The 2025 PV Module Manufacturing ***Quality Report***

Trends in **PV Module Manufacturing Quality** from Independent Quality Assurance

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Introduction

In 2024, the photovoltaic (PV) module manufacturing market experienced significant changes due to regulatory policy, new facility capacity, cell technology, product design, and bill-of-material (BOM) supply chain shifts. Kiwa PI Berlin, a leading global technical advisor and quality assurance provider, has supported module buyers to help navigate these ongoing market influences. The data summarized in this 2025 PV Module Manufacturing Quality Report substantiates why buyers continue to recognize the value of partnering with an experienced global quality assurance provider to effectively manage quality for their PV module procurement.

Policy changes within the **U.S. market** significantly impacted PV module supply for buyers and manufacturers. The U.S. saw increased domestic manufacturing capacity, driven by the IRA (Inflation Reduction Act) and a push for onshoring the solar supply chain. However, trade policies, including ongoing enforcement of the UFLPA (Uyghur Forced Labor Prevention Act), and launch of a new AD/CVD (Antidumping and Countervailing Duty) investigation created uncertainty and kept prices high. This fueled a rapid shift in PV cell sourcing, bolstering the economic case for investing in U.S. solar manufacturing.

Within the **European market**, challenges such as high-level module inventory, grid capacity limitations, and fluctuating consumer demand due to declining energy prices impacted market growth. The EU set ambitious climate targets with supportive structures to increase growth, including financial incentives and revised renewable energy targets from member states.

These market influences impacted sellers by requiring adaptations to supply chain sourcing strategies, relocating production, and building new facilities while balancing overcapacity and low module pricing. Chinese manufacturers, who dominate the global market, faced steep declines in profits and even posted losses. These combined pressures unfortunately impact manufacturers' ability to support robust quality control mechanisms within their facilities and supply chain, resulting in higher than average non-conformance findings during production

Overall, while 2024 was a challenging year for the PV module manufacturing industry, it has highlighted **the need for buyers and investors to actively manage PV equipment quality**. Combined use of tools such as pre-production factory audits, supply chain traceability assessments, production oversight, pre-shipment inspections, and lab testing, enable buyers to improve quality during product production. Data presented in this report will provide insights in quality management that Kiwa PI Berlin observed through factory-based quality assurance. Our goal is to help buyers and investors better understand the latest manufacturing quality trends to actively manage quality and protect investments.

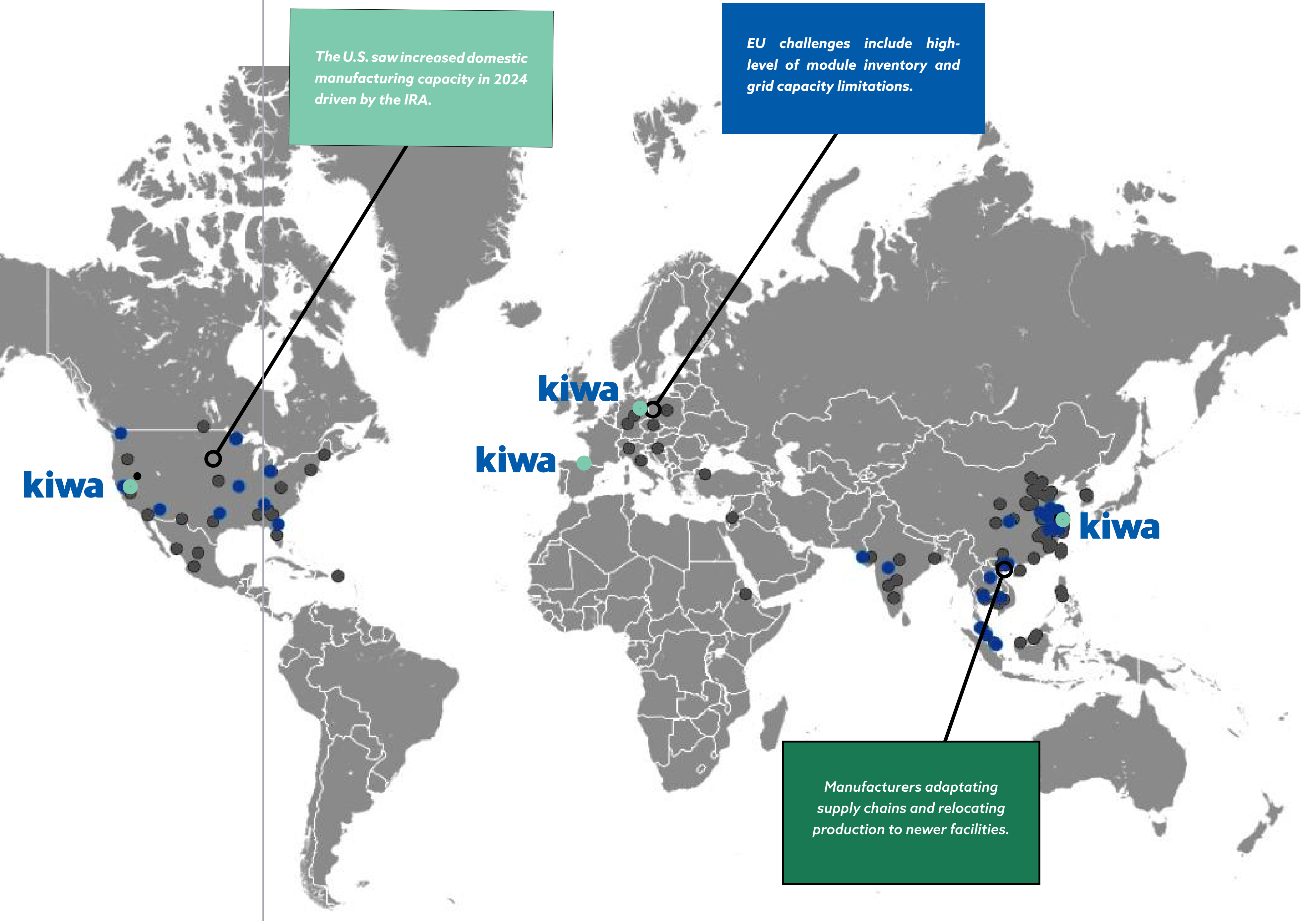

Figure 1. Global map of factories Kiwa PI Berlin has audited

Manufacturing Quality *Over Time*

Over nearly a decade, Kiwa PI Berlin has conducted comprehensive PV module quality assurance for over 125 module manufacturers. This process involved production oversight, pre-shipment inspections, and testing; resulting in the creation of a **module defects database** which is leveraged for manufacturing quality benchmarking. Fluctuations in annual defect rates reflect overlying **quality trends driven by various market influences including technological advancements**, policy adaptations, supply chain shifts, and commercial dynamics.

The analysis in this report is based on Kiwa PI Berlin's quality assurance data obtained over the past decade and throughout 2024. Figure 2 shows in 2016, the PV module industry achieved a relatively low defect rate of 0.65%, attributed to the relative maturity of polycrystalline silicon solar cell modules and standardized product design and production processes. Growing share of monocrystalline silicon solar cell modules in 2017 and 2018 brought significant technical change in materials, processes, and equipment. While these advancements pushed the industry forward, they also **led to an increase in quality issues and defect rates** identified by Kiwa PI Berlin.

As monocrystalline silicon solar cell modules matured, the defect rate decreased slightly in 2019. However, rapid adoption of larger wafers, multi-busbar technology, and increased module size in 2020 caused another spike in defect rates. Despite challenges posed by the COVID-19 pandemic, the industry stabilized in 2021 and 2022, with annualized defect rates improving compared to the previous year. This improvement can be attributed to more refined manufacturing processes, enhanced automation, and the integration of intelligent in-process defect detection systems, such as automated soldering machines and advanced quality control measures.

