Solar Array Aerial Inspections:

A comparative analysis of airplanes and drones

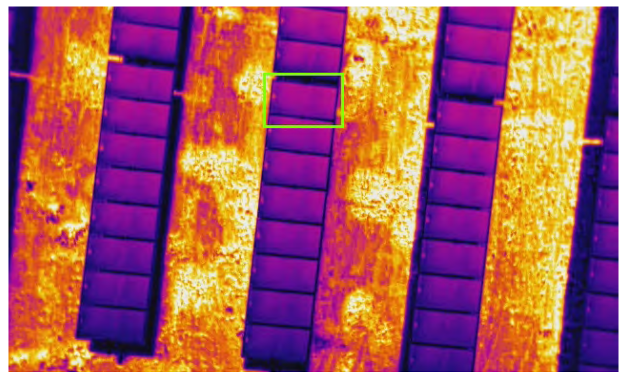
zeitview.com

Table of Contents

Executive Summary

Aerial inspections can help operators of commercial and utility-scale PV systems optimize maintenance, output and revenue. Traditional aircraft and drones are both excellent tools for the job, but they have different advantages.

Airplanes carry bigger payloads and cover wide areas quicker. They are well suited for operators with a portfolio of projects or large-scale sites that need annual full inspections. Drone inspections can be conducted on demand. UAVs are ideal for inspections of small-to-mid-range solar plants and detailed inspections of suspected problem areas at plants of any size.

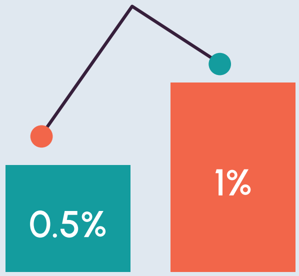


Zeitview is the market leader in intelligent aerial imagery for both wind and solar power projects. We created this white paper to provide an overview of how aerial inspections can assist in maximizing energy generation from commercial and utility-scale PV systems. It explains how the combination of aerial sensors, machine learning and data analytics is making it possible to assess equipment condition and prioritize maintenance and repairs—cheaper, faster and better. And it provides guidance for decision makers who want to know whether inspections by traditional or drone aircraft are best for their needs.

Introduction: Aerial inspections for solar power systems

The shift to solar energy is accelerating as people around the world respond to climate change. To meet ambitious climate goals, we need to bring a lot more solar power systems online and keep them running at peak efficiency. Aerial inspections help optimize solar power output from commercial and utility-scale PV arrays, from initial site scouting to ongoing spot checks.

Exposure to solar radiation, weather and environmental conditions like wildlife, vegetation and erosion all degrade PV equipment. Making things more complicated, a defect in a single solar module can significantly affect the performance of a complete string. And modules decrease in performance at different rates.



Median annual power degradation rate for solar panels[1]

Planes and drones equipped with data-collection technology can rapidly detect issues and monitor PV systems large and small, on a regular basis. They do this work at far less expense than either technicians working on foot or autonomous mobile robots. Drones and manned aircraft can pinpoint both obvious anomalies like cracked and delaminating panels and subtle electrical issues, like potential induced degradation (PID).

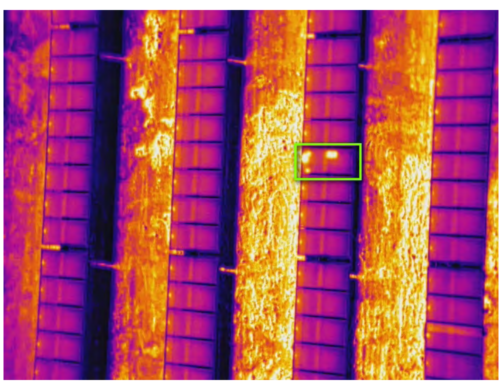
Read on to learn how drones and planes help maximize solar energy output from commercial and utility-scale arrays. See a case example comparing data quality for the two aircraft for several mid-sized solar plants. And get guidance on which aircraft is right for different scenarios.

