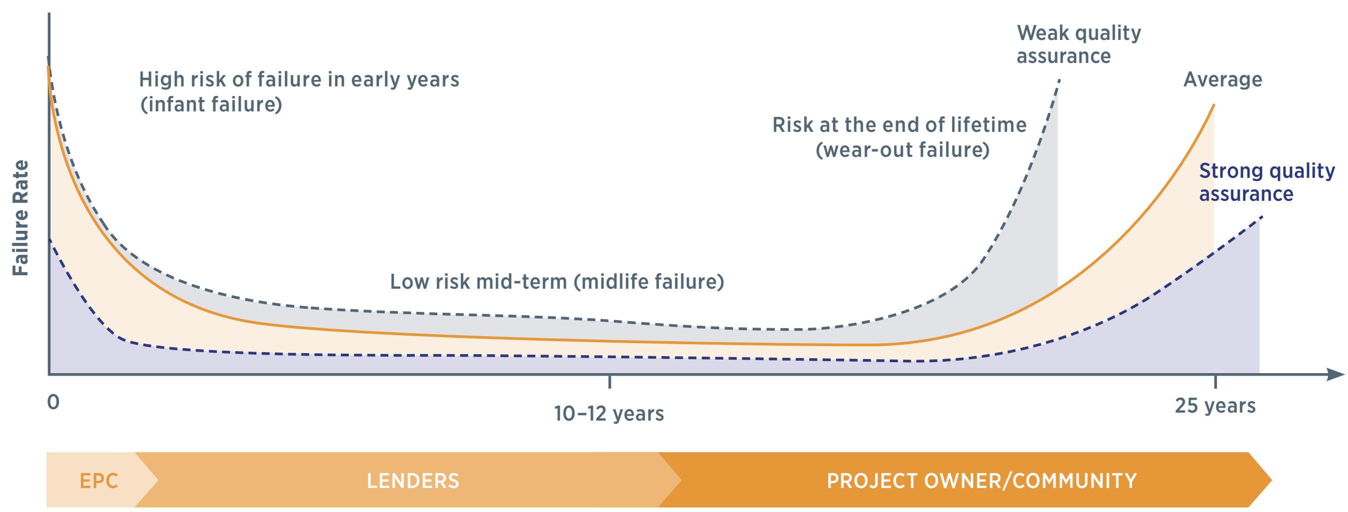
Despite its significant progress, the global market for solar PV is still hampered by the technical risk within the solar PV technology lifecycle. Multiple stakeholders experience the failure curve of such technologies, where the liability gradually transfers to the project life cycle.

In the early stages of development, the risk of failure is usually at the expense of the EPC contractor and project developer who, often are liable for only a minimum number of years, which makes them focus on short-term quality aspects.

During the planning and development phases, the effect of quality measures, such as obtaining accurate solar irradiation data, has a significant effect on the energy yield of the entire PV system, especially when each of the various technical characteristics may have an impact on the energy yield. The lower the uncertainty, the lower will be the risk premiums and, in turn, the better will be the financial outcome. The less failures occurring during the midlife of the technology, the higher the revenues will be for lenders and project owners alike. As the PV system reaches the end of its life cycle, malfunctions will happen more regularly (i.e: wear) (see Figure 4.1.). Thus, to ensure the efficient operation of a power plant, the risk failure should be lessened as much as possible.

This section is based on information from the Solar Bankability publication, ***Technical risks in PV projects: Report on technical risks in PV project development and PV plant operation*** (Solar Bankability, 2017). Table 41 provides an overview of the factors that contribute to overall uncertainties of energy yield.

Figure 4.1. Failure curve of solar photovoltaics



Based on Solar World, 2016

The risk of breakdowns and defects of PV system components are a significant cost factor. The Solar Bankability project developed an approach to assess the cost/benefit trade-offs by determining a cost priority number (CPN) for a selected amount of common failures. This figure includes a combination of repair costs (e.g. labour, maintenance, cleaning and transportation) and cost of downtime of (a part of) the PV system. The CPN method is a valuable method in assessing costs and benefits of technical issues, also failures with a low energy loss per year should not be disregard as power losses may increase over the years and existing or impending failures could impose safety risks and result into additional costs.

With regard to the Horizon 2020 project, funded by the European Union, Solar Bankabilty provides an overview of CPNs in its report for modules, inverters, cabling and other components (e.g. mounting structures, combiner boxes and transformers) (Solar Bankability, 2017). The top ten CPN are presented in Table 42 and are a result of a sample of projects analysed in its report.

Table 4.1. Factors contributing to energy yield uncertainty

Factor	Overall Uncertainty Range
Insolation variability Plane of array transposition model	± 4–7% ± 2–5%
Temperature coefficients and temperature effects	± 0,02%/ oC (5% relative error for crystalline-silicon-based modules)
Temperature deviation due to environmental conditions	1–2 oC (± 0.5–1%) Up to ±2% if environmental conditions are not included
Inverter model Photovoltaic array model	±0.2% to ±0.5% for the inverter model ±1% to ±3% for the photovoltaic array model
Degradation	± 0.25–2%
Shading	Site dependent
Soiling	± 2% (also site dependent)
Spectral mismatch (modelled)	± 0.01%–9% (depending on photovoltaic technology) ± 1% to ±1.5% for c-Si
Nominal power	± 1–2%
Overall uncertainty	± 5–10%

Source: Solar Bankability, 2017

Table 4.2. Top ten cost priority numbers for photovoltaic modules

Failures Photovoltaic Modules	Cost per Number Each Year in Euros/kilowatt peak (U.S. dollar/kilowatt peak)
Improperly installed	15.45 (17.10)
Glass breakage	10.10 (11.18)
PID (potential induced degradation)	7.75 (8.58)
Snail track	6.48 (7.17)
Defective back sheet	4.43 (4.90)
Delamination	3.59 (3.97)
Hotspot	2.98 (3.29)
Soiling	2.87 (3.18)
Shading	2.02 (2.24)
Broken module	1.65 (1.83)

Source: Solar Bankability, 2017.

Note: The cost priority number is an indication of preventive and corrective operation and maintenance (Euros/kilowatt peak/year) (Solar Bankability, 2015)

The CPN indicates the costs of potential failures and thus, together with previously addressed uncertainties, determines the magnitude of the accompanying risk for PV systems. These risks can be reduced through QI services such as standardisation (PV installer) certification, inspections and testing. The overall CPN of a PV plant with no mitigation measures in place is approximately EUR 100/kWp/year (USD 110.7/kilowatt peak (kWp)/year). This value reduces to EUR 10–20/kWp/year (USD 11.07–22.14/kWp/year) when cost-effective preventive and corrective mitigation measures are introduced.

4.2 The importance of quality assurance in photovoltaic and energy development

Relevant messages for policy makers, industry associations, project developers and investors in countries where there is a focus on solar PV or on energy, in general, are as follows:

- QI is essential to assure the performance and safety of PV systems;
- the PV industry evolves at a fast pace and the process of international standardisation tends to develop too slowly to match certain industry developments;
- further standardisation, certification, inspections and testing services are clearly necessary, especially standardisation regarding the durability of solar modules;
- solar PV requires comprehensive knowledge and understanding to enable the deployment of QI services, despite it being a relatively simple power generation technology;
- there is a clear need to define the concrete quality requirements in national programs to develop solar PV;
- certification schemes for PV systems and their installers are crucial in emerging and mature markets;
- public guidelines for the effective design and installation of distributed and off-grid PV systems in developing countries are essential in the face of low entry barriers for suppliers and developers; and
- QI development for PV should be incremental, paralleling the development of its market.

4.3 Development and implementation of quality infrastructure: Key gaps and challenges

QI in its entirety is complex, involving numerous interacting organisations and stakeholders. This section describes the key challenges of implementing QI, while prescribing potential solutions.

Durability testing

Banking sector discussions indicate that durability testing, according to international standards, does not assure the expected life cycle of a PV systems to be beyond 20 years. Experience indicates that the lifetime of some equipment tested accordingly may reach only 10 years, a period insufficient to achieve a return of investment. A reason mentioned is that such standards were developed years ago, when the lifetime of projects was not of concern and not to be over stringent with manufacturers. During the last decade, however, global testing and inspection bodies, such as Atlas 25+, DNV GL, Fraunhofer USA, PHOTON International GmbH, SGS and TÜV, have developed schemes which aim for lifetime durability testing in laboratory conditions.

Recommendation: In order to facilitate the quality assessment of a single batch of PV modules, the private sector should incorporate batch acceptance testing in large wholesale procurements or utility-scale projects. This will strengthen confidence in the quality of the batch over the long term (see Section 4.4).

Standards across the value chain

Although international standards are incorporated in all stages of the PV value chain, further work is necessary in terms of their application in the installation, operation, maintenance, documentation and decommissioning.

Recommendation: In creating a minimum of quality criteria, project developers, owners and investors should demand conformity with international codes and standards in terms of PV procurement tenders and contracts.

IEC standards can serve as a starting point in the formulation of EPC tender and contract documentation. Details of applicable standards for each area (e.g. PV modules; electrical systems; controls and monitoring processes; foundations and mounting systems; and performance monitoring) should be clearly outlined and succinct so as to avoid conflict with national standards and thus ensuring the prevailing standard to be used. Contract bidding and agreement documents also should include a request for certification so as to enhance QI.

End-of-life of photovoltaic modules: Challenges and opportunities

As the global PV market grows, so will the volume of decommissioned PV systems. With regard to panel waste, cumulative waste streams are expected to have reached 43 500–250 000 metric tonnes by the end of 2016, reflecting approximately 0.1–0.6% of the cumulative mass of all installed PV panels. In the meantime, PV panel waste streams will increase further. Given an average panel lifetime of 20–30 years, large amounts of annual waste are anticipated in the early 2030s, equivalent to 4% of installed PV panels in that year. Waste amounts by the 2050s are anticipated to match the mass contained in new installations (6.7 million tonnes) (IRENA and IEA-PVPS, 2016).

While the growing waste streams present a new environmental challenge, there are nevertheless unprecedented opportunities to create value from the recovery of raw materials by solar PV end-of-life industries. It is therefore essential that international standards adequately address not only the QI in terms of the full life cycle of a PV system, but also extend the value chain from the decommissioning stage to options for waste management (e.g. treatment, recovery).

Recommendation: Public and private sectors should encourage QI throughout the entire life of a PV plant, including its decommissioning and waste management. Treatment and recycling options should be ensured, with potential for reuse in the photovoltaic sector so as to achieve a holistic QA PV system framework.

To achieve the best material recovery outcome from end-of-life PV systems, QI should be integrated in the early stage of system design. The material composition in terms of treatment and recycling also should be evaluated in parallel.

Cost

Comprehensive QI can be costly to the PV industry, requiring the support of government. Investment is essential for installer training, test laboratories and their accreditation, certification bodies and organisations that develop the standards. These costs easily exceed USD 10 million, as establishing a complete PV test laboratory, alone, requires an investment, of such order of magnitude. Testing and certification processes of PV component product lines, cost USD 50 000–100 000. Such substantial costs hamper the speed in which QI can be developed and implemented. There are additional costs within the PV industry that are unaccounted for in the absence of comprehensive QI, especially in new markets where it can lead to project loss and turndown of new business.

Recommendation: Governments should provide funding to kick start QI development as the solar PV market grows. Government support is especially vital during the emergence of a market, when its capacities are not yet fully developed.

Nascent markets implementing QI, for example, begin with limited efforts to keep costs low. When starting the adoption of standards for PV equipment and installations, they should comply with the expected levels of quality and performance. Rather than create new standards, it is more effective to adopt a minimum set of requirements, based on available international standards, thus allowing time to establish efficient import controls, installation guidelines, lists of accepted equipment, certification and testing in future stages. Participation in international standards committees is also recommended, at a minimum to contribute to the drafting of new standards.

The development of national testing laboratories should centre on the commissioning phase, as well as on system inspection to ensure that procedures conform not only to national, but also to international standards and best practices, such as IEC 62446 (commissioning test and inspection) and IEC 61829 (on-site measurement of I-V characteristics for c-Si modules). While testing procedures should be conducted according to prevailing standards, it is acceptable to engage the services of unaccredited testing entities. Furthermore, the integration of simple devices (e.g. multi-meters and thermal cameras) should be considered essential.

Pace of industry progress

The speed in which QI standardisation services and certification is developing lags behind that of the PV industry, making it a challenge to tie in with certain industry developments. The requirements of financiers are becoming more stringent compared to international standards, exemplified by the bankability prerequisites for PV equipment, as well as an assurance of the energy production of a new PV power plant.

Recommendation: The private sector should demand new and updated standards, as well as participate in the processes of standardisation. Governments, on their part, should encourage national standardisation groups to join international standardisation committees in order to influence the pace of the process and ensure knowledge exchange. By doing so, not only will international standards benefit from country input, but national industries will be able to improve penetration into international markets.

In-country solar photovoltaic knowledge

Although solar PV is a relatively simple power generation technology, it does require comprehensive knowledge and understanding in terms of QI deployment. Given that various actors in the energy sector often do not expose the technical skills necessary to guide QI implementation, they should seek guidance from those who have the knowledge and expertise to better position QI.

Recommendation: Governments should identify and develop in-country or regional expertise in PV technology to advice policy makers, project developers and investors. It is essential to capture the knowledge that present within a country from universities, associations and research centres as well as knowledge from the industry itself. Development of PV knowledge, therefore, should be supported, with international agencies may be useful until in-country expertise is sufficiently developed, preferably through industrial and academic networks.

Implementation of guidelines

At the global level, there are limited policies, regulations and codes in place that refer to utility-scale PV systems. This is not surprising given that the entry barrier for such systems is usually high, and implementing QI services tends to be the responsibility of privately owned companies. For distributed and off-grid systems, however, QI policy measures are vital due to the low entry requisites for PV system developers. The lack of QI in distributed and off-grid PV installations, furthermore, has a larger impact on the end user. Public authorities have the social responsibility to ensure the public receives safe and reliable electricity.

Recommendation: Governments, together with industry experts and relevant associations, should facilitate and support the development and implementation of public guidelines for the faultless installation and design of PV installations. Such guidelines may be (i) in the form of a manual for installers, including best practices and standards; (ii) as certifications; (iii) incorporated in specific laws relating to the connection of PV systems to the grid; or (iv) be included in government incentive schemes.

Quality of photovoltaic system installation

New technologies can impose a certain degree of risk. While high-quality, certified PV products (e.g. modules, inverters) may be purchased or applied,system failures are present and being caused by installation errors.

Recommendation: Governments should encourage the development of appropriate certification schemes for PV systems and installers. Certification is necessary to ensure that PV systems meet relevant safety standards, given that there are currently few standard protocols that certify the entirety of a PV system. The certification process of an entire solar PV system generally consists of a detailed design, review, audit, inspection and pilot test.

The certification of installers is important to ensure the quality of distributed and off-grid systems. Training and certification are critical from the early stage of market development through to its expansion so as to reduce potential operational problems. There are various approaches to certification at the regional and national levels.

Counterfeit markets

Substandard PV products – often produced in parallel markets in some nations – gain entry into various countries through uncontrolled border crossings. As a consequence, system components do not go through the required standards testing due to a lack of government resources and infrastructure.

Products that are imported are often not registered at customs by importers and dealers due to a lack of understanding of the importance of minimising the entry of substandard products into the local market. As a consequence, and given their low cost relative to certified products, customers select the second-rate products with the ultimate risk of consumer dissatisfaction and less confidence in the PV system.

> **Recommendation:** It is imperative that governments improve collaboration between the various border control agencies, as well as enforce the protection of goods entering the country.
>
> Importers should be made aware of the technology, customs registration process and their role in the supply chain. The end user should be informed of the importance of ensuring the selection of certified products.

4.4 Cost and benefits

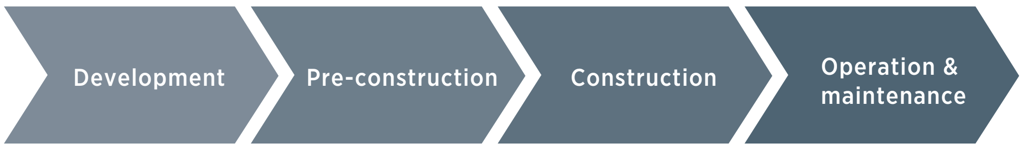
This section offers five examples of the costs and benefits of implementing QI services in PV markets during the various stages of utility-scale PV plant development (see Figure 4.2.). While they are selected for their relevance to the evaluation of monetary potential in a cost/benefit analysis. It should be noted that these examples a complete set of QI measures for the development stages.

Development: Reduction of solar resource uncertainty and yield uncertainty

Requirements that are put in place by financiers are becoming more stringent than international standard compliance. An example of this is the requirements that are placed on the certainty of the electricity production of a planned PV power plant.

Utility-scale PV plants are generally constructed with funds provided from third-party lenders or investors at a given interest rate. Prior to funding a project, a financial model is developed, detailing the economics of the project throughout its lifetime. A basic parameter in the financial model, the annual energy production of the plant, is derived for an initial yield or energy production assessment. Input for this assessment is the solar irradiance, known as the solar resource.

Figure 4.2. Four stages of project development



The assessment indicates the central estimate (P50) and the uncertainty relating to this value. To increase the security of the return of the investment for the bank, the assumed future energy production is often not based on the P50 value and, instead, on the P90 (with a probability of 90%, future energy production will exceed this value), P95 or P99 value. The P90 value is related to the P50 value through the uncertainty. The higher the uncertainty, the lower the P90 value.

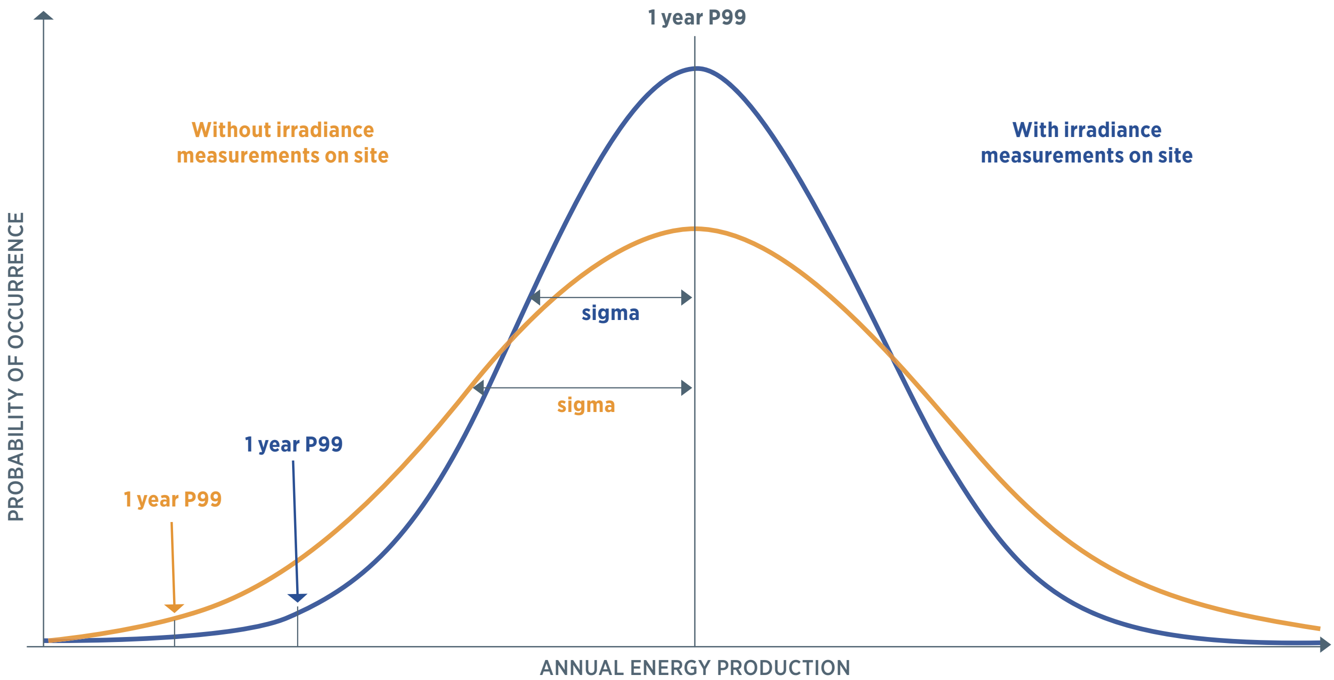
In the absence of long-term reference data from a nearby meteorological station or good quality satellite data, the uncertainty of the irradiance data often dominates the overall uncertainty of the P50 estimate. In this case, installing a temporary monitoring station at or close to the project location may considerably reduce the uncertainty. The monitoring duration should be at least one year to adequately correlate the site conditions with those of the nearest locations having long-term historic data.

As an indication for the order of magnitude, the reduction of the uncertainty from 8% to 6% – which are typical values for assessments with and without measured data – leads to an increase of the P99 value by approximately 6% and of the P90 by 3%. The lender rewards this with better conditions for the loan. In other words, the availability of higher quality irradiance data allows for a more reliable energy assessment with a lower uncertainty, leading to a lower risk of the investment and a better loan. Figure 4.3. exemplifies the increase of the P99 value due to the reduction of the uncertainty, based on the existence of measurement data.

Pre-construction: Prevention of low plant yields due to early thermal cycle stress testing

Batch acceptance testing should be incorporated in large wholesale procurements or utility-scale projects. PV modules are constructed from several materials, each with varying coefficients of thermal expansion. As ambient temperature and irradiance fluctuate, materials expand or contract. When adjacent materials have mismatched coefficients of thermal expansion (e.g. silicon solar cells and metal busbar ribbons), the interface experiences stress, causing aging (e.g. solder joint fatigue).

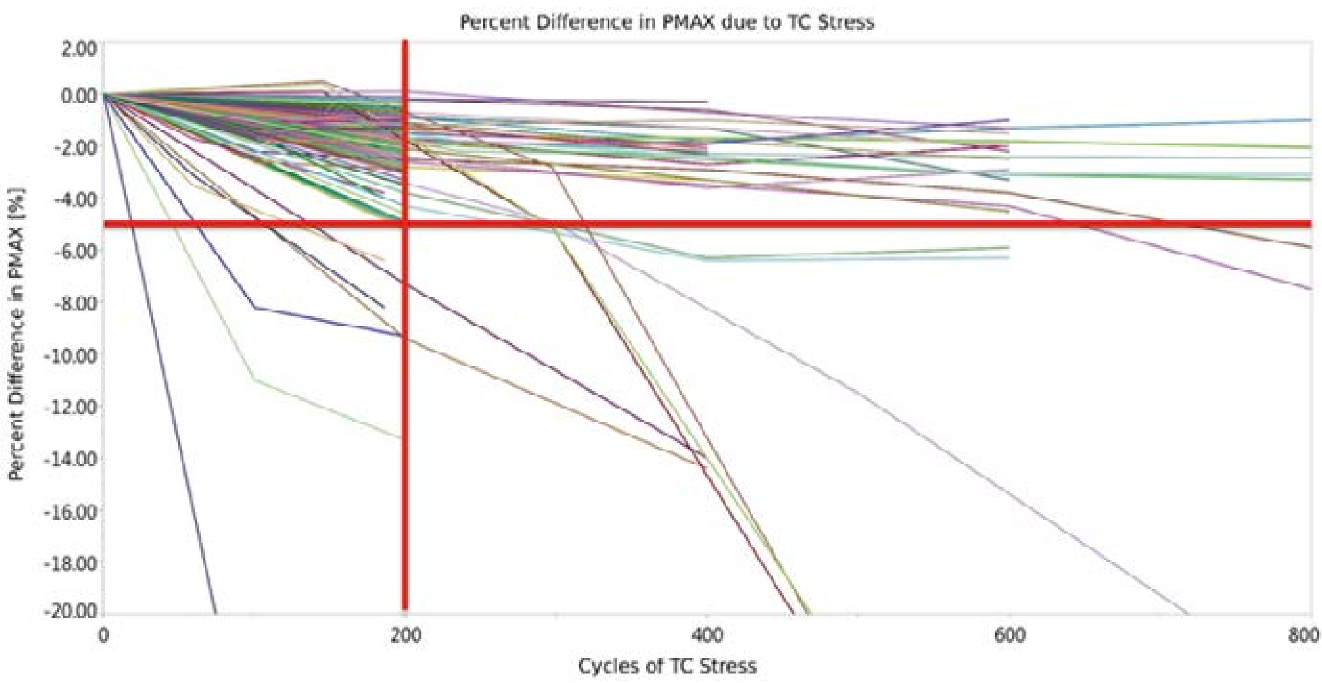
Figure 4.3. Increase of P99 value with measurement data



Though most projects require UL and/or IEC certification to ensure a minimum of module robustness, it is widely accepted that these certification standards are not sufficient to demonstrate PV module reliability or consistency. The scope of the IEC 61215 tests accounts only for a higher probability of so-called infant mortality and leaves aside a number of common potential causes of failure. This means that the IEC 61215 tests are only well suited to weed out modules that would likely fail within the first years in the field. Modules which do not pass the test can also have a higher chance of creating a safety hazard in the field compared to those that do not fail the IEC test, and should therefore not be allowed to be installed. Recent third-party tests show, however, that 6% of commercial PV modules tested do not pass the IEC 61215 thermal cycling test (DNV GL, 2016a). Most of these modules were UL and/or IEC certified. These modules are considered non-conforming to the standards.

Figure 4.4. shows the module performance degradation of a certain market share of PV modules during cycles of thermal stress testing. The vertical red line shows the 200 cycles limit of the IEC 61215, whereas the horizontal red line indicates the fail/pass threshold of 5% maximum power degradation in the same standard. Several modules do not pass the 5% degradation criterion after 200 cycles of thermal stress testing; some modules pass the IEC standard after 200 cycles but do not meet the 5% degradation limit after 200 to 800 cycles; and some modules stay within the 5% degradation limit even after 800 cycles.

Figure 4.4. Results for numerous photovoltaic modules in thermal cycle stress testing



Source: DNV GL, 2015

Notes: PMAX = maximum power degradation; TC = thermal cycle.

Applying the 200-thermal cycle IEC tests for PV module defect screening is becoming a common and effective batch acceptance test, screening for serial defects for PV module procurement in large residential or commercial procurements or utility-scale projects. Batch acceptance testing is a quality instrument that reduces the risk of accepting a module batch of quality below the standard. It is done through PV module sampling; that is, selecting a set of modules out of a specific batch. This step builds confidence in that the production process and bill of materials are representative of commercial production.