In 2023 and 2024, the PV module industry faced new challenges due to shifting policies, increased demand for supply chain transparency, and the expansion of manufacturing into new regions. Additionally, the transition from PERC to TOPCon technology and the doubling of production capacity by the end of 2024 introduced complexities that contributed to higher defect rates in recent years. These factors highlight the **stress and interplay between innovation, market dynamics, and quality assurance** in the PV module industry.

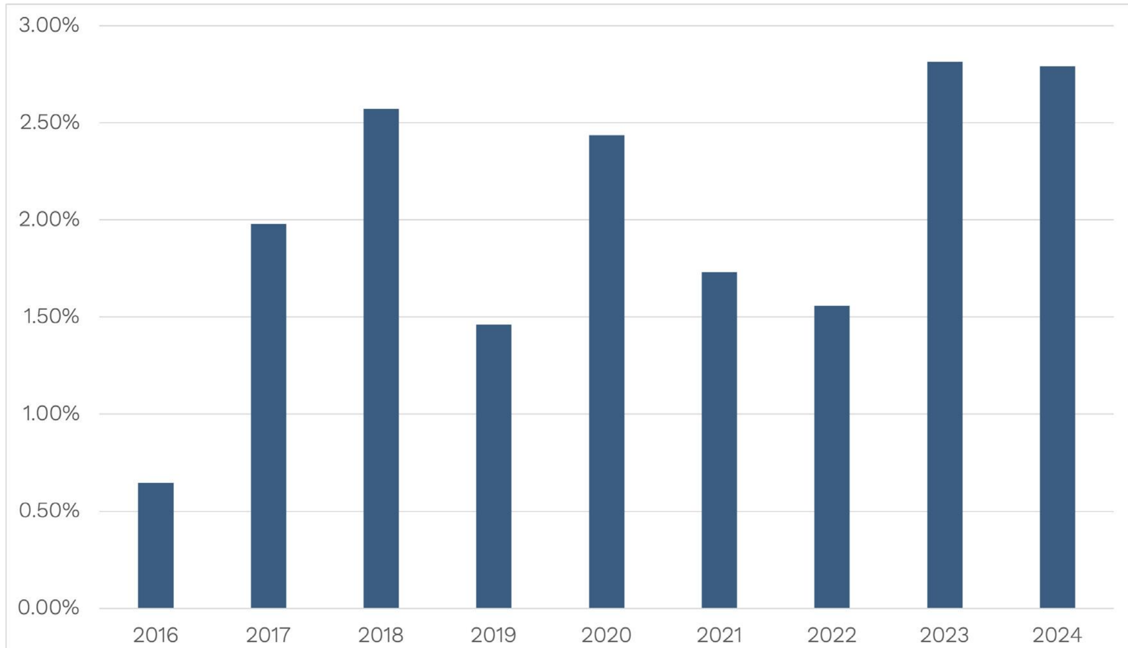

Figure 2. Annual defect ratio

Factory *Audits*

Kiwa PI Berlin conducts on-site, independent factory audits of PV module manufacturers, encompassing all technologies and product designs. In 2024, Kiwa PI Berlin performed approximately 100 PV module factory audits globally, producing comprehensive reports based on direct observations and expert evaluations of factory operations. These audits assess every aspect of manufacturing that could impact PV module safety, reliability, and performance.

During an audit, Kiwa PI Berlin experts inspect and evaluate all manufacturing aspects, equipment, and documentation, including:

- Quality management systems
- Materials management
- Verification and inspection processes
- Equipment control, maintenance, and calibration
- Production validation, qualification, and testing

Key Takeaways

Kiwa PI Berlin has identified these key takeaways from factory audits in 2024:

- A higher level of quality issues (findings) are identified in new factories and regions.
- Manufacturers have a range of finding results across regions and different factory locations; major findings that impact product quality range between 2 – 7 findings on average per audit.
- The same brand name does not necessarily have the same level of quality across multiple factory locations.
- Dynamic quality assurance planning helps appropriately scale activities depending on manufacturer experience, audit findings, and regional considerations.

Factory Audit Grading Analysis

Figure 3 provides a detailed breakdown of the number of findings categorized as Major and Minor defects observed during factory audits. The analysis reveals that over 70% of factories reported three or more Major findings, while only 8% of factories recorded three or fewer Minor findings. After an audit Kiwa PI Berlin requests manufacturers complete corrective actions prior to the buyer's production which may include modifications in various specifications, equipment, factory layout, quality management systems, and ensuring BOM compliance.

This data highlights significant challenges in PV module manufacturing lines, emphasizing that a considerable number of Major findings have the potential to impact product reliability and performance. For the analysis and reporting of factory audit results, we have excluded Critical findings considering observations in this category were relatively few. This wide variation in Major findings continues to validate the need for pre-production diligence including factory audits.

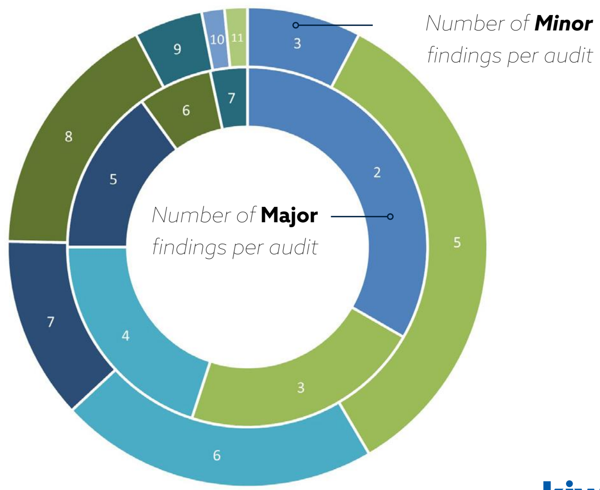

Figure 3. Breakdown of the number of audit findings

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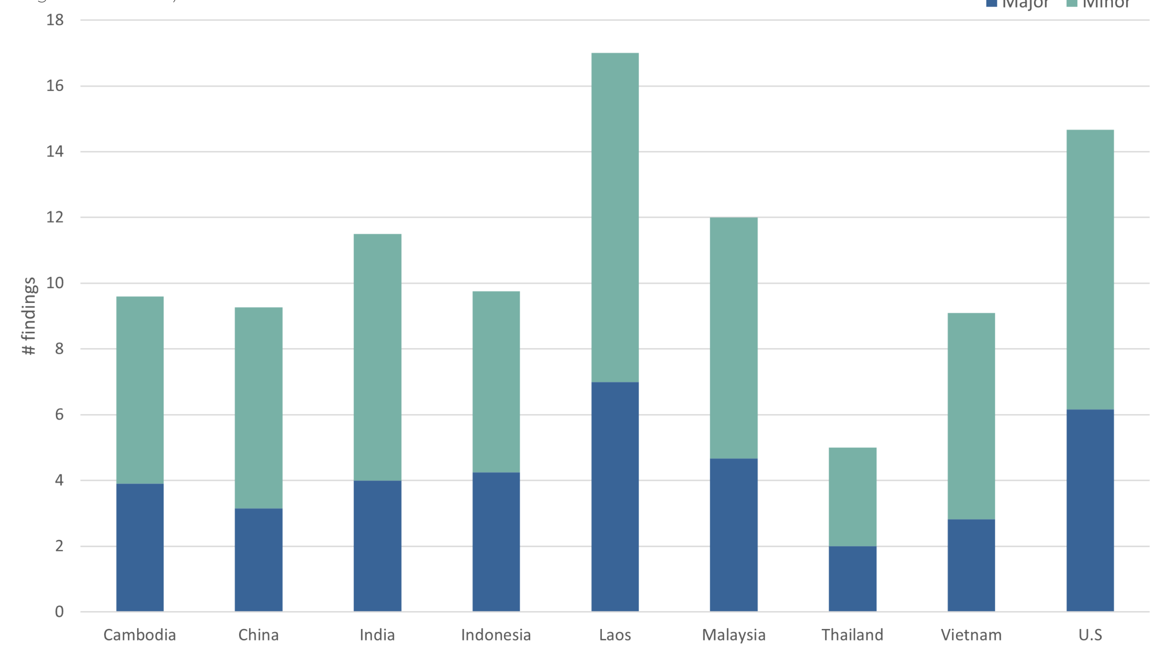
Figure 4. Factory audits of PV module manufacturers located in different countries



Regional Variability

Over the past 2-3 years, PV module manufacturing locations continued shifting to new countries due to tariffs and market demand. As shown in Figured 4 Kiwa PI Berlin's factory audit records for 2024 reveal a higher number of findings in factories located in recently developed PV manufacturing hubs, such as the U.S, Laos, and India. Common quality findings identified in these factories include insufficient training for the equipment operators, poor equipment conditions, material mishandling, and operational inefficiencies. Tracking and addressing these factors when working with newer manufacturing facilities is essential to mitigate these risks, and ensure effective resolution through corrective actions.