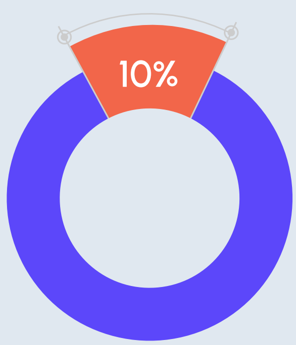
[1] STAT FAQs Part 2: Lifetime of PV Panels | State, Local, and Tribal Governments | NREL

The most common problems detected by aerial PV inspections

Manned aircraft and drones can identify a wide variety of anomalies with solar power equipment. Aerial inspections find both visible and hidden defects that may affect energy output, using high-resolution (RGB) imagery and infrared sensing.

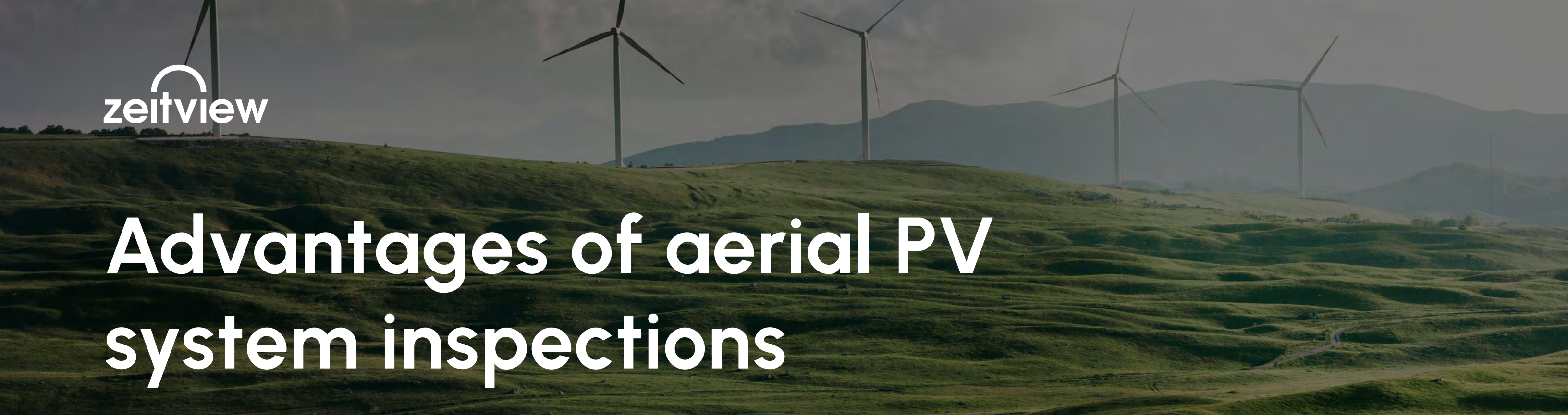
Problems detected through high-resolution photos and video	Problems detected through thermal sensing
Soiling *(dirt, snow, dust)*	Hot spots
Tracker issues *(off-tilt or off-angle panels)*	Diode short-circuit or burnout
Cracks and micro-cracks	Reverse polarity *(incorrect wiring)*
Broken glass	Fuse, junction box, array combiner, inverter failures
Delamination	Offline panel
Snail trail *(panel discoloration)*	Faulty cables
Erosion at the base of mounts	String outages
Shadowing *(vegetation, buildings)*	PID *(potential induced degradation)*
Animal nests	





Common energy yield loss from soiling[2]

[2] https://www.energy.gov/articles/getting-most-out-solar-panels



Advantages of aerial PV system inspections

Efficiency

Aerial inspections are fast, so facility managers can typically do them more frequently and cheaply. The imagery and data collected help operators prioritize maintenance and get an up-to-date view of equipment. To scout new projects, drones or planes can survey hundreds of acres in hours, and multiple sites in the same day. These programs also scale easily as global solar portfolios grow.