Observing this from the cost/benefit perspective of a 20 MW plant in the United States, the following can be determined based on the assumptions mentioned. The degradation rate assumption that is applied in the financial model during project development may arguably be lowered if there is no failing module in the batch acceptance test. Assuming that batch testing triggers (everything else being equal) a reduction of the assumption on the degradation rate from 0.75% a year to 0.4–0.6% a year. Taking as an assumption a lifetime of 25 years, an energy yield of 1000 kWh/y/kWp and an electricity price of USD 0.10/kWh results in an additional cumulative cash flow between USD 450 000 and USD 1 million (taking a discount factor of 5% into account). Comparing this financial benefit to the typical costs of batch acceptance testing of approximately USD 50 000 shows that this typical QI measure pays off generously.

Construction: Higher plant outputs due to performance testing

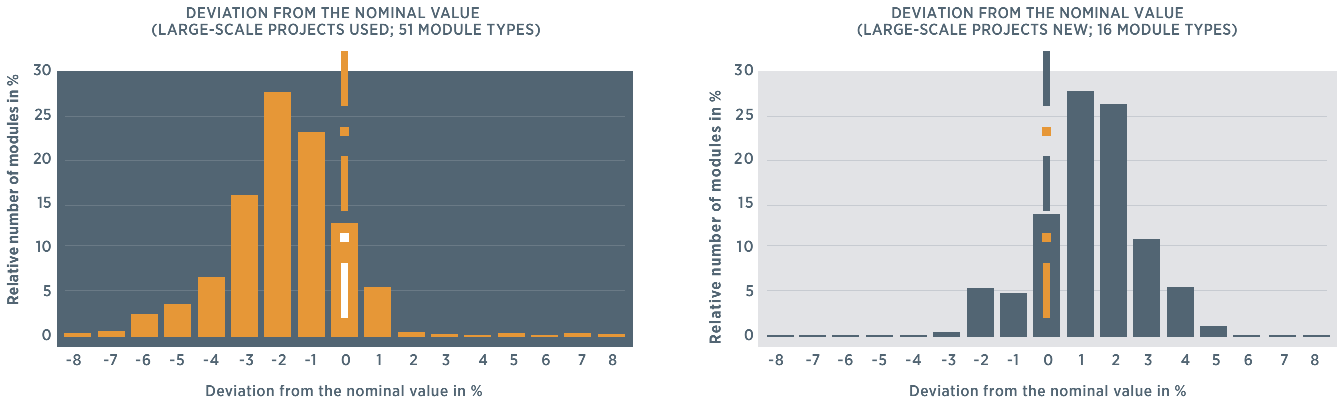
Independent testing of the PV modules is worth negotiating in an EPC contract, since it results in better modules delivered for the project and, hence, a larger energy production. This example applies for projects in which the number of modules is agreed in a contract. It does not consider degradation and, rather, focuses on the initial performance of the modules.

In order to comply with the financial requirements set for a PV plant, it must be assured that the actual installed capacity matches the planned capacity as defined in the EPC contract. As a first step, the power of the individual PV modules is summed up. This information (flash test power) is generally provided by the module manufacturer that measures each individual module at the end of the manufacturing process. Measurements of the "real" module power in independent laboratories, however, have shown that the real power is often lower than the nominal power. Results from such study are presented in Figure 4.5. (left part). Roughly 500 PV modules comprising 51 module types have been independently measured without informing the module manufacturer. The 51 module types can be assumed to be representative for the crystalline PV module market in the period from 2010 to 2013. Most modules were measured prior to installation (85%). The real module power of most of the modules (>80%) is in the range of 0% to 3% below the nominal power. On average, this deviation is roughly −1.5%. Assuming the measured modules are representative of the projects where they are installed, these projects may generate revenues that are below expectation from the beginning of operation. Aware of this, independent engineers, experienced EPC, investors and banks strongly recommend an independent module power measurement of a representative number of modules before installation.

Figure 4.5. (right part) presents the power measurements from modules for a project in which the module manufacturer was aware that independent laboratory testing was negotiated into the project contract. The diagram shows the results from 1000 measurement comprising 16 module types. All these types are among those shown in the left diagram. The real module power of most of the modules (>80%) is in the range of 0% to 3% above the nominal power. On average, this deviation is roughly +1.5%.

This result is a clear signal for the importance of negotiating independent module power measurements in the EPC contract. It also calls for informing the module manufacturer that such measurements are going to take place.

Figure 4.5. Independent confirmed module power versus nominal power



Source: TÜV Rheinland, 2014

Note: Module manufacturer is not aware of independent measurement (left) and module manufacturer has been informed about independent measurement (right).

In terms of the economic benefit of this indicator, for a 20 MW plant with approximately 70 000 PV modules, it is recommended to obtain an independently confirmed module power for a minimum of 45 modules in order to achieve a statistically relevant result. The measurement should take place during the construction phase, before the modules are installed on site. The cost for the measurement, including transport, may be within the range of EUR 5 000 and EUR 10 000 (USD 5 535–11 070). Assuming that the EPC price for the plant is in the range of EUR 1100/kWp and EUR 1300/kWp (USD 1 217.7–1 439.1/kWp), the price for the measurements does not exceed 0.1% of the initial investment. If the benefit of the measurement is an increase of between 2% and 3% in installed capacity, as shown in Figure 4.5., an increase of the generated electricity each year of approximately the same amount can be assumed. Therefore, it is reasonable to assume that an initial additional investment of less than 0.1% of the EPC price is causing a revenue increase of approximately 2% to 3%. With an assumed plane of array irradiance of 2 400 kWh/square meter (m^2)/year (fixed mounted installation in Southern Europe) and a kWh-sales price of EUR 0.10 (USD 0.1107), this is an annual increase of approximately EUR 75 000 to EUR 115 000 (USD 83 025–127 305) for the 20 MW PV plant mentioned. On a MW basis, this equals an investment of EUR 250 to EUR 500 (USD 276.75–553.50) versus an annual revenue of EUR 4 000 to EUR 6 000 (USD 4 428–6 642).

This example applies in the case when the performance of individual modules is to be maximised. In some projects, a certain minimum (peak) power is agreed. In this case, the contractor may choose to add a certain number of modules to the project to realise the contracted power in case the modules should underperform. This approach would avoid the cost of testing, but would include costs for additional modules and certain BoS components. If the PV plant should still underperform following installation, flash and other tests of the modules may be required, but those are out of the scope of this example.

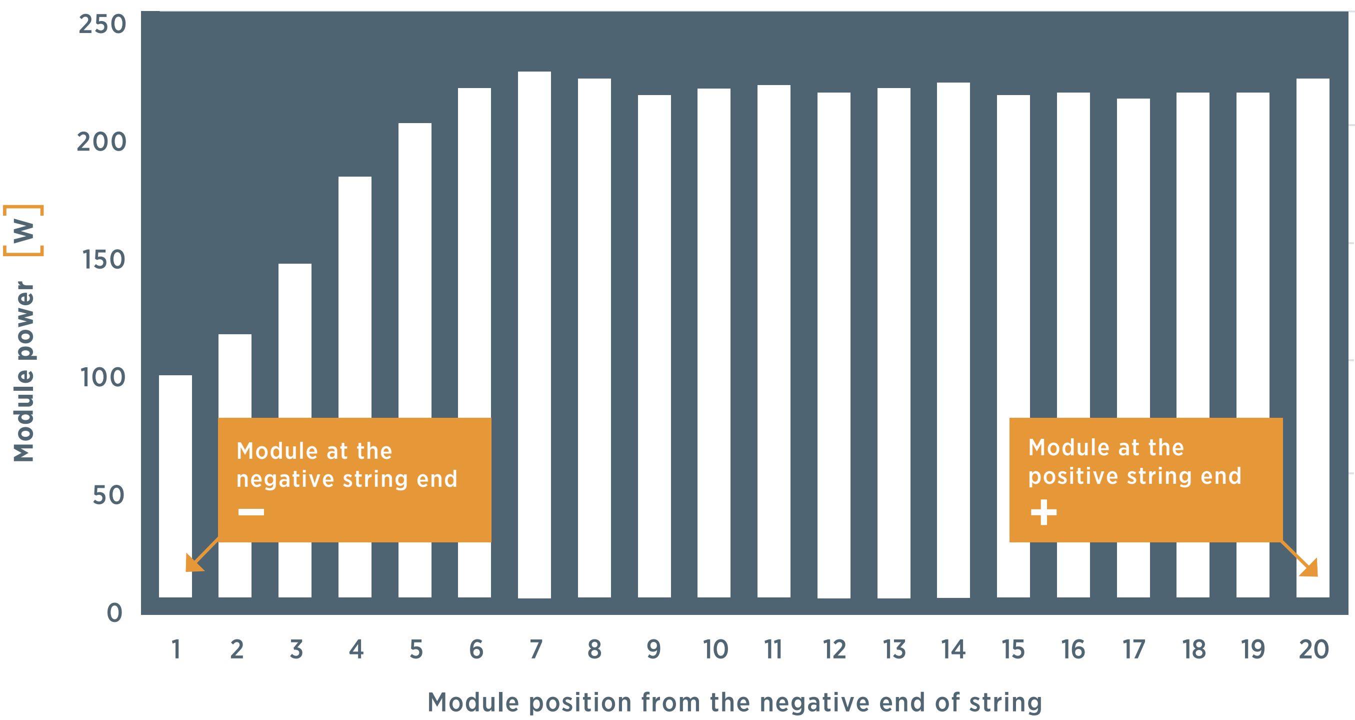
Operation and maintenance: Potential induced degradation reduction through inspection

PID poses a substantial risk for PV power plants. It can partly be mitigated during the design phase. Due to limited knowledge and experience with pre-construction testing, inspection after installation adds benefits for limited costs.

PID has been found to cause considerable power output degradation in PV systems. The effect was first reported by Sunpower, manifesting in their n-type c-Si solar cell modules (Sunpower, 2009), and later becoming widely known in commercial modules with standard p-type solar cells (Berghold et al, 2010). The affected modules were all tested and certified according to IEC 61215 design qualification and type approval for terrestrial c-Si PV modules. This standard, however, does not examine the stress that high system voltages may have on the modules in a natural environment over time. Due to PID, modules may suffer from considerable power degradation. Generally, only a minor part of modules, exposed to a certain potential with respect to the ground, is affected. For standard commercial modules (p-type) the degradation correlates with higher negative voltage. Therefore, the modules at the negative end of the module strings are often more degrading. The effect is reversible and power may be recovered by applying a reverse voltage. This requires additional equipment, however, and may take – depending on the climatic conditions – up to months or even years for full recovery.

One exemplary case is a 6 MW plant, commission in 2008, located in Southern Europe with c-Si modules installed on 1-axis horizontal tracking systems. After two years of operation, the owner noticed a reduction of performance in some areas of the plant and ordered a detailed analysis of the system, which indicated that the modules at the negative end of the module strings showed considerable power degradation of up to 60%, as shown in Figure 4.6. The overall degradation on the plant level was approximately 4% more than what is to be expected after two years of operation. Similar observations have been made in other PV power plants.

Figure 4.6. Module power as function of position in module string



Note: W = Watt

In order to define technical specifications for testing on the PID resistance of PV modules before being installed in the field, IEC delegates from the U.S. national committee submitted a New Work Item Proposal to the IEC TC82 in December 2011. After approval of the proposal, a Committee Draft was circulated in March 2013. National committees from the United States (leading), Austria, Belgium, Germany, Italy, Japan and Spain were mainly involved in the development. Over 80 comments from 10 nations were received on the draft. It turned out that the mechanisms causing PID were not fully understood and that no single international standard could be agreed upon. Therefore, a Draft Technical Specification was circulated for comments in September 2014 and approved by 100% of the 23 voting members. In August 2015, IEC TS 62804-1:2015 was published, defining procedures to test and evaluate the durability of c-Si PV modules to the effects of high-voltage stress. Two test methods are defined that do not inherently produce equivalent results, given as screening tests. Neither test replicates all of the factors that exist in the natural environment that could affect the PID rate, which vary significantly depending on the location of the installation. The tests validate that many modules have negligible susceptibility. For those that do show susceptibility, manufacturers have a basis for making improvements to further limit PID. Moreover, modules that do not have good PID test results can be relegated for systems where the circuits are functionally earthed to prevent PID. On a project level, PID testing can be applied for batch acceptance.

A revision of the standard is scheduled for 2019. Technical specifications in the revised version are expected to considerably reduce PID issues in PV plants with tested modules.

With regard to the economic benefit, the price for the forensic analysis of a 6 MW PV plant during which PID is detected to be the root cause for degradation, together with the undertaking of corrective actions, may be in the range of EUR 15 000 to EUR 25 000 (USD 16 605 to USD 27 675). Assuming the EPC price for the plant is in the range of EUR 1 100/kWp and 1 300 EUR/kWp (USD 1 217.7/kWp and USD 1 439.1/kWp), the price for the forensic analysis and the implementation of the corrective actions does not exceed 0.4% of the initial investment. Plants suffering from PID show a typical underperformance of 3% to 5%. The recovery of the degraded power due to PID is not immediate. Assuming 100% of the power is recovered after one year, the additional investment of less than 0.4% of the EPC price causes an increase of 3% to 5% of the revenues from the second year of implementation. With an assumed in-plane irradiance of 2 400 kWh/m^2/year (fixed mounted installation in Southern Europe) and a kWh sales price of EUR 0.10 (USD 0.1107), this represents an annual increase of between EUR 35 000 (USD 38 745) and EUR 60 000 (USD 66 420) for the 6 MW PV plant. On a MW basis, this typically means an investment of between 2 500 EUR/MW and EUR 4 000/MW (USD 2 767.5/MW and USD 4 428/MW) versus annual revenues of between EUR 6 000/MW and EUR 10 000/MW (USD 6 642/MW and USD 11 070/MW).

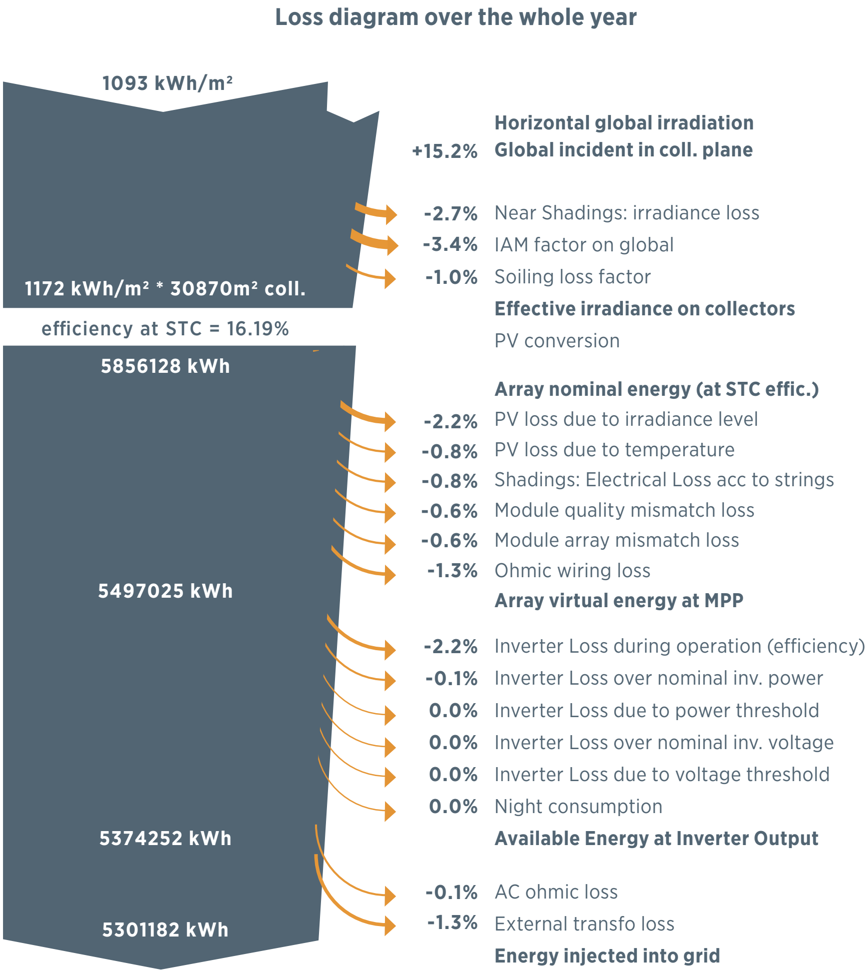
Operation and maintenance: Effects of soiling and cleaning of photovoltaic modules

Soiling of PV modules leads to the reduced electricity production of a PV power plant. Its magnitude can be partly assessed during the design phase. Due to limited global experience, and due to the fact that soiling is a phenomenon that highly depends on local circumstances, testing prior to construction is beneficial for limiting losses.

Soiling is one of the many loss factors that can be considered. For a PV power plant, the loss factors are visualised in a Sankey loss diagram.

Figure 4.7. shows an example of such a diagram, with the annual irradiance on the PV modules per m^2 and the loss factors that lead to a final electricity production. Optical losses are indicated from the top of the diagram down to PV conversion. Electrical losses are presented after PV conversion. The soiling loss factor is a percentage of the irradiance and it can amount to a large absolute value if the soiling factor is great. The factor is a fixed yearly value for all the years of the life time of the PV system.

Figure 4.7. Example of a Sankey loss diagram



Notes: kWh = kilowatt hours; m² = square meter; IAM = incident angle modifier; PV = photovoltaic; STC = standard test conditions; MPP = maximum power point.

The factors that influence dust settlement are:

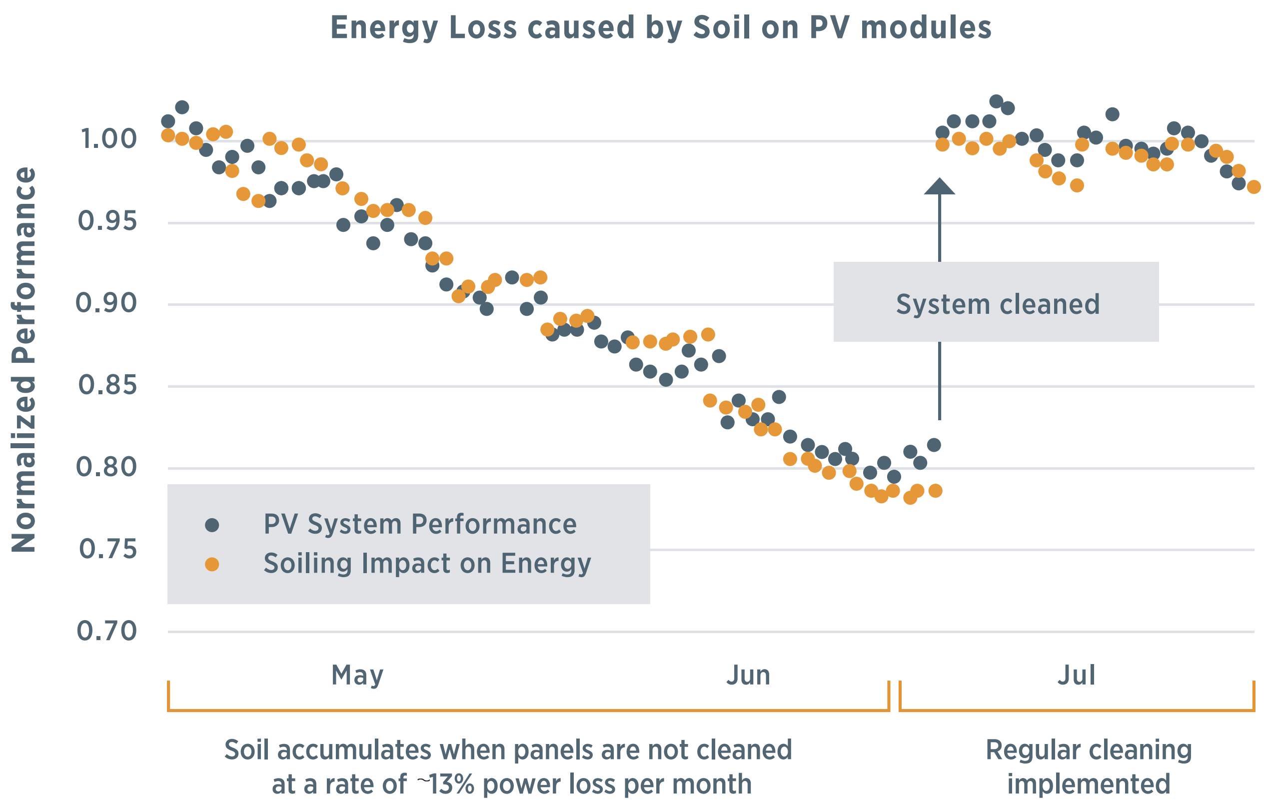
- site characteristics: vegetation, traffic, air pollution
- ambient temperature, humidity, and precipitation
- PV system tilt angle and orientation, including their wind exposure
- dust properties: type, size, density and shape
- wind speed and wind rose
- texture and characteristics of the glass.

The topics written in bold are aspects that can be influenced during the design of the PV power plant. The non-bold factors cannot be controlled in the engineering phase and these factors are very local. Additional soiling investigation is required, although neither standards nor uniformed testing methods yet exist for soiling.[4]

Rain and other forms of precipitation have a cleaning effect on soiled PV modules. Already from a few degrees tilt angle of the PV modules, soiling is reduced by rainfall. At some locations in the world, dry periods extend to weeks or months, preventing the natural cleaning of the modules by rain. Soiling can be significant, and cleaning of the PV modules could be an option.

Figure 4.8. shows the effect of cleaning on a PV system in the desert of California (Caron and Littmann, 2013). The soiling resulted in a power loss rate of 13% a month. After regular cleaning, the soiling loss was reduced to a few percentage points on average.

Figure 4.8. Effect of cleaning of a heavily soiled photovoltaic system



Source: Caron and Littmann, 2013

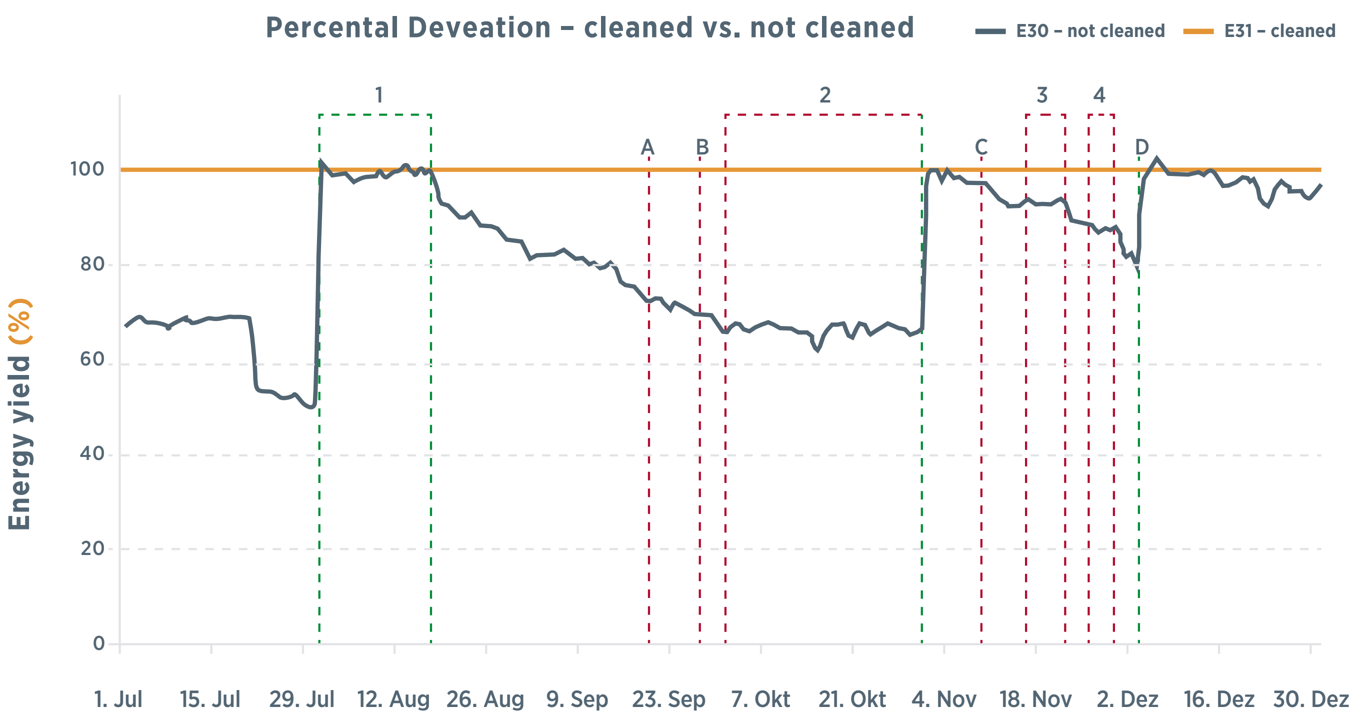
Note: PV = photovoltaic.

4 IEC 61724 Edition 2 will include a definition of soiling loss and how to measure it, when it is published in 2017.

Even higher soiling levels are reported; see Figure 4.9. (TÜV Rheinland, 2015). In this figure, energy yield losses up to 45% are reported. Yield losses of more than 5% within one week are possible. The location is probably heavily subject to dust settlement and the cleaning effects of rainfall after a long dry period are substantial.

Soiling is a very site-dependent characteristic. The cost/benefit trade-off for deploying cleaning procedures depends on the (local) costs for cleaning and energy gain. Regular cleaning of all the PV modules can be considered if the annual soiling loss factor is 5–6% or more.

