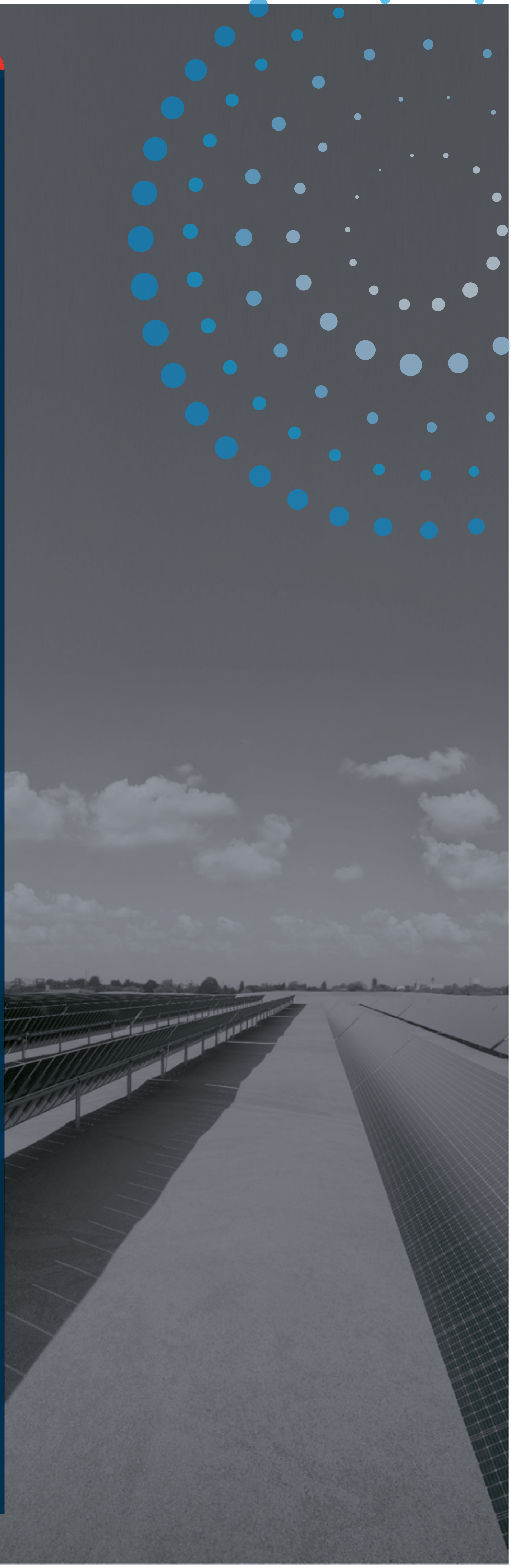
Tracker Development Solutions that Increase Reliability and Reduce Operation and Maintenance Costs

October 2021

White Paper



TrinaTracker

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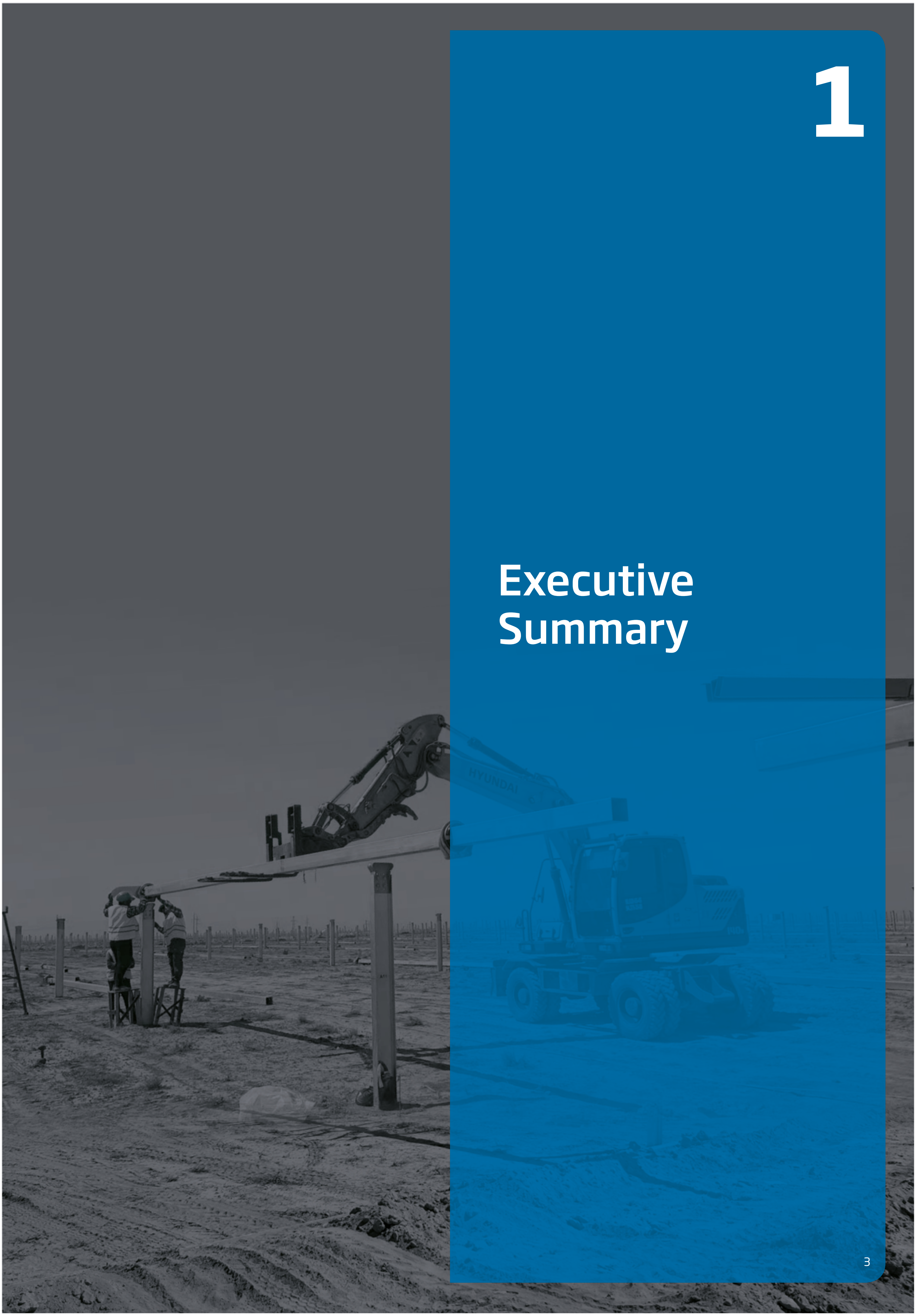
TrinaTracker