ROI

Operators can improve build quality with baseline inspections of new assets. Aerial sensors spot degradation like PID before it spreads and damages other parts of a module like glass, frame and mounting structure—or even entire strings. Permanent damage to expensive capital equipment is easier to avoid. All kinds of anomalies are quickly identified, keeping everything in good repair for maximal power output and revenue.

Safety

Frequent inspections from the air keep workers at a safe distance from mid or high-voltage, fragile equipment, reducing a lot of occupational risks. These include working around electrical equipment and trip-and-fall for crews on field walks. Aerial data collection also picks up electrical shorts caused by bird nests and other debris lodged under solar panels, which can lead to fires.

Advanced data analysis

Thermography from the ground doesn't achieve the angle of observation necessary for actionable data. Aircraft equipped with thermal imaging payloads capture high-fidelity aerial data for the entire solar plant. Operators can create digital twins, automate the analysis of images collected via machine learning and surface insights not possible with ground-based analytics tools.

Selecting the right aircraft for the job: airplanes vs drones

Drones and airplanes are both valuable aerial inspection tools. Here are the main considerations for selecting which is best, from the amount of area to cover to airspace regulations to cost and more.

Which aircraft is best for your scenario?

	Manned Aircraft	Drone
Use cases	▪ Initial site surveys for a single or multiple large-scale prospective projects ▪ Pre-construction planning and bid optimization ▪ Verify construction and set performance baselines ▪ Semi-annual inspections for a portfolio of facilities or plants spread across large swaths, to track against baselines, verify overall plant integrity and reduce performance degradation ▪ For multiple large project sites in dispersed geographies ▪ Pre-sale or acquisition inspections	▪ Initial site surveys for mid- or small-sized projects ▪ Pre-construction planning and bid optimization ▪ Construction progress tracking ▪ Verify construction and set performance baselines ▪ Semi-annual inspections of medium- to small-scale PV plants and commercial facilities, to track against baselines, verify overall plant integrity and reduce performance degradation ▪ On-demand inspections and spot checks to assess areas of concern ▪ Pre-sale or acquisition inspections
Maximum coverage area per day	▪ Typically 500MW /day, 3,000 acres or as many as 60 rooftop installations ▪ 1.7GW /day	▪ Up to 20 to 30MW /day, 100 acres
Lead time	▪ Requires advance scheduling, ranging typically between 2-4 weeks ▪ Often scheduled spring and fall ▪ May be performed on demand, depending on facility size and locale	▪ Standard lead time is 2 weeks, but DroneBase can often deploy within 48 hours ▪ Expedited and on-demand projects possible

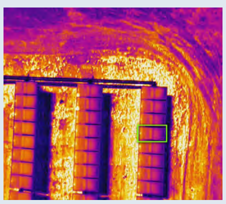
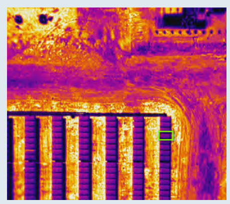
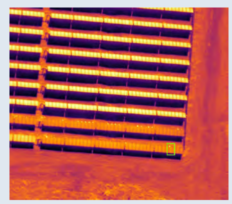
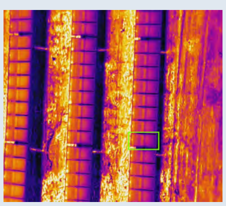
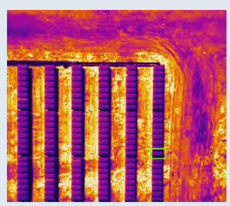
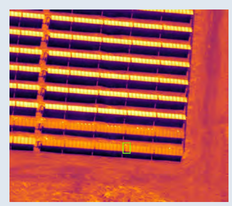
Selecting the right aircraft for job airplanes vs drones (continued)

