

Industry Trends in PV Module Quality from over 250 Factory Audits

This study analyzes trends in PV module quality from over 250 independent factory audits conducted on more than 120 manufacturers by PI Berlin since 2012. The results provide useful insights into the major trends in PV modules over time, by region of manufacturing as well as by manufacturing capacity, location and level of automation.

Using audits to assess quality

Why conduct audits?

Photovoltaics (PV) have been adopted as a major renewable energy source globally. The construction of PV systems is capital intensive and systems are expected to perform and generate power for more than 25 years. The performance and reliability of PV modules, the core energy generating component in any PV system, must be carefully evaluated before a system is constructed and financed as PV modules cannot be easily repaired or replaced once installed.

A factory audit is an essential tool to evaluate PV module quality and assess long-term performance and reliability. A consistent, high level of manufacturing quality in mass production is a significant driver of PV module quality.

Laboratory-based durability testing is a complementary tool designed to assess the quality of materials and components used in a particular module. However, the procedures and processes used to assemble modules in mass production have an equally important influence on long-term performance and reliability.

Good quality materials and components, for example, can be negatively impacted by a poor quality manufacturing process. And a good quality manufacturing process won't improve the quality of poor materials or components. *Both* good material and manufacturing quality are needed to ensure long-term module performance and reliability.

To assess manufacturing quality, buyers and financiers often hire independent third parties to conduct an audit of manufacturing quality at a particular factory in advance of production for a specific project.



Figure 1: PI Berlin factory auditors discussing the details of PV module manufacturing

Audits designed to understand risk

Factory audits provided by third parties often differ in terms of their aim, scope and auditing techniques. PI Berlin focuses on audits designed to assess risk for the buyer or investor – a process which doesn't just assess the manufacturers' compliance to their own quality standards, but also evaluates risks in the standards themselves. This ensures that all manufacturers are held to the same high standard and results can be bench-marked across manufacturers.

A PI Berlin factory audit typically consists of the following major components:

- Certification compliance
- Bill of material (BOM) controls
- Incoming quality controls (IQC)
- In-line process and quality controls (IPQC)
- Outgoing quality controls (OQC)
- Equipment maintenance and calibration
- Supplier, quality, product and engineering change management
- Human resource management

The bulk of an audit is spent on the actual production floor assessing active manufacturing processes and controls. First-hand observations, in-depth questioning, 'live' stress-testing of controls and multi-level validation of any identified risks are all used to generate an accurate quality assessment.



Figure 2: PI Berlin assessing a PV module lamination process

Audits followed by quality assurance

A well-conducted audit can deliver buyers and investors with useful, relevant, actionable information about the modules before purchasing or financing decisions are made – and under what terms those decisions should be taken.

A factory audit typically identifies a specific list of risks ('findings') and consequent areas for improvement. The buyer can then make a future purchasing decision contingent upon the manufacturer taking sufficient corrective action in advance of production for a particular project.

An assessment of risk in advance of production for a particular project can minimize the risk of poor quality occurring during production for the project.

Third party quality assurance (QA) is then usually applied during production, including production oversight, pre-shipment testing and inspection. QA will verify that the desired level of quality is also being maintained during production. If sufficient quality is not being maintained, action can be taken to quarantine and remedy any modules with suspect quality before they are shipped.

Assessing quality throughout the production flow

Typical audit scope

A well-developed PV module manufacturing quality audit will typically follow the production flow of a PV module, usually defined as follows:

- Material storage and preparation

- Cell soldering – tabbing and stringing
- Layup and cross connector soldering
- Lamination
- Framing and final assembly
- Cleaning
- Electrical and safety testing
- Electroluminescence (EL) defect imaging
- Final quality controls and packaging

Furthermore, the product design itself is evaluated as it can have an impact on the production procedures and processes required to manufacture the module correctly. Conversely, production methods may impact the modules ability to deliver its intended design features.



Figure 3: PI Berlin assessing PV module inspection processes

The quality factors reviewed by a PI Berlin audit team are primarily those that can have the greatest influence on the expected long-term performance and reliability of PV modules, such as cell soldering and lamination. The quality of these processes is often invisible in the finished PV module and can only be evaluated by observing the production processes themselves. In these situations, poor quality cannot be 'inspected' out of a module.