When developing an appropriately sized quality assurance plan, Kiwa PI Berlin recommends a **dynamic quality assurance** coverage model. For example, when purchasing modules from a developing manufacturing region, starting quality assurance efforts with increased coverage and tighter inspection sampling rates can be a valuable tool. This helps assess early production for your project(s) following factory audits and corrective action verification visits prior to production start.

While country location is a significant factor, variations among different factory locati-ons from the same manufacturer have been observed during our audits. For instance, as illustrated in Figure 5, six audits were conducted for a PV module manufacturer at different manufacturing sites located in various coun-tries. Despite these factories operating under the same quality management system (QMS), a wide range of findings was observed across the different locations.

These discrepancies emphasize that while the overarching QMS framework is consistent, the implementation of specific aspects and manufacturing processes can vary significantly between factories. This variation underscores the critical importance of auditing each manuacturer's facility. The same brand name does not necessarily mean the same level of quality across factory locations. Routine factory audits help ensure that manufacturers adhere to their own standard operating procedures and inspection criteria, minimizing risks to reliability, safety, and performance.

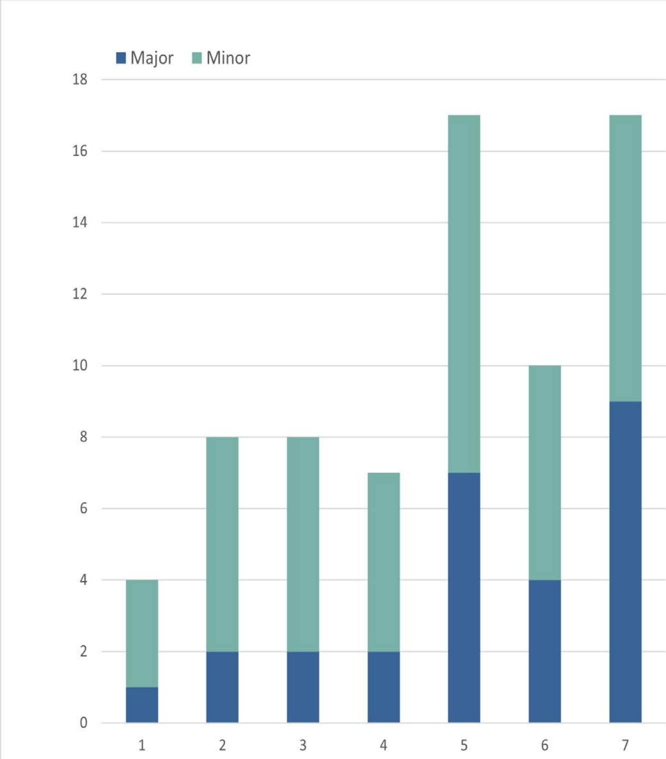


Figure 5. Audit findings for a PV module manufacturer at different manufacturing sites

Factory Audit Benchmarking

Kiwa PI Berlin's audit reports summarize all observations and findings, accompanied by an overall benchmarked rating for the audited factory workshop. Figure 6 presents the results of all 2024 audits, categorized by manufacturer and ranked by quantity of findings. The rankings are developed based on Kiwa PI Berlin's audit benchmarking criteria, which factors in the severity and impact of each finding on product reliability, safety, and performance.

Factory audits have become industry practices to qualify new factories, enhancements and additions to production lines, or for qualification of manufacturers for buyer's approved vendor lists. Factory audits provide buyers with a list of findings to be addressed before production through implementation of ma-nufacturer corrective actions. In addition to resolving quality findings prior to your produc-tion, these audits serve as an essential input developing appropriate sized quality assurance plan during active production.

In summary, factory audits empower stakeholders to make informed decisions on manufacturer selection, enhance equipment quality for their projects, and proactively manage risks associated with PV module production.

For more information on developing a quality assurance plan, see Kiwa's PV Module Procurement Best Practices, which is based on five fundamental rules for PV module buyers:

1) A PV module's quality is determined by the quality of its component parts and manufacturing consistency.
2) Adequate testing prevents failures & underperformance. Warranties do not.
3) Manufacturers set their own quality standards unless buyers intervene.
4) Trust but verify the quality of deliver-ed modules.
5) Have a plan to address issues before they arise.