Figure 4.9. Effects of cleaning photovoltaic modules

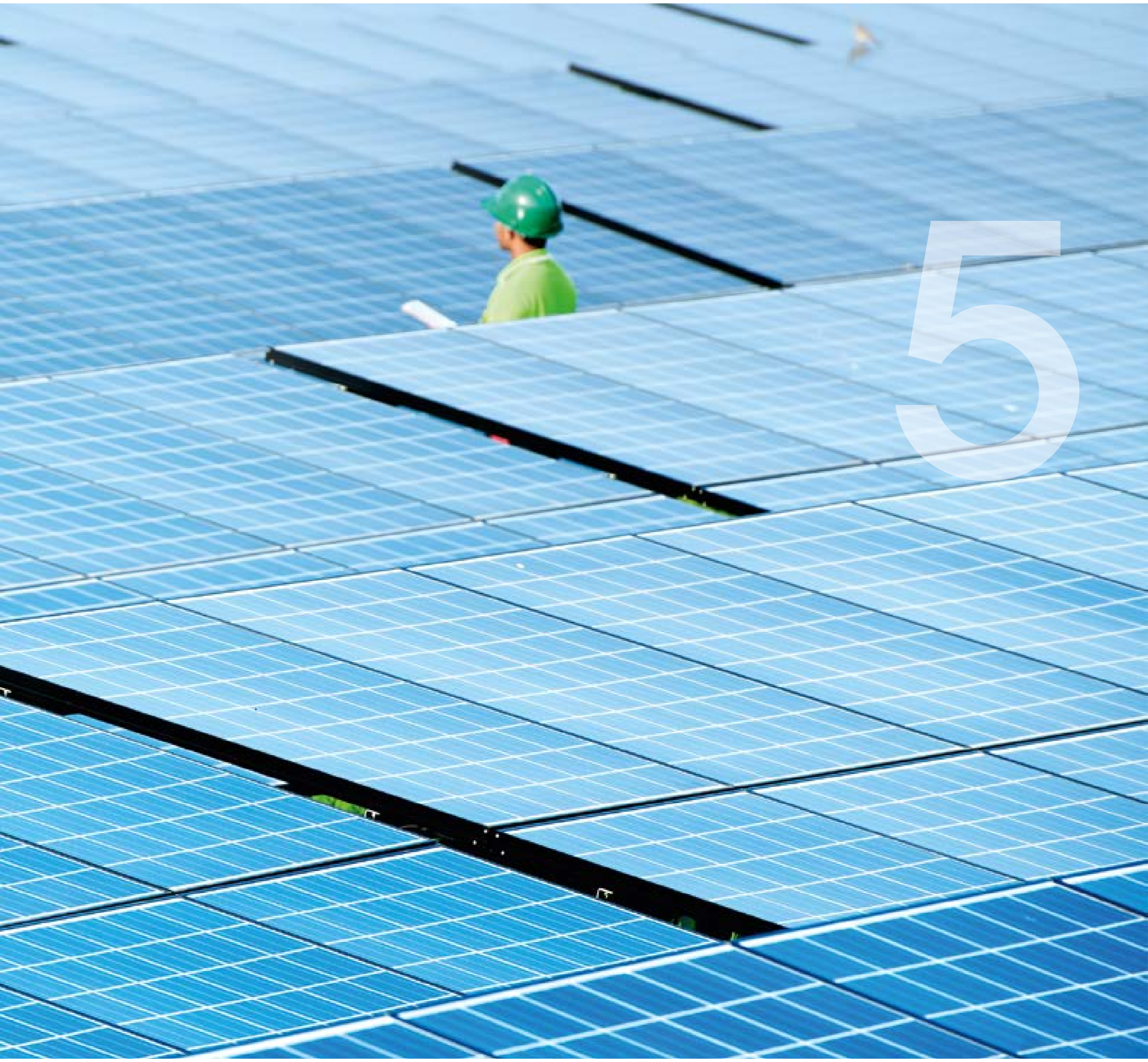


Source: TÜV Rheinland, 2015

Notes: Section 1: cleaning; Sections 2, 3, 4: no cleaning; from D: rainfall and no manual cleaning.

Quality infrastructure development strategy for

SOLAR PHOTOVOLTAIC SYSTEMS


5

Quality infrastructure development strategy for solar photovoltaic systems

The development of QI is highly relevant to the growth of the market. QA has shown to build the necessary credibility among stakeholders to grow the market. Eleven country case studies are provided, describing the implementation of different measures that ensure the quality of PV technology and their results for market development. From these country findings, a recommendation of different stages for QI development for the PV market is provided. Policy makers can easily use this staged approach to understand and initiate appropriate measures in developing QI.

5.1 Country cases

In this section, eleven country cases are provided from developed and developing countries. The cases reflect experiences in developing and implementing QI for off-grid applications, distributed generation, and utility-scale PV systems. These country examples showcase the implementation of specific measures for different market development stages. The implementation of QI elements appears highly dependent on the country's experience and the development status of its PV market. Relevant lessons learnt are highlighted and used as a basis to build the staged approach.

Figure 5.1. presents the 11 countries that have been reviewed. Information was obtained from desk research efforts and interviews with national experts.

Figure 5.1. Photovoltaic development status: Country overview

	UTILITY SCALE	DISTRIBUTED GENERATION	OFF-GRID
DEVELOPING	Egypt Chile	China Philippines	India Tanzania
DEVELOPED	USA Germany	Singapore The Netherlands	Australia

Off-grid applications

Various country case studies are presented with regard to the PV development status, current and anticipated challenges and possible scenarios for the advancement of QI in off-grid systems.

Country case: Australia

At the end of 2016, total installed capacity in Australia exceeded 5 GW. The installed capacity of off-grid systems at the end of 2014 stood at 148 MW (IRENA, 2016a).

Since 2001, the government has been supporting RE generation through mandatory RE targets, which force the Australian electricity retailers to meet the obligations or to pay a shortfall charge. Compliance is demonstrated through RE certificates that can be traded between retailers.

To be eligible for the government's small-scale technology certificates, the PV system must be (Clean Energy Regulator, 2016a):

- designed and installed in compliance the guidelines of Australian Standards and the Clean Energy Council (CEC);
- installed by a CEC-accredited designer and installer, meeting CEC guidelines;
- compliant with local requirements, including the grid code, and;
- installed using equipment from the CEC list of approved solar products that meet Australian and international standards.

To update approved component lists and maintain the quality of products, the CEC undertakes a screening process in the market. Accreditation guidelines for stand-alone systems are not yet available but will be issued soon. Regarding the licensing procedure, the CEC has different levels of accreditation which comprise specific modules for grid-connected and off-grid systems. The CEC also promotes continuous training for installers to improve the quality of the PV market.

Several government and non-government bodies support and develop the solar market framework, and fund programmes in R&D. These are, among others, the Clean Energy Regulator – which veils for the correct deployment of certificates – CEC, Clean Energy Finance Corporation and Australian Renewable Energy Agency.

Australia has some testing laboratories, such as PV LAB Australia, TÜV Rheinland and CSIRO, partnering with the Australian Renewable Energy Agency. The National Association of Testing Authorities, the government body for accreditation in Australia, has accredited the CSIRO solar cell measurement laboratory under IEC 17025 (general requirements for the competence of testing and calibration laboratories).

In addition to its development of national standards and codes (as identified in Section 3.1 and Section 6.1), Australia participates in TC82 of the IEC for the development of international PV standards. There is legislation for financial penalties in case of non-compliance with national standards (see Section 6.1).

Challenges

Australia's first challenge is to reduce investor uncertainty in the regulatory framework, created by several changes that occurred between 2008 and 2014. In addition, Australia maintains a certification[5] process for PV installers and designers in parallel with the eligible equipment requirements, which focus on small-scale projects. This has led to problems with some utility-scale projects where the installers are not appropriately trained.

As perceived in the industry, the CEC solar component approval process is not very thorough and only tests a small sample. This has led to inferior solar equipment being installed and having failed. In order to mitigate all these issues, Australia has a compliance procedure through a demerit process of installers that deliver low-quality equipment and issuance of a solar retailer code of conduct.

Possible scenarios for further quality infrastructure development

Australia is currently in the advanced stage of development of its PV market, as it has a good QI for off-grid applications. This was enabled by the continuous support from government in direct and indirect incentives, the creation of funding agencies and collaboration with the private sector. Australia is in the position to continue improving its existing QI and remains in pace with new QI developments. Focus should be placed on the challenges described above. An exhaustive survey and performance testing of the systems and products installed would help to reduce the installation of bad quality products.

5 Referred to in Australia as accreditation.

Country case: India

Among other renewable energies, the solar energy potential is the highest in India as the solar resource is mostly homogeneous over the country, up to 2 200 kWh/m²/year. According to governmental sources (MNRE, 2016a), at the end of January 2016 the total grid-connected PV capacity was 5.25 GW, while off-grid capacity reached 300 MW. Since 1992, the government has supported the generation of RE through the Ministry of New and Renewable Energy (MNRE). In 2010, a specific plan was launched for solar, the Jawaharlal Nehru National Solar Mission (Government of India, 2016), or simply National Solar Mission (NSM) which aims to install 100 GW (Press Information Bureau Government of India Cabinet, 2015) of grid-connected power and 2 GW of off-grid solar applications (including 20 million solar lights) by 2022 through a three-phase plan with annual targets. Special focus on off-grid applications is described in the NSM, with the aim of delivering electricity and light to rural areas without grid penetration.

India is a participating country in IEC TC82 and has adopted international standards through the national standardisation body of India, Bureau of Indian Standards (BIS). BIS has also developed national standards for storage systems (IS 13369, IS 15569 and IS 15767). According to the guidelines (Government of India, 2014) for the implementation of off-grid solar PV applications under the NSM and to obtain the above-mentioned subsidies, minimal technical requirements and standards outlined for solar PV system have to be complied with. This refers to the conformity of PV modules to the latest addition of any of the IEC or equivalent BIS Standards for PV module design (IEC 61215/IS 14286, IEC 61646, IEC 62108), for safety qualification (IEC 61730) and for corrosion testing if applicable (IEC 61701). Other BoS components, such as storage batteries, also must comply with the corresponding IEC/BIS standard. The certificates must be issued by a test laboratory accredited by MNRE or IEC. A list of manufacturers that comply with the requirements is publicly listed on the MNRE website (MNRE, 2016b).

India aims to develop a strong internal manufacturing industry across the PV value chain. NSM targets support its development, as the incentives for solar generation are granted under local content requirement. Import tax on PV equipment is lower than on other electrical equipment (although no QI requirements pertain to this).

India has established a research council with experts from the academic and industry ecosystem with the aim of guiding the technology development in the country. The National Centre for Photovoltaic Research and Education oversees education and training programmes, technology research and simulation of plant performance. The National Institute of Solar Energy is involved in facilitating the certification and testing of the modules for policy compliance. It is also involved in the demonstration, standardisation, interactive research, training and testing of solar technologies and systems (NISE, 2016).

The National Institute of Wind Energy oversaw development of a solar irradiation map (NIWE, 2016) of the country. It has a spatial resolution of 3 × 3 kilometers and counts with 121 ground measurement stations around the country.

At a state level, public projects using off-grid PV for rural electrification tend to favour the cheapest quote, running the risk of compromising quality. State policies pertaining to off-grid PV projects in Gujarat were noted to be more stringent. The stringency focused on improving the level of quality while continuing to be cost competitive. Gujarat has piloted the country's first solar village, with a considerable number of installed solar pumps, stand-alone PV systems and home lighting systems. The state facilitates decentralised and off-grid solar.

Challenges

The main challenges for the solar market in India are relevant to the QA of the technology, the installers and the installations themselves. No certification process for the installers is implemented to ensure their compliance with prevailing standards and state-of-the-art skills.

Even though certificates issued by accredited test laboratories are requested by the MNRE, regular control of the PV module characteristics could be more positive. Initiatives in some states have been taken in this regard. For example, in Gujarat, specific policies drive to undertake inspections of the installation and equipment by third-party agencies. Several testing and inspection bodies in India, such as the National Institute of Solar Energy, Electronics and Quality Development Centre and UL, have been certified. It is important that other testing and inspection bodies also obtain certification in the future.

Potential scenarios for building off-grid quality infrastructure

India has a good QI for off-grid applications and the PV industry, in general, due to the continuous support for solar energy from the government in the last years, including direct and indirect incentives, the creation of funding agencies and collaboration with the private sector. General elements which do not strictly relate to off-grid QI can be further developed, such as component testing, adoption of international standards, certification and inspection schemes, inclusion of quality criteria in public programmes, criteria for commissioning and accreditation of public laboratories.

Country case: The United Republic of Tanzania

The Government of the United Republic of Tanzania (hereinafter also referred to as "Tanzania") fixed targets to electrify 50% of the population by 2025 and is supporting the development of alternative energy technologies. A national PV project initiative, supporting off-grid PV household electrification, was launched in 2002 by the government and private donors. Since 2008, approximately 6 megawatt peak off-grid PV systems have been installed. Financing initiatives exist for the installation of off-grid systems on schools, clinics and public facilities. In 2008, a Small Power Purchase Scheme for mini-grids was launched to promote the development of utility-scale power producer projects. A feed-in tariff (FiT) scheme exists for projects connected to the grid, although the tariffs are not attractive for PV plants.

Tanzania does not participate in the TC82 group of the IEC for the development of PV standards. Through its governmental institution – the Tanzania Bureau of Standards (TBS) – however, Tanzania has adopted relevant IEC PV-system standards (Tanzania Bureau of Standards, 2017) and each product on the Tanzanian market must be compliant with this list of standards. A Pre-shipment Verification of Conformity to standards has been introduced to ensure the quality of imported products. Certificates of conformity are issued by appointed agents by TBS (i.e. Bureau Veritas, SGS and Intertek) for products compliant with relevant Tanzanian technical regulations or approved standards.

To maintain market surveillance, TBS periodically buys and tests sample products of the solar market and, if they fail the test, they are removed from the market and destroyed. The shop owner must prove the existence of conformity certificates for the products to avoid fines.

Importers must register their brands and products with the Business Registrations and Licensing Agency (BRELA, 2017) to be protected by the government against counterfeit products. If their products fail the tests, the importer must pay for all the costs relative to the removal of the products from the market. Currently, no licensing of installers is required in Tanzania.

Challenges

Various inter-governmental institutions operate in the RE market. The absence of coordination, however, hinders their ability to share experiences, work efficiently or enhance organisational structures in support of the market.

Despite the control system in place, a parallel market of substandard products has developed (counterfeit market) because importers and dealers lack an understanding of the importance of the product registration process in minimising the distribution of substandard products in the market. Substandard products enter the country through uncontrolled border crossings due to insufficient government resources and infrastructure. Moreover, TBS lacks the human and technical resources to correctly test equipment according to standards. Consequently, counterfeit products are selected by customers because of their lower cost relative to certified products, further exacerbating the performance of PV systems, customer dissatisfaction and loss of confidence.

Potential scenarios for building a quality infrastructure

Confidence in the standard rollout strategy should be improved by enhancing regulation measures to protect end users and encourage fair competition in the market. Collaboration should be improved between the various institutions that control the importation of goods. Communication to importers should be made clear regarding PV technology and the product registration process, as well as their role in the value chain. End users should be informed about the importance of selecting registered products.

Distributed generation

This section relates to QI in distributed generation systems. It summarises the current PV development status as well as the challenges that are present and actions to address them effectively.

Country case: China

By the end of 2015, China had a cumulative installed capacity of 43 GW of solar PV, surpassing that of Germany according to China's National Energy Administration and Fraunhofer Institute (PV Magazine, 2016). This 43 GW was almost four times higher than the installed capacity in 2014 and the nation is targeting 150 GW of solar PV capacity by 2020. While utility-scale PV will form a larger proportion of installed capacity, the rooftop PV sector in China is expected to see significant growth in coming years. This is mainly due to the government's supportive policies towards promoting distributed PV generation, policies which include the introduction in 2013 of FiTs for rooftop PV systems. The relevant grid company must also pay for any surplus power the owner of the rooftop solar system feeds into the grid at the local benchmark price of coal-fired power.

China has successfully demonstrated the use of QI in the areas of testing and standards adoption. The China Quality Certification Centre (CQC) is the national certification body of China that is authorised by the Certification and Accreditation Administration of China to conduct PV product certification and testing. The development of domestic standards in China is robust and can be classified as national and industry standards. The Standardization Administration of China performs similar functions as technical committees in international bodies. For example, the organisation's SAC/TC90 and IEC's TC82 solar committee are similar in their interests and scope of work. China also has a strong presence within IEC TC82 and, more recently, has been influential in the development of international standards. The strong presence of established PV manufacturers in China, such as Trina Solar and Suntech, is an important factor that has led to the successful development of Chinese standards; they have helped to spearhead the development process as part of the standards committee.

Challenges

China has taken significant steps in implementing QI in the areas mentioned above. Given its large market size, the government is in the process of improving areas where QI may be lacking. One such area that has been highlighted is the development of PV installation standards in China. A key challenge here is relevant to the lack of support from the industry in helping to develop national standards relating to installation. This absence of support from the industry generally is due to insufficient weight given to PV installation processes as compared to other PV standards relating to modules and components. Furthermore, installation standards would require a consolidation of several general structural and electrical standards. It may be a challenge to rollout such PV installation standards and procedures in China due to the sheer size of the market.

Potential scenarios for building quality infrastructure

Given the challenges in developing PV installation standards, a preliminary step may be to provide certification for installers. Currently, there is no requirement for a licensed electrician to carry out the electrical works and installation of rooftop PV.

Country case: Singapore

With an average annual solar irradiance of 1150 kWh/m^2 and approximately 50% more solar radiation than temperate countries, solar energy appears attractive for Singapore. Its land area is limited, however, and the solar market consists entirely of distributed generation through rooftop PV systems. While the market is relatively small, with only 33 megawatt peak installed capacity as of 2014, it is developing rapidly with a compound annual growth rate of 109% (NSR, 2016).

According to the Electricity Act, a PV installation needs to comply with the codes of practice and guidelines issued by the Energy Market Authority. This basically refers to the Singapore Standard (CP5) Code of Practice for Electrical Installations. Under this law, a licensed electrical worker needs to be engaged to undertake the installation according to the codes of practice.

Singapore participates in TC82 of the IEC for the development of PV standards, and emphasises adopting international safety standards for PV installations. Singapore provides guidelines for adopting IEC 61215, 61646 and 60439-1 relating to PV module and the electrical safety standards of components. These standards are clearly outlined in the Handbook for solar photovoltaic systems (EMA and BCA, 2009). This document was released by the Building Construction Authority and Energy Market Authority, jointly developed by the public and private sectors and academic institutions. Similarly, on the installation side, SPRING Singapore released its own national standard, SS601, that outlines the minimum requirements for system documentation, commissioning tests and inspections and which is based on IEC 62446. The Singapore Standards Council, together with SPRING Singapore, serves as a national accreditation body for the development of national standards. PV standards are currently being handled by the Electrical and Electronic Standards Committee.

The Solar Energy Research Institute of Singapore is actively involved in the testing and certification of modules in accordance with international standards. While the research institute itself does not provide IEC certificates, it is accredited under VDE (Germany), a certified body that issues IEC certificates. While the testing is not mandated by local authorities, the Solar Energy Research Institute of Singapore tends to play an active role in promoting the quality of rooftop PV installations through pre-installation testing in Singapore.

Singapore has been able to track the development of rooftop PV. The information is publicly available at the National Solar Repository website. This online platform also serves as a benchmarking tool, as it provides a detailed database on various system sizes, technology and performance. Although this is done on a voluntary basis, to date close to 49% of total installed capacity have signed up with the repository.

The quality of PV modules installed in Singapore tends to be relatively high, although there is an absence of specific regulations that ban the sale of substandard PV modules. While Singapore promotes a free market for PV modules and barriers to enter the market are relatively low, consistent enforcement of contract law, strong border protection and a good tendering framework have created a stable regulatory environment and favoured relatively higher levels of PV standards in Singapore. Section 6.1 provides a case study on Singapore's regulatory approach to tenders.

Challenges

Although solar PV has reached grid parity, it still faces significant challenges to increase its market share due to the potential impact of the stability of the grid that results in additional grid charges. Besides the bulk of the residential rooftops in Singapore are publicly owned high-rise buildings. This poses a challenge for private persons to invest in solar PV.

As for improving the quality of rooftop PV in Singapore, there appears to be a gap in ensuring that licenced electrical workers are adequately trained to handle the installation of solar PV on rooftops. Current regulations do not require these workers to go through solar specific training. While the minimum requirements outlined in SS601 may meet safety standards, they may not necessarily ensure a high-quality installation.

Another area that was highlighted was the improvements needed to be made in the evaluations of tender documents, whereby a shift of focus is needed from price towards quality. Quality criteria are rather subjective and do not specifically stipulate proven experience.

Country case: The Netherlands

The Dutch solar market is dominated by distributed generation. At the beginning of 2016, installed capacity passed 1.4 GWp[6], with significant growth in the last three years. The combination of decreasing PV prices, combined with a net-metering incentive, appears to underlie this. Public tenders for utility size are rare, although the country has a financial incentive system in place for RE, referred to as SDE+ (Stimulering Duurzame Energieproductie). In 2014, this led to some megawatt-system initiatives that are to be expected under construction in the short term.

The net-metering incentive is not linked to any QI-measure. The SDE+ incentive prescribes only a specific way for energy measurement.[7]

6 Discussion with Wilfried van Sark, Utrecht University, in January 2016

7 Ibid.

Industry associations (i.e. Holland Solar) and initiatives (i.e. National Action Plan Solar Power) are in place, and regularly provide a market and sector status update. Installer certification has been established since 2013, based on EU Directive 2009/28/EG on renewable energy sources. From the 1800 companies in the Netherlands that are registered as installers, 30 are currently certified (see Section 3.4). since approximately two years ago; none have entered bankruptcy.[8]

Demonstration sites have been erected (e.g. city of Heerhugowaard, City of the Sun (Heerhugowaard Stad Van De Zon, 2017)) and background studies have been carried out, capturing the potential of PV for the country (PBL and DNV GL, 2014). Testing and certification of PV components is often done in Germany although PV test facilities are available at the Energy Research Centre of the Netherlands. The Netherlands has laboratories available to test BoS components, such as inverters and cables, at the DNV GL facility in Arnhem.

In some provinces, PV-related companies are supported by local government. The central government supports knowledge development in companies by subsidising innovation projects that are jointly executed by firms and knowledge institutions (e.g. Top-consortia for Knowledge and Innovation, TKI Solar Energy).

Challenges

Market surveillance (at least installation registration, and thus the monitoring of cumulative installed capacity) in the Netherlands is not very structured. There is an obligation to register new grid-connected installations, but this is not being enforced. It is assessed that 80% of the country's installations are administered; that is, approximately 320 000 PV-systems.[9] While the country is moving into a potential growth stage, an adaptation would be appropriate.

The Dutch PV market is small to require a national module test laboratory; still, innovative companies (e.g. Eternal Sun and Solartester) are deploying test facilities for (mobile) equipment testing. These initiatives are instigated among others by observed PV modules accessing the market and not matching IEC standards.

As the Dutch solar market focuses on rooftop applications, and some PV technologies are rather unknown to the public, a challenge remains to inform future private PV owners when purchasing a PV system. Large emphasis and trust is placed on the installer's knowledge and quality level in terms of selecting components and executing installation works. The challenge to ensure the high quality of installers remains.

Country case: The Philippines

With high solar irradiation, and with one of the highest retail tariffs in Asia, the appeal for PV deployment in the Philippines is obvious (Manila Standard Today, 2015). As of December 2015, 124 projects have been registered with the Department of Energy, totalling 4.2 GW. The Renewable Energy Act of 2008 sets forth the government's policy objective that has helped the expansion for RE deployment in the country. The Energy Regulatory Commission, in 2010, formulated in consultation with other stakeholders the FiT rules. Under the Renewable Energy Act, net metering was listed as an incentive for RE development in grid-connected areas. Through the installation of PV systems up to 100 kW, house owners and commercial establishments can now participate in the net-metering programme.

The Philippines has taken its first steps towards introducing QI in PV systems. The Department of Energy released its first e-guidebooks in 2014 for utility and rooftop PV projects alike, outlining the use of IEC standards for the procurement and construction of PV equipment (DOE and GIZ, 2014a; DOE and GIZ, 2014b). For FiT qualification, a standardised administrative framework has been adopted and legislated where evaluation of a developer's technical qualifications and the technical soundness of RE equipment utilised is carried out before a RE service contract and Certificate of Compliance are issued. The requirement to obtain a Certificate of Compliance also allows for market surveillance activities that the DOE regularly publishes on its website with regard to the number of pipeline and grid-connected projects.

8 Discussion with Gerard van Amerongen, Holland Solar, in January 2016

9 Discussion with Wilfried van Sark, Utrecht University, in January 2016

Challenges

The country's PV market is clearly growing, but QI elements have not been completely developed. Regulatory barriers tend to be a key challenge in the Philippines, where rooftop PV developers often cite the existing legal and administrative processes to be complex. With the incorporation of QI elements into public policy, a situation of over-regulation could be faced, discouraging the growth of PV.

A lack of awareness among rooftop solar PV owners regarding existing legal and administrative procedures was also identified in this study. For effective incorporation of QI elements, recognition of the value of QI should be communicated with rooftop PV owners.

A relevant challenge, on the side of the developers, would be to enhance the attractiveness of incentive schemes. For example, only systems of 100 kW or lower are allowed to connect to the grid under net metering. For this segment of PV systems, rather than local utilities crediting the consumer the retail price, they credit a lower than average generation cost of electricity. To integrate QI into net metering, the Philippines could further encourage the adoption of net metering schemes or develop new rules to improve its attractiveness. The United States provides a good example of how QI has been incorporated with net metering schemes.

The Philippines also faces challenges in controlling the sale of substandard PV equipment. The market tends to be quite open to cheap and low-quality PV equipment, some of which reputedly consists of stolen goods.

Potential scenarios for building quality infrastructure

Firstly, the accreditation of PV installers, or the formalisation of licensed training courses for installation of PV systems, could be introduced. This can be a mean to minimise the increasing number of companies that offer substandard services for PV installations.[10] Secondly, guidelines for testing and certification of panels are beneficial. These could incentivise the establishment of a PV equipment testing infrastructure to ensure that the PV equipment being sold complies with relevant standards.

Utility-scale photovoltaic systems

Country case studies are covered in this section for utility-scale systems. A review is made of the current developments and challenges of PV systems, as well as potential outlines for the advancement of QI in distributed generation systems.

Country case: Chile

While Chile's solar market, as of end-2015, has 750 MW installed and 2.3 GW in construction, it is a relatively young market. The main drivers of solar deployment in Chile are government support for renewables through policies and financing and the high solar irradiation along the north of the country. In 2008, the government implemented renewable quota obligations to all electricity sales with a target of 20% by 2025. The government has announced a target of a 70% share of renewables by 2050. To achieve the current quota, Chile allows RE producers to achieve long-term power purchase agreements with distribution companies through public tenders. Regarding distributed generation, Chile offers a net metering scheme for RE installations up to 100 kW.

Currently, Chile participates as an observer in the IEC TC82 group, and IEC standards are included in its installation manual for small size installations – mandatory for eligibility for the net-metering scheme underlined above. No references are required for utility-scale projects.

Apart from direct policies, the government is committed with solar PV energy through the development of industry, human resources and R&D. The government of Chile created organisations, such as the National Centre for Innovation and Promotion of Sustainable Energy (CIFES) and the Production Development Corporation (CORFO) with the aim of boosting the adoption of RE. Funds under tender were issued for the development of R&D. Under this scheme were developed SERC Chile (Solar Energy Research Center), the Atacama Desert Solar Platform (Plataforma Solar De Atacama (PSDA)) and several excellence centres for the development and training of human resources. The University of Chile has developed a public irradiance map and the solar desert platform is testing PV installations under specific Atacama Desert conditions. Chile aims to develop a national standard and certification

10 Discussion with Wilfried van Sark, Utrecht University, in January 2016.

process for PV projects under such conditions, and is financing the development of new PV modules to withstand them.