	Manned Aircraft	Drone
Reporting delivery time	▪ Turnaround for processed data and reports approximately 5 days, depending on installation size	▪ Turnaround for processed data and reports approximately 5 days, depending on installation size
RGB resolution for photos and videos	▪ 2.5 cm/pixel GSD[1] standard ▪ 1 cm/pixel GSD optional	▪ 3 cm/pixel GSD standard ▪ 1.5 cm/pixel GSD optional
Thermal imagery resolution	▪ 6.5 cm/pixel GSD standard ▪ 3 cm/pixel GSD optional	▪ 5.5 cm/pixel GSD standard ▪ 3 cm/pixel GSD optional
Accuracy	▪ For topographical surveys, +/- 5 cm ▪ For thermographic surveys, individual panels ▪ Mid-wave infrared technology used, allowing more sensitive and accurate temperature detection	▪ For topographical surveys, +/- 5 cm ▪ For thermographic surveys, individual panels ▪ Long-wave IR technology used, requiring closer proximity to achieve same temperature sensitivity
Locational factors	▪ In areas with busy airspace where drones aren't permitted ▪ When wind presents a challenge for drone flights	▪ In areas with less air traffic ▪ In stable weather without blustery winds
Typical cost	▪ Thermal and RGB data capture for one 550 MW, 3,000-acre solar farm ▪ For 3 utility-scale solar farms like the above: $9000-$10,000	▪ Thermal and RGB data capture for one 10 MW, 45-acre solar farm: $2000-$3000

Comparing airplane vs drone data quality for solar plant inspections

To explore tradeoffs between cost and data granularity, Zeitview compared thermal data for both airplane and drone flights at several mid-sized solar facilities. We inspected sites with a wide variety of expected anomalies. Two drone missions and one airplane mission were flown under similar weather conditions and a minimum solar irradiation level of 600W/m^2. Our key findings:

- *Detection of anomalies is high using drones at two different resolutions as well as an airplane.*
- *Anomalies due to single-cell-affected modules are far more obvious in airplane imagery.*

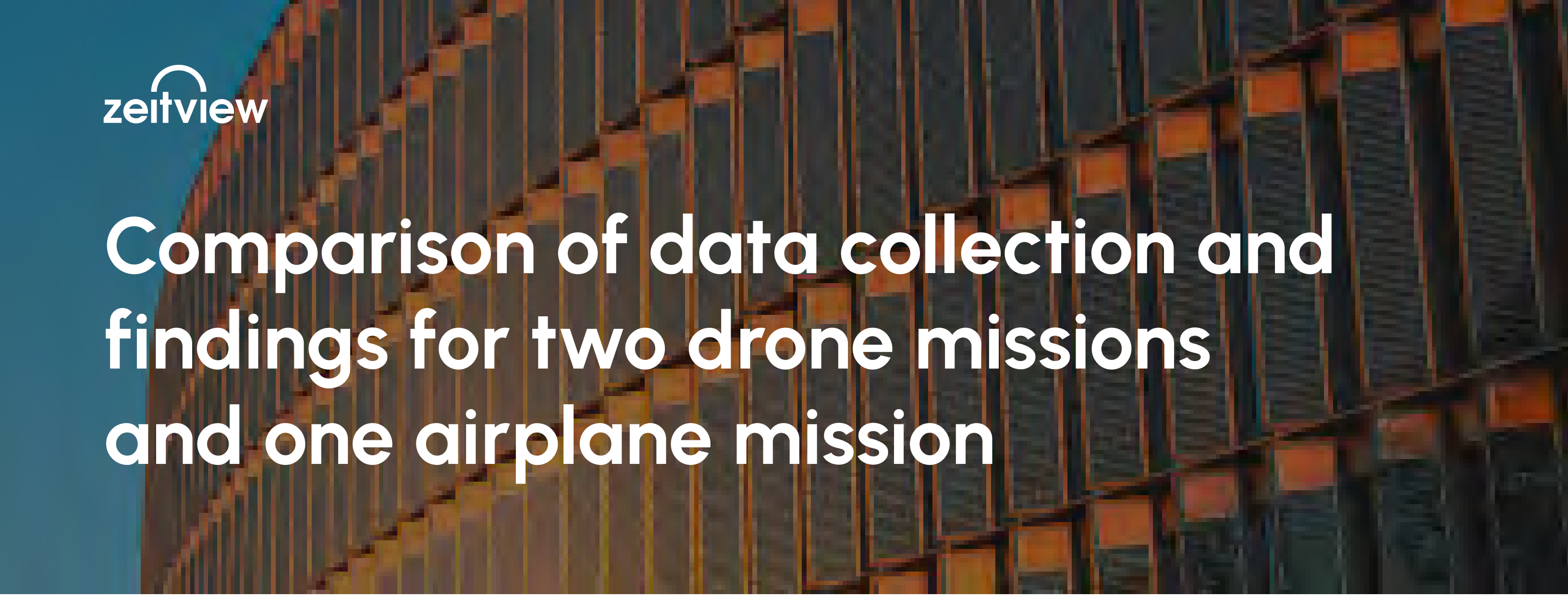
	UAV 3cm/px GSD	UAV 6.5 cm/px GSD	Aircraft 6.5 cm/px GSD
Single cell hotspot detection (2 examples)			
			