Lastly, an assessment of factory management systems is conducted, representing the factory's ability to adequately define and control procedures including those that can have a secondary influence on quality such as supply chain, product and human resource management. These procedures are often assured by ISO 9001 certification, but ISO certification itself has little bearing on whether modules are built to industry best-practice standards or not.



Figure 4: PI Berlin auditing PV module lay-up processes

Risk-based quality ratings

Based on the audit, PI Berlin generates a quality rating for each PV module manufactured at a particular factory. The rating is based on the quantity and severity of audit findings. Findings are categorized dependent on the type and extent of risks to module reliability and performance, as shown below.

Table 1: Audit finding classification

Finding	Severity
Critical	May create a safety hazard, cause early-life product field failure or significant performance loss.
Major	May cause under-performance or more rapid performance degradation over time than expected.
Minor	Unlikely to cause under-performance or more rapid performance degradation in modules built today, but could escalate if controls are not improved.

The quality rating of PV modules, and their associated manufacturer, falls into one of five categories based on the overall quantity and severity of audit findings as shown in Table 2.

The ratings are differentiated by the expected performance of the module over time. This, in turn, represents system performance risk and financial risk to buyers and investors.

The ratings may also be workshop specific. A single factory can often have multiple workshops producing the same module but each workshop may have a different quality rating. Restricting supply to specific workshops can therefore often assist in obtaining consistent quality.

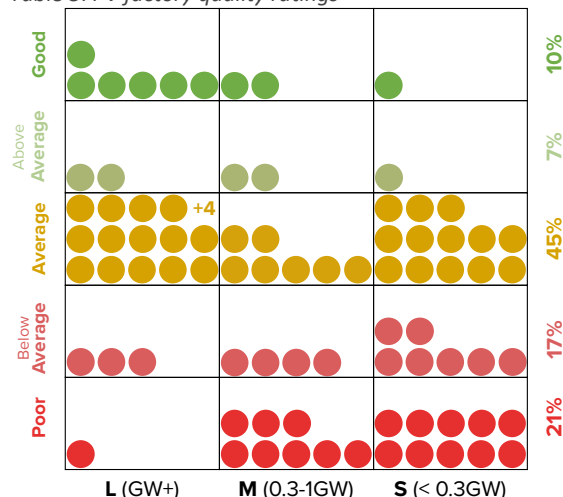
Table 2: Classification of quality ratings

Rating	Performance Risk
Excellent	None
Above average	Limited incremental degradation
Average	Moderate incremental degradation
Below average	Long-term failure or significant degradation
Poor	Early-life failure or safety hazard

Manufacturer benchmarking

Over the past 7 years, PI Berlin has conducted more than 250 audits of more than 120 mainstream module manufacturers. A benchmarked quality rating was assigned after each audit. The quality ratings generated from the most recent audits are shown in Table 3 – each circle representing a different manufacturer. They are split into three groups depending on the size of the manufacturer – roughly equating to the classic definition of Tier 1, 2 and 3 manufacturers.

Table 3: PV factory quality ratings



A significant portion of manufacturers (40.2 %) were rated as “Average”. Only a small portion (8.2 %) of manufacturers fell into the Excellent category. This has been a consistent picture over the past 7 years of auditing.

A typical factory falling into the Average category often lacks contemporary quality management tools such as well-deployed Statistical Process Control (SPC), Total Quality Management (TQM), Cost of Quality (CoQ) or Six Sigma. Manufacturers who achieve Excellent quality ratings often have one

or more well-implemented quality management tools and a company culture which is genuinely focused on quality from top to bottom.

After more than 20 years of industrial-scale PV module manufacturing, the industry is still developing in terms of using well-established quality management systems for mass production. It has long been the perception that buying from Tier 1 manufacturers will avoid quality problems and the associated investment risks, however benchmarked quality ratings show that buying from a Tier 1 manufacturer is not always a guarantee of quality.

Based on PI Berlin quality ratings, risks are reduced, but not eliminated, by a manufacturer's increasing size, and smaller manufacturers can provide equivalent or better quality than some larger manufacturers.