Industry associations and initiatives are in place (e.g. Acesol and ACERA). No testing facilities and certification bodies are present, although the government expects to have in place them in coming years.

Challenges

Chile's challenges are the dearth of industrial infrastructure, qualified personnel, specific standards shaped to its climatic conditions, test laboratories and certification bodies. Chile has launched the National Strategic Programme on Solar Industry (Programa Estratégico Nacional de Industria Solar (PES), a specific roadmap for solar energy to address the before mentioned breaches during the next ten years, but actors are sceptical of its implementation if government support – together with the industry sector – is limited. Chile is participating as an observer in the IEC TC82 group and attempting to influence the standardisation process to integrate the specific conditions of the Atacama Desert.

The requirements defined in the public tenders undertaken by government mainly focus on grid compliance and on the commercial offer that could pose an issue of quality for future installations. Lenders have appointed engineers and technical advisors to review the equipment (international standards mainly apply) and mitigate the risk link to the lack of defined technical requirements.

Potential scenarios for building quality infrastructure

Chile is progressing with building and incorporating QI in its PV market. The support of the government for RE through policies, investment and development mechanisms helps to create the most important QI elements, such as test laboratories, certification bodies, national standards and metrology laboratories. It also supports the establishment of local content through actors in the PV value chain (e.g. manufacturers, developers and installers).

In order to improve the confidence of investors, Chile could incorporate a utility-scale PV plant manual, similar to the one it issued for residential-sized systems. These should define the minimum standards, certifications and requirements for solar PV systems in a regulation or directive, including equipment and installation. For the residential and off-grid market, Chile could introduce a quality check on imported products, in order to guarantee the quality of PV products.

Country case: Egypt

In 2008, the Government of Egypt adopted a New National Renewable Energy Strategy. The existing PV power capacity in 2012 was 15 MW (MEED, 2014), mainly for small-scale projects on rooftops. The government, however, aims to support the development of large-scale projects connected to the grid for which the fixed target for 2017 is to install 4 000 MW large-scale solar and wind energy capacity. In 2014, a FiT scheme was issued to help achieve the target. Inside this scheme, the government also supports the cost of permits and several preliminary studies, including an environmental impact assessment.

Egypt participates in the IEC TC82 group, although no mandatory application has been located. Neither certifications, an accreditation process for the solar market nor a market surveillance system exist in Egypt. While grid operators and lenders do track the progress of solar PV plants, the information is not publicly available.

There are only a few organisations that are involved in the solar energy sector, such as the New and Renewable Energy Authority (NREA), Regional Center for Renewable Energy and Energy Efficiency, Electric Utility and Consumer Protection Regulatory Agency, RE&EE Testing & Certification Center and the Egypt Solar Industry Association. These organisations work in the development of the solar energy market, although no coordination and clear regulatory framework exists. This makes PV developments in Egypt sensitive to delays. The lack of QI has so far not hampered the development of utility-scale PV systems, which is dominated by large international companies and professional organisations.

It is notable that NREA deploys a transparent tender process, using qualified third-party agencies to outline tender requirements for utility-scale PV systems; this has a positive effect on the level of QI. Regarding the distributed sector, a certification process of the installers is undertaken by NREA for grid-connected systems below 500 kW. The criteria are published on the NREA website.

Challenges

In 2014, requirements defined in public tender documents mainly focus on the engagement of companies to be compliant with the grid code, which was not available at that stage. Concerns on the PV equipment and installers (e.g. standards, certifications, testing) were limited. Lenders have appointed engineers and technical advisors to review the equipment, based on international standards, and mitigate the risk linked to the lack of clearly defined technical requirements. The regulatory framework is now finalised and the grid code is under process, although how the regulation will be implemented is not yet clear.

Egypt also faces issues of confidence from developers and lenders alike for the ambitious programmes started by the government. Although the projects are expected to eventually be financed and commissioned, delays may occur as stakeholders also await the development of other projects, according to experts interviewed for the present report. This lack of confidence seems to be mainly relevant to current political instability and the volatility of the local currency above a lack of QI, the latter of which is mitigated through the appointment of specialists.

Potential scenarios for building quality infrastructure

To improve the confidence of investors, the government should create an organisation that is responsible for the regulation and monitoring of the solar market. This organisation should act independently and introduce minimum standards, certifications and requirements for PV systems; introduce quality check methods on imported products; provide information and training on QA; and focus on the development of local capacity and competencies in order to develop a sustainable market.

Country case: Germany

Germany has the most mature solar PV industry globally, despite the low solar resource available (average 1200 kWh/m^2/year). With approximately 39.5 GW installed at the end of 2015, it has been leading the world's PV capacity until recently, when the annually installed rate decreased compared to other countries. The current target is to reach 66 GW by 2030. Approximately 25% of the installations correspond to centralised applications.

The German case is of the best success stories in relation to FiTs. The driving factor behind this growth came 15 years ago when the Erneuerbare-Energien-Gesetz was passed and which is still in place. The utilities are forced to buy the power of RE producers as a priority at predetermined rates depending on the technology. The Erneuerbare-Energien-Gesetz implemented a FiT that has been lowered constantly since its inception in 2004, based on a drop in system costs due to the technological progress, along with market development. Germany has also ensured access to the grid for solar installations − as grid operators are obliged to connect all renewable systems to the grid – by strengthening the implementation of policy and reducing power production from non-renewable sources.

Early in 2015, the Federal Cabinet announced that it would be phasing out the FiT policy in favour of a reverse-bid tender process, whereby the buyer will collect bids from the sellers. The Federal Network Agency will announce calls for proposals to create a competitive system. In April 2016, new tender guidelines will be introduced promoting fairer competition and raising the prices from the FiT. A pilot platform for the PV tendering process was launched in 2015, which will be a 'pass-as-bid' process, with the highest bid creating the price. Bidders winning the tender will receive the FiT. QI plays a role merely on grid-code compliance (see Section 6.2).

Regulatory frameworks are well established within the German industry and form much of the global standard. Deutsche Kommission Elektrotechik is responsible for developing national standards, authorising QI quality institutes such as Fraunhofer-Institut für Solare Energiesysteme ISE (technology research and production development); TÜV Rheinland (certification); Verband der Elektrotechnik und Informationstechnik e.V. (PV plant quality testing); and the National Metrology Institute of Germany (metrology calibration) which, among others, have formed the basis of growing confidence within the sector in Germany and worldwide. Germany has led the creation of prevailing international standards, and their institutes and quality organisations are used around the world. Strong infrastructure, coupled with regulated tariffs, has produced a capital financing platform utilised by federally owned by the bank (KfW).

Challenges

The PV industry in Germany has been declining in the last few years, although it remains strong with BSW reporting 45 000–50 000 full-time jobs. Output has decreased in the wafer production and cell manufacturing sectors over recent years; however, silicone production has increased linearly (Wacker Chemie AG being the main manufacturer). Apart from the modules, most of the BoS of the plant is manufactured in Germany, as well as the equipment to manufacture PV modules worldwide. Although QI is not directly influenced by the local production scale, the industry's decline could influence technology assurance progression.

Potential scenarios for building quality infrastructure

Germany can be considered a fully mature PV market, although new developments, such as its focus on metrology aspects of PV systems, should be grasped by the current QI. If the QI is not sufficient, it should be enhanced accordingly.

Country case: United States

The United States remains among the countries with fastest growing PV capacity, having added 6.8 GW in 2015 and 11.2 GW in 2016. As of the end of 2016, the United States had the fourth greatest cumulative installed capacity in the world, at nearly 33 GW. Solar capacity additions in 2015 represented nearly 30% of all new generation capacity in the United States. Overall growth in the PV market has been driven by a critical combination of federal and state level incentive policies and rapidly declining system costs.

Codes and standards addressing PV technology, products, safety, and installation are well developed in the United States. The NEC that governs electrical installations has had a chapter dedicated to PV since 1984 and it has driven several safety-related initiatives, such as requirements for arc-fault detection and de-energisation measures for firefighter safety (NFPA, 2016). Product standards have developed primarily through national organisations such as UL and the American National Standards Institute. Foremost among them are UL 1703 governing modules since 1986, and UL 1741 which governs inverters and was first published in 1999. Several grid-code-related standards were established early and have lasting impact, such as IEEE 929 governing utility protective relaying, IEEE 519 governing harmonics and, more recently, IEEE 1547 which supersedes the earlier standards and govern the interconnection of distributed generation. IEEE standards inform state- and utility-specific requirements, which can vary from location to location, sometimes significantly.

Despite the national centric nature of PV-related codes and standards, the United States PV industry has significant involvement, and leadership roles in IEC TC82 have made great efforts to ensure harmonisation with IEC standards to the extent possible.

Project-level certification or approval occurs in several disconnected forms: regulatory compliance to the National Electric Code (NEC) as determined by city and county governments, utility inspections and agreements, state level check-lists that enable incentive payments, certification of installers (e.g. through NABCEP) and independent engineering reviews commissioned by project financiers.

Challenges

While the overall outlook for the U.S. PV utility-scale market is strong, there are technical and regulatory challenges to address. Areas with high-density solar resources (e.g. California) are anticipated to create local distribution network issues, placing greater emphasis on self-consumption policies over net metering. Advanced utility functions will be required of inverters for customers in California, beginning in 2016, to meet state utility requirements.

Transmission capacity remains a challenge as well, due to a lack of capacity where solar resources are high and there is a lack of coordinated planning by state and regional sectors to enable the integration of renewable resources.

Potential scenarios for building quality infrastructure

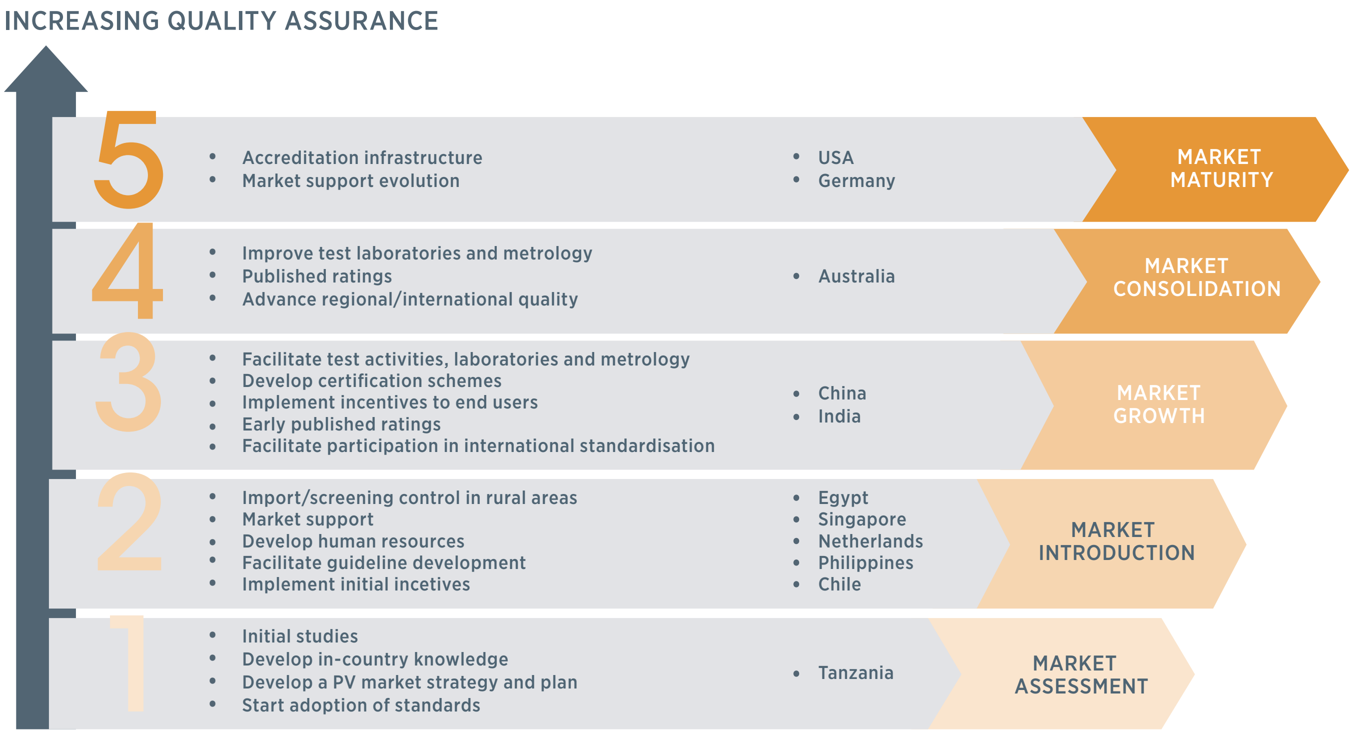
Sustained involvement by U.S. standards experts in IEC TC82 will likely result in further harmonisation of U.S. and IEC standards, as will greater overall adoption of IEC standards in the national regulatory framework. It is anticipated that more uniform project certification processes, such as the development of the IECRE conformity assessment programme, will also play a greater role in future QI in the United States. For utility-scale systems, in particular, it is installation requirements will continue to be further differentiated from those of retail customer systems, due to several factors:

- the 2017 NEC will, for the first time, have a dedicated chapter governing utility-scale PV (effectively eliminating requirements that were historically developed for residential and commercial systems not appropriate for large ground mount systems);
- use of IEC standards and IECRE conformity assessments applicable to large scale projects; and
- addition of PV-related topics to the National Electrical Safety Code, which is the NEC equivalent for utility-scale power plants.

5.2 Five-step approach to develop and implement quality infrastructure

IRENA uses a five-stage approach for the development of QI for RE technologies. These stages relate to the maturity of the respective RE market. The recommended measures on each stage are flexible, as their implementation will depend on several variables in each individual country. The stages and measures proposed for PV technology are a combined result of the analysis of country cases outlined in the previous section and IRENA's present approach to policy makers (IRENA, 2015). This approach is a guide which aims to provide the necessary tools to policy makers to ramp up action in the PV market with QA. Figure 5.2. shows the five-stage approach for solar PV technology.

Figure 5.2. Quality measures in countries at each stage of market development



The well-tuned incremental approach helps to raise the bar for quality requirements as country capabilities and PV markets grow. In other words, balancing the QI requirements, depending on the country context, in a way in which they are not so low that they allow the deployment of very poor quality systems, but also not so stringent that local capacity of technology suppliers and institutions are not able to cope with. Most of the countries are found to start with basic requirements for the PV market, such as education and an initial framework with basic guidelines. Depending on the country's electrical grid status, government emphasis is given to grid-connected or off-grid applications, but most of the QA present is centred on distributed generation. Incentives and specific programmes are deployed in most of the case study countries in multiple ways to support the PV development according to market growth. When reaching market maturity, incentives tend to vanish at the time the QI is implemented. The steps proposed allow the correct development of the PV market through a successive implementation of QI measures.

Stage 1: Market assessment and pre-development

At this stage, it is considered that no significant PV market exists in the country. The government intends to develop the market due to the growing interest in renewable energies, fuel savings and environmental improvement. The first steps would be initial studies and a search for quantitative knowledge.

Specific actions may include:

- Initial studies: Governments should recognise the potential for PV development in their country by funding initial studies to determine the solar resource, PV demand, economic impact and integration with the grid. Solar resource may be determined through on-site measurements, using monitoring stations that comply with ISO 9060 or satellite-derived data, an example is shown in Figure 5.3. The equipment and studies may be provided and undertaken by recognised companies. In developing countries, some international institutions, such as the World Bank, have provided finance for these studies. Initial studies are a significant action that most of the countries should undertake, as has been the case in Australia, Chile and Germany.

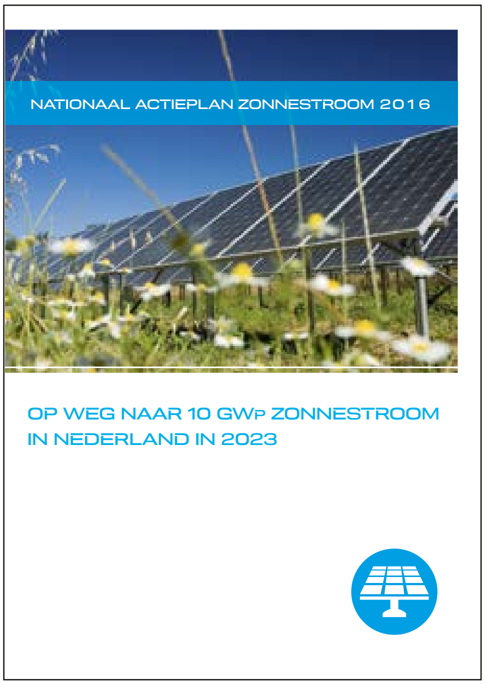
Figure 5.3. Irradiation map of the Netherlands

Source: Solargis, 2016

- Develop in-country knowledge: Governments should support the creation of internal knowledge of PV to not only foster development but also to build up existing the in-country knowledge of universities, associations, research centres and industry-related stakeholders. Workshops for knowledge sharing and building up networks should be held with the assistance of international agencies. Examples of such knowledge are available in Australia, Germany and the United States, as described in the previous section.

- Develop a PV market strategy and plan: A roadmap outlining the different phases of PV development and the QI measures to incorporate can ensure government commitment. The necessary organisations should support development and operation, and define an implementation schedule. Chile and the Netherlands (see Figure 5.4.) are good examples in terms of a development of a strategy plan, Strategic Program of the National Solar Industry (Programa Estratégico Nacional de Industria Solar) and the National Action Plan on Solar Power, respectively.

Figure 5.4. National action plan of The Netherlands



Source: DNV GL, 2016b

Start the adoption of standards: While standardisation is not a governmental responsibility, nevertheless, public agencies should be able to encourage the development of organisational structures and processes according to international best practices. Since equipment and installations should comply with standards that regulate the PV industry, the formation of a national group for standards and the adoption of minimum requirements through international standards that are already available should be ensured. Minimum international standards should be IEC 61215, IEC 61646, IEC 62446-1, IEC 61730 and IEC 62804 for PV modules and IEC 62109 and IEC 61000 (EMC compliance) for inverters. These will allow the establishment of import controls, installation guidelines, lists of accepted equipment, certification and testing throughout the project. Participation in international standards development is highly recommended, with collaboration in the drafting of new and/or updated standards. Currently, the IEC TC82 is composed of 38 participating countries that are developing standards. The countries analysed in this publication have adopted international standards, with most including them as a mandatory implementation through codes and guidelines.

11 See http://smartgridtv.nl.

Stage 2: Market introduction

While an emerging PV system market may be incipient with importers, local systems manufacturers and/or starting business, local content will depend on the capacity of a country to generate this type of industry and the availability of technical skills. For quality control, government should immediately implement initial policies to ensure that imports comply with quality standards and also publicly support PV through demonstration projects.

Specific actions may include:

- Strengthen border controls: Off-grid PV installations in rural developing areas, where there is limited centralised supervision over PV equipment standards. Governments may institutionalise bodies which develop country-specific standards that require certification, such as the CE mark, or parallel IEC and U.S. UL standards. The private sector may be involved in these bodies in order to, foster discussions with a view to developing the quality element, in general. Import control standards should be implemented to prevent counterfeit products from entering the solar PV supply chain as well as increase the entry level barrier by disqualifying substandard PV equipment manufacturers and suppliers. A list of certified equipment should be available, including those eligible for government incentives, as is the case in Australia and Tanzania.

- Support the market: To demonstrate market viability, government should show that it is actively supporting the PV market through demonstration projects that will raise public awareness and encourage local industry. Research institutes or academia should be involved to expand on the knowledge, exemplified by the initiatives taken (i) in Tanzania, where a pilot project for installing PV systems in rural areas was financed, and (ii) in the Netherlands where the province of Utrecht co-financed a smart-grid demonstration involving 300 private PV-powered households and approximately 15 local companies and schools.[11] The development of new PV modules, based on the conditions of the Atacama Desert Solar Platform in Chile, is also considered a pilot project to develop industry in the country.

- Develop human resource capacity: To ensure the technical skills and expertise of personnel in the installation of PV systems, training courses for installers and designers should be in place to improve the quality of systems in the long term. Training, which may be a part of a mandatory licensing process, should be conducted by local or international experts with content that includes an understanding of PV modules, inverters, grid connection, and electrical cabling, among others. One significant example is that offered in Australia through its Clean Energy Council licensing and training scheme. While India still lacks installation process regulations, companies such as Schneider Electric and Simpa Networks offer training programmes.

- Facilitate guideline development: Government should ensure that public guidelines for the correct design and installation of PV systems are followed. This should be carried out in liaison with experts and the PV industry and associations, such as in Australia and Singapore (see Section 5.1 and Section 0 respectively). The guidelines can be in the form of a manual for installers that includes best practices and mandatory standards or requirements to be followed for certification. These guidelines may be contained in the issuance of specific laws for the requirements of connecting PV systems into the grid or to enter into the government incentive schemes.

- Implement initial incentives: Government incentives significantly drive the development of the PV market but without a correct deployment and assurance of high quality, they it can be ineffective for the future consolidation. At the initial stage of development, incentives for a tax reduction on imports of PV equipment can be considered, such as those implemented in Chile and India.[12] Limited incentives can also attract investors, developers and EPC companies creating competence and first commercial systems.. These incentives may be limited by the total installed capacity and these should be implemented through government tenders to avoid error and failure. Australia adopted this type of incentive with a FiT formula for a limited time. Initial incentives by the German government were implemented in two phases to support the development of rooftop PV installations. The first included 1 000 households (International Solar Energy Society, 2008) and the second, 100 000 households.

Stage 3: Market growth

At this stage, the PV systems market is still small, although there is some local industry and imports begin to increase. QI elements must be fully developed at this stage, in tandem with relevant national policies.

Specific actions may include:

- Facilitate test activities, laboratories and liaison with metrology: The implementation of test laboratories allows the testing of systems and equipment. At first, testing may be focused on the commissioning and inspection phases of the PV system to ensure that procedures and performance are in line with national and/or international standards and best practices. Private sector stakeholders, such as financing bodies, may request testing as a prerequisite. In the regulated area governments can require compliancy of PV systems to national grid codes, while it is up to the private sector to develop the services that comply with prerequisites. A National Metrology Institute is able to secure the traceability chain of secondary and industrial calibration laboratories. A public sector knowledge network with academia and other relevant institutions can accelerate the development of test activities and laboratories. Some international standards to be considered should be IEC 62446 on the Commission Test Inspection and IEC 61829 on the On-Site Measurement of I-V Characteristics for c-Si modules. While the testing procedures should be conducted according to prevailing standards, there is no need for laboratories to be accredited.

- Implement certification schemes: Certification is necessary to ensure that equipment complies with relevant standards. The process may be performed by an independent, non-public organisation that adheres to the appropriate guidelines. Australia and Germany are countries that have certification schemes. It is not unusual, however, that the certification process be performed in countries with high equipment manufacturing capacity, such as China, Germany or the United States. Certification also relates to a process or system, such as the certification of PV installers (Section 3.4).

- Implement incentives for end users: Incentives for end users can boost PV market growth, although its need will depend on the LCOE of the system and electricity costs, given that countries

12 Imports are sampled at the border in India, although it is not clear whether or not there are QI requirements that pertain to tax incentives on imported PV equipment.

within grid parity (or approximating it) are self-financed. In any case, direct upfront investment incentives to end users of PV systems (e.g. renewable energy grants, tax credits) should be implemented once quality is guaranteed in terms of QI, so that they apply only to productive and long-life systems. For example, Australia has a renewable certification scheme that is available only to those installations that comply with guidelines and standards established by the government. Energy incentive policies, such as FiTs and net metering, also may be considered. These demand less direct links to QI, in that financial compensation is obtained by the PV-system owner only after electricity on a kWh basis has been injected into the grid, so on a kWh-basis.

- Early published ratings: Despite the various standards and certification requirements, the mass production of PV products and relevant commercial interests can lead to quality uncertainty with regard to performance in the field. It is essential that independent data is available in terms of project economics and support schemes for the industry. PV system ratings should be published by a certification body, based on test laboratory reports, as in the case of the United States. Ratings also may be issued by a that is independent from a test laboratory and certification body, such as Photon, a solar power publication. This privately published German magazine has been publishing about PV technology and relevant commercial products since 1996. In 2009, Photon started a laboratory to independently test solar modules and inverters, a time when Germany was showing signs of market growth stage.

- Participate in international standardisation activities: At this stage, government should encourage private sector stakeholders to join and/or participate in national standardisation groups and international standards-making groups, such as the IEC TC82, to influence the standardisation process and exchange knowledge. While this action is more appropriate in Stage 4, to be involved at the earlier stage will ensure that countries are more abreast of market developments and country overlap. Participation in such groups contributes to the integration of country-specific conditions and aspects into international standards which, in turn, can facilitate the penetration of national industries into the global market. This is exemplified by the development of the new IEC 62892 relating to climate standard for particular conditions, influenced by various countries such as Australia.

Stage 4: Market consolidation

By Stage 4, the market is sufficiently large and strong to be considered consolidated. Governments should focus on the implementation of the final set of QIs which will build on those from earlier stages.

Specific actions may include:

- Improve test laboratories and metrology: During Stage 4, test laboratories conduct tests of key PV system equipment that will be installed locally in order to prove their durability and performance. Reliance on primary national standards in key laboratories, with their traceability directly linked to the International System of Measurement Units, will contribute to the improvement of national metrology institutes. As in previous stages, public actors should develop an institutional framework that includes not only accreditation bodies, but also the testing and relevant services of private actors. While there is no requirement at this stage for test laboratories and certification bodies to be accredited, they should be required to follow international standards and prepare for accreditation. The support for countries and regions entering this phase should come from already established international private organisations that have a subsidiary office in a country where the market is ripe. Germany's TÜV Rheinland, for instance, has test laboratories and services in various countries that rely on German knowledge and expertise. The main PV equipment to be tested is PV modules, inverters and mounting structures. The first goal of testing is to ensure the quality of commercial PV modules, being performed according to prevailing international standards for durability, degradation, resistance to special conditions and electrical behaviour, among others. Some international standards to be considered should be IEC 61215, IEC 61646, IEC 60904, IEC 61701, IEC 61345, IEC 61853 and IEC 62716. Testing supports the research of new solar cells and PV modules, as in the case of Chile's Atacama Desert Solar Platform. Utility inverters require special facilities and expansive spaces due to their size and weight.