- Data for the drone sensing 6.5cm per pixel ground sample distance[3] (GSD) at first seemed to indicate underperformance compared to the other two aircraft in detecting modules with bypass diode anomalies.
- But a more in-depth review of the data showed that it was most likely external factors (differences in irradiation and temperature on different flight dates or times of the day) that caused this discrepancy.

INSIGHT

The quality of imagery and data is sometimes more affected by time of day or ambient temperature than it is by the choice of aircraft.

[3] Ground sample distance (GSD) is the amount of ground covered by each pixel in an aerial digital photo. The GSD represents the size of one pixel on the ground.



Comparison of data collection and findings for two drone missions and one airplane mission

	Drone mission 1 3cm per pixel GSD	Drone mission 2 6.5cm per pixel GSD	Airplane mission 6.5cm per pixel GSD
Facility capacity	1.5MW	1.5MW	5MW
Thermal sensor and infrared imagery specs	▪ 13 mm or 19 mm focal length ▪ 640 x 512 pixels resolution ▪ 50Mk sensitivity[4] ▪ Radiometric capability: *LWIR (long-wave infrared) sensor used, requiring lower flight altitude to capture precise temperature data*	▪ 13 mm or 19 mm focal length ▪ 640 x 512 pixels resolution ▪ 50Mk sensitivity ▪ Radiometric capability: *LWIR (long-wave infrared) sensor used*	▪ 100 mm focal length ▪ 1280 x 720 pixels resolution ▪ 20Mk sensitivity ▪ Radiometric capability: *MWIR (mid-wave infrared) sensor used, temperature data captured in every pixel of images*
RGB orthomosaic *(high-res photography)* specs	1.5 GSD	1.5 GSD	1.5 GSD

	Automated data collection time	Time on target[5]	Time on target	Time on target
	Data analysis time	100 minutes	85 minutes	45 minutes
Type and number of defects detected	Bypass-diode-activated module	66	59	66
	Isolated/underperforming module	73	73	73
	Missing module	4	4	4
	Multi-hotspot-affected module	1	1	3
	Single-hotspot-affected module	27	22	37

[4] Thermal sensitivity is the ability of sensors to detect temperature differences, measured in milliKelvins (mK). The lower the mK, the greater the precision in temperature data.

[5] The time required to inspect targeted assets during a scan. Drone time ranges from hours to weeks, and airplane time from minutes to hours, depending on facility size, flight speed, irradiation, ambient temperature and other factors.

Technology requirements for aerial solar inspections

There are three ingredients to getting accurate data and actionable insights from aerial inspections. First is the proper aircraft. For facilities producing more than 10 MW or spanning more than 45 acres, consider manned aircraft.