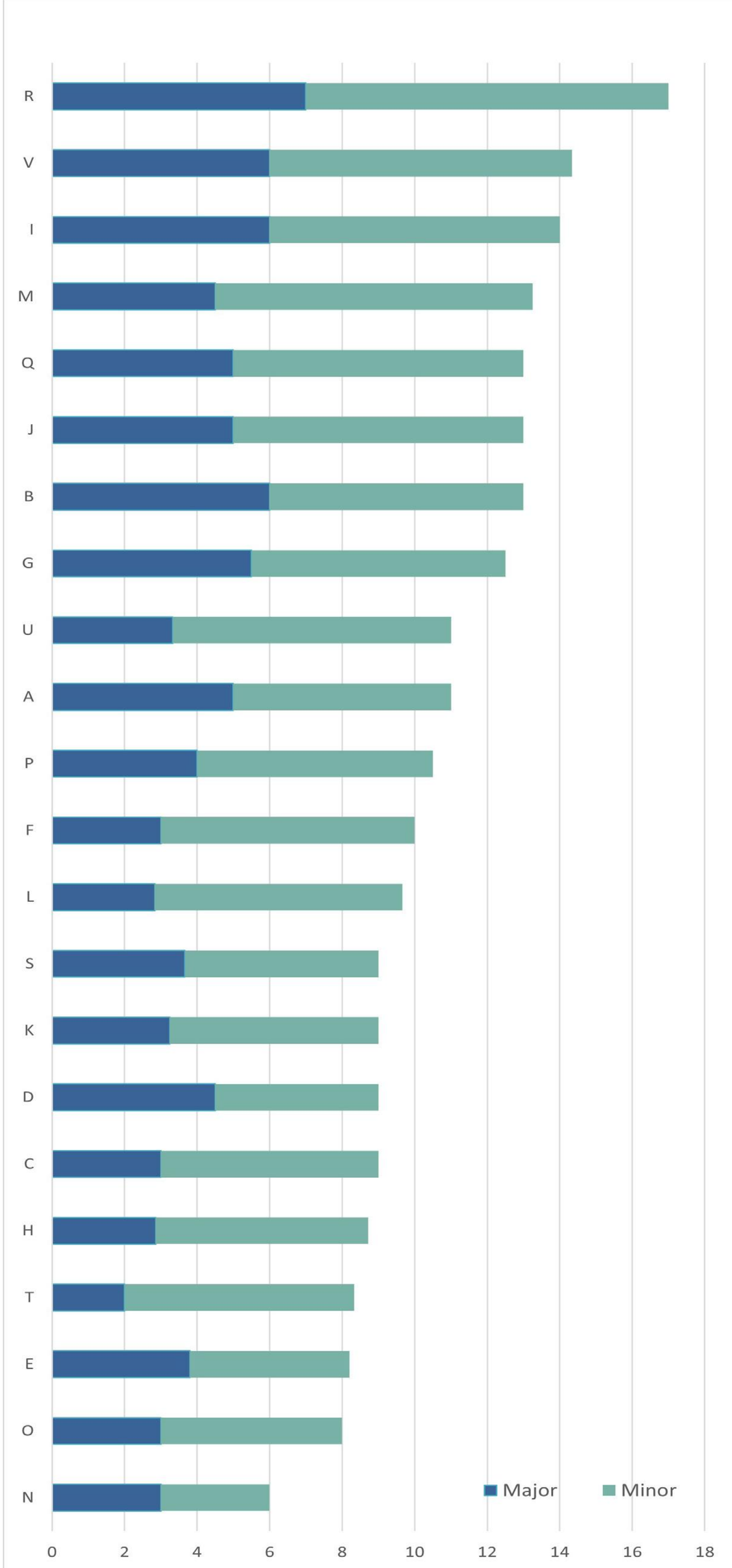


Figure 6. Audit findings for different PV module manufacturers

Production oversight ensures the correct application of materials, processes, and production controls.

Production **Oversight**

Kiwa PI Berlin provides real time, in-factory production oversight of PV module production, deploying quality assurance engineers to monitor and ensure correct application of required materials, processes, and production controls. Production oversight ensures the correct application of production procedures, applying conformance criteria at each stage, including:

- **Bill of Materials (BOM)** - verification and certification compliance
- **Incoming quality control (IQC)** – procedures and inspections
- **Material storage** - expiry and preparation controls
- **Equipment** - calibration, maintenance, and cleaning
- **Production processes -** such as cell cutting, soldering, lamination, framing, junction box placement, soldering, product inspections, and testing.

Key Takeaways

Kiwa PI Berlin has identified these key takeaways while performing production oversight:

- The most common findings occurred at the layup station in production lines, followed by soldering, and junction box application.
- New cell technologies including TOPCon production lines have higher volumes of findings compared to more mature PERC production lines.
- Buyers can benchmark various manufacturers by leveraging average production oversight metrics, such as the quantity and severity of findings normalized per conducted production oversight visit.

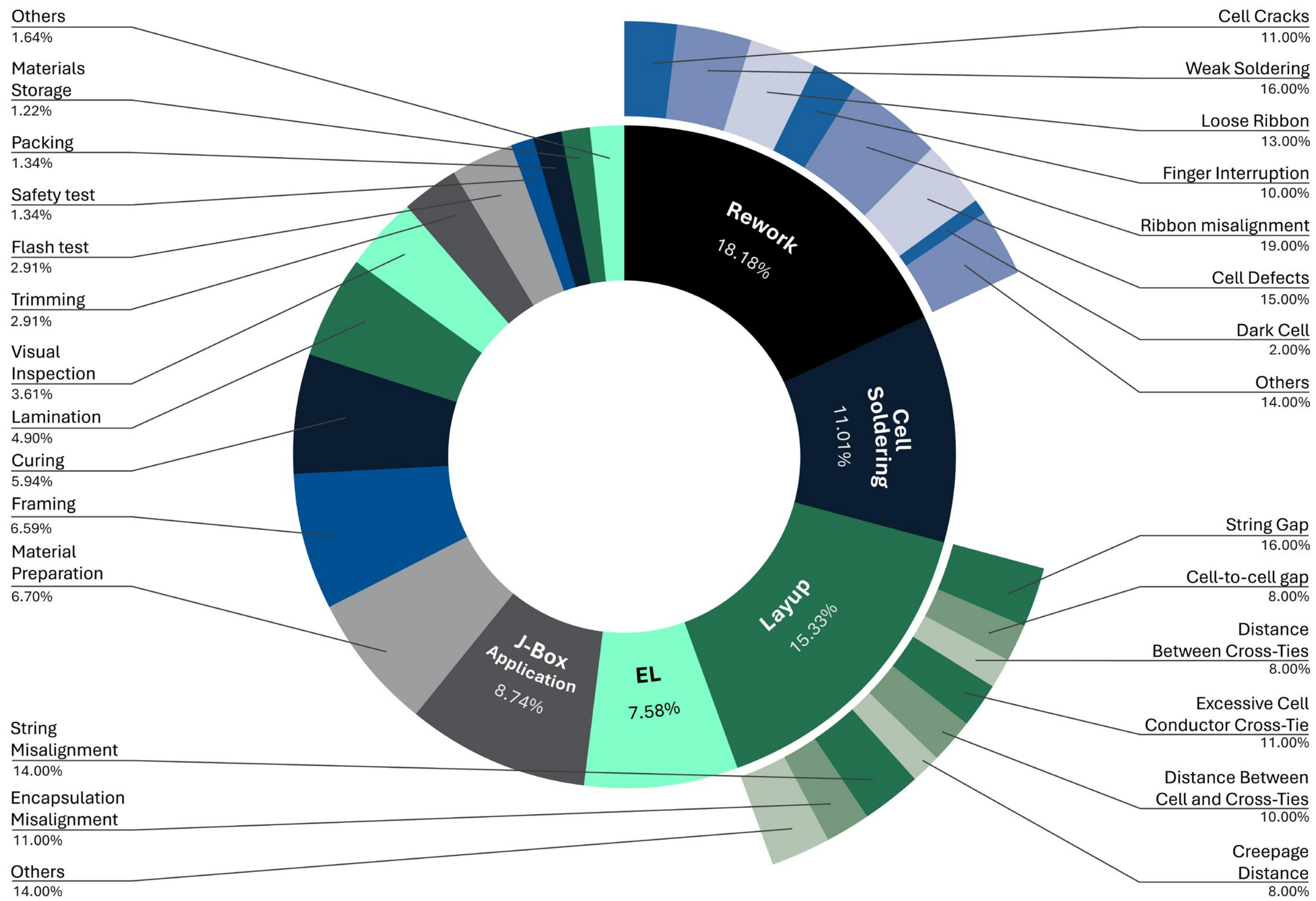


Figure 7. Percentages of findings across production steps.

Active Production Assessment

Kiwa PI Berlin's active and continuous production oversight process provides a comprehensive summary of all production findings observed in 2024. As illustrated in Figure 7, the varying finding rates at diffe-rent production stages, emphasizing the need for enhanced process control and quality assurance throughout the entire module manufacturing process. As shown, the highest finding occurrences were observed in Rework, Layup, Cell Soldering, and Junc-tion Box Application & Soldering.

Rework Process

In recent years, rework ratios have increased due to the introduction of new cell technologies and designs, such as TOPCon and HJT. Oversight observations confirm that these advanced technologies are par-ticularly sensitive to soldering parameters and machine calibration. Therefore, soldering equipment and processes must be continuously monitored and optimized to ensure consistent quality.

Rework, often involving manual soldering, introduces high risks to module reliability and performance. Unfortunately, issues from manual processes are often undetectable during production and do not affect a module's immediate power output. However, they contribute to various forms of module degradation over time under operational stresses, including thermal, mechanical, and UV exposure.

Layup Process

The second most common finding category is related to the layup process. Among these findings, cell string misalignment and improper gap spacing are frequent issues, posing reliability and safety risks, including hotspots and potential fire hazards.

Recent trends have shown a significant increase in layup-related findings, driven by two factors:

- Adoption of POE (polyolefin elastomer) as module encapsulant, which has a glossier, low-friction surface compared to EVA, making it challenging to maintain string alignment.
- Increasing dimensions of PV cells, which have reduced the allowable gap between strings and cells, heightening the importance of precise alignment.