Larger factories (> 3 GW capacity per year) were less likely to have "Below Average" or "Poor" ratings compared to smaller factories (≤ 1 GW per year). This maybe the result of larger companies being able to invest in quality management systems. However, the significant amount of larger manufacturers with an "Average" rating should not be ignored.

Trends in quality

The PV industry has had many ups and downs, and so has manufacturing quality. The spread in quality ratings over the past four years was examined by PI Berlin and is shown in Figure 5. The number of manufacturers audited annually has been between 25 and 40. This is large enough to be representative

of industry trends in manufacturing quality even if the same manufacturers are not audited every year.

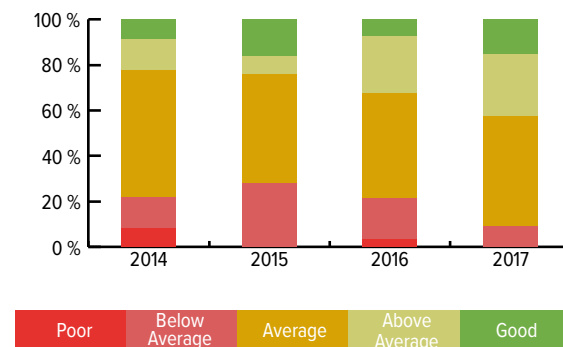


Figure 5: Quality rating trends from 2014 to 2017 normalized over all manufacturers audited each year

The analysis shows that the share of manufacturers with an "Excellent" and "Above Average" rating has gradually increased over the past four years. This is evidenced in a decreasing number of findings identified during factory audits. As the chart in Figure 6 shows, the total number of findings (critical, major and minor combined) has slowly been declining. Notably, critical findings have almost disappeared.

PV module quality, in general, has been improving over the past four years.

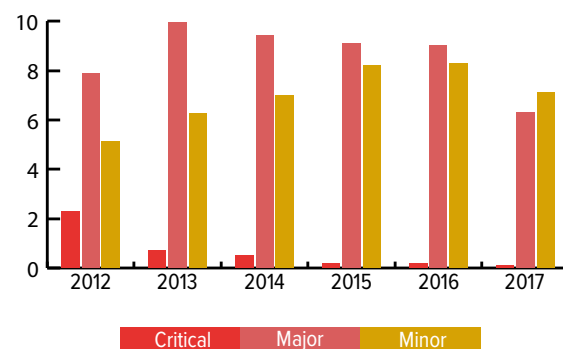


Figure 6: Average quantity of findings per factory audit from 2012 to 2018

Some of the reasons for this trend may include increasing attention to quality by buyers and investors (partly as a result of more third-party auditing), the growing maturity of the industry and higher levels of automation and more advanced production technologies.

This slow trend has been achieved against the background of rapidly declining Average Selling Prices (ASPs) – prices have dropped almost 70 % over the same period (2012 to 2018) and the bill of materials used to manufacture modules has been constantly changing and evolving.

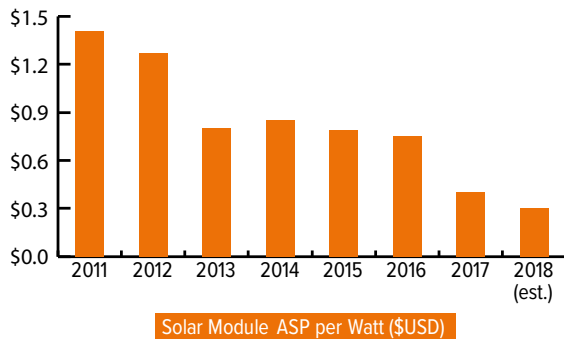


Figure 7: Solar module ASP per watt (\$USD, Source: RS Energy

Quality versus capacity

Over the past few years, many larger manufacturers have doubled or even tripled their manufacturing capacity to meet growing market demand. Analyzing the relationship between quality and capacity in Figure 8, it is clear that larger manufacturers have typically demonstrated better and more consistent quality than smaller manufacturers.

This trend can primarily be explained by economies of scale. The cost advantages that larger manufacturers can leverage due to the scale of operation allows them to upgrade factories with higher levels of automation, acquire better materials at lower prices as well as attract and retain higher qualified staff.

The larger manufacturers have also typically attracted more attention from large-scale buyers and investors concerned about quality and willing to work with the manufacturer to make improvements.