1

Executive Summary

1 Executive Summary

Availability

Uptime / Total Time. Availability can be applied to individual components or a system as a whole. When it applies to components, it is a simple calculation and the data is easily collected. On the other hand, calculating systems involves greater complexity since different components must be considered.

BNEF

Bloomberg New Energy Finance

Corrective Maintenance

= Unplanned Maintenance

CAD

Computer-Aided Design

CAPEX

Capital Expenditure

Direct O&M Activity

Operation and Maintenance activities implemented during the lifetime of the installation (Unplanned/Corrective Maintenance).

Estimated MTBF

Tracker uptime/number of tracker failures that occur during the operational phase of the plant.

FR

Failure Rate

FEM

Finite Element Method

FMEA

Failure Mode and Effects Analysis

Grid Parity

When alternative energy sources can generate power at a levelized cost of electricity (LCOE) less than or equal to the price of the existing electricity grid

Indirect O&M Activity

Actions taken during tracker engineering design and production to reduce direct O&M activities during the project's operational phase.

IRENA

International Renewable Energy Agency

IRR

Internal Rate of Return

LCOE

Levelized Cost of Energy

MTBF

Mean Time Before Failure" is defined as the average number of hours the tracker operates without failure. It may be constructed based on yearly data and will be bounded by statistical analysis. Each component of the tracker should have its MTBF clearly identified. Combining these data into one statistical metric will be done with an averaging scheme, representing the tracker as a system of components. Tracker documentation will describe the MTBF strategy in terms of this averaging.

NDCs

Nationally Determined Contributions

O&M

Operation and Maintenance

OPEX

Operating Expenditures

Preventive Maintenance

Regularly scheduled maintenance of the tracker implemented to prevent failure of the tracker components and tracker malfunctions.

PV

Photovoltaic

R&D

Research & Development

Regular Scheduled Maintenance

= Preventive Maintenance

Scheduled Battery Replacement

The standard period of the electro-mechanical guarantee of trackers is 5 years (more pertinently, including the batteries for the tracker self-power units). The schedule depends on the battery performance over the course of its lifetime.

TCU

Tracker Control Unit

Unplanned Maintenance

Tracker maintenance in regard to repair/ replacement of components or to prevent /repair tracker malfunctioning or underproduction.

> **O&M** costs and and long-term project reliability are crucial factors when evaluating tracker purchases. **TrinaTracker**, a leading tracker solution supplier that prioritizes customer- oriented products and service design, illustrates in this paper how its product design and post-interconnection procedures help to **reduce O&M cost and LCOE.**

The proportion of renewable energy in comparison with overall energy generation is rapidly increasing, contributing to the bulk of the reduction in greenhouse gas emissions needed to reach the environmental commitments of the **Paris Agreement** by 2050.