For sites this, drones such as the following models are in common use:

- DJI M300, M2EA M600, M210, M210 RTK
- DJI Inspire 1
- Any UAV capable of carrying an appropriate thermal sensor *(640 x 512 resolution, with radiometric capability, 13 mm or 19 mm focal length or 9 mm with M2EA drone)*

Second, the aircraft payload should include an RGB camera (minimum rating 18 megapixels, or 12MP if using a dual-camera sensor) and an infrared sensor. Available thermal sensors include: H20T; Zenmuse XT2 R and XT R; Flir Duo Pro R and Vue Pro R; Workswell Wiris; and Mavic 2 Enterprise.

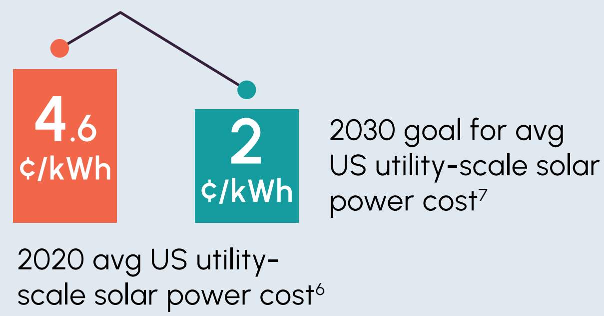
Data analysis capabilities are the third element. Organizations can hire a data expert to review and interpret ALL the imagery collected, which rapidly becomes infeasible as an inspection program scales. Another approach is to build a custom AI platform to automate much of the analysis. Or, operators can integrate a third-party solution built specifically for aerial inspections.

zeitview

Why Zeitview

The US Department of Energy has a goal to slash the cost of solar power generated by utility-scale facilities by more than half by 2030. Zeitview's technology produces insights that can help solar operators achieve this capacity, by maximizing output from every solar module.

The Zeitview Solar Insights platform combines intelligent aerial imaging and machine learning to optimize performance of assets over their full lifecycle—siting, development, engineering, procurement, construction, operations and maintenance, sale and decommissioning.



Leading data solutions for the global solar industry

- In-depth data analytics
- Automated identification of O&M issues with the greatest economic and power impacts
- Intuitive dashboard: advanced filters, reporting templates, access management
- Tens of millions of panels inspected
- Professional flight operations from a network of over 80,000 UAV operators worldwide
- A network of full-scale aircraft pilots across the US
- North American Solar Scan, a cost-effective solution for operators with large portfolios spanning multiple regions