Larger capacity can be leveraged to obtain better materials at a lower cost and ensure more consistent manufacturing quality with higher levels of automation.

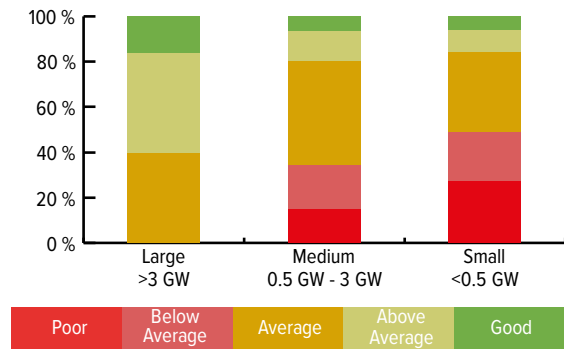


Figure 8: Quality ratings compared to factory size (based on 2017 industry-wide audit results).

Quality versus location of manufacturing

Since 2011, PI Berlin has conducted audits in 16 countries around the world, enabling a comparison of PV module quality ratings by location of manufacturing.

The graph in Figure 9 shows the aggregate quality ratings for manufacturers in different locations based on audit results from the *past two years*.

In general, manufacturers in China, Southeast Asia and Korea achieved higher quality ratings compared to those in India, Europe, the USA and Mexico. This is also evident when comparing the number of audit findings in the different regions (see Figure 10).

The reason for this perhaps counter-intuitive result is that manufacturing in Asia has reached true mass production. This has led to the creation of a complete supply chain ecosystem designed to support production. This includes a wide variety of manufacturing equipment and material vendors.

This has enabled module manufacturers in these locations to source good quality local materials and equipment at competitive prices, as well as develop a strong skills base in engineers and operators that are needed to run large factories.

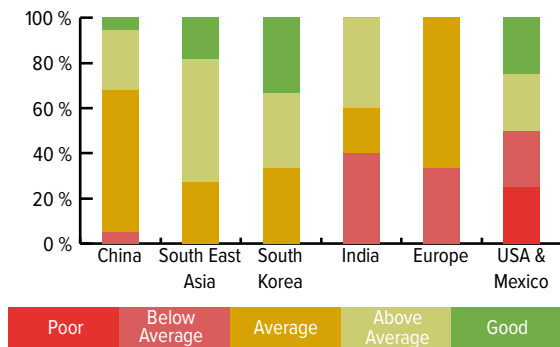


Figure 9: Quality ratings by different regions of manufacturing (audits conducted from mid-2016 to mid-2018).

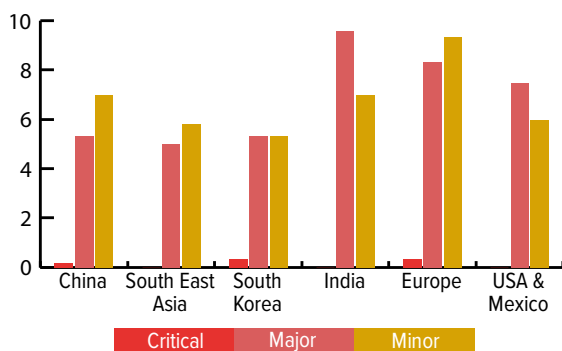


Figure 10: Average number of audit findings by different regions of manufacturing (audits conducted from mid 2016 to mid 2018).

Quality between factories within a manufacturer

Module manufacturing has spread globally, driven by new, emerging brands, local manufacturing incentives and protective tariffs. It is now common for a manufacturer to operate multiple factories in different countries - or hire contract manufacturers (OEMs) in different countries outside their country of origin.

Figure 11 shows the quality ratings of different factories within seven different Tier 1 and Tier 2 manufacturers. While around half of them have consistent quality ratings among their different factories, the other half were inconsistent.

Two manufacturers have three factories with three different quality ratings. These manufacturers are not providing consistent quality from all their factories.