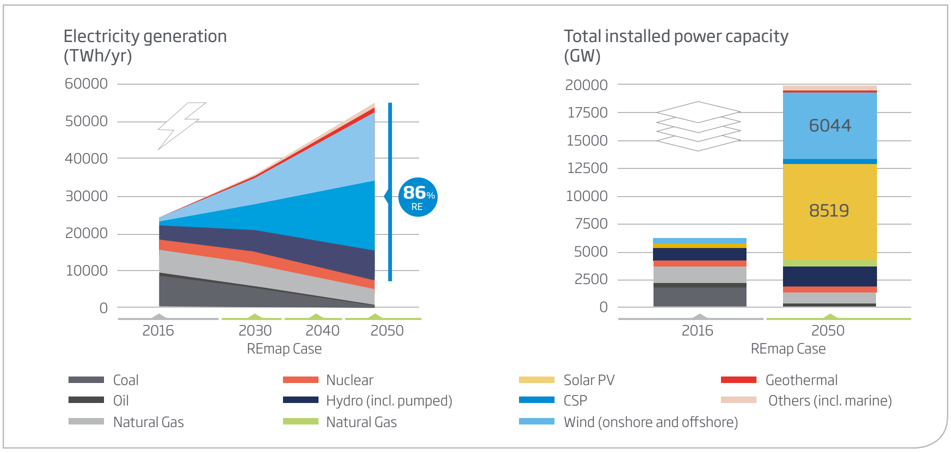
Moreover, according to the **International Renewable Energy Agency (IRENA)** the world added more than 260 gigawatts (GW) of renewable energy capacity in 2020, exceeding 2019 by almost 50 per cent.

Specifically, solar photovoltaic is estimated to generate a quarter (25%) of the total global electricity needs by 2050, becoming one of the top energy sources. The rapid increase of photovoltaic energy is mainly due to the innovations along the entire value chain that lead to higher energy production and accelerated **cost reductions**.

The steady **decline in LCOE** in large scale solar installations has already contributed to achieving grid-parity in many markets. In addition to energy production optimization, **O&M** costs and and long-term project reliability are crucial factors when evaluating tracker purchases. The average lifetime of solar installations is between 20 to 25 years. This means that the price that clients pay for operation and maintenance services can make a difference in the return of investment of the business.

TrinaTracker, a leading tracker solution supplier that prioritizes customer-oriented products and service design, illustrates in this paper how the design of its products and post-interconnection procedures help to **reduce O&M costs, LCOE and ensure high life-time reliability of the tracker systems**.

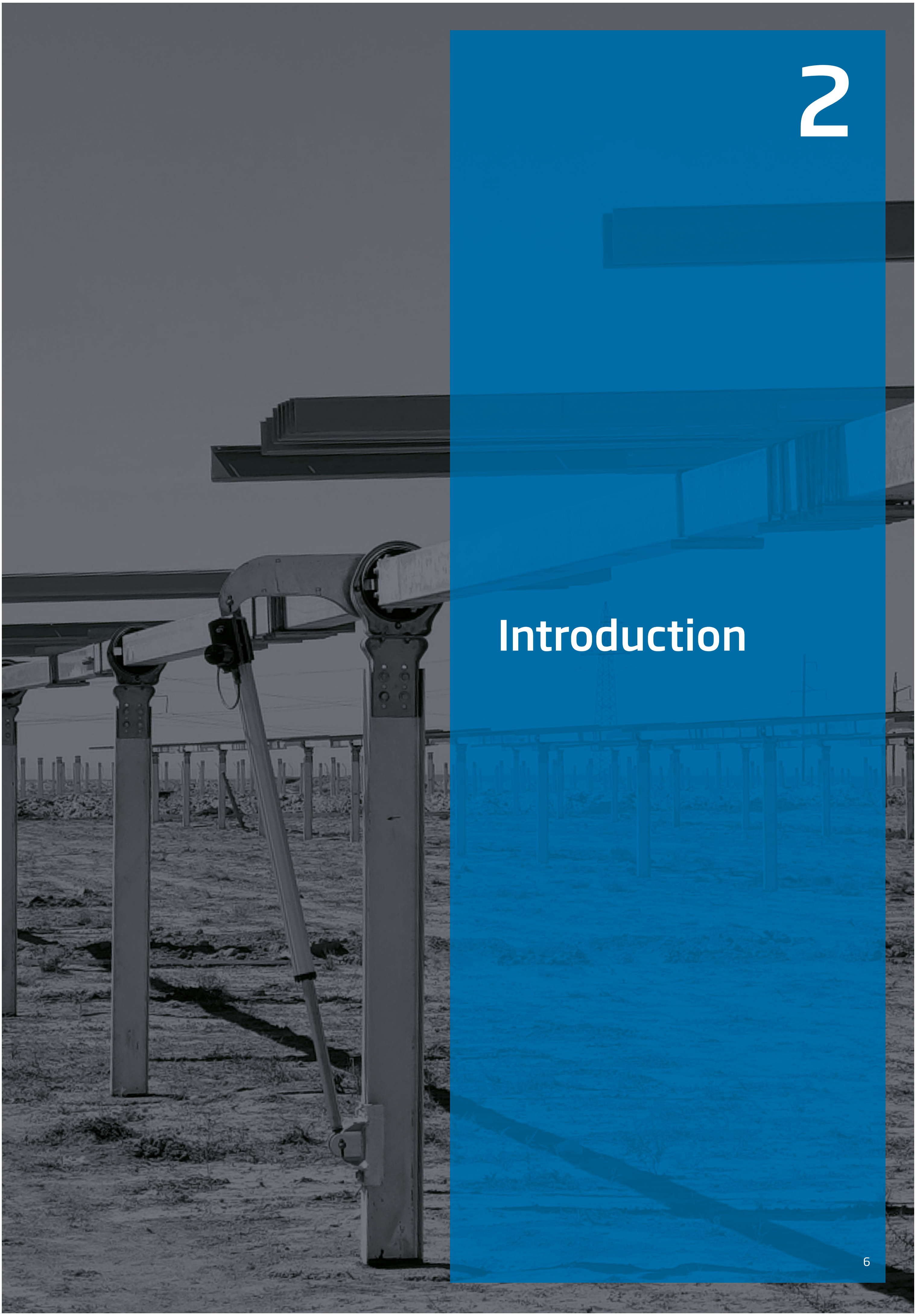
Renewable energy is growing in terms of proportion of global energy structure