Junction Box

Junction box findings, such as improper application, inadequate sealing, poor soldering, and misalignment are among the most frequently observed defects during oversight inspections. These issues are particularly critical, as they can significantly impact module reliability, safety, and long-term performance, and in some cases, pose fire hazards.

The number of junction box-related defects has increased in recent years with development of half-cell modules, which require three junction boxes per module. These junction boxes are connected to the ribbons using soldering methods, with two ribbons soldered per box—resulting in six soldering points per module.

The increased complexity of half-cell modules raises the likelihood of soldering-related defects, making robust quality control even more essential. Weak soldering, in particular, is concerning due to its latent nature—it is often difficult to detect during production but can deteriorate over time under operational stress or long-term field conditions. These challenges highlight the need for rigorous material inspections, process validation, and consistent process control to ensure long-term module reliability and safety.

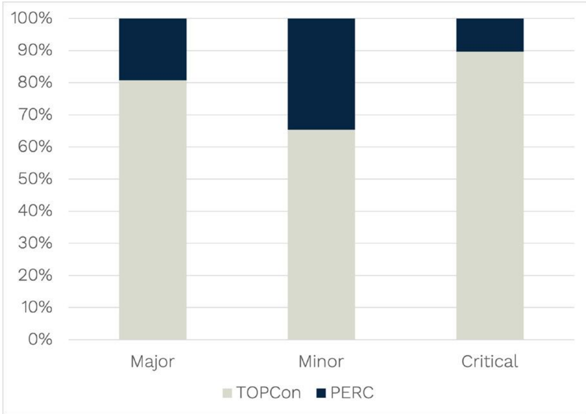


Figure 8. Rates of production oversight findings by cell technology, observed across all findings witnessed.

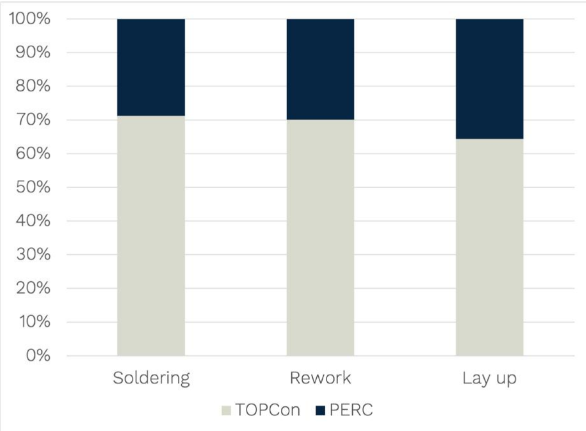


Figure 9. TOPCon and PERC modules soldering, rework, and layup production oversight finding ratios

Cell Technology Variances

A detailed analysis of oversight findings, primarily related to cell technologies, TOPCon and PERC, is presented in Figure 8. The data reveals that the ratio of observed findings in modules utilizing TOPCon cells is significantly higher than in those with PERC cells. This disparity stems from production limitations and challenges associated with TOPCon cell technology.

As illustrated in Figure 9, the most significant contributors to the higher defect ratio in TOPCon modules are soldering, rework, and layup processes. As discussed earlier, these findings have escalated in recent years with the introduction of new cell designs and technologies, which pose additional manufacturing challenges. In contrast, PERC cells are less prone to these production challenges due to their relatively mature and well-optimized manufacturing processes. This maturity translates to a lower incidence of findings, as demonstrated in the comparative analysis.

The analysis highlights the need for enhanced production oversight and stringent quality controls, particularly for emerging cell technologies like TOPCon. By addressing these chal-lenges proactively—through improved process monitoring, equipment calibration, and staff training—manufacturers can reduce defect rates and ensure consistent product quality as the industry continues to adopt next-generation cell designs.

Production Oversight Benchmarking

Based on comprehensive oversight findings for PV module manufacturers worldwide, an overall ranking has been developed, as illustrated in Figure 10. Findings have been categorized into three distinct classes—Minor, Major, and Critical—based on their impact on module reliability, safety, and performance.

To facilitate a fair comparison of product quality across different manufacturers, data has been normalized using the average of the quantity and severity of findings per production oversight visit. As shown, the range of findings varies significantly, with a stark contrast between the top five manufacturers and the bottom three.

In summary, this type of analysis allows buyers to benchmark manufacturers This wide disparity highlights the importance of continuous quality monitoring and detailed oversight to ensure consistency and adherence to reliability and performance standards.

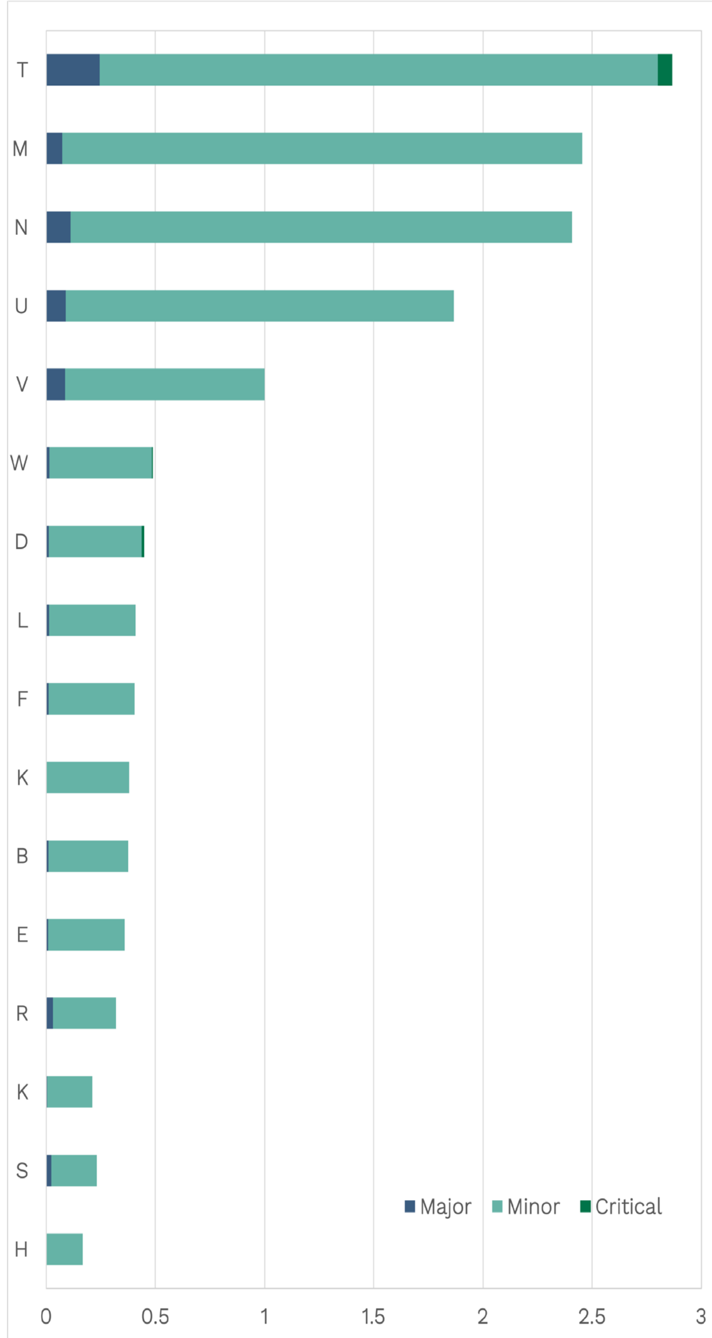
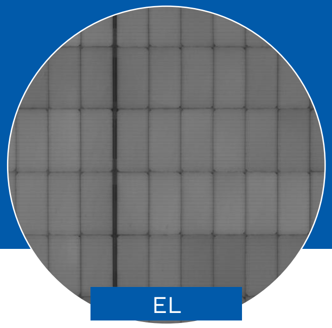
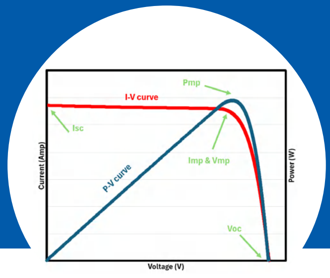