- Publish ratings: Although various industry magazines were already publishing relevant data prior to the German PV market having reached its consolidation stage, it is envisaged that as other regions reach the market consolidation, 'published ratings' will be developed and published to serve a specific region.

- Participate in regional and international QI advances: If not already involved, countries should support the participation of national experts in international technical committees, such as those of the ISO and/or the IEC. This will benefit markets through the incorporation of country-specific aspects into international PV standards.

Stage 5: Market maturity

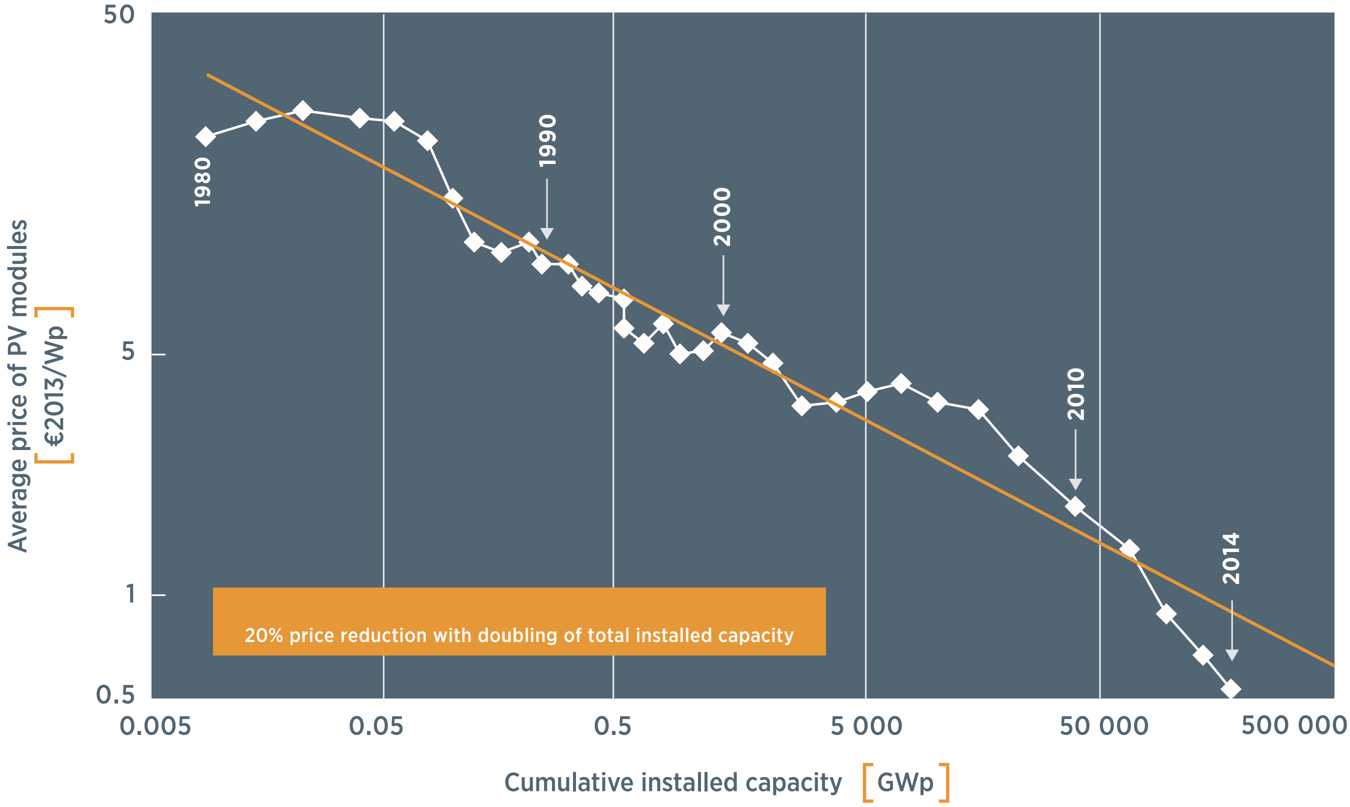
The market is considered to be fully mature and the industry well developed at Stage 5. QI has been successfully implemented and the cost has been absorbed by the huge volume generated by the market. The main objective at this stage – when public support is reduced and the PV market is self-sustainable – is QI accreditation.

Specific actions may include:

- Accreditation: The accreditation process should be performed for the test laboratories, certification bodies, training institutes and inspection bodies. Germany and the United States are good models for laboratory accreditation (IECEE, 2016a). Governments should take into account when instating accreditation bodies that it takes some time to realise accreditation of the testing, inspection and certification bodies (i.e. approximately one to two years). While this is performed, conditional approvals may be sufficient.

- Support market evolution: As long as the PV market has more volume, is stable and is self-sufficient, governments may gradually remove certain earlier incentives. The ramp down may be applied gradually according to market evolution, reflecting Germany in terms of its FiT incentive. Figure 5.5. illustrates the decline of the PV module price with the increase of installed capacity. At a certain point, the cost of systems and implemented QI may be below the electricity price, becoming an unnecessary direct incentive for the end user. At Stage 5, the market is sufficiently mature to create its own mechanisms to dilute the upfront installation costs and to sustain the training and licensing of qualified installers as a country enters the international market.

Figure 5.5. Historical price development of photovoltaic modules in relation to cumulative installed capacity worldwide



Source: Fraunhofer ISE (2016).

Notes: PV = photovoltaic; € = Euro; Wp = Watt peak; GWp = gigawatt peak.

Integration of Quality Infrastructure INTO PUBLIC POLICY

6

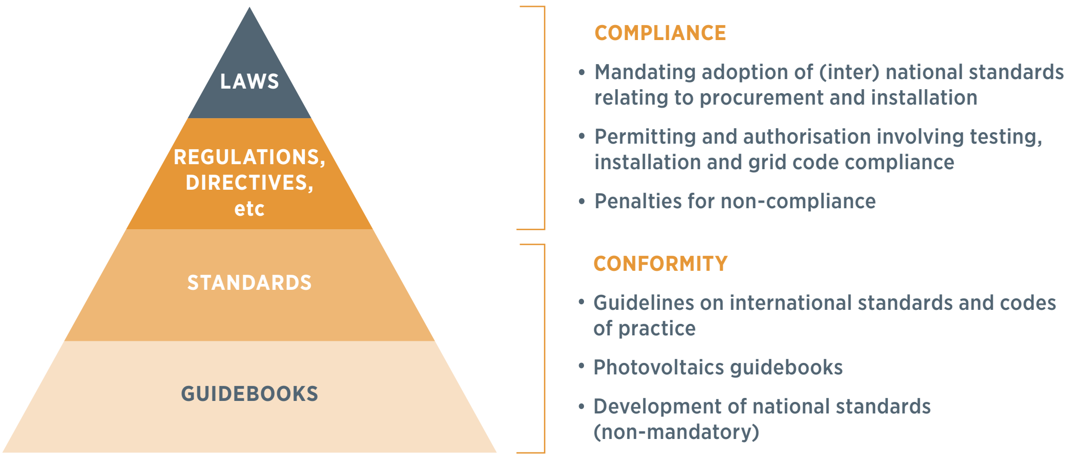
Integration of Quality Infrastructure into Public Policy

Integrating QI into public policy is a challenge in developing countries as much as it is in developed countries as ensuring quality is commonly ranked as a low priority when compared with affordability. Section 6.1 discusses how public policy – legislative and non-legislative – can refer to QI components by illustrating various country success stories. Section 6.2 provides an assessment of how incentive mechanisms for PV can be integrated within QI, accompanied by gap areas and recommendations. Section 6.3 reviews international quality standards on imported equipment, with an analysis of best-practice cases. Also presented are various proposed approaches for different PV segments for developing and developed countries alike.

6.1 How public policy can refer to QI components

Public policy is defined as an action taken by government to address public issues. These actions are based on a system of values and norms and can be legislative or non-legislative. Legislative actions include laws, technical regulations, decrees and other actions outlined by a statutory body. Non-legislative actions could include safety guides, public procurement and codes of conduct.[13]

Figure 6.1. Different levels of public policy



13 Using and referencing ISO and IEC standards to support public policy.

The above illustration provides the various levels of public policy mechanisms that can be utilised to address public issues. In the context of QI, two broad areas are discussed in more detail. The first mainly serves as a form of conformity for the PV industry, focusing on guidelines that outline international standards, published guidebooks and the development of national standards, codes and practices. This section includes country examples where conformity to international or national standards is outlined.

The second area focuses on compliance in terms of policy documentation, regulations and laws that pertain to the adoption of international standards, national standards and codes of practice. It also provides details of the permitting and authorisation in selected countries that illustrate how compliance is ensured through mandatory testing and licensing, as well as penalties of non-compliance.

In Table 6.1., a summary of policies, regulations and codes that refer to QI is included for each PV segment. For each area, a more in-depth account with potential improvements is suggested under each subsection. A further finding from this study is the limited number of policies, regulations and codes that refer to utility-scale systems (with the exception of grid-code compliance). This finding is not surprising, given that the barrier to entry for utility-scale systems are usually high and QI tends to be the responsibility of privately owned companies. With distributed and off-grid systems, however, a regulatory oversight is critical, given the low entry barrier for developers. Also, a lack of QI in a distributed and off-grid installation can have a larger impact on end use consumers. Regulatory bodies have the social responsibility to ensure the public receives safe and reliable electricity.

Table 6.1. Summary of policies, regulations and codes citing quality infrastructure in each photovoltaics segment

Public Policy Instruments That Refer to Quality Infrastructure Elements		Distributed				Utility				Off-grid		
		China	Singapore	Philippines	Netherlands	United States	Egypt	Chile	Germany	Australia	India	The United Republic of Tanzania
Conformity	Guidelines and guidebooks		✓	✓		✓			✓	✓	✓	✓
	Development of national standards	✓	✓			✓		✓	✓	✓		
Compliance	Adoption of standards (Photovoltaic components)	✓	✓			✓				✓	✓	✓
	Adoption of standards (Installation)		✓							✓		
	Testing of photovoltaic modules and components	✓				✓				✓		✓
	Formal training requirements, installer certification				✓	✓				✓		
	Certification of grid code compliance	✓	✓	✓	✓	✓	✓	✓	✓	NA	NA	NA
	Penalties for non-compliance	✓	✓		✓	✓				✓	✓	✓

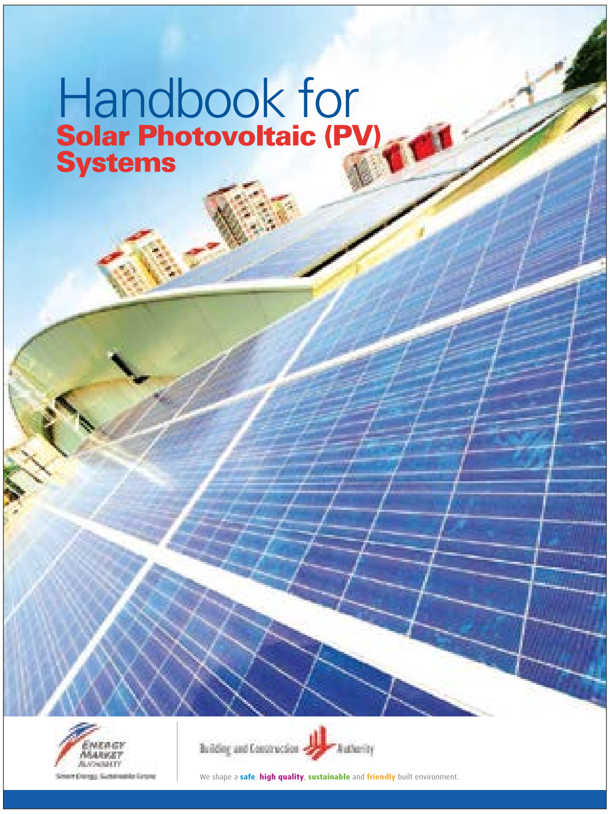
Conformity

Development of national standards and guidelines are most relevant during the installation and operation stages of of PV systems. In developing QI, it is worth outlining the guidelines of various PV standards as a starting point, with a view to publishing them on relevant government websites and/or incorporated into official handbooks.

Guidelines and handbooks

In Singapore, the Handbook for solar photovoltaic (PV) systems was produced in consultation with industry partners, academic institutions and regulators (EMA and BCA, 2009). Developing countries, such as the Philippines and Tanzania, are also publishing their own handbooks on solar PV systems. Various other countries outline in their handbooks the international standards on the design and specifications of PV modules which include – but are not limited to – IEC 61215, 61646 and 61730.

Figure 6.2. Handbook for solar photovoltaics



Source: EMA & BCA, 2009.

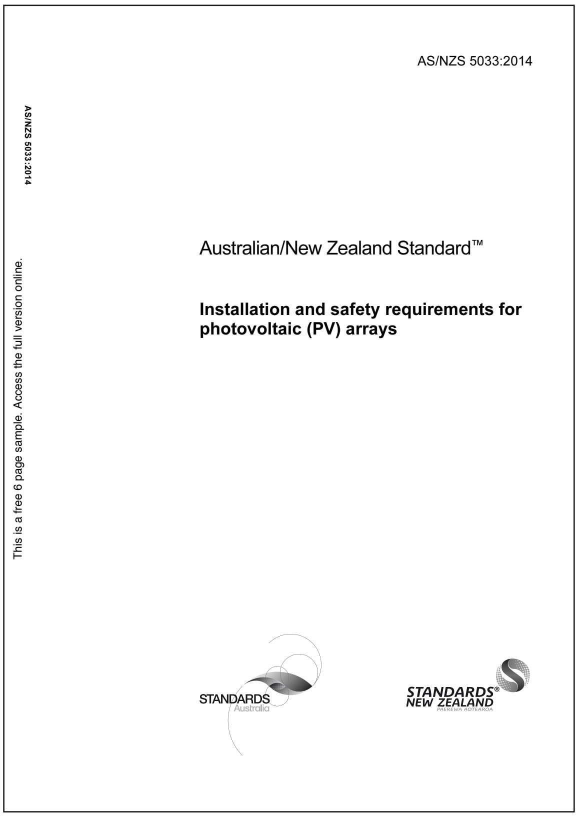
Similarly, in the United States, there are some commonly referenced IEC standards in publications that provide a thorough overview of PV components and systems. The National Renewable Energy Laboratory, the U.S. Department of Energy's federal laboratory, publishes reports that reference numerous IEC standards that cover measurement, performance, and safety issues, such as module safety and qualification standards (IEC 61215 and IEC 61646); environment-specific testing (e.g. IEC 61701, salt mist corrosion); and QA (IEC/TS 62941 guideline for increased confidence in PV module design qualification and type approval). Other standards are commonly referenced that address the ultraviolet ray exposure of components, qualification for BoS components, and commissioning.

Development of national standards

The development of national PV standards for modules and other PV-related equipment is usually not very common in most countries. Although many, including India, Germany and Singapore recommend the adoption of international standards pertaining to modules and other PV related equipment. China is one of the few countries that has adopted IEC standards, as well as developed its own national standards for the design and specifications of PV modules and inverters.

With respect to installation and safety, developed countries are increasingly creating their own national standards, such as Australia and Singapore. These nationally developed standards are released by local standards committees in consultation with various government agencies. In Singapore, SS601 was developed by the Singapore Standards Committee, in collaboration with the Solar Energy Research Institute, Building and Construction Authority and Housing Development Board. In Australia, AS/NZS:5033, which also applies in New Zealand, was generated by Standards Australia, Standards New Zealand and Australia's Clean Energy Council (see Figure 6.3). In the Philippines, the Department of Energy is in the process of drafting national standards relating to the sale of solar panels.

Figure 6.3. Installation and safety requirements for phovoltaic arrays (AS/NZS: 5033)


AS/NZS 5033:2014

AS/NZS 5033:2014

This is a free 6 page sample. Access the full version online.

Australian/New Zealand Standard™

Installation and safety requirements for photovoltaic (PV) arrays

STANDARDS Australia

STANDARDS® NEW ZEALAND

Source: Standards Australia, 2017

Compliance

Policies on the adoption of standards

This section focuses on identifying policy documents that mandate the adoption of international or national standard, considered the next critical step towards the improvement of QI in PV systems in specific countries. International standards legislation relating to PV modules and components takes place more so in developed economies, several of which are outlined below:

United States

In the United States, the 2014 NEC governs the installation of PV systems in most jurisdictions and dictates the use of UL standards for modules, inverters, combiner boxes, mounting equipment, and other BoS components. To date, 39 states are in the process of adopting updated editions of NEC. Below is an extract from Colorado's revised statute C.R.S 12-23-106 on license requirements (emphasis added):

2(a) An applicant for a journeyman electrician's license shall furnish written evidence that the applicant has had the following:

(III) Effective January 1, 2011, during the last four years of training, apprenticeship, or practical experience in wiring for, installing, and repairing electrical apparatus and equipment for electric light, heat, and power, at least two hundred eighty-eight hours of training in safety, the national electrical code and its applications...

China

In China, the Energy Administration Department under the State Council, together with the National Grid, provides regulatory oversight on the adoption of Chinese standards for RE deployment. More details of these standards are provided in the country cases in Section 5.1.According to the PRC Renewable Energy Law (2005) Chapter 3: Industrial guidance and technical support:

Article 11: The administrative department for standardisation under the State Council shall set and publish the technical standards of the State for grid- connected power generation with renewable energy and other standards of the State for the technology and products relating to renewable energy, for which the technical requirements need to be uniform throughout the country.

[...]

Article 14: "Planning and construction of power grid enterprises and in accordance with the renewable energy development and utilization, and shall obtain the administrative license or submitted for the record grid-connected renewable energy companies signed agreements and acquisitions within its network coverage in full conformity with technical standards for grid-connected electricity of grid-connected renewable energy projects. Power generation companies have an obligation to cooperate with power grid enterprises safeguard network security" [Extract from Legislation, translated from Chinese with Microsoft translator] (NPC, 2016a)

India

The Ministry of New and Renewable Energy released minimal technical requirements and standards for solar PV systems, stating that PV modules must conform to the latest addition of IEC or equivalent BIS Standards for PV module design (MNRE, 2013).

Part III, Section 17, of the draft National Renewable Energy Act 2015 on Technical and Safety Standards provides the following:

The Ministry in consultation with its agencies shall ensure publishing updated set of technical, safety and quality standards by which all manufactured RE equipment, RE products and RE fuels shall comply.

Australia

The Clean Energy Regulator is the main regulatory body that has oversight over RE policies, standards, compliance and enforcement in Australia. PV modules installed in Australia must be certified and approved to AS/NZ 5033 for the installation and safety requirements for photovoltaic (PV) arrays. This standard is referred to in AS/NZS 3000: wiring rules (CEC, 2016a) and is legislated in every Australian state and territory. In the Australian Capital Territory, for instance, the relevant legislation is the Electricity Safety Act 1971 (ACT) that provides the following in Section 5: Compliance with AS/NZS 3000 (ACT, 2016).

(1) A person commits an offence if—
- (a) the person carries out electrical wiring work; and
- (b) the work does not comply with AS/NZS 3000 as in force—
- (i) when the work is completed; or
- (ii) if the work is not completed—when the work is carried out.

Another key policy area in which Australia advocates the use of national PV standards is through the use of incentive mechanisms (see Section 5.1).

Singapore

The Energy Market Authority in Singapore provides legislation under the Electricity Act regarding PV installation, whereby electricity licensees shall comply with the codes of practice and other standards of performance issued by the Authority (Singapore Power, 2016). Reference is also made to the Singapore Standard (CP5) Code of Practice for Electrical Installations, which PV array junction boxes, PV generator junction boxes and switch gear assemblies and stipulates compliance with IEC standards. The Electricity Act provides:

Section 17(1): The Authority may give directions for or with respect to codes of practice and other standards of performance and procedures to be observed by electricity licensees and other persons […]

Section 18(1): "Every electricity licensee shall comply with the codes of practice and other standards of performance issued or approved under section 16 and directions given under section 17.

In addition, CP5 provides, with respect to compliance with standards 612.511.1: "The PV array junction box, PV generator junction box and switchgear assemblies shall be in compliance with IEC 60439-1.

Permitting and authorisation

Permitting and authorisation processes in the development, installation and commissioning of a PV system plays a valuable role in ensuring compliance. The role of the regulatory authority is to ensure that these processes, as well as regulations and guidelines, are complied with and adhered to, respectively. Only then solar PV systems can obtain documentary proof, indicating that they have followed certain standards outlined. In most cases, electrical grid-code compliance and certification is deemed to be mandatory in most countries.

Mandatory testing, in terms of permitting and authorisation, is limited in most countries. Usually certification as "proof" of compliance is not mandatory, with the exception of a few countries. China's national certification body, CQC, is authorised by the Certification and Accreditation Administration of China to conduct PV product certification (Figure 6.4.), with seven laboratories contracted by CQC to provide such testing services. CQC is a trademark that ensures PV developers comply with national standards for PV modules and components.

Figure 6.4. Sample of quality management system certificate

Source: Solar Clarity, 2014

Formal installer training and certification, accredited by government-linked agencies is closely related to national standards on PV installation and safety. Such requirements, however, only take place in Australia and the Netherlands.

Penalties for non-compliance

The integration of QI in policies that surround non-compliance is vital, such as those that relate to financial penalties and the loss of business licenses, as well as the level of enforcement. Legislation surrounding non-compliance is present in several developed and developing countries across the three PV segments.

In Australia, installers not in compliance with national standards are liable to a financial penalty of up to AUD 37 500 (firms) or up to AUD 7 500 (individuals), pursuant to Legislation Act 2001.

In Singapore, under section 14 of the Electricity Act:

If the Authority is satisfied that an electricity licensee is contravening, or is likely to contravene or has contravened any condition of its electricity licence, any code of practice or other standard of performance applicable to the licensee, any provision of this Act or any direction (including a direction under paragraph (a)) issued by the Authority to or applicable to the electricity licensee, the Authority may by notice in writing to the electricity licensee do one or more of the following:

(a) direct the electricity licensee to do or not do such things as are specified in such direction;

(b) require the electricity licensee to provide a performance bond, guarantee or any other form of security on such terms and conditions as the Authority may determine; and

(c) require the electricity licensee to pay a financial penalty of an amount not exceeding 10% of the annual turnover of that part of the licensee's business in respect of which the licensee holds a licence, ascertained from the licensee's latest audited accounts, or an amount not exceeding USD 1 million, whichever is higher.

- The level of enforcement of these penalties is fairly low in cases where the issue is deemed not to pose an immediate safety threat. In general, enforcement is carried out through routine and non-scheduled checks by electrical inspectors, with more of a focus on the electrical safety on PV installations. In the case of non-compliance in Australia, an inspector is required to ensure that electrical contractors resolve any non-compliance issues. In the United States, the non-compliance means that the PV system is not allowed to operate. System owners must take the necessary steps to rectify items or issues that are identified as non-compliant by the authority having jurisdiction or utility, and are only allowed to begin operation once those issues are resolved.

In the case of Tanzania, the TBS enforces compliance through its market surveillance on solar products sold in shops. Shop owners who do not provide conformity certificates for the products they sell will have their goods confiscated and destroyed at the shop owner's expense (TAREA, 2015).

Country cases

Various cases are highlighted in this section in terms of the different types of PV systems (off-grid, distributed and utility-scale).

China: Implementation of national standards

China is one of the few countries that has developed standards for PV systems. This, including the technical and safety specifications of modules and inverters, energy resource assessments and design specifications, among others. A list of more than 40 major PV standards exists at the national level (Chinese Standard, 2016). For example, GB 50797-2012 relates to the design of a PV station (see Figure 6.5.). Support for the development of local standards mainly stems from a PV manufacturing sector that is strong, with companies such as Suntech and Trina Solar. Worth noting is that national standards do not necessarily foster international industrial collaboration or trade.

Figure 6.5. National Standard GB 50797-2012


GB
GB 50797 - 2012
光伏发电站设计规范
Code for design of photovoltaic power station

Source: Chinese Standard, 2016

The Standardisation Administration of the People's Republic of China is the standards organisation authorised by the State Council of China to coordinate the work relating to standards. National PV standards are integrated into the overall certification process through a CQC or CGC certification. To obtain a CQC certification for c-Si PV modules, for instance, the developer must comply with standards and testing methods by following either GB/T 9535 or IEC 61215. Certification also includes an initial factory inspection and follow-up inspection and supervision (see CQC33-471541-2009-Certification Rules).[14]

14 For an example, see https://www.jinkosolar.com/ftp/CQC7980.pdf.

Regulatory authorities from the National Grid also perform spot checks to inspect facilities, whereby evidence of certification may be requested. In terms of installation, the study observes a gap in developing national standards, created by the lack of interest and incentive of the private sector to champion their development in terms of PV installation and safety.

Singapore: Regulatory approach to tenders

The tender process serves as a critical interface between the stages of PV system development, component supply and installation. Solar developers with their vast experience can easily take advantage of a poorly prepared tender document and leave the consumer or developer prone to quality issues. Hence is essential to have a good regulatory framework for tendering that will not only ensure the quality of PV products and services, but also will call for a higher level of transparency, leading to the overall improvement of bidding and healthy competition. This may be in the form of a set of rules that clearly outlines and describes the tender and procurement processes.

The Government of Singapore has centralised its tendering, government tenders are announced on an online platform (i.e. GeBIZ). The bidding for solar PV projects is no different, with public tenders for developing and installing PV systems being managed and issued by the Housing Development Board. This streamlined process provides a certain level of standardisation and evokes transparency across the solar PV market.

This tendering approach allows for periodic improvements to the quality of documents. As highlighted by PV developers, the design of tenders in Singapore has improved in recent years, since tenders can be critically evaluated for specific issues (e.g. determination of solar leasing tariff rates, trade-off between price and quality).

India: National and state quality infrastructure approaches for off-grid systems

The National Institute of Solar Energy in India facilitates the integration of module testing and certification into policy. Its role includes PV demonstration, standardisation, interactive research, training and testing of solar technologies and systems. It is an effective interface between government, industry and solar energy stakeholders within the country.

At the state level, public projects that require off-grid PV for rural electrification tend to favour the cheapest quote at the expense of quality. In Gujarat, however, state policy with regard to off-grid PV is more stringent, with the aim of improving the level of quality in a cost-competitive way. Gujarat has piloted India's first solar village, with a considerable number of installed solar pumps, stand-alone PV systems and home lighting systems. The state facilitates decentralised and off-grid solar applications that follow its guidelines, as well as those of the MNRE.