IRENA VIew

PV electricity is leading the energy revolution. It is expected that global solar energy will reach **8519 GW** by 2050.
PV energy will definitely grow into the main energy with significant market potential and perspectives

Chart 1: Breakdown of electricity energy sources



2

Introduction

2 Introduction

The principal appeal of solar energy is its increasing cost-competitiveness, which, combined with the continually improving technology, guarantees low LCOE

The global energy landscape is undergoing a profound transformation. Clean energies have progressed at an unprecedented pace over the past decade. Renewables have consistently surpassed expectations, with new records and an increasing number of countries committing to their respective energy transitions.

One of the central element of energy transformation is the commitment by governments to implement the **Nationally Determined Contributions** (NDCs) driven by the **Paris Agreement**.

Bloomberg New Energy Finance (BNEF) estimated that between now and 2050, 77% of investments in new power generation would be in renewables. National policies, high energy production and reductions in operating costs are attracting investors to the clean energy market.

Specifically, **utility-scale photovoltaic energy** has become an attractive investment area since installation and interconnection times are short, and it involves low risk since energy production can be easily predicted.

However, the principal appeal of solar energy is its increasing **cost-competitiveness**, which, combined with the continually improving technology, guarantees low LCOE.

The selection of PV systems is therefore driven by their contribution to **lower LCOE**, which depends on their power generation capacity, installation cost and operating costs over the lifetime of the project.

Proper and well-planned preventive operation and maintenance activities are important to reduce failure rate and energy loss.

Operation and maintenance costs are important and have a critical impact on levelized cost of energy and profitability of utility-scale PV plants. While the expected lifetime of utility-scale solar PV projects has increased over time, the anticipated **Operating Expenditures** (OpEx) have decreased significantly.

Unlike the initial investment, operating costs are unstable and subject to external factors. They include scheduled and unscheduled maintenance, operations personnel, land lease costs, property taxes, and other ongoing operations costs.

$$\text{LCOE} = \frac{\text{Initial Investment} + \text{O\&M Cost}}{\text{Energy Production}}$$