Figure 10. Global ranking of oversight findings across PV module manufacturers

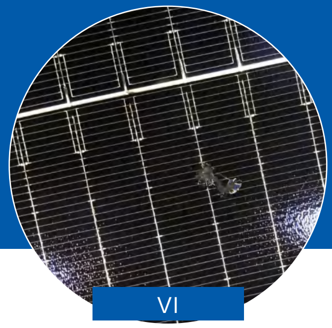
Pre-Shipment *Inspections*



EL



IV



VI

End-of-Line Inspections

Kiwa PI Berlin performs end-of-line inspections of a finished goods to validate the manufacturer's quality control procedures before shipment. These "reinspections" are conducted on a sample basis according to agreed quality standards and ISO 2859-1:1999. Sampling methodology follows a standard inspection level; all defects identified are documented and evaluated in accordance with the Accepted Quality Limit (AQL). Pre-shipment inspections are a high-value quality assurance activity that act as a final gate to verify quality before it is shipped to the buyer's project sites or warehouse facilities.

In 2024, Kiwa PI Berlin conducted PSI for approximately **92,000 PV modules**, providing fundamental insights into production quality across various manufacturers and batches. Kiwa PI Berlin normalizes this inspection data which can help buyers benchmark manufacturers.

Common Types:

Pre-shipment inspections occur on modules that have already passed through the manufacturer's own internal inspections related to contractually agreed to criteria. Common pre-shipment inspections include:

- **Electroluminescence Imaging (EL)**
  EL imaging detects cell defects based on inspection criteria and continues to serve as an essential tool to identify invisible defects such as microcracks, finger interruptions, or shunt issues.
- **Flash Testing (IV)**
  IV (flash) testing captures electrical parameters for each sampled module; this includes verification that the required power tolerance and bifaciality are within compliance.
- **Visual Inspection (VI)**
  In-depth visual inspections identify and classify defects such as scratches, edge chips, contamination, and frame gaps.

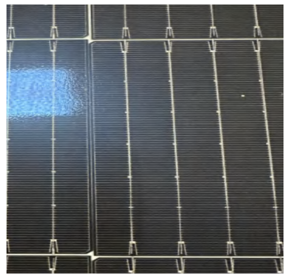
92,000 modules inspected

Key Takeaways

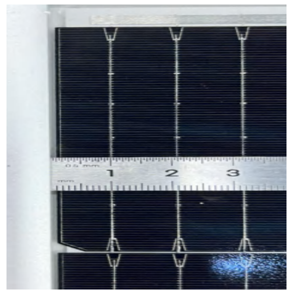
Kiwa PI Berlin has identified these key takeaways from performing pre-shipment inspections:

- Leading defects identified across 2024 are PV cell metallization and cell cracking; followed by frame material and assembly defects.
- Per ISO and Kiwa PI Berlin's experience, tighter acceptable quality levels (AQL) with stringent inspection criteria is one of the most rigorous ways to screen for defective finished goods. Buyers should negotiate these in supply contracts to steadily improve market and manufacturing standards.
- Increased defect rates are found at newer manufacturing hubs, aligning with production oversight trends.
- The trend to higher cell related defect rates, points to the need and benefit of auditing cell-specific production facilities.
- Benchmarking pre-shipment inspection results at levelized criteria, allows buyers to compare and contrast quality from their suppliers.

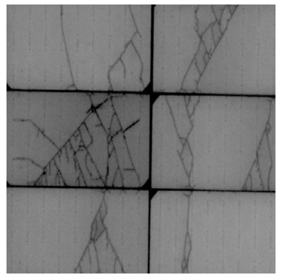
Defect Examples



String-to-String Gap
Two cells from adjacent strings are in contact. Can lead to internal short circuits causing underperformance or safety concerns.



Creepage Distance
The distance between the live part (cell) and the glass edge is below the minimum specified requirement. Poses a risk to individuals, the module, and the overall system.



Branching Cracks
Multiple cells in the module exhibit branching cracks. Increased likelihood of module degradation and potential fire hazards due to hot spot formation.

Frame Corner Gap
An open corner gap indicates issues with frame assembly, which can compromise the module's mechanical performance and increase the risk of glass breakage.

Defect Distributions

Cell Defects

The distribution of defects identified during these inspections is illustrated in Figure 11. Each segment represents a specific defect type and its percentage of total defects observed, offering a clear visualization of recurring issues in PV module production. Defects are non-conformances related to inspection criteria agreed to (or provided by the manufacturer) as it relates to a buyer's supply contract.

As shown in Figure 11, over 22% of defects observed in module production are directly related to cells. A key factor contributing to the prevalence of cell-related defects is the industry-wide transition from PERC to TOPCon cell technology. This shift in cell design and technology has significantly influenced the occurrence of defects, as evidenced by the oversight findings.

Figure 11 provides a detailed breakdown of sub-categories of cell defects, illustrating the percentage occurrence of each defect type relative to the total defects. The "Metallization" sub-category accounts for the largest share (39%) of cell defects, making it the most prevalent type. This underscores challenges TOPCon cells face during production, where metallization-related issues are frequently introduced into the module manufacturing process.

Another significant defect sub-category is "Cell Cracks," which represent a substantial issue in terms of cell quality, process control, and in-process inspection. Cracks can significantly compromise structural integrity of cells, ultimately impacting reliability and performance of modules.

The remaining sub-categories represent various other cell quality issues, reflecting multifaceted risks posed by cell defects to the overall reliability and operational performance of PV modules.

This data highlights a critical need for robust quality control measures, and benefit of auditing cell-specific production facilities prior to production. Addressing these challenges is essential to reducing the incidence of cell-related defects, thereby improving overall quality and long-term reliability of PV modules.