The public tender process includes the engagement of a third-party agency to assist in the identification of specifications, including a summary of inspection service requirements and standards for PV components, pumps and batteries. At the development stage, flash test reports and certifications for panels and inverters are reviewed, and output is rigourously tested during and after plant construction. For instance, testing is carried out to ensure that the output of solar pumps is within 10% of the specified amount. Test reports, as well as the design of supporting structures, drainage and SCADA supervisory control and data acquisition systems must strictly comply with IEC standards.

6.2 Incorporation of quality infrastructure requirements in incentive policies

One of the reasons that the implementation of QI within PV systems is overlooked is due to the lack of perceived benefit. In terms of PV installations, a RE framework that stipulates a minimum of quality standards as pre-requisites for incentives is being considered in the various countries. An overview of incentive polices, based on various countries, is presented below.

Overview of incentive policies

Feed-in tariffs

FiTs are typically long-term contracts (15–25 years) that involve a purchase agreement with the utility and RE producer. The purchase agreement is at a guaranteed rate that may decrease over time, as specified in the agreement itself. Germany spearheaded this incentive policy mechanism in 1990, serving as the cornerstone for several FiTs around the globe. Over the years, various innovative FiT policies (e.g. fixed price, premium price, sliding premium price) have been developed and tested in a number of markets (NREL, 2010). The focus here is limited to assessing how QI requirements can be or could have been integrated with the allocation of FiTs for utility-scale solar projects.

A key reason for favouring FiTs over investment subsidies is because an investment subsidy does not guarantee that a developer goes through with the project and injects electricity to the grid. With a FiT policy, it ensures incentives are obtained only after electricity is being injected. In Germany, the study finds that incentive policies are hardly tied to QI. No specific license to generate electricity is required in the German system apart from:

- complying with the prevailing Grid Code;
- showcasing a declaration of conformity for the inverter (Konformitätserklärung zur VDEW-Richtlinie von Wechselrichtern zur Netzeinspeisung), and
- registration at the Federal Network Agency (Bundesnetzagentur).

Given the maturity of the solar industry in Germany, however, there is a high level of confidence in PV developers and EPC contractors to follow closely nationally outlined guidelines. Germany continues to demonstrate PV quality in utility and rooftop sectors alike. This, however, may not be the case for countries that are starting to develop PV capabilities. Incorporating QI elements as part of the FiT qualification could help to increase transparency on module manufacturers and EPC contractors, thus improving overall investor confidence in PV systems in the target country. An appropriate administrative framework for FiT qualification is a common way to incorporate QI.

In the Philippines, through a RE service contract, the Department of Energy evaluates the developer's technical capabilities. It also checks the technical soundness of the RE equipment utilised. Under the DOE Department Circular 2009-07-001, Section 6c provides for the following application requirements:

(i) By himself, the corporation itself, through the member-firms, in case of a joint venture/consortium, or through employment of service providers, the RE Applicant shall include in its technical submission proof of its on-going or completed contracts/agreements similar to or congruent with the nature of work being proposed[…].

(iii) The key personnel of the RE applicant must have sufficient and relevant work experience in connection with the project being applied for. For this purposed the Curriculum Vitae of the management and technical personnel must be submitted..

(iv) This shall be evaluated based on the technical and environmental soundness, sufficiency and appropriateness of company-owned and leased equipment that will be used for the project.

Furthermore the Department of Energy shall determine the eligibility of the project under the FIT system for the Energy Regulatory Commission (ERC) for the processing a mandatory Certificate of Compliance (CoC). Part of the requirements of obtaining a CoC, outlined by the ERC in Resolution 7, Series of 2013, Section 2, includes specific technical requirements for large photovoltaic generation systems.

2.7.3. The VRE Generator shall demonstrate to the System Operator that the VRE Generating Facilities installed complies with the requirements indicated… through a certification issued by the PVS manufacturer, stating that its PVS has been tested and certified in a reputable laboratory showing compliance with the stated requirements.

Power Quality: …Connection Point shall not exceed the values established in Article 3.2.6.6 of the PGC… 2.7.2. Upon the connection of PVS, the Total Harmonic Distortion (THD) of the voltage and the Total Demand Distortion (TDD) of the current at the Connection Point shall not exceed the limits established in Article 3.2.4.4… .

Regulations under DOE Circular 2013-05-0009 -- Guidelines for the Selection Process of Renewable Energy Projects Under Feed in Tariff System and the Award of Certificate for Feed In Tariff Eligibility -- outline the need for RESC and DOE nomination of eligibility for processing of a CoC.

Section 3. Pre-Qualification Stage: only those RE Developers with valid and subsisting RESCs may apply for eligibility and inclusion of their project under the FIT System.

Section 4. Evaluation Process. The RE Developer shall be responsible in securing other regulatory requirements and the necessary permits in relation to its obligations under the RE Guidelines and the provisions of the RESC consistent with its Work Plan.

Section 6. Issuance of Certificate of Endorsement for FIT Eligibility. … DOE… shall… nominate eligibility of the project under the FIT system to the Energy Regulatory Comission (ERC) for the processing of a Certificate of Compliance under the FIT System…

In Japan, following the occurrence of the nuclear event in Fukushima, the country experienced acceleration in the deployment of solar PV. FiTs were promoted (10 Years net metering for small PV (<10kW), 20 years full-scale FiT for large PV (>=10kW)); however, the market grew faster than the FiT law had originally intended. The most significant difference was on the large systems (>=10kW) that were originally planned to be installed at 0.2~0.3GW/year, but expanded quickly to approximately 10GW/year. A key take away of this occurrence is to contemplate market growth projections when elaborating policies and regulations, accompanied simultaneously by laws and standards that prepare beforehand the market to ensure a certain level of quality on new deployments.

Tax credits and rebates

Tax credits and rebates are usually offered to encourage the use of RE sources. Such incentive schemes are flexible in providing assistance to different segments of the PV market that vary across countries and states.

In more mature markets such as the United States, tax credits and rebates have been continuously redesigned to better cater to different PV system owners. The federal renewable electricity production tax credit is an inflation-adjusted, per-kWh corporate tax credit for electricity generated. This tax has been renewed and expanded numerous times since its original inception in 1992. For distributed PV systems, several state-level incentive programmes can be utilised. For example, in the State of California, the California Solar Initiative is one of the largest solar rebate programmes, with a budget of USD 2.167 billion (Go Solar California, 2016).

The incorporation of state- and national-level standards for the certification of installers and PV components has partially contributed to the success of these programmes, where end users have benefitted from a more reliable PV system. A case in point is Colorado Springs Utilities which recommends that all PV systems be designed and installed by professional installers certified by the Colorado Solar Energy Industries Association or the NABCEP (U.S Department of Energy, 2016). In California, the California Energy Commission provides a list of eligible equipment that follows safety certification from nationally recognised testing laboratories. Projects applying for the California rebate programme must use certified PV modules and inverters from the commission's list of eligible equipment for programme qualification (Green Riverside, 2016).

Relevant legislation on the establishment of eligibility criteria and standards for solar rebates, administered in California, are found in Section 25782 of the California Public Resources Code:

The commission shall, by January 1, 2008, in consultation with the Public Utilities Commission, local publicly owned electric utilities, and interested members of the public, establish eligibility criteria for solar energy systems receiving ratepayer funded incentives that include all of the following:

(1) Design, installation, and electrical output standards or incentives

…

(4) The solar energy system has a warranty of not less than 10 years to protect against defects and undue degradation of electrical generation output

…

(8) The solar energy system is installed in conformance with the manufacturer's specifications and in compliance with all applicable electrical and building code standards.

Renewable energy certificates

Renewable energy certificates (REC) are tradable instruments that are used to meet voluntary RE targets and compliance requirements. These certificates also are used to recoup a portion of the cost of purchasing and installing a PV system.

Given the nature of RECs, where external parties buy these certificates to fulfil voluntary or mandatory requirements, credibility in terms of traceability of RE generated is often emphasised. In the United States, for example, the Green-e Energy is the most well-established certification for RECs (Sustainability Round Table Inc., 2012). The certification standards usually focus on ensuring that RECs meet the environmental and consumer protection standards, as well as verifying the source and time of generation. The European Energy Certification System serves a similar certification role whereby it ensures the traceability of RECs, mostly among European countries.

Quality requirements relating to the safety of installation and reliability of PV components is not currently part of the process of obtaining RECs in most international markets, with the exception of Australia (Sustainability Round Table Inc., 2012), where its Clean Energy Regulator serves as a central regulatory authority in overseeing the implementation of RECs in Australia. In addition to ensure traceability, the Clean Energy Regulator, together with Australia's Clean Energy Council, ensures a project is properly certified for its design and installation. For instance, before a system is eligible for small-scale technology certificates, the system owner needs to ensure that the installation complies with the Clean Energy Council code of conduct, design and installation guidelines, and that it follows national standards such as the AS/NZS installation and safety requirements for PV arrays.

The requirements above, set out by the Clean Energy Regulator, is based on the Renewable Energy (Electricity) Act 2000 pertaining to the establishment of an inspection scheme for the underlying small generation units of RE certificates. Under section 23AAA (Regulations to establish scheme for inspection of new installations of small generation units) of this Act, it states that:

(1) The regulations must establish a scheme for the inspection of the installation of small generation units for which certificates have been created [...]

(2a) [...] each year a statistically significant selection of small generation units that were installed during that year must be inspected for conformance with Australian standards and any other standards or requirements relevant to the creation of certificates in relation to that small generation unit [...]

(c) [...] any failures to comply with standards or other requirements relevant to the creation of certificates in relation to small generation units, to State, Territory or Commonwealth bodies with responsibility for the enforcement and administration of those standards or requirements.

Net metering schemes

A net metering scheme typically allows customers of rooftop solar or other distributed generators to be credited for the sale of any excess electricity generated. Since the sale of this electricity can only be executed via the grid, there has been significant debate surrounding the level of incentives provided under net metering schemes.

Currently regulations surrounding net metering schemes do not provide a framework to include QI for PV systems. Instead, net metering regulations pertaining to grid safety are more widely adopted around the world. A common approach introduces capacity limits on the PV system that is eligible for net metering. Grid companies, state and privately owned, can influence the administrative procedure for obtaining a net metering agreement to a large extent. This introduces the risk of over-regulation on the basis of grid safety. In the Philippines, for example, in addition to a distribution impact study, the distribution utility may request the applicant to conduct a distribution asset study. If the study requires new assets to be in place, such as additional transformers to be installed, management fees will be billed on a monthly basis to the customer. While these requirements are in place to enhance the safety of distribution systems, it tends to disincentivise small-scale PV owners.

Given the success of net metering schemes, as observed in parts of Europe and in the United States, policy makers could potentially incorporate PV QI as a form of pre-qualification for net metering. This would provide a more balanced approach in helping reduce loss of revenue to utilities by increasing the entry-level barrier, at the same time improving the level of QI in PV systems.

Renewable energy grants

There are several international initiatives that provide RE grants, specifically in support of rural electrification. Tanzania is one of the countries selected to benefit from the Scaling-Up Renewable Energy in Low Income Countries Program, a part of the Climate Investment Funds managed by the Strategic Climate Fund. In 2012, the World Bank funded the Lighting Rural Tanzania project in partnership with the Rural Energy Agency. This grant programme supported private enterprises in developing new business models to supply affordable energy in rural areas. Another example is the Sustainable Solar Market Package, a public programme provided by the Tanzanian government for the installation, provision of maintenance and spare parts; conducting training of end users and off takers for public facility solar PV systems and street lights. Such RE grant schemes in Tanzania tend to benefit from compulsory PV standards outlined by TBS; TZS 925 (Part 2):2007(E) solar photovoltaic power systems test procedures for main components – installation, maintenance, testing and replacement of batteries. The Standards Act 2008 that deems TBS standards as compulsory provides the following:

(20-1): The Minister may, on the recommendation of the Bureau [...] (a) declare a standard for any commodity or for the manufacturing, production, processing or treatment of any commodity to be compulsory standard in relation to it with effect from the date specified...

Similar examples of QI incorporated with international grants supporting the installation off-grid PV systems can be found in India. Under the first phase of the Jawaharlal Nehru National Solar Mission to implement off-grid PV plants, minimal technical requirements for qualification of the programme are outlined. This includes information on the adoption of international standards for modules, authorised testing laboratories where testing and accreditation must be obtained, warranty enforcements and identification and traceability requirements. An excerpt of the technical requirements for this grant from an official MNRE document is provided in Figure 6.6. A list of manufacturers that have complied and successfully received capital subsidies from this programme are publicly listed on the MNRE website.

While several of these incentives and minimal technical requirements outlined are aimed towards providing public services, the study finds that such government-initiated projects for off-grid PV installations tend to be very price sensitive and focus on installing a large number of systems with the least cost possible. Having a good regulatory framework for tendering was found to be an important element in ensuring that such projects ensure good quality and do not suffer from price pressure. A well-specified tender document can be used to ensure that developers only utilise high-quality PV components and accredited installers while, at the same time, they continue to be cost competitive. Examples of this are observed in Egypt and Singapore, where a transparent tendering process and the use of qualified third-party agencies to outline tendering requirements can help to improve the level of QI in PV systems.

Figure 6.6. Excerpt of the technical requirements of the programme on "Off-grid and Decentralized Solar Applications"

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ANNEXURE-3

MINIMAL TECHNICAL REQUIREMENTS/ STANDARDS FOR OFF-GRID/ STAND-ALONE SOLAR PHOTOVOLTAIC (PV) POWER PLANTS/ SYSTEMS TO BE DEPLOYED UNDER THE NATIONAL SOLAR MISSION

1. PV MODULES:

1.1 The PV modules must conform to the latest edition of any of the following IEC / equivalent BIS Standards for PV module design qualification and type approval:

Crystalline Silicon Terrestrial PV Modules	IEC 61215 / IS14286
Thin Film Terrestrial PV Modules	IEC 61646
Concentrator PV Modules & Assemblies	IEC 62108

1.2 In addition, the modules must conform to IEC 61730 Part 1- requirements for construction & Part 2 - requirements for testing, for safety qualification.

1.3 PV modules to be used in a highly corrosive atmosphere (coastal areas, etc.) must qualify Salt Mist Corrosion Testing as per IEC 61701.

2. BALANCE OF SYSTEM (BoS) ITEMS/ COMPONENTS:

2.1 The BoS items / components of the SPV power plants/ systems deployed under the Mission must conform to the latest edition of IEC/ equivalent BIS Standards as specified below**:

BoS item/component	Applicable IEC/equivalent BIS Standard	
	Standard Description	Standard Number
Power Conditioners/ Inverters*	Efficiency Measurements Environmental Testing	IEC 61683 IEC 60068 2 (6,21,27,30,75,78)
Charge controller/ MPPT units*	Design Qualification Environmental Testing	IEC 62093 IEC 60068 2 (6,21,27,30,75,78)
Storage Batteries	General Requirements & Methods of Test Tubular Lead Acid	IEC 61427 IS 1651/IS 133369
Cables	General Test and Measuring Methods PVC insulated cables for working Voltages up to and including 1100 V-Do-, UV resistant for outdoor installation	IEC 60189 IS 694/ IS 1554 IS/IEC 69947

*Must additionally conform to the relevant national/international Electrical Safety Standards.

Source: MNRE, 2010

6.3. International measures to control the quality of imports

Import control measures are applied predominantly to enforce health, environmental and security and safety standards. Although several countries, including Australia, Germany and the United States, have incorporated QI into their public policy on solar PV, none of them has incorporated PV-specific import controls. In the US, import control tariffs are put in place based on PV equipment manufacturing locations and not based on quality. This is the case for several reasons. Firstly, incorporating PV standards with import control could risk breaching international trade agreements. Secondly, there are several challenges to implementing such border control in large land-locked countries. Lastly, there is the risk of over-regulation, since there could be overlaps with existing policies that govern PV standards at the state or provincial level, especially for grid-connected PV projects.

The study finds PV-specific standards integrated in import control measures may be more suited for off-grid PV installations – especially in rural areas – where there is much lesser centralised supervision over PV equipment standards and procedures. Import control could, in turn, contribute to the prevention of counterfeit products from entering the solar PV supply chain as well as increase the entry-level barrier by disqualifying substandard PV equipment manufacturers and suppliers. Tanzania has taken first steps to address this issue by requiring importers to register their brands with the Business Registrations and Licencing Agency in order to be protected by the government against counterfeit or substandard products. Periodically, the Tanzanian Bureau of Standards, a governmental body, performs inspections at the importer/deliverer shops. They select samples of new products to be tested. In case some of the products fail the tests, the shop owner must pay for all the costs relative to the removal of the products from the market. This action is taken only if the shop owner does not have the Certificate of Conformity for the product.

To ensure that such standards are non-discriminatory and do not create unnecessary obstacles to trade, the study suggests import control measures specific to PV to be based on international quality management system (QMS) standards. QMS standards tend not to be domain specific; rather, they facilitate knowledge transfer easily across several specific domains. Industry-specific international QMS standards, used to control the quality of imports, are now found in several other sectors such as the automotive, aerospace, telecommunications, health and food sectors.

In Singapore, a national level QMS system, based on ISO9001:2015, has been incorporated with import control for medical devices. Companies that are involved in wholesale and/or the import of medical devices in Singapore are required to pass a Good Distribution Practice for Medical Device in Singapore certification audit prior to applying for an Importer or Wholesaler's Licence. In order to be certified by the certification bodies, companies are required to have implemented a QMS that adheres to current good distribution practices (HSA, 2012).

An industry-specific PV, based on ISO 90001, would serve as a starting point in controlling the quality of imported PV equipment. There are ongoing discussions within the PV industry to develop such an industry-specific QMS standard (NREL, 2014). Promoting ISO 90001 in developing countries through multilateral/mutual recognition arrangements could also help to prevent the breach of existing international trade agreements. Such arrangements can provide significant technical underpinning to the calibration, testing and inspection of accredited conformity assessment bodies. The health and telecommunications sectors are examples where multilateral/mutual recognition arrangements have been developed (Singapore Statutes Online, 2002).

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Appendix A

International standards for solar photovoltaic systems

Descriptions of standards are primarily extracted from https://webstore.iec.ch/home.

Doc Reference: DNV GL SE-0078 – Project Certification of Photovoltaic plants			
Main elements of the PV plant	**Standard/Rules that should apply**	**Description (from https://webstore.iec.ch/publication)**	**System concerned by this standard**
Site conditions and plant layout	IEC 62548 – Photovoltaic (PV) arrays – Design requirements	Abstract IEC/TS 62548:2013(E) sets out design requirements for photovoltaic (PV) arrays including d.c. array wiring, electrical protection devices, switching and earthing provisions. The scope includes all parts of the PV array up to but not including energy storage devices, power conversion equipment or loads. The object of this Technical Specification is to address the design safety requirements arising from the particular characteristics of photovoltaic systems. Attention is drawn to a project in the IEC 60364 series under joint development between IEC TCs 64 and 82, which will, when published, cancel and replace the present technical specification.	All Excluded the energy storage device for the off-grid application
Electrical installations and components	IEC 62548 – Photovoltaic (PV) arrays – Design requirements		All Excluded the energy storage device for the off-grid application
	IEC 62093 – Balance-of-system (BoS) components for photovoltaic systems – Design qualification natural environments	Abstract Establishes requirements for the design qualification of BoS components used in terrestrial photovoltaic systems. Is suitable for operation in indoor, conditioned or unconditioned; or outdoor in general open-air climates, protected or unprotected. Is written for dedicated solar components such as batteries, inverters, charge controllers, system diode packages, heat sinks, surge protectors, system junction boxes, maximum power point tracking devices and switch gear, but may be applicable to other BoS components.	All
	IEC 603364-6 – Low-voltage electrical installations – Part 6: Verification	Abstract Provides requirements for initial verification, by inspection and testing, of an electrical installation to determine, as far as reasonably practicable, whether the requirements of the other parts of IEC 60364 have been met and requirements for the reporting of the results of the initial verification. The initial verification takes place upon completion of a new installation or completion of additions or of alterations to existing installations. Provides requirements for periodic verification of an electrical installation to determine, as far as reasonably practicable, whether the installation and all its constituent equipment are in a satisfactory condition for use and requirements for the reporting of the results of the periodic verification.	All
Solar Modules	IEC 60904 – Photovoltaic devices – ALL PARTS		
	IEC 60904-1 – Photovoltaic devices – Part 1: Measurement of photovoltaic current-voltage characteristics	Describes procedures for the measurement of current-voltage characteristics of photovoltaic devices in natural or simulated sunlight. Lays down basic requirements for the measurement, defines procedures for different measuring techniques in use and shows practices for minimising measurement uncertainty.	All

Doc Reference: DNV GL SE-0078 – Project Certification of Photovoltaic plants			
	IEC 60904-2 – Photovoltaic devices – Part 2: Requirements for photovoltaic reference devices	IEC 60904-2:2015 RLV contains the International Standard and its Redline version. The Redline version is available in English only. The Redline version provides you with a quick and easy way to compare all the changes between this standard and its previous edition. The Redline version is not an official IEC Standard, only the current version of the standard is to be considered the official document. IEC 60904-2:2015 gives requirements for the classification, selection, packaging, marking, calibration and care of photovoltaic reference devices. This standard covers photovoltaic reference devices used to determine the electrical performance of photovoltaic cells, modules and arrays under natural and simulated sunlight. The main technical changes with regard to the previous edition are as follows: – addition of a test procedure in simulated sunlight of subsequent measurement of primary and secondary reference device; – definition of standard test conditions; – reduction of allowed diffuse component for secondary reference cell calibration.	All
	IEC 60904-3 – Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data	IEC 60904-3:2008 describes basic measurement principles for determining the electrical output of PV devices. The principles given in this standard are designed to relate the performance rating of PV devices to a common reference terrestrial solar spectral irradiance distribution. Covers testing in both natural and simulated sunlight. The main changes with respect to the previous edition include an extended wavelength range and the use of uniform wavelength intervals.	All
	IEC 60904-4 – Photovoltaic devices – Part 4: Reference solar devices – Procedures for establishing calibration traceability	IEC 60904-4:2009 sets the requirements for calibration procedures intended to establish the traceability of photovoltaic reference solar devices to SI units as required by IEC 60904-2. Applies to photovoltaic (PV) reference solar devices that are used to measure the irradiance of natural or simulated sunlight for the purpose of quantifying the performance of PV devices. The use of a PV reference solar device is required in the application of IEC 60904-1 and IEC 60904-3.	All
	IEC 60904-5 – Photovoltaic devices – Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method	IEC 60904-5:2011 describes the preferred method for determining the equivalent cell temperature (ECT) of PV devices (cells, modules and arrays of one type of module), for the purposes of comparing their thermal characteristics, determining NOCT (nominal operating cell temperature) and translating measured I-V characteristics to other temperatures. The main technical changes with regard to the previous edition are as follows: – added method on how to extract the input parameters; – rewritten method on how to calculate ECT; – reworked formulae to be in line with IEC 60891.	All
	IEC 60904-7 – Photovoltaic devices – Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices	IEC 60904-7:2008 describes the procedure for correcting the bias error introduced in the testing of a photovoltaic device, caused by the mismatch between the test spectrum and the reference spectrum and by the mismatch between the spectral responses (SR) of the reference cell and of the test specimen. The procedure applies only to photovoltaic devices linear in SR as defined in IEC 60904-10. This procedure is valid for single junction devices but the principle may be extended to cover multijunction devices. This new edition includes the following changes with respect to the previous one: description of when it is necessary to use the method and when it may not be needed; addition of new clauses.	All
	IEC 60904-8 – Photovoltaic devices – Part 8: Measurement of spectral responsivity of a photovoltaic (PV) device	IEC 60904-8:2014 specifies the requirements for the measurement of the spectral responsivity of both linear and non-linear photovoltaic devices. The spectral responsivity of a photovoltaic device is used in cell development and cell analysis, as it provides a measure of recombination and other processes occurring inside the semiconductor or cell material system. The main technical changes with respect to the previous edition are listed below: – re-writing of the clause on testing; – addition of a new clause for the measurement of series-connected modules; – addition of the requirements of ISO/IEC 17025.	All
	IEC 60904-9 – Photovoltaic devices – Part 9: Solar simulator performance requirements	Defines classifications of solar simulators for use in indoor measurements of terrestrial photovoltaic devices; solar simulators are classified as A, B or C for each of the three categories based on criteria of spectral distribution match, irradiance non-uniformity on the test plane and temporal instability. Provides the required methodologies for determining the rating achieved by a solar simulator in each of the categories. The main change with respect to the previous edition consists of a redefinition of the classifications and additional measurement procedures.	All

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	IEC 60904-10 – Photovoltaic devices – Part 10: Methods of linearity measurement	IEC 60904-10:2009 describes procedures used to determine the degree of linearity of any photovoltaic device parameter with respect to a test parameter. It is primarily intended for use by calibration laboratories, module manufacturers and system designers. The main technical changes with regard to the previous edition are as follows: – added clause for two-lamp method for Isc linearity; – removed clause on spectral responsivity nonlinearity because it is not used by any PV testing/calibration group.	All
	IEC 61215 – Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval	Lays down requirements for the design qualification and type approval of terrestrial photovoltaic modules suitable for long-term operation in general open-air climates, as defined in IEC 60721-2-1. Determines the electrical and thermal characteristics of the module and shows, as far as possible, that the module is capable of withstanding prolonged exposure in certain climates.	All
	IEC 61730-1 – Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction	IEC 61730-1:2004+A1:2011+A2:2013 Describes the fundamental construction requirements for photovoltaic modules in order to provide safe electrical and mechanical operation during their expected lifetime. Addresses the prevention of electrical shock, fire hazards, and personal injury due to mechanical and environmental stresses. Pertains to the particular requirements of construction and is to be used in conjunction with IEC 61215 or IEC 61646. This consolidated version consists of the first edition (2004), its amendment 1 (2011) and its amendment 2 (2013). Therefore, no need to order amendments in addition to this publication.	All
	IEC 61730-2 – Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing	IEC 61730-2:2004+A1:2011 Describes the testing requirements for photovoltaic modules in order to provide safe electrical and mechanical operation during their expected lifetime. Addresses the prevention of electrical shock, fire hazards, and personal injury due to mechanical and environmental stresses. Outlines the requirements of testing and is to be used in conjunction with IEC 61215 or IEC 61646. This consolidated version consists of the first edition (2004) and its amendment 1 (2011). Therefore, no need to order amendment in addition to this publication.	All
	IEC 61853-1 – Photovoltaic (PV) module performance testing and energy rating – Part 1: Irradiance and temperature performance measurements and power rating	IEC 61853-1:2011 describes requirements for evaluating PV module performance in terms of power (watts) rating over a range of irradiances and temperatures. The object is to define a testing and rating system, which provides the PV module power (watts) at maximum power operation for a set of defined conditions. A second purpose is to provide a full set of characterisation parameters for the module under various values of irradiance and temperature.	All
	IEC 61646 – Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval	IEC 61646:2008 lays down requirements for the design qualification and type approval of terrestrial, thin-film photovoltaic modules suitable for long-term operation in general open-air climates as defined in IEC 60721-2-1. This standard applies to all terrestrial flat plate module materials not covered by IEC 61215. The significant technical change with respect to the previous edition concerns the pass/fail criteria.	All
	IEC 62108 – Concentrated photovoltaic (CPV) modules and assemblies – Design qualification and type approval	Specifies the minimum requirements for the design qualification and type approval of concentrator photovoltaic modules and assemblies suitable for long-term operation in general open-air climates. The test sequence is partially based on that specified in IEC 61215. Determines the electrical, mechanical, and thermal characteristics of the CPV modules and assemblies and shows that the CPV modules and assemblies are capable of withstanding prolonged exposure in climates described in the scope.	All
	EN 50380 – Datasheet and nameplate information for photovoltaic modules	Technical specifications and information from the manufacturer about the PV modules (http://www.boutique.afnor.org/norme/nf-en-50380/specifications-particulieres-et-informations-sur-les-plaques-de-constructeur-pour-les-modules-photovoltaiques/article/767594/fa124008)	All