O&M Costs of a Photovoltaic Installation

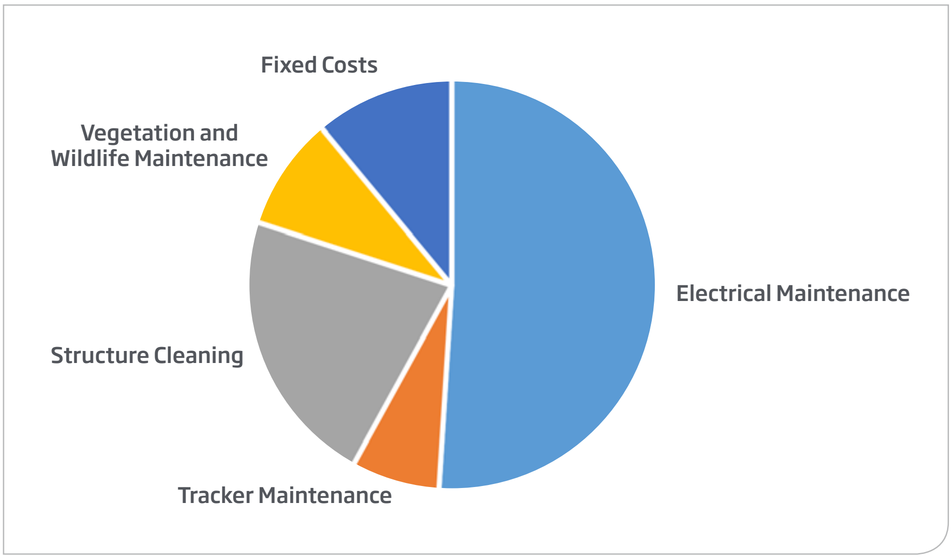
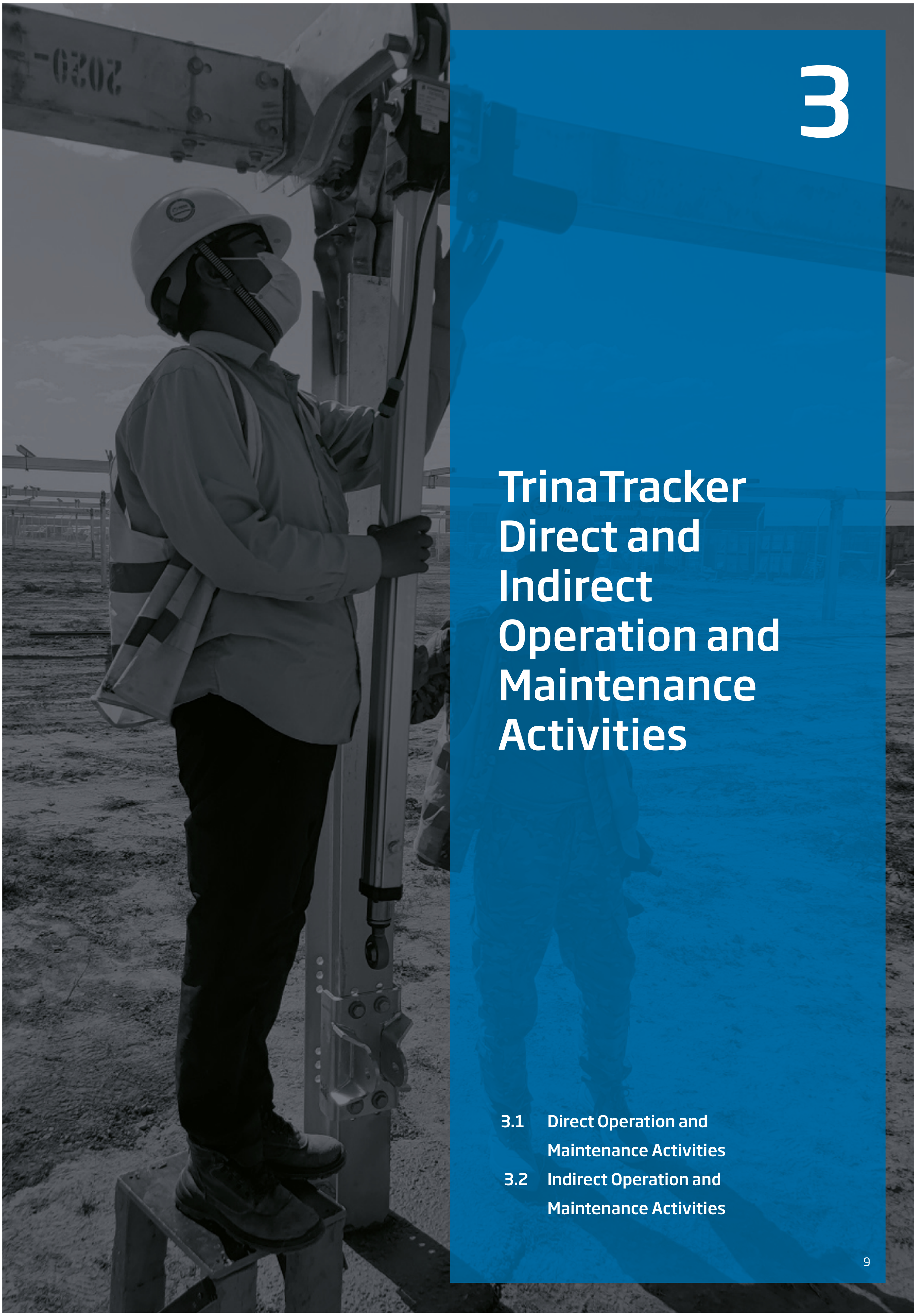


Chart 2: Average breakdown of operation and maintenance costs



3

TrinaTracker Direct and Indirect Operation and Maintenance Activities

3.1 Direct Operation and Maintenance Activities

Tracker operation & maintenance activities are classified as direct or indirect activities

Tracker operation & maintenance activities are classified as **direct** or **indirect activities**.

Direct operation and maintenance activities are all of the tasks associated with **preventive maintenance** that are implemented to avoid predictable tracker failures.

Direct activities include tasks such as greasing components, checking electrical and mechanical joints and supervising pile tolerances.