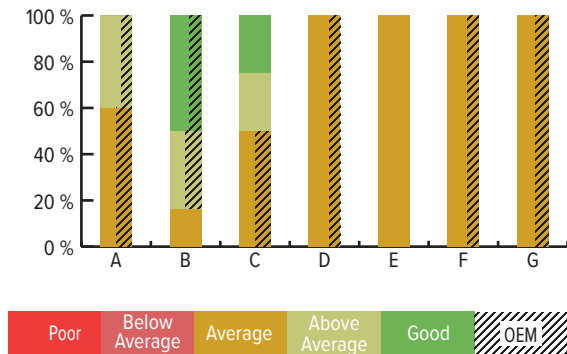


Figure 11: Quality ratings of different factories within manufacturers (manufacturers A through G).

To understand the quality of PV modules from a particular manufacturer, it is necessary to know exactly which factory manufactures them.

Quality trends over time within the same manufacturer

Analyzing the quality ratings for individual manufacturers over the past five years, most manufacturers have improved or maintained their ratings. Between 2015 and 2017, around 50 % of audited manufacturers achieved better ratings than previous years. Competition and ever-increasing customer demands on quality have generally been pushing improved quality.

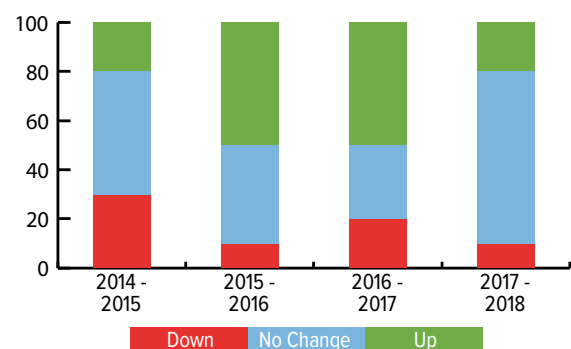


Figure 12: Quality rating changes by year (by a portion of manufacturers audited in each year that increased, stayed the same or lowered their quality rating)

Meanwhile, there have been always a small number of manufacturers whose quality ratings have declined over time – often due to the declining health of the company itself or their inability to compete successfully.

Quality versus automation

When a buyer is trying to select a manufacturer, a question often comes up: does more automation produce better quality? Based on our analysis, the correlation between automation and quality is indeed strong.

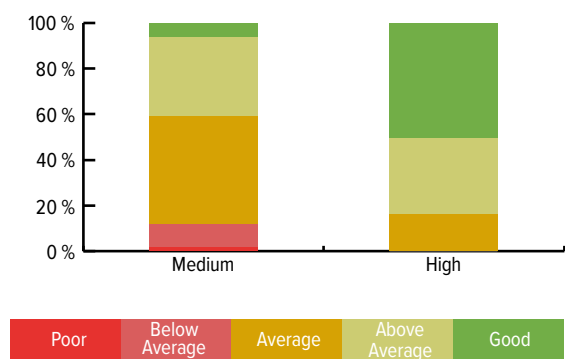


Figure 13: Quality ratings with different degrees of manufacturing automation

More automation usually means less room for human error and more consistent manufacturing processes. It can remove some of the inherent inconsistencies in manual production.

However, automation should not be taken as an 'automatic' assumption of quality. Automation relies on skilled engineers to set-up, monitor and maintain the equipment correctly. Poorly managed automated equipment can also consistently produce large volumes of poor quality product. In other words, automation in the wrong hands can produce poorer quality than a well-controlled manual process.

Conclusion

In conclusion, more than 250 audits conducted over the past five years has shown that module quality in the industry has been improving, even against the backdrop of rapid industry growth, persistent cost pressures and no relevant international quality standards for PV modules.

The auditing has also challenged some important perceptions - Tier 1 manufacturers don't always produce high-quality modules, not all factories within a particular manufacturer produce the same quality modules and that Asia, in general, produces higher quality modules than other regions.

The lack of many manufacturers falling into the 'Excellent' quality rating category also means that it remains incumbent on the buyer and investor to pay attention to module quality in order to avoid performance and reliability risk.

Third party risk assessments like factory audits have proven to be a valuable tool in helping to identify and avoid such risks.

About the Author



Stella Su is Senior Auditor and Manager at PI Berlin AG in Shanghai, China. She has over nine years of experience in PV manufacturing and has audited more than 80 factories in Asia and Europe. Stella Su had

many years of experience in module and wafer quality management, technology transfer and contract manufacturer management before joining Solar-Buyer (now part of PI Berlin). Stella Su is leading the PI Berlin Shanghai team conducting factory audits and quality assurance works for clients around the globe.