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Inverters	IEC 61000-6-1 – Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments	Applies to electrical and electronic apparatus intended for use in residential, commercial and light-industrial environments. Immunity requirements in the frequency range 0 Hz to 400 GHz are covered. No tests need to be performed at frequencies where no requirements are specified. This generic EMC immunity standard is applicable if no relevant dedicated product or product-family EMC immunity standard exists. This standard applies to apparatus intended to be directly connected to a low-voltage public mains network or connected to a dedicated DC source which is intended to interface between the apparatus and the low-voltage public mains network. This standard applies also to apparatus which is battery operated or is powered by a non-public, but non-industrial, low-voltage power distribution system if this apparatus is intended to be used in the locations described below. The environments encompassed by this standard are residential, commercial and light-industrial locations, both indoor and outdoor. The following list, although not comprehensive, gives an indication of locations which are included: – residential properties, for example houses, apartments; – retail outlets, for example shops, supermarkets; – business premises, for example offices, banks; – areas of public entertainment, for example cinemas, public bars, dance halls; – outdoor locations, for example petrol stations, car parks, amusement and sports centres; – light-industrial locations, for example workshops, laboratories, service centres. Locations which are characterised by being supplied directly at low voltage from the public mains network are considered to be residential, commercial or light-industrial. The immunity requirements have been selected to ensure an adequate level of immunity for apparatus at residential, commercial and light-industrial locations. The levels do not, however, cover extreme cases, which may occur at any location, but with an extremely low probability of occurrence. Not all disturbance phenomena have been included for testing purposes in this standard but only those considered as relevant for the equipment covered by this standard. These test requirements represent essential electromagnetic compatibility immunity requirements. Test requirements are specified for each port considered.	All
	IEC 61000-6-2 – Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity for industrial environments	Applies to electrical and electronic apparatus intended for use in industrial environments, as described below. Immunity requirements in the frequency range 0 Hz to 400 GHz are covered. No tests need to be performed at frequencies where no requirements are specified. This generic EMC immunity standard is applicable if no relevant dedicated product or product-family EMC immunity standard exists. This standard applies to apparatus intended to be connected to a power network supplied from a high or medium voltage transformer dedicated to the supply of an installation feeding manufacturing or similar plant, and intended to operate in or in proximity to industrial locations, as described below. This standard applies also to apparatus which is battery operated and intended to be used in industrial locations. The environments encompassed by this standard are industrial, both indoor and outdoor. The immunity requirements have been selected to ensure an adequate level of immunity for apparatus at industrial locations. The levels do not, however, cover extreme cases, which may occur at any location, but with an extremely low probability of occurrence. Not all disturbance phenomena have been included for testing purposes in this standard, but only those considered as relevant for the equipment covered by this standard. These test requirements represent essential electromagnetic compatibility immunity requirements.	MV PV system
	IEC 61000-6-3 – Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments	IEC 61000-6-3:2006+A1:2010 This part of IEC 61000 for EMC emission requirements applies to electrical and electronic apparatus intended for use in residential, commercial and light-industrial environments. Emission requirements in the frequency range 0 Hz to 400 GHz are covered. No measurement needs to be performed at frequencies where no requirement is specified. This generic EMC emission standard is applicable if no relevant dedicated product or product-family EMC emission standard exists. This standard applies to apparatus intended to be directly connected to a low-voltage public mains network or connected to a dedicated DC source, which is intended to interface between the apparatus and the low-voltage public mains network. This standard applies also to apparatus which is battery operated or is powered by a non-public, but non-industrial, low-voltage power distribution system if this apparatus is intended to be used in the locations described below. The environments encompassed by this standard are residential, commercial and light-industrial locations, both indoor and outdoor.	All

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	IEC 61000-6-4 – Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments	IEC 61000-6-4:2006+A1:2010 This part of IEC 61000 for EMC emission requirements applies to electrical and electronic apparatus intended for use in industrial environments as described below. Emission requirements in the frequency range 0 Hz to 400 GHz are covered. No measurement needs to be performed at frequencies where no requirement is specified. This generic EMC emission standard is applicable if no relevant dedicated product or product-family EMC emission standard exists. This standard applies to a apparatus intended to be connected to a power network supplied from a high or medium voltage transformer dedicated to the supply of an installation feeding manufacturing or similar plant, and intended to operate in or in proximity to industrial locations, as described below. This standard applies also to apparatus, which is battery operated and intended to be used in industrial locations.	MV PV system
	IEC 61683 – Photovoltaic systems – Power conditioners – Procedure for measuring efficiency	Describes guidelines for measuring the efficiency of power conditioners used in stand-alone and utility-interactive photovoltaic systems, where the output of the power conditioner is a stable a.c. voltage of constant frequency or a stable d.c. voltage	All
	IEC 62109-1 – Safety of power converters for use in photovoltaic power systems – Part 1: General requirements	IEC 62109-1:2010(E) applies to the power conversion equipment (PCE) for use in photovoltaic systems where a uniform technical level with respect to safety is necessary. Defines the minimum requirements for the design and manufacture of PCE for protection against electric shock, energy, fire, mechanical and other hazards. Provides general requirements applicable to all types of PV PCE.	All
	IEC 62109-2 – Safety of power converters for use in photovoltaic power systems – Part 2: Particular requirements for inverters	IEC 62109-2:2011 covers the particular safety requirements relevant to d.c. to a.c. inverter products as well as products that have or perform inverter functions in addition to other functions, where the inverter is intended for use in photovoltaic power systems. Inverters covered by this standard may be grid-interactive, stand-alone, or multiple mode inverters, may be supplied by single or multiple photovoltaic modules grouped in various array configurations, and may be intended for use in conjunction with batteries or other forms of energy storage. This standard must be used jointly with IEC 62109-1.	All
	IEC 62116 – Utility-interconnected photovoltaic inverters – Test procedure of islanding prevention measures	IEC 62116:2014 provides a test procedure to evaluate the performance of islanding prevention measures used with utility-interconnected PV systems. This standard describes a guideline for testing the performance of automatic islanding prevention measures installed in or with single or multi-phase utility interactive PV inverters connected to the utility grid. The test procedure and criteria described are minimum requirements that will allow repeatability. Major changes with respect to the previous edition concern the DC power source and test conditions.	LV/MV PV system
	EN 50524 – Data sheet and name plate for photovoltaic inverters		All
	EN 50530 – Overall efficiency of grid connected photovoltaic inverters		All
	EN 50178 – Electronic equipment for use in power installations		All
Junction boxes	IEC 61000	IEC 61000-6-1 – Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments IEC 61000-6-2 – Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity for industrial environments IEC 61000-6-3 – Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments IEC 61000-6-4 – Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments	All

Doc Reference: DNV GL SE-0078 – Project Certification of Photovoltaic plants			
Power Transformers (Sr>100 kVA)	IEC 60076 – ONLINE COLLECTION – Power transformers	Yearly subscription to the power transformers collection. Access online all parts and sections with a user friendly interface and navigation. Bookmark and comment functions are also available. Have a look at all the publications available in this collection and consult freely the preview here.	MV PV system
	IEC 60076	IEC 60076-1 – Power transformers – Part 1: General IEC 60076-2 – Power transformers – Part 2: Temperature rise for liquid-immersed transformers IEC 60076-3 – Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air IEC 60076-4 – Power transformers – Part 4: Guide to the lightning impulse and switching impulse testing – Power transformers and reactors IEC 60076-5 – Power transformers – Part 5: Ability to withstand short circuit IEC 60076-6 – Power transformers – Part 6: Reactors IEC 60076-7 – Power transformers – Part 7: Loading guide for oil-immersed power transformers IEC 60076-8 – Power transformers – Part 8: Application guide IEC 60076-10 – Power transformers – Part 10: Determination of sound levels IEC 60076-10-1 – Power transformers – Part 10-1: Determination of sound levels – Application guide IEC 60076-11 – Power transformers – Part 11: Dry-type transformers IEC 60076-12 – Power transformers – Part 12: Loading guide for dry-type power transformers IEC 60076-13 – Power transformers – Part 13: Self-protected liquid-filled transformers IEC 60076-14 – Power transformers – Part 14: Liquid-immersed power transformers using high-temperature insulation materials IEC 60076-15 – Power transformers – Part 15: Gas-filled power transformers IEC 60076-16 – Power transformers – Part 16: Transformers for wind turbine applications IEC 60076-18 – Power transformers – Part 18: Measurement of frequency response IEC 60076-21 – Power transformers – Part 21: Standard requirements, terminology, and test code for step-voltage regulators	MV PV system
	IEC 60721	IEC 60721-1 – Classification of environmental conditions – Part 1: Environmental parameters and their severities IEC 60721-2-1 – Classification of environmental conditions – Part 2-1: Environmental conditions appearing in nature – Temperature and humidity IEC 60721-2-2 – Classification of environmental conditions – Part 2-2: Environmental conditions appearing in nature – Precipitation and wind IEC 60721-2-3 – Classification of environmental conditions – Part 2-3: Environmental conditions appearing in nature – Air pressure IEC 60721-2-4 – Classification of environmental conditions – Part 2-4: Environmental conditions appearing in nature – Solar radiation and temperature IEC 60721-2-5 – Classification of environmental conditions – Part 2: Environmental conditions appearing in nature – Section 5: Dust, sand, salt mist IEC 60721-2-6 – Classification of environmental conditions. Part 2: Environmental conditions appearing in nature. Earthquake vibration and shock IEC 60721-2-7 – Classification of environmental conditions. Part 2: Environmental conditions appearing in nature. Fauna and flora IEC 60721-2-8 – Classification of environmental conditions – Part 2: Environmental conditions appearing in nature – Section 8: Fire exposure IEC 60721-2-9 – Classification of environmental conditions – Part 2-9: Environmental conditions appearing in nature – Measured shock and vibration data – Storage, transportation and in-use IEC 60721-3-0 – Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Introduction IEC 60721-3-1 – Classification of environmental conditions – Part 3 Classification of groups of environmental parameters and their severities – Section 1: Storage IEC 60721-3-2 – Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 2: Transportation	

Doc Reference: DNV GL SE-0078 – Project Certification of Photovoltaic plants			
	IEC 60721	IEC 60721-3-3 – Classification of environmental conditions – Part 3-3: Classification of groups of environmental parameters and their severities – Stationary use at weatherprotected locations IEC 60721-3-4 – Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 4: Stationary use at non-weatherprotected locations IEC 60721-3-5 – Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 5: Ground vehicle installations IEC 60721-3-6 IEC 60721-3-7 – Classification of environmental conditions – Part 3-7: Classification of groups of environmental parameters and their severities – Portable and non-stationary use IEC 60721-3-9 – Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 9: Microclimates inside products IEC 60721-4-0 – Classification of environmental conditions – Part 4-0: Guidance for the correlation and transformation of the environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 – Introduction IEC 60721-4-1 – Classification of environmental conditions – Part 4-1: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 – Storage IEC 60721-4-2 – Classification of environmental conditions – Part 4-2: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 – Transportation IEC 60721-4-3 – Classification of environmental conditions – Part 4-3: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 – Stationary use at weatherprotected locations IEC 60721-4-4 – Classification of environmental conditions – Part 4-4: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 – Stationary use at non-weatherprotected locations IEC 60721-4-4 – Classification of environmental conditions – Part 4-4: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 – Stationary use at non-weatherprotected locations IEC 60721-4-5 – Classification of environmental conditions – Part 4-5: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 – Ground vehicle installations IEC 60721-4-6 – Classification of environmental conditions – Part 4-6: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 – Ship environment IEC 60721-4-7 – Classification of environmental conditions – Part 4-7: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 – Portable and non-stationary use IEC 60721-4-5 – Classification of environmental conditions – Part 4-5: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 – Ground vehicle installations	
	IEC 60076-11 – Power transformers – Part 11: Dry-type transformers	Applies to dry-type power transformers (including auto-transformers) having values of highest voltage for equipment up to and including 36 kV and at least one winding operating at greater than 1,1 kV. Applies to all construction technologies	All
	IEC 60076-16 – Power transformers – Part 16: Transformers for wind turbine applications	IEC 60076-16:2011 applies to dry-type and liquid-immersed transformers for rated power 100 kVA up to 10 000 kVA for wind turbine applications having a winding with highest voltage for equipment up to and including 36 kV and at least one winding operating at a voltage greater than 1,1 kV.	MV PV system

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High-voltage switchgears	IEC 62271 – High-voltage switchgear and controlgear – ALL PARTS	This pack contains the following standards: IEC 62271-1 ed1.1 IEC 62271-3 ed2.0 IEC 62271-4 ed1.0 IEC 62271-100 ed2.1 IEC 62271-101 ed2.0 IEC 62271-102 ed1.2 IEC 62271-103 ed1.0 IEC 62271-104 ed2.0 IEC 62271-105 ed2.0 IEC 62271-106 ed1.0 IEC 62271-107 ed2.0 IEC 62271-108 ed1.0 IEC 62271-109 ed2.1 IEC 62271-110 ed3.0 IEC 62271-111 ed2.0 IEC 62271-112 ed1.0 IEC 62271-200 ed2.0 IEC 62271-201 ed2.0 IEC 62271-202 ed2.0 IEC 62271-203 ed2.0 IEC 62271-204 ed1.0 IEC 62271-205 ed1.0 IEC 62271-206 ed1.0 IEC 62271-207 ed2.0 IEC TR 62271-208 ed1.0 IEC 62271-209 ed1.0 IEC TS 62271-210 ed1.0 IEC 62271-211 ed1.0 IEC TR 62271-300 ed1.0 IEC TR 62271-301 ed2.0 IEC TR 62271-302 ed1.0 IEC TS 62271-304 ed1.0 IEC TR 62271-305 ed1.0 IEC TR 62271-306 ed1.0 IEC TR 62271-307 ed1.0 IEC TR 62271-310 ed2.0 IEC/IEEE 62271-37-013 ed1.0 IEC/IEEE 62271-37-082 ed1.0	MV PV system
	Germany the federal health and safety law (Arbeitsschutzrecht) and BGI 753 by BG ETEM (Berufsgenossenschaft Energie Textil Elektro Medienerzeugnisse)	National requirements for Germany for the SF6	MV PV system
	IEC 61936-1:2010+AMD1:2014 subclause 7.5.4 – Power installations exceeding 1 kV a.c. – Part 1: Common rules	IEC 61936-1:2010+A1:2014 provides common rules for the design and the erection of electrical power installations in systems with nominal voltages above 1 kV a.c. and nominal frequency up to and including 60 Hz, so as to provide safety and proper functioning for the use intended.	Off-grid/LV systems

Doc Reference: DNV GL SE-0078 – Project Certification of Photovoltaic plants			
	EN 50251		All
	IEC 60227	IEC 60227-1 – Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V – Part 1: General requirements IEC 60227-2 – Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V – Part 2: Test methods IEC 60227-3 – Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V – Part 3: Non-sheathed cables for fixed wiring IEC 60227-4 – Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V – Part 4: Sheathed cables for fixed wiring IEC 60227-5 – Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V – Part 5: Flexible cables (cords) IEC 60227-6 – Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V – Part 6: Lift cables and cables for flexible connections IEC 60227-7 – Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V – Part 7: Flexible cables screened and unscreened with two or more conductors	All
	IEC 60228 – Conductors of insulated cables	Specifies the nominal cross-sectional areas, in the range 0,5 mm² to 2 500 mm², for conductors in electric power cables and cords of a wide range of types. Requirements for numbers and sizes of wires and resistance values are also included. These conductors include solid and stranded copper, aluminium and aluminium alloy conductors in cables for fixed installations and flexible copper conductors. The standard does not apply to conductors for telecommunication purposes. The applicability of this standard to a particular type of cable is as specified in the standard for the type of cable. Unless indicated to the contrary in a particular clause, this standard relates to the conductors in the finished cable and not to the conductor as made or supplied for inclusion into a cable. Informative annexes are included giving supplementary information covering temperature correction factors for resistance measurement (Annex B) and dimensional limits of circular conductors (Annex C). The principal changes with respect to the previous edition are as follows: a) the consolidation of material from IEC 60228A; b) addition of a definition for nominal cross-sectional area; c) an increase in the range of conductor sizes in Tables 1 and 2; d) addition of a note that solid aluminum alloy conductors, having the same dimensions as aluminum conductors, will have a higher resistance; e) strengthening of the recommendations for dimensional limits of compacted stranded copper conductors.	All
	IEC 60502 – Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) – ALL PARTS	IEC 60502-1 – Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) – Part 1: Cables for rated voltages of 1 kV (Um = 1,2 kV) and 3 kV (Um = 3,6 kV) IEC 60502-2 – Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) – Part 2: Cables for rated voltages from 6 kV (Um = 7,2 kV) up to 30 kV (Um = 36 kV) IEC 60502-4 – Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) – Part 4: Test requirements on accessories for cables with rated voltages from 6 kV (Um = 7,2 kV) up to 30 kV (Um = 36 kV) IEC 60840 – Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) – Test methods and requirements	All
	IEC 60364-5-52 – Low-voltage electrical installations – Part 5-52: Selection and erection of electrical equipment – Wiring systems	IEC 60364-5-52:2009 deals with the selection and erection of wiring systems. This third edition cancels and replaces the second edition, published in 2001, and constitutes a technical revision. The main changes with respect to the previous edition are as follows: – Subclause 521.4 introduces minor changes with regard to busbar trunking systems and powertrack systems. – Subclause 523.6 introduces minor changes with regard to the sizing of cables where harmonic currents are present. – A new sublause 523.9 concerning single-core cables with a metallic covering has been introduced. – Clause 525 introduces changes in the maximum value of voltage drop permitted between the origin of the consumer's installation and the equipment which should not be greater than that given in the relevant annex. – Clause 526 introduces minor changes to electrical connections including additional exceptions for inspection of connections and additional notes. – Clause 528 introduces additional requirements with regard to proximity of underground power and telecommunication cables. – Clause 529 introduces minor changes to selection and erection of wiring systems in relation to maintainability, including cleaning. The contents of the corrigendum of February 2011 have been included in this copy.	All

Doc Reference: DNV GL SE-0078 – Project Certification of Photovoltaic plants			
Lightning protection	IEC 62305-3 – Protection against lightning – Part 3: Physical damage to structures and life hazard	IEC 62305-3:2010 provides the requirements for protection of a structure against physical damage by means of a lightning protection system (LPS), and for protection against injury to living beings due to touch and step voltages in the vicinity of an LPS (see IEC 62305-1). This second edition cancels and replaces the first edition, published in 2006, and constitutes a technical revision. This edition includes the following significant technical changes with respect to the previous edition: 1) Minimum thicknesses of metal sheets or metal pipes given in Table 3 for air-termination systems are assumed as not able to prevent hot-spot problems. 2) Steel with electro-deposited copper is introduced as material suitable for LPS. 3) Some cross-sectional areas of LPS conductors were slightly modified. 4) For bonding purposes, isolating spark gaps are used for metal installations and SPD for internal systems. 5) Two methods simplified and detailed are provided for evaluation of separation distance. 6) Protection measures against injuries of living beings due to electric shock are considered also inside the structure. 7) Improved information for LPS in the case of structures with a risk of explosion are given in Annex D (normative). This bilingual version (2012–06) corresponds to the monolingual English version, published in 2010-12.	All
	German DIN EN 62305-3 Supplement 5		
Monitoring system			
Loads, structural and foundation design	EN 1990 (Eurocode 0) – Basis of structural design		All
	EN 1991 (Eurocode 1) – Actions on structures		All
	EN 1997 (Eurocode 7) – Geotechnical design		All
	ISO 12944 – Paints and varnishes -- Corrosion protection of steel structures by protective paint systems – Part 5: Protective paint systems	http://www.iso.org/iso/catalogue_detail.htm?csnumber=41862 ISO 12944-5:2007 describes the types of paint and paint system commonly used for corrosion protection of steel structures. It also provides guidance for the selection of paint systems available for different environments and different surface preparation grades, and the durability grade to be expected. The durability of paint systems is classified in terms of low, medium and high.	All
	ISO 2394 – General principles on reliability for structures	ISO 2394:2015 constitutes a risk- and reliability-informed foundation for decision making concerning design and assessment of structures both for the purpose of code making and in the context of specific projects.	All
	EN 1993 (Eurocode 3) – Design of steel structures		All
	EN 1999 (Eurocode 9) – Design of aluminium structures		All

Doc Reference: DNV GL SE-0078 – Project Certification of Photovoltaic plants			
Solar tracking systems	IEC 61000-6-x – Electromagnetic compatibility (EMC)	IEC 61000-6-1 – Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments IEC 61000-6-2 – Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity for industrial environments IEC 61000-6-3 – Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments IEC 61000-6-4 – Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments	All
	IEC 62817 – Photovoltaic systems – Design qualification of solar trackers	IEC 62817:2014 is a design qualification standard applicable to solar trackers for photovoltaic systems, but may be used for trackers in other solar applications. The standard defines test procedures for both key components and for the complete tracker system. In some cases, test procedures describe methods to measure and/or calculate parameters to be reported in the defined tracker specification sheet. In other cases, the test procedure results in a pass/fail criterion. This standard ensures the user of the said tracker that parameters reported in the specification sheet were measured by consistent and accepted industry procedures. The tests with pass/fail criteria are engineered with the purpose of separating tracker designs that are likely to have early failures from those designs that are sound and suitable for use as specified by the manufacturer.	All
	IEC TS 62727 – Photovoltaic systems – Specification for solar trackers	IEC/TS 62727:2012(E) provides guidelines for the parameters to be specified for solar trackers for photovoltaic systems and provides recommendations for measurement techniques. The purpose of this test specification is to define the performance characteristics of trackers and describe the methods to calculate and/or measure critical parameters. This specification provides industry-wide definitions and parameters for solar trackers. Keywords: solar photovoltaic energy, solar trackers	All
	ISO 12100 – Safety of machinery – General principles for design – Risk assessment and risk reduction	ISO 12100:2010 specifies basic terminology, principles and a methodology for achieving safety in the design of machinery. It specifies principles of risk assessment and risk reduction to help designers in achieving this objective. These principles are based on knowledge and experience of the design, use, incidents, accidents and risks associated with machinery. Procedures are described for identifying hazards and estimating and evaluating risks during relevant phases of the machine life cycle, and for the elimination of hazards or sufficient risk reduction. Guidance is given on the documentation and verification of the risk assessment and risk reduction process.	All
	ISO 14121-1 – Safety of machinery – Risk assessment – Part 1: Principles	This standard has been revised by: ISO 12100:2010. ISO 14121-1:2007 establishes general principles intended to be used to meet the risk reduction objectives established in ISO 12100-1:2003, Clause 5. These principles of risk assessment bring together knowledge and experience of the design, use, incidents, accidents and harm relating to machinery in order to assess the risks posed during the relevant phases of the life cycle of a machine. ISO 14121-1:2007 provides guidance on the information that will be required to enable risk assessment to be carried out. Procedures are described for identifying hazards and estimating and evaluating risk. It also gives guidance on the making of decisions relating to the safety of machinery and on the type of documentation required to verify the risk assessment carried out. It is not applicable to risks posed to domestic animals, property or the environment.	All
Operation and maintenance	IEC 62446 – Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection	IEC 62446:2009 defines the minimal information and documentation required to be handed over to a customer following the installation of a grid connected PV system. Also describes the minimum commissioning tests, inspection criteria and documentation expected to verify the safe installation and correct operation of the system. Is written for grid connected PV systems only.	LV/MV systems
	IEC 61724 – Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis	Recommends procedures for the monitoring of energy-related photovoltaic (PV) system characteristics, and for the exchange and analysis of monitored data. The purpose is the assessment of the overall performance of PV systems.	Off-grid PV system

Doc Reference: DNV GL SE-0078 – Project Certification of Photovoltaic plants			
	IEC 60904 – Photovoltaic devices – ALL PARTS	This pack contains the following: IEC 60904-1 ed2.0 – Photovoltaic devices – Part 1: Measurement of photovoltaic current-voltage characteristics IEC 60904-2 ed3.0 – Photovoltaic devices – Part 2: Requirements for photovoltaic reference devices IEC 60904-3 ed2.0 – Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data IEC 60904-4 ed1.0 – Photovoltaic devices – Part 4: Reference solar devices – Procedures for establishing calibration traceability IEC 60904-5 ed2.0 – Photovoltaic devices – Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method IEC 60904-7 ed3.0 – Photovoltaic devices – Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices IEC 60904-8 ed3.0 – Photovoltaic devices – Part 8: Measurement of spectral responsivity of a photovoltaic (PV) device IEC 60904-9 ed2.0 – Photovoltaic devices – Part 9: Solar simulator performance requirements IEC 60904-10 ed2.0 – Photovoltaic devices – Part 10: Methods of linearity measurement	All
Component and personnel safety	ISO/IEC 31010 – Risk management – Risk assessment techniques	IEC/ISO 31010:2009 is a dual logo IEC/ISO supporting standard for ISO 31000 and provides guidance on selection and application of systematic techniques for risk assessment. This standard is not intended for certification, regulatory or contractual use. NOTE: This standard does not deal specifically with safety. It is a generic risk management standard and any references to safety are purely of an informative nature. Guidance on the introduction of safety aspects into IEC standards is laid down in ISO/IEC Guide 51.	All
Grid code compliance			
Manufacturing	ISO 9001 – Quality management systems – Requirements	ISO 9001:2015 specifies requirements for a quality management system when an organisation: a) needs to demonstrate its ability to consistently provide products and services that meet customer and applicable statutory and regulatory requirements, and b) aims to enhance customer satisfaction through the effective application of the system, including processes for improvement of the system and the assurance of conformity to customer and applicable statutory and regulatory requirements. All the requirements of ISO 9001:2015 are generic and are intended to be applicable to any organisation, regardless of its type or size, or the products and services it provides.	All
Transport and installation			
Transportation surveillance	IEC 62759 – Photovoltaic (PV) modules – Transportation testing – Part 1: Transportation and shipping of module package units	IEC 62759-1:2015 describes methods for the simulation of transportation of complete package units of modules and combined subsequent environmental impacts. This standard is designed so that its test sequence can co-ordinate with those of IEC 61215 or IEC 61646, so that a single set of samples may be used to perform both the transportation simulation and performance evaluation of a photovoltaic module design.	All
Installation surveillance			
Commissioning	IEC 62446 – Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection	see above	LV/MV systems

Doc Reference: DNV GL SE-0078 – Project Certification of Photovoltaic plants			
Performance monitoring	IEC 61724 – Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis	see above	All
Measurements	IEC 60904 – See above	see above	All
Measurements of crystalline modules	IEC 61829 – Photovoltaic (PV) array – On-site measurement of current-voltage characteristics	IEC 61829:2015 specifies procedures for on-site measurement of flat-plate photovoltaic (PV) array characteristics, the accompanying meteorological conditions, and use of these for translating to standard test conditions (STC) or other selected conditions. This new edition includes the following significant technical changes with respect to the previous edition: – it addresses many outdated procedures; – it accommodates commonly used commercial I-V curve tracers; – it provides a more practical approach for addressing field uncertainties; – it removes and replaces procedures with references to other updated and pertinent standards, including the IEC 60904 series, and IEC 60891.	All
Measurement of the lightning protection system	IEC 62305-3 – Protection against lightning – Part 3: Physical damage to structures and life hazard	see above	All

Appendix B

Methods and equipment necessary for photovoltaic module testing

Descriptions of standards are extracted primarily from the standards themselves.