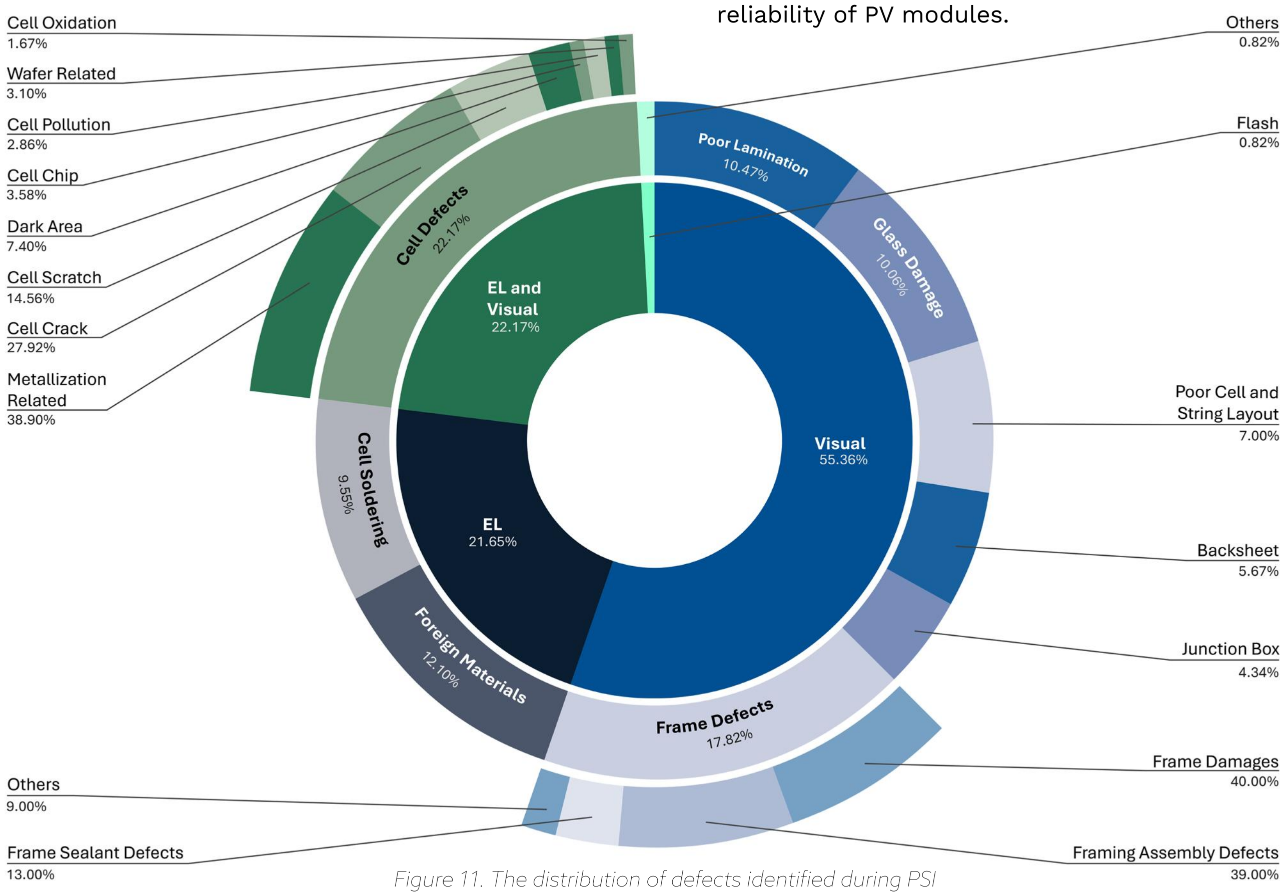


Figure 11. The distribution of defects identified during PSI

Frame Defects

As seen in Figure 11, frame defects (defects related to frame damage and frame assembly) represent the second largest defect category with a rate of 17.82%. This high percentage highlights the critical need for stringent quality control measures for incoming materials and robust handling, packaging, and transportation practices to mitigate damage risks.

The "frame damages" sub-category accounts for the largest share (40%) of frame defect findings, making it the most prevalent sub type primarily attributed to material quality issues. Although these defects are most common, severity of these superficial frame defects are minor with limited performance impact. However, consistent monitoring and material quality assurance are essential to minimize their occurrence.

Framing and assembly related defects represent a close second, comprising 39% of total frame defects. These defects arise from issues during framing and assembly process, such as frame gaps, improper alignment, or sharp corners. Unlike material-related defects, framing defects pose a higher risk to the safety and mechanical performance of the module, emphasizing the need for strict process controls and operator training during framing.

Sealant defects represent the smallest portion of frame damage at 13%. These defects typically result from inaccuracies or inconsistencies in the sealant application process. While less frequent, sealant defects can allow moisture ingress and potentially compromise the structural integrity of the frame, leading to long-term reliability concerns.

The data underscores the multifaceted nature of frame damage in PV modules, with defects stemming from material quality, process inconsistencies, and sealant application errors. To address these challenges, manufacturers must adopt a comprehensive quality assurance strategy, encompassing stringent material inspection, process optimization, and enhanced operator training. This approach will not only minimize frame damage but also ensure reliability, safety, and long-term performance of PV modules.

Other Defects

Foreign Materials (12.1%), Poor Lamination (10.47%), and Glass Damage (10.06%) highlight challenges in material quality, process control, and manufacturing practices that significantly impact PV module performance, reliability, and safety. Contamination during production can lead to issues such as moisture ingress and mechanical degradation, while poor lamination increases the risk of delamination, structural instability, and environmental exposure. Glass damage, including scratches, compromises mechanical strength and resistance to stresses like mechanical loads. Addressing these defects requires stringent material quality control, optimized process steps, and regular maintenance and calibration of manufacturing equipment to ensure stable production and long-term module reliability.

Glass Breakage During Testing from Kiwa PVEL

Related to framing issues, Kiwa PVEL observed an increase in module breakage during the Product Qualification Program's Mechanical Stress Sequence. This sequence includes static mechanical load (SML) and dynamic mechanical load (DML) testing when mounted using Nextracker's 400 mm mounts). Even with a reduced SML test load of ±1800 Pa (compared to the ±2400 Pa minimum requirement for the IEC/UL 61215 standard), multiple modules from a range of manufacturers have broken due to weaknesses in the glass, the frame, and/or other root causes.

This includes a recent example where the manufacturer determined that an insufficient amount of silicone sealant was applied to the frame channel, resulting in the laminate becoming liberated from the frame channel and the glass breaking. Reducing the amount of sealant and/or using a less expensive sealant are cost-cutting measures that must be vetted before acceptance. These can be verified during Kiwa PI Berlin's factory audits and production oversight.

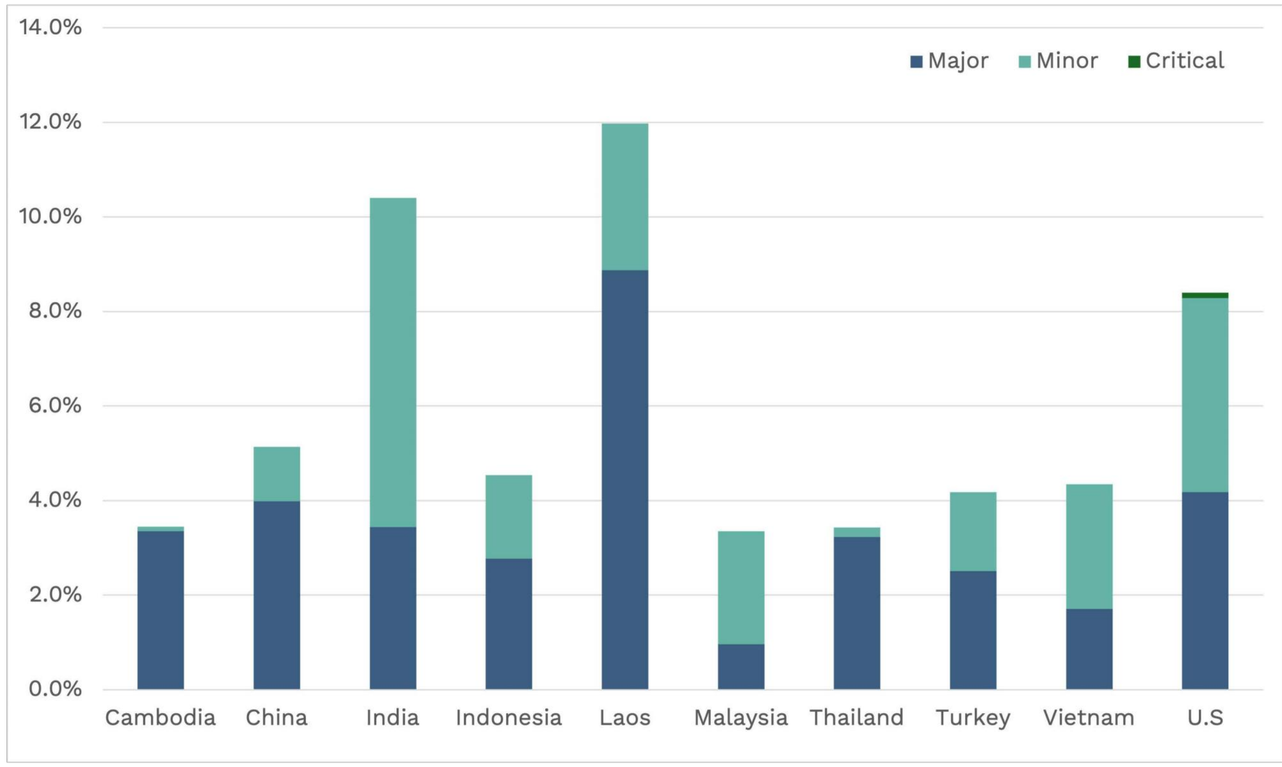


Figure 12. Defect rates observed during PSI across various manufacturing countries

Regional Differences

Figure 12 illustrates defect rates observed during PSI across various manufacturing coun-tries. Laos, India, and the U.S. exhibit the highest defect rates, exceeding 8% (percentages noted are per batch of PSI samples) This trend can be attributed to the substantial increase in new manufacturing capacities installed over the past year. The rapid expansion in these regions likely introduced challenges related to quality control, operational stability, and work-force training, which have resulted in elevated defect rates.