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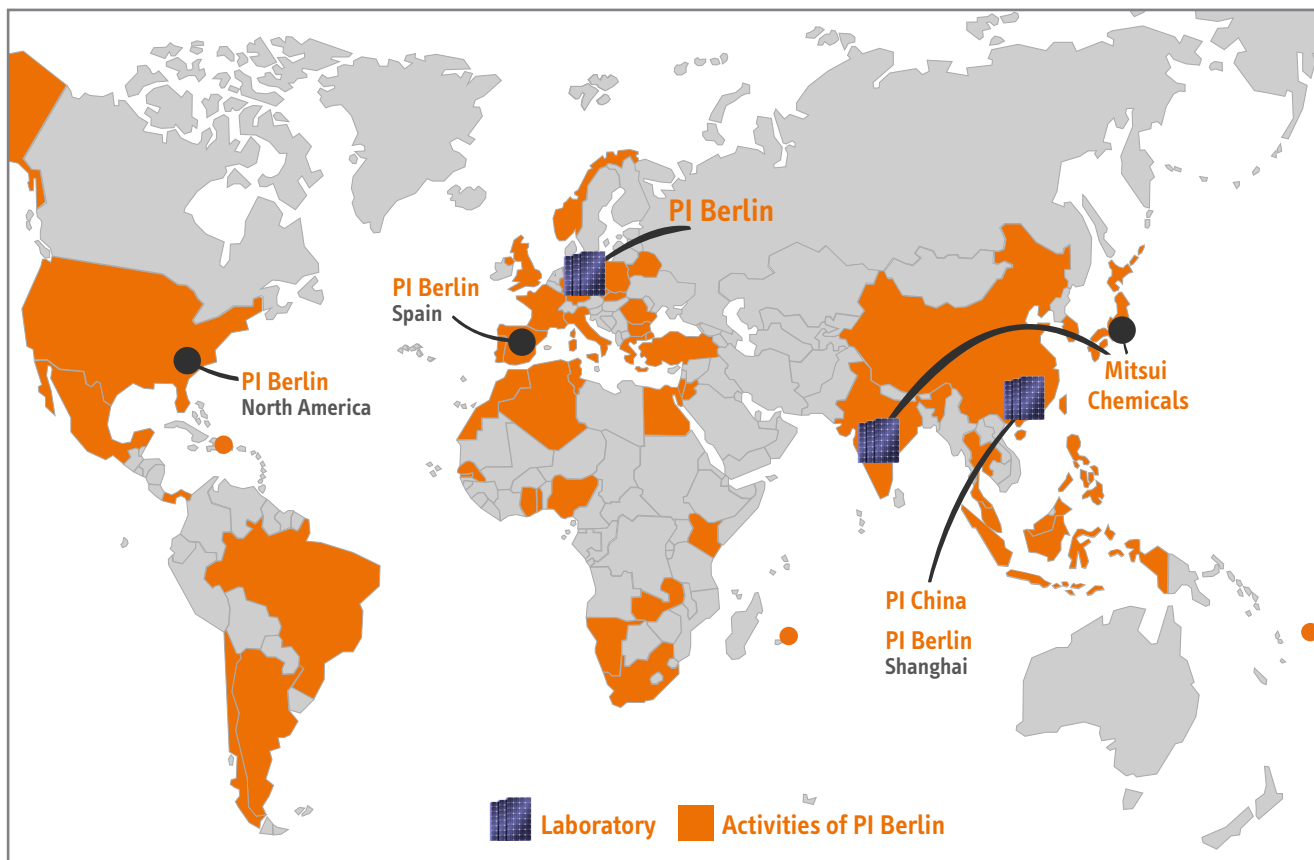
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With its experienced team of researchers, scientists and engineers, PI Berlin offers a wide range of design, testing and evaluation services with a focus on the risk management and quality assurance of PV equipment and complex PV power plants.

PI Berlin has supported 7.5 GW of PV power plants worldwide, with over 250 audits conducted on over 120 manufacturers producing more than 67 GW of PV equipment annually.

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