Standard	Test	Equipment	Description
IEC 61215	10.2 Maximum power determination	Light Source	a) A radiant source (natural sunlight or a solar simulator class B or better in accordance with IEC 60904-9).
		Reference Cell for measuring the light source	b) a PV reference device having a known short-circuit current versus irradiance characteristic determined by calibrating against an absolute radiometer in accordance with IEC 60904-2 or IEC 60904-6;
		Mounting Fixture	c) A suitable mount for supporting the test specimen and the reference device in a plane normal to the radiant beam.
		Module Temperature Sensor	d) A means for monitoring the temperature of the test specimen and the reference device to an accuracy of ±1 °C and repeatability of ±0,5 °C.
		I-V Tester	e) Equipment for measuring the current of the test specimen and reference device to an accuracy of ±0,2% of the reading;
		I-V Tester	f) Equipment for measuring the voltage of the test specimen and reference device to an accuracy of ±0,2% of the reading.
IEC 61215	10.3 Insulation test	Hi-Pot Tester	a) DC voltage source, with current limitation, capable of applying 500 V or 1 000 V plus twice the maximum system voltage of the module
IEC 61215	10.4 Measurement of temperature coefficients	Light Source	a) a radiant source (natural sunlight or solar simulator, class B or better in accordance with IEC 60904-9) of the type to be used in subsequent tests;
		Reference Cell for measuring the light source	b) a PV reference device having a known short-circuit current versus irradiance characteristic determined by calibrating against an absolute radiometer in accordance with IEC 60904-2 or IEC 60904-6;
			c) any equipment necessary to change the temperature of the test specimen over the range of interest;
		Mounting Fixture	d) a suitable mount for supporting the test specimen and the reference device in the same plane normal to the radiant beam;
		Module Temperature Sensor	e) a means for monitoring the temperature of the test specimen and reference device to an accuracy of ±1 °C, and repeatability of ±0,5 °C;
		I-V Tester	f) equipment for measuring the current of the test specimen and reference device to an accuracy of ±0,2% of the reading;
		I-V Tester	g) equipment for measuring the voltage of the test specimen and reference device to an accuracy of ±0,2% of the reading;
IEC 61215	10.5 Measurement of nominal operating cell temperature (NOCT)	Mounting Fixture	a) an open rack to support the test module(s) and pyranometer in the specified manner. The rack shall be designed to minimise heat conduction from the modules and to interfere as little as possible with the free radiation of heat from their front and back surfaces; NOTE In the case of modules not designed for open-rack mounting, the test module(s) should be mounted as recommended by the manufacturer.
		Light Source Measurement	b) a pyranometer, mounted in the plane of the module(s) and within 0,3 m of the test array;
		Wind Speed Measurement	c) instruments to measure wind speed down to 0,25 m·s–1 and wind direction, installed approximately 0,7 m above the top of the module(s) and 1,2 m to the east or west;

Standard	Test	Equipment	Description
		Ambient Temperature Measurement	d) an ambient temperature sensor, with a time constant equal to or less than that of the module(s), installed in a shaded enclosure with good ventilation near the wind sensors;
		Module Temperature Measurement	e) cell temperature sensors, attached by solder or thermally conductive adhesive to the backs of two solar cells near the middle of each test module, or other equipment necessary for IEC-approved measurement of cell temperature;
		Data Acquisition System	f) a data acquisition system with temperature measurement accuracy of ±1 °C to record the following parameters within an interval of no more than 5 s: – irradiance, – ambient temperature, – cell temperature, – wind speed, – wind direction.
IEC 61215	10.6 Performance at STC and NOCT	Light Source	a) A radiant source (natural sunlight or a solar simulator class B or better) in accordance with IEC 60904-9.
		Reference Cell for measuring the light source	b) A PV reference device in accordance with IEC 60904-2 or IEC 60904-6. If a class B simulator is used, the reference device shall be a reference module of the same size with the same cell technology to match spectral response.
		Mounting Fixture	c) A suitable mount for supporting the test specimen and the reference device in a plane normal to the radiant beam.
		Module Temperature Sensor	d) A means for monitoring the temperature of the test specimen and the reference device to an accuracy of ±1 °C and repeatability of ±0,5 °C.
		I-V Tester	e) Equipment for measuring the current of the test specimen and reference device to an accuracy of ±0,2% of the reading.
		I-V Tester	f) Equipment for measuring the voltage of the test specimen and reference device to an accuracy of ±0,2% of the reading.
		Module Temperature Controller	g) Equipment necessary to change the temperature of the test specimen to the NOCT temperature measured in 10.5.
IEC 61215	10.7 Performance at low irradiance	Light Source	a) A radiant source (natural sunlight or a solar simulator class B or better) in accordance with IEC 60904-9.
		Light Filters	b) Equipment necessary to change the irradiance to 200 W·m–2 without affecting the relative spectral irradiance distribution and the spatial uniformity in accordance with IEC 60904-10.
		Reference Cell for measuring the light source	c) A PV reference device in accordance with IEC 60904-2 or IEC 60904-6. If a class B simulator is used, the reference device shall be a reference module of the same size with the same cell technology to match spectral response.
		Mounting Fixture	d) A suitable mount for supporting the test specimen and the reference device in a plane normal to the radiant beam.
		Module Temperature Sensor	e) A means for monitoring the temperature of the test specimen and the reference device to an accuracy of ±1 °C and repeatability of ±0,5 °C.
		I-V Tester	f) Equipment for measuring the current of the test specimen and reference device to an accuracy of ±0,2% of the reading.
		I-V Tester	g) Equipment for measuring the voltage of the test specimen and reference device to an accuracy of ±0,2% of the reading.
IEC 61215	10.8 Outdoor exposure test	Irradiance Meter	a) A device capable of measuring solar irradiation, with an uncertainty of less than ±5%.
		Mounting Fixture	b) Means to mount the module, as recommended by the manufacturer, co-planar with the irradiation measuring device.
		Electrical Load	c) A load sized such that at STC the module will operate near the maximum power point.
IEC 61215	10.9 Hot-spot endurance test	Light Source	a) Radiant source 1. Steady-state solar simulator or natural sunlight capable of an irradiance of not less than 700 W·m–2 with a non-uniformity of not more than ±2% and a temporal stability within ±5%.
		Light Source	b) Radiant source 2. Class C steady-state solar simulator (or better) or natural sunlight with an irradiance of 1 000 W·m–2 ± 10%.
		I-V Tester	c) Module I-V curve tracer.
		Covers	d) Set of opaque covers for test cell shadowing in 5% increments.
		Temperature Sensor	e) An appropriate temperature detector, if required.

Standard	Test	Equipment	Description
IEC 61215	10.10 UV preconditioning test	Module Temperature Controller	a) Equipment to control the temperature of the module while it is irradiated by UV light. The equipment must be capable of maintaining the module temperature at 60 °C ± 5 °C.
		Module Temperature Sensor	b) Means for measuring and recording the temperature of the module(s) to an accuracy of ±2 °C. The temperature sensors shall be attached to the front or back surface of the module near the middle. If more than one module is tested simultaneously, it will suffice to monitor the temperature of one representative sample.
		UV Light Sensor	c) Instrumentation capable of measuring the irradiation of the UV light produced by the UV light source at the test plane of the module(s), within the wavelength ranges of 280 nm to 320 nm and 320 nm to 385 nm with an uncertainly of ±15%.
		UV Light Source	d) A UV light source capable of producing UV irradiation with an irradiance uniformity of ±15% over the test plane of the module(s) with no appreciable irradiance at wavelengths below 280 nm and capable of providing the necessary irradiation in the different spectral regions of interest as defined in 10.10.3.
IEC 61215	10.11 Thermal cycling test	Test Chamber	a) A climatic chamber with automatic temperature control, means for circulating the air inside and means to minimise condensation on the module during the test, capable of subjecting one or more modules to the thermal cycle.
		Mounting Fixture	b) Means for mounting or supporting the module(s) in the chamber, so as to allow free circulation of the surrounding air. The thermal conduction of the mount or support shall be low, so that, for practical purposes, the module(s) are thermally isolated.
		Module Temperature Sensor	c) Means for measuring and recording the temperature of the module(s) to an accuracy of ±1 °C. The temperature sensors shall be attached to the front or back surface of the module near the middle. If more than one module is tested simultaneously, it will suffice to monitor the temperature of one representative sample.
		Power Supply	d) Means for applying a current equal to the STC peak power current of the module(s) under test.
		Amp Meter	e) Means for monitoring the flow of current through each module during the test.
IEC 61215	10.12 Humidity-freeze test	Test Chamber	a) A climatic chamber with automatic temperature and humidity control, capable of subjecting one or more modules to the humidity-freeze cycle.
		Mounting Fixture	b) Means for mounting or supporting the module(s) in the chamber, so as to allow free circulation of the surrounding air. The thermal conduction of the mount or support shall be low, so that, for practical purposes, the module(s) is (are) thermally isolated.
		Module Temperature Sensor	c) Means for measuring and recording the module temperature to an accuracy of ±1 °C. (It is sufficient to monitor the temperature of one representative sample, if more than one module is being tested.)
		Continuity Tester	d) Means for monitoring, throughout the test, the continuity of the internal circuit of each module.
IEC 61215	10.13 Damp-heat test	Test Chamber	a) A climatic chamber with automatic temperature and humidity control, capable of subjecting one or more modules to the humidity and temperature of Test temperature: 85 °C ± 2 °C Relative humidity: 85% ± 5%
		Mounting Fixture	b) Means for mounting or supporting the module(s) in the chamber, so as to allow free circulation of the surrounding air. The thermal conduction of the mount or support shall be low, so that, for practical purposes, the module(s) is (are) thermally isolated.
		Module Temperature Sensor	c) Means for measuring and recording the module temperature to an accuracy of ±1 °C. (It is sufficient to monitor the temperature of one representative sample, if more than one module is being tested.)
IEC 61215	10.14 Robustness of terminations test		Tensile test: as described in IEC 60068-2-21, test Ua, with the following provisions: – all terminations shall be tested; – tensile force shall never exceed the module weight. Bending test: as described in IEC 60068-2-21, test Ub, with the following provisions: – all terminations shall be tested; – method 1–10 cycles (1 cycle is 1 bend in each opposite direction).

Standard	Test	Equipment	Description
IEC 61215	10.15 Wet leakage current test	Immersion Tank	a) A shallow trough or tank of sufficient size to enable the module with frame to be placed in the solution in a flat, horizontal position. It shall contain a water/wetting agent solution meeting the following requirements: Resistivity: 3 500 Ω·cm or less Surface tension: 0,03 N·m–1 or less Temperature: 22 °C ± 3 °C The depth of the solution shall be sufficient to cover all surfaces except junction box entries not designed for immersion.
		Spray Equipment	b) Spray equipment containing the same solution.
		Power Supply	c) DC voltage source, with current limitation, capable of applying 500 V or the maximum rated system voltage of the module, whichever is more.
		Resistance Measurement	d) Instrument to measure insulation resistance.
IEC 61215	10.16 Mechanical load test	Test Fixture	a) A rigid test base which enables the modules to be mounted front-side up or front-side down. The test base shall enable the module to deflect freely during the load application.
		Continuity Tester	b) Instrumentation to monitor the electrical continuity of the module during the test.
		Load	c) Suitable weights or pressure means that enable the load to be applied in a gradual, uniform manner.
IEC 61215	10.17 Hail test	Moulds for hail	a) moulds of suitable material for casting spherical ice balls of the required diameter. The standard diameter shall be 25 mm but any of the other diameters listed in Table 2 may be specified for special environments.
		Freezer	b) A freezer, controlled at –10 °C ± 5 °C.
		Storage Container	c) A storage container for storing the ice balls at a temperature of –4 °C ± 2 °C.
		Hail launcher	d) A launcher capable of propelling an ice ball at the specified velocity, within ±5%, so as to hit the module within the specified impact location. The path of the ice ball from the launcher to the module may be horizontal, vertical or at any intermediate angle, so long as the test requirements are met.
		Mounting Fixture	e) A rigid mount for supporting the test module by the method prescribed by the manufacturer, with the impact surface normal to the path of the projected ice ball.
		Balance	f) A balance for determining the mass of an ice ball to an accuracy of ±2%.
		Velocity Meter	g) An instrument for measuring the velocity of the ice ball to an accuracy of ±2%. The velocity sensor shall be no more than 1 m from the surface of the test module.
IEC 61215	10.18 Bypass diode thermal test	Module Temperature Sensor	a) Means for heating the module to a temperature of 75 °C ± 5 °C.
		Temperature Recorder	b) Means for measuring and recording the temperature of the module(s) to an accuracy of ±1 °C.
		Diode Temperature Sensor	c) Means for measuring the temperature of any bypass diodes provided with the module. Care should be taken to minimise any alteration of the properties of the diode or its heat transfer path.
		Power Supply	d) Means for applying a current equal to 1.25 times the STC short-circuit current of the module under test and means for monitoring the flow of current through the module, throughout the test.
Proposed	Potential Induced Degradation	Test Chamber	
		Power Supply	

Standard	Test	Equipment
UL1703 Section 19	Temperature test	Outdoor Test Fixture Thermocouple
UL1703 Section 20	Voltage and current measurements test	Same as IEC 61215 10.2
UL1703 Section 21	Leakage current test	DC Power Supply Current meter
UL1703 Section 22	Strain relief test	20 pound weight Stop watch
UL1703 Section 23	Push test	20 pound force tool per UL1703 Section 23 4 pound force tool per UL1703 Section 23
UL1703 Section 24	Cut test	Cut Tool per UL1703 Section 24
UL1703 Section 25	Bonding path resistance test	Power Supply Volt meter Amp meter
UL1703 Section 26	Dielectric voltage-withstand test	Same as IEC 61215 10.3
UL1703 Section 27	Wet insulation-resistance test	Same as IEC 61215 10.15
UL1703 Section 28	Reverse current overload test	DC Power Supply Current meter
UL1703 Section 29	Terminal torque test	Torque wrench
UL1703 Section 30	Impact test	2-in (51-mm) diameter smooth steel sphere weighing 1.18 lb
UL1703 Section 31	Fire test	Recent update to UL1703 has changed this test.
UL1703 Section 33	Water spray test	Water spray fixture per UL1703 Section 33
UL1703 Section 34	Accelerated aging test	Oven for aging Tensile load tester
UL1703 Section 35	Temperature cycling test	Same as IEC 61215 10.11
UL1703 Section 36	Humidity test	Same as IEC 61215 10.13
UL1703 Section 37	Corrosive atmosphere test	Salt Spray chamber
UL1703 Section 38	Metallic coating thickness test	
UL1703 Section 39	Hot-spot endurance test	power supply IR source irradiance source
UL1703 Section 40	Arcing test	Light Source Power Supply
UL1703 Section 41	Mechanical loading test	Same as IEC 61215 10.16
UL1703 Section 42	Wiring compartment securement test	35 pound load
Production Line Tests		
UL1703 Section 43	Factory Dielectric Voltage-Withstand Test	Same as IEC 61215 10.3
UL1703 Section 44	Factory Voltage, Current, and Power Measurements Test	Same as IEC 61215 10.2
UL1703 Section 45	Grounding Continuity Test	Continuity tester (ohmmeter)

Appendix C

Equipment summary for electromagnetic compatibility immunity and emissions testing

Test	Equipment	Description
Electrostatic discharge immunity tests to IEC 61000-4-2 **Radiated, radio-frequency, and electromagnetic field immunity tests to IEC 61000-4-3** **Electrical fast transient/burst immunity tests to IEC 61000-4-4** **Surge immunity tests to IEC 61000-4-5** **Immunity to conducted disturbances induced by radio-frequency fields, to IEC 61000-4-6**	Test chamber	Test room must be one of the following: • an anechoic chamber (required specifically for -4-3), • room containing a copper or aluminium ground plane • screened room in which either the floor or one wall acts as a ground plane The room contains the unit under test and the relevant disturbance generators per below.
	Direct current (DC) and alternating current (AC) power supplies	Controlled DC supplies to simulate the photovoltaic DC source, and AC supplies to simulate the mains. These are separated from the test room.
	Resistive load banks	Controlled resistive load to simulate different inverter or equipment loading.
	Artificial mains network	Impedance network to couple disturbance voltages to the measurement equipment and decouples the test circuit from the supply mains.
	Artificial DC network	Impedance network to decouple conducted disturbances originating from the laboratory DC source.
	Miscellaneous test hardware	Such as optional electromagnetic induction filters for the power supplies, insulating materials to isolate components, capacitive coupling clamps for indirect DC injection (electrical fast transcient/burst tests) or for auxiliary power ports.
	Electrostatic discharge generator for -4-2 tests	Power supply capable of creating electrostatic discharge voltages in 8–30 kilovolt (kV) range,
	Antenna (vertical and horizontal) for -4-3 tests	Antenna to create radiated radio and electric and magnetic fields.
	EFT/burst generator for -4-4 tests	Power supply with maximum pulse amplitude (type 2 kV or more) and spike frequency capabilities
	Surge generator for -4-5 tests.	Power supply to create surge combination wave pulses, e.g. 2 kV or more.
	RF generator for -4-6 tests.	Power supply to create radio frequency signals, e.g. 0.15 megahertz to 80 megahertz.
Low frequency emissions tests to IEC 61000-3-2 and IEC 61000-3-12	AC power source and specialised measurement equipment.	AC grid or simulator, 61000-3-2 applies to outputs up to 16A, and 61000-3-12 applies to outputs up to 75A. Detailed requirements for measurement equipment are defined in IEC 61000-4-7.
High frequency emissions testing according to applicable CISPR requirements and US FCC Part 15B	General – Use of same basic equipment as used in immunity tests	Radiated high frequency emission test can be conducted in a semi anechoic chamber or an open area test site. The conducted high frequency emission test is carried out with artificial mains and DC networks specified in CISPR11.
Conducted emissions	AC artificial mains network (AMN)	Couples the disturbance voltage to the measuring receiver and decouples the test circuit from the supply mains.
	DC artificial network (DC-AN)	Provides necessary decoupling from conducted disturbances originating from the laboratory DC power source.
Radiated emissions	Power supplies and antenna	Similar to equipment for immunity testing for radiated fields to IEC 61000-4-3

Table 1. Main certifications for photovoltaic systems*

*See http://inspire.irena.org/Pages/standards/search.aspx

Report IEA-PVPS T5-06: 2002

Standard	Description
ISO/IEC 17000:2004 Conformity assessment – Vocabulary and general principles	ISO/IEC 17000:2004 specifies general terms and definitions relating to conformity assessment, including the accreditation of conformity assessment bodies, and to the use of conformity assessment to facilitate trade. A description of the functional approach to conformity assessment is included as a further aid to understanding among users of conformity assessment, conformity assessment bodies and their accreditation bodies, in both voluntary and regulatory environments. ISO/IEC 17000:2004 does not set out to provide a vocabulary for all of the concepts that may need to be used in describing particular conformity assessment activities. Terms and definitions are given only where the concept defined would not be understandable from the general language use of the term or where an existing standard definition is not applicable
ISO/IEC 17020:2012: Conformity assessment – Requirements for the operation of various types of bodies performing inspection	ISO/IEC 17020:2012 specifies requirements for the competence of bodies performing inspection and for the impartiality and consistency of their inspection activities. It applies to inspection bodies of type A, B or C, as defined in ISO/IEC 17020:2012, and it applies to any stage of inspection.
ISO/IEC 17021:2011: Conformity assessment — Requirements for bodies providing audit and certification of management systems (ISO/IEC 17021:2011)	ISO/IEC 17021:2011 contains principles and requirements for the competence, consistency and impartiality of the audit and certification of management systems of all types (e.g. quality management systems or environmental management systems) and for bodies providing these activities. Certification bodies operating to ISO/IEC 17021:2011 need not offer all types of management system certification. Certification of management systems is a third-party conformity assessment activity. Bodies performing this activity are therefore third-party conformity assessment bodies. This standard has been revised by: ISO/IEC 17021-1:2015 ISO/IEC 17021-1:2015 Conformity assessment -- Requirements for bodies providing audit and certification of management systems -- Part 1: Requirements ISO/IEC 17021-1:2015 contains principles and requirements for the competence, consistency and impartiality of bodies providing audit and certification of all types of management systems. Certification bodies operating to ISO/IEC 17021-1:2015 do not need to offer all types of management system certification. Certification of management systems is a third-party conformity assessment activity and bodies performing this activity are therefore third-party conformity assessment bodies.
ISO/IEC 17022:2012 Conformity assessment – Requirements and recommendations for content of a third party audit report on management systems	To be updated
ISO/IEC 17024:2012: Conformity assessment — General requirements for bodies operating certification of persons	ISO/IEC 17024:2012 contains principles and requirements for a body certifying persons against specific requirements, and includes the development and maintenance of a certification scheme for persons.
ISO/IEC 17025:2005: Conformity assessment – General requirements for the competence of testing and calibration laboratories	To be updated

Standard	Description
ISO/IEC 17067:2013: Conformity assessment -- Fundamentals of product certification and guidelines for product certification schemes	ISO/IEC 17067:2013 describes the fundamentals of product certification and provides guidelines for understanding, developing, operating or maintaining certification schemes for products, processes and services. ISO/IEC 17067:2013 is intended for use by all with an interest in product certification, and especially by certification scheme owners.
ISO 50001:2011: Energy Management	ISO 50001:2011 specifies requirements for establishing, implementing, maintaining and improving an energy management system, whose purpose is to enable an organisation to follow a systematic approach in achieving continual improvement of energy performance, including energy efficiency, energy use and consumption. ISO 50001:2011 specifies requirements applicable to energy use and consumption, including measurement, documentation and reporting, design and procurement practices for equipment, systems, processes and personnel that contribute to energy performance. ISO 50001:2011 applies to all variables affecting energy performance that can be monitored and influenced by the organisation. ISO 50001:2011 does not prescribe specific performance criteria with respect to energy. ISO 50001:2011 has been designed to be used independently, but it can be aligned or integrated with other management systems. ISO 50001:2011 is applicable to any organisation wishing to ensure that it conforms to its stated energy policy and wishing to demonstrate this to others, such conformity being confirmed either by means of self-evaluation and self-declaration of conformity, or by certification of the energy management system by an external organisation. ISO 50001:2011 also provides, in Annex A, informative guidance on its use.
ISO/IEC Guide 65: General requirements for Bodies operating Product Certification Systems	To be updated
MCS010: Product Certification Scheme Requirements: Factory Production Control Requirements Issue 1.5	To be updated
MCS017: Product Certification Scheme Requirements: Bespoke Building Integrated Photovoltaic Products Issue 1.0	To be updated
MCS004: Product Certification Scheme Requirements: Solar Collectors Issue 3.1	To be updated
MCS005: Product Certification Scheme Requirements: Solar Photovoltaic Modules Issue 2.4	To be updated

*http://inspire.irena.org/Pages/standards/search.aspx.

Appendix D

Overview of photovoltaic standards in the IECEE* CB scheme

Categories	Products	IEC Standards	
PV	Photovoltaics	PVRS 5A (ed.1) PVRS5 (ed.1) PVRS6A (ed.1) PVRS6 (ed.1) PVRS 7A (ed.1) PVRS7 (ed.1) PVRS11A (ed.1) PVRS11 (ed.1) 60891 (ed.1) 60891 (ed.1); am1 60891 (ed.2) 60904-1 (ed.1) 60904-1 (ed.2) 60904-2 (ed.1) 60904-2 (ed.1); am1 60904-2 (ed.2) 60904-3 (ed.1) 60904-3 (ed.2) 60904-4 (ed.1) 60904-5 (ed.1) 60904-5 (ed.2) 60904-6 (ed.1) 60904-6 (ed.1); am1 60904-7 (ed.2) 60904-7 (ed.3) 60904-8 (ed.2) 60904-9 (ed.1) 60904-9 (ed.2) 60904-10 (ed.1) 60904-10 (ed.2)	61194 (ed.1) 61215 (ed.1) 61215 (ed.2) 61345 (ed.1) 61646 (ed.1) 61646 (ed.2) 61683 (ed.1) 61702 (ed.1) 61721 (ed.1) 61727 (ed.2) 61730-1 (ed.1) 61730-1 (ed.1); am1 61730-1 (ed.1); am2 61730-2 (ed.1) 61730-2 (ed.1); am1 61829 (ed.1) 61853-1 (ed.1) 62093 (ed.1) 62108 (ed.1) 62109-1 (ed.1) 62109-2 (ed.1) 62116 (ed.1) 62116 (ed.2) 62124 (ed.1) 62257-9-5 (ed.1) 62446 (ed.1)

* IEC Conformity Assessment for Electrotechnical Equipment and Components.

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