Countries such as China, Indonesia, Vietnam, and Turkey report moderate defect rates, ranging from approximately 4% to 5%. China, with its extensive manufacturing capacity and diversity of manufacturers, experiences significant variations in product quality and technology, which contribute to fluctuations in its defect rates. In contrast, Indonesia and Turkey, despite adding new production capaci-ties in recent years, have leveraged their more established experience. Thailand, Cambodia, and Malaysia report relatively low defect rates, remaining slightly above 2%. These countries benefit from mature manufacturing systems, advanced quality control protocols, and effi-cient supply chain management.

This analysis underscores how varying levels of experience, infrastructure maturity, and quality control influence defect rates across manufacturing countries. Rapid expansion in countries like Laos, India, and the U.S. highlights the importance of stabilizing operations and enhancing quality systems to mitigate risks. Conversely, countries with more established manufacturing ecosystems, such as Malaysia, Thailand, Cambodia, and China demonstrate the advantages of maturity and operational efficiency in PV module production.

PSI Benchmarking

Figure 13 illustrates the defect rate per kilowatt (kW) observed during the conducted PSI across different manufacturers. The data shows a wide range of defect rates from manufacturer to manufacturer, highlighting significant variability in manufacturing quality.

Several factors contribute to these variations, including the effectiveness of each company's Quality Management System (QMS), level of training and experience within teams, and presence of standard work procedures and instructions. A well-established QMS plays a crucial role in maintaining consistent production standards and minimizing defects, while expertise and training of factory personnel are critical in reducing human error.

Furthermore, clear and consistently followed standard operating procedures help to minimize deviations and ensure uniformity in the production process. This analysis underscores how varying levels of experience, infrastructure maturity, and quality control systems impact defect rates across manufacturing companies. Addressing these factors is key to improving product quality and ensuring consistent performance across different factories. In summary, benchmarking manufacturers through the use of levelized PSI data allows buyers to enhance quality control in their produced modules.

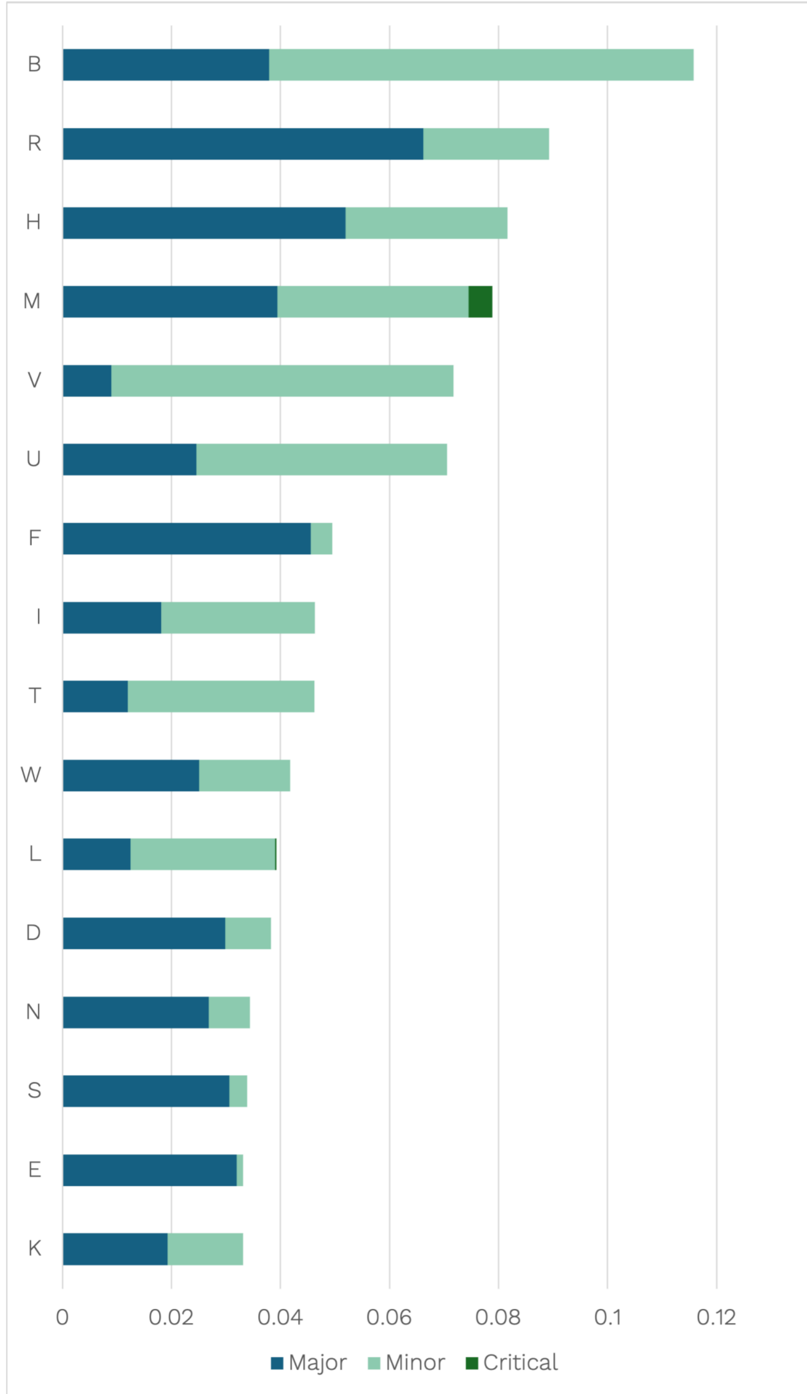


Figure 13. Defect rates observed during PSI across different factories

Conclusion

While 2024 was a challenging year for the PV module manufacturing industry, it has **the need for buyers and investors to actively manage PV equipment quality**. Through the use of pre-production factory audits, supply chain traceability assessments, production oversight, pre-shipment inspections, and lab testing, buyers must leverage the tools at their disposal to improve quality of their modules.

The data presented provided insights observed through regular factory-based quality assurance trips to manufacturers throughout the world by Kiwa PI Berlin, with the goal of helping buyers and investors in the industry better understand the latest manufacturing quality trends and the importance of appointing an independent third party quality assurance company to protect the investment in solar technology.

Kiwa PI Berlin have been providing technical advisory and quality assurance services for over a decade across the globe, and are trusted by the world's top utilities, investors, developers, and EPCs to independently review, assess, and advise on quality management and contracting requirements. Kiwa PI Berlin teams and subject matter experts in Asia, Europe, and the Americas; creating trust, and driving progress reducing manufacturing quality risk for your global PV and storage assets.

About Kiwa PI Berlin

Kiwa PI Berlin provides expert technical diligence, procurement, and quality assurance services for a wide range of solar installers, integrators, project developers, utilities and investors. We enable our clients to manage technical risk associated with the investment or procurement of PV equipment. We leverage direct relationships with PV module, inverter and battery manufacturers, apply our expertise to qualified manufacturers and independently verify quality, reliability, and performance.

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