Tracker Operation & Maintenance Activities				
Type	**Component**	**Actions**	**Phase**	**Mitigation measures**
Direct	Preventive Maintenance of Motor	Grease Motors	Operation	Reduction of (N° Motors/MWp)
Direct	Preventive Maintenance of Actuator	Grease Actuator	Operation	Reduction of (N° Actuators/MWp)
Direct	Preventive Maintenance of Bolted Joints	Checking torque tightening values	Operation	Reduction of (N° Bolted joints/MWp)
Direct	Preventive Maintenance of Bearings	Visual checking	Operation	Reduction of (N° Bearings/MWp)
Direct	Preventive Maintenance of TCUs	Check Electrical & Mechanical connections	Operation	Reduction of (N° TCUs/MWp)
Direct	Motor Overconsumption	Supervise correct pile tolerances	Assembly	Pile section and new bearing design
Direct	Sensors package	Check Electrical & Mechanical connections	Operation	

Table 1: Example of direct Tracker operation and maintenance activities

Activities carried out to solve component failures or malfunctions are categorized as **corrective maintenance or unplanned maintenance activities**. When motor overconsumption occurs, reducing the lifetime of the installation, the activities carried out to resolve this issue are considered corrective maintenance or unplanned maintenance activities.

All corrective activities have associated costs that have an impact on the LCOE of the plant. The costs of electro-mechanical or mechanical components that resulted in tracker failure can be classified as:

1. **Cost of the component replacement**, including labor, supply and logistics costs.
2. **Cost of lost energy production** while the tracker is not operating.

Smart control and monitoring

TrinaTracker SCADA is a next-generation smart tracker control system that enables PV power plant owners and authorized operators to monitor and securely control their PV systems. This enhanced control system increases production yield and enables reliable operation across a wide range of weather conditions.

Numerical Solar Tracker Solution

The existing solar tracker is intelligently transformed, so that the traditional solar tracker is not only a power device for improving the power generation of photovoltaic modules, but an intelligent tracking solution integrating intelligent tracking, remote control, data acquisition, online analysis, intelligent operation.

Centralized Intelligent Operation

With the help of digital technology, the digital solar tracker solution provides global-oriented, integrated and full-process automatic management and operation means, improves the operation efficiency of the solar tracker and reduces the maintenance cost, which make it is possible to centralize intelligent operation of the global mass tracking support, and give full play to the scale operation effect.

Image 1: SCADA Dashboard

3.2 Indirect Operation and Maintenance Activities

Indirect O&M Activities associated to the tracker are the **compatibility of Module Cleaning System** (robot/machinery) with tracker design and the **Ground-Module Clearance**.

- **The Module Cleaning System** must be considered during the tracker design process to ensure compatibility. It typically has a low-cost impact on the tracker's CAPEX and high effectiveness in energy production during operation.
- **The Ground - Module Clearance** will determine the frequency of herbicides campaign and O&M Costs derived from one or other value.

Tracker Operation & Maintenance Activities			
Type	**Component**	**Actions**	**Phase**
Indirect	Modules Cleaning	Compatibility between Tracker - Cleaning Robot	Design
Indirect	Grass Height	Herbicide campaigns	Design

Table 2: Example of indirect Tracker operation and maintenance activities

Machinery Cleaning

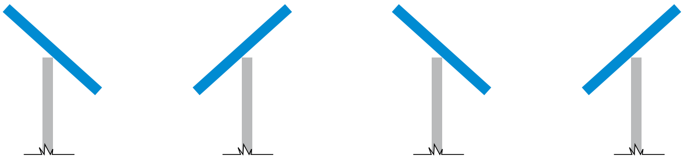


Image 2: Vanguard 2P optimal tracker position

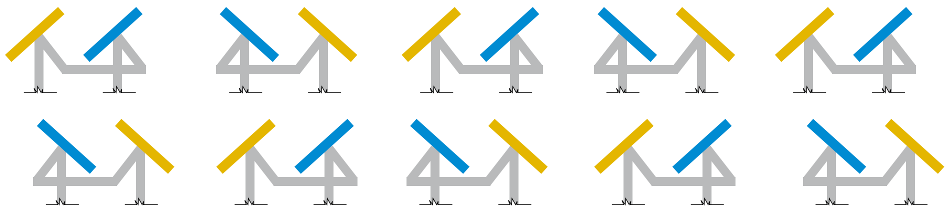


Image 3: Agile 1P optimal tracker position

Dual-row trackers can enable cost-effective cleaning by placing adjacent trackers in reverse tilt and cleaning adjacent rows on different trackers that face each other, before reversing the tilt and cleaning the remaining rows.

Design Compatibility with Robot Cleaning

TrinaTracker worked in collaboration with established cleaning robot companies to co-design a quality robot-integrated solution.

Although implementing the **TrinaTracker** cleaning robot solution has higher impact on the project's CAPEX and OPEX than traditional cleaning, the robot also helps achieve **higher energy production and IRR**.