[6] 2030 Solar Cost Targets | Department of Energy

[7] 2030 Solar Cost Targets | Department of Energy

Aerial Inspections for the Solar Array Lifecycle: A Quick Reference Guide

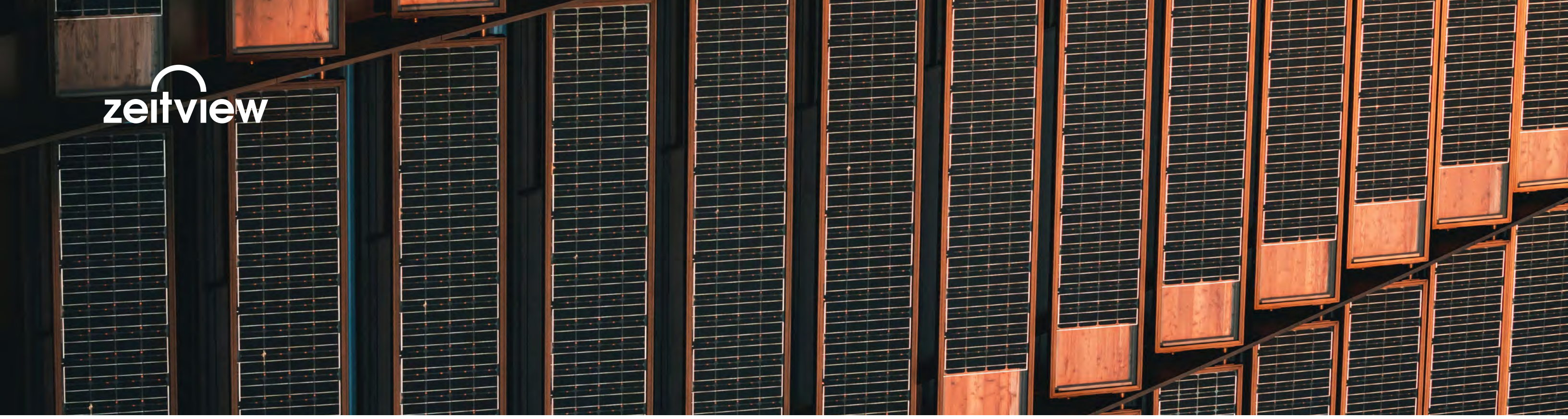
Zeitview's platform helps solar power operators manage assets over their full lifecycle—siting, pre-planning, engineering, procurement, construction, operations and maintenance, sale and decommissioning.

1. Using our flight management tool, drones or manned aircraft capture high-resolution aerial imagery and geolocation data for a site or facility.
2. A digital visual record of each solar module is created, for automated inventory management.
3. Periodic flyovers collect thermal and other data that are analyzed using machine learning, with anomalies automatically flagged for review.
4. Our dashboard calculates how much repairs will cost if not fixed, estimating revenue and kilowatt hour losses based on local energy pricing and the types and ages of panels.
5. Maintenance gets prioritized to tackle the most critical items first.
6. Reporting is simplified, with image-rich templates and advanced filters.

Here's our short guide to the many types of information that can be gathered by aerial inspections of solar equipment to optimize operations at every project phase.

Siting, pre-planning, engineering, procurement

- High-resolution topographic maps or 3D terrain models
- Data to compare potential acquisition sites
- Energy yield estimates
- Construction cost estimates
- How to fit the greatest number of PV modules
- Optimal panel angles given the terrain
- What tracking for panels is best
- Shade simulations and analysis



Construction

- High-resolution building progress imagery
- Equipment tracking
- Worker safety checks
- Perimeter security
- As-built assessments

Commissioning

- Inspection of every panel to verify working order
- Detection of defects to be corrected by install team
- Capture of baseline performance for warranty purposes
- Orthomosaic maps portraying the full facility
- 3D models (digital twins) of projects

Operations and maintenance

- Soiling (dirt, snow, dust)
- Tracker issues (off-tilt or off-angle panels)
- Cracks and micro-cracks
- Broken glass
- Delamination
- Snail trail
- Erosion at the base of mounts
- Panel shading (vegetation, buildings)
- Hot spots
- Diode short-circuit or burnout
- Shorted cells
- Reverse polarity (incorrect wiring)
- Fuse, junction box, array combiner, inverter failures
- Offline panel
- Faulty cables
- String outages
- PID (potential induced degradation)
- Cell browning/discoloring
- Transformer leaks
- Broken conduits
- Animal signs
- Vandalism
- Perimeter fence condition
- Power line condition

Sale

- Performance assessment of every panel (not just a sampling)
- Detection of defects
- Orthomosaic site maps
- 3D models (digital twins) of full facility

Decommissioning

- Imagery to prove out completion of site restoration

About Zeitview

Zeitview is the leading intelligent aerial imaging company for high-value infrastructure, providing businesses with fast, actionable, real-time insights to recover revenue, reduce risk, and improve build quality. Headquartered in Santa Monica, California, Zeitview serves customers in the solar, wind, insurance, construction, real estate and critical infrastructure industries. Trusted by the largest enterprises in the world, Zeitview is active in over 70 countries. Learn more at www.zeitview.com

Learn more about the value of aerial inspections:
https://zeitview.com/industries/solar