Customized design

Assembly Supervision

Bridge and Robot Testing

O&M Supervision

4

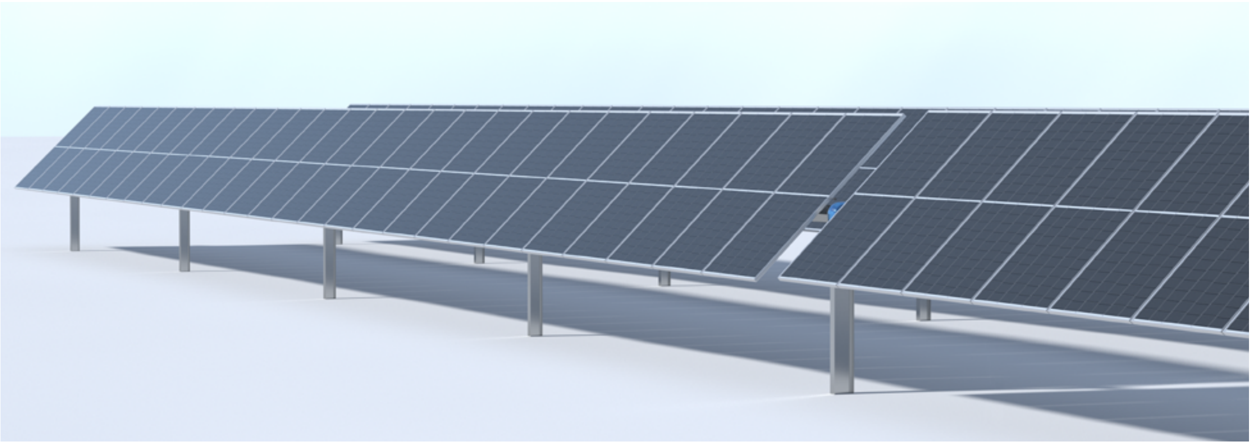
Components Reduction and Design Improvement

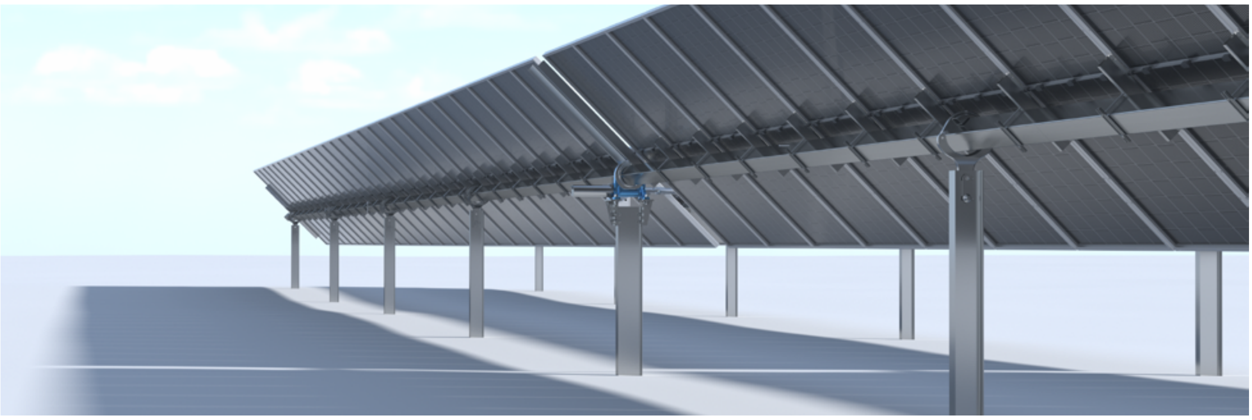
4.1

Reducing Component Quantities

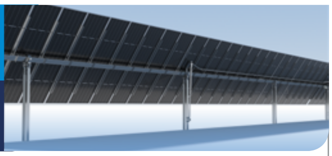
Reducing the number of components leads to a decrease in operation and maintenance service activities and cost. The optimization of the quantities of certain components can therefore have a significant impact on LCOE.

1. **Nº Motors** per **MWp**
2. **Nº Actuators** per **MWp**
3. **Nº Bearings** per **MWp**
4. **Nº TCUs** per **MWp**
5. **Nº Bolted joints** per **MWp**





Decrease of components in Vanguard 2P upgraded design compared to the previous 2P model



- Each **Vanguard 2P** tracker can handle **0.062 MW (+101%)** compared to 0.031 MW installed in the previous 2P series.
- **17 Vanguard 2P** trackers are enough to complete **1 MW (-50%)**, compared with 33 previous model 2P trackers required to complete the same capacity.
- Tracker weight was reduced **(-16%) per MW**, from previous 2P model (≈ 59.60 ton) to **Vanguard 2P** (≈ 49.60 ton).
- The reduction of critical tracker components per MW is:
  - Bearings **(-49%)**
  - Motors **(-50%)**
- Bolted joints per MW (which are potential failure points) have a **26%** decreased in units in the new **Vanguard 2P**.
- **Vanguard 2P** design is compatible with large-format modules 550 to 600+Wp. Therefore, less number of modules are needed for the same installation capacity.

TrinaTracker has achieved a considerable **reduction in failure rates** by updating its previous 2P model with a new tracker design that incorporates smaller number of components. This means that the upgraded **Vanguard 2P** requires less mantenance activities, lower **O&M** expenditure and lower power loss as consequence of discontinue periods of operations for reparing or replacing tracker components in comparison with the previous 2P traker model.

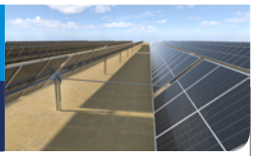
Tracker	Module (Wp)	Module (N°/Tracker)	Power (MWp/Tracker)	Nº Trackers / MWp	Weight (Kg/MWp)	Bearings (N°/MWp)	Motorized Actuators (N°/MWp)	Total Actuators (N°/MWp)	Motors (N°/MWp)	Joints (N°/MWp)
Previous 2PX45	340	90	0.031	32.68	59,641	261.4	32.7	32.7	32.7	19,608
Vanguard 2PX56	550	112	0.062	16.23	49,656	132.9	16.2	53.2	16.2	14,844
Comparison between previous 2P and **Vanguard 2P**	61.8%	24.4%	101.3%	-50.3%	-16.7%	-49.1%	-50.3%	62.8>%	-50.3%	-24.3%

Table 3: Comparison between Vanguard 2P and previous 2P model regarding quantity of components

(*) Data taken from BOM, Procurement Plan and Technical Set of Drawings corresponding with a typical distribution of outer (32%), border (46%) and inner (26%) trackers.

(*) Data is for the purposes of illustration, based on a typical distribution.

Decrease in components in Agile 1P upgraded design compared to design of the previous 1P dual-row model



- **Agile 1P** tracker can handle **0.061 MW (+50%)** of power compared to 0,041 MW installed in one previous dual-row tracker.
- **16 Agile 1P** trackers are sufficient to complete **1 MW (-33%)** compared to the 25 trackers required for the previous version of 1P dual-row series.
- The reduction of critical tracker components per MW is:
  - TCUs **(-33%)**
  - Bearings **(-11%)**
  - Motors **(-33%)**
- Bolted Joints (which are potential failure points) have a **33%** decreased in units per MW in new **Agile 1P**
- **Agile 1P** design is compatible with large-format modules 550 to 600+Wp. Therefore, less number of modules are needed for the same installation capacity.

TrinaTracker has achieved a considerable **reduction in failure rates** by updating its previous 1P dual-row model with a new tracker design that incorporates less number of components. The upgraded **Agile 1P** requires less maintenance. Consequently the new optimized tracker achieves higher energy production and lower **O&M** cost due to the reduction of discountinued periods of operations dedicated to corrective maintenance.

Tracker	Module (Nº/Tracker)	Power (MWp/Tracker)	Nº Trackers / MWp	Weight (Kg/MWp)	Bearings (Nº/MWp)
Previous 1P dual-row	74	41	0,02	1.832	294,8
Agile 1P	111	61	0,02	2.668	262,1
Comparison between **Agile 1P** and previous 1P dual-row model	50,0%	50,0%	-33,3%	45,7%	-11,1%

Table 4: Comparison between **Agile 1P** dual-row and and previous dual-row model regarding quantity of components

(*) Data taken from BOM, Procurement Plan and Technical Set of Drawings corresponding with a typical distribution of outer (32%), border (46%) and inner (26%) trackers.

(*) Data is for the purposes of illustration, based on a typical distribution.

4.2 Design Improvement

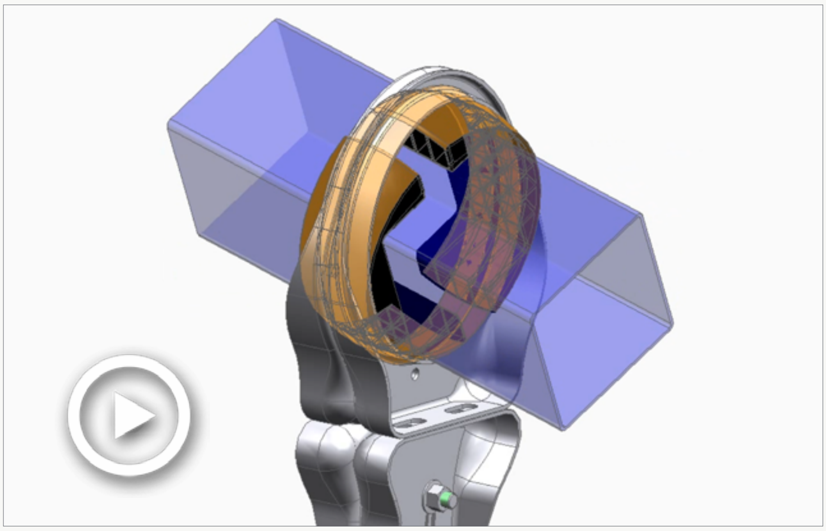
Piles

- C-shaped piles were removed in New model **Vanguard 2P**x56 design and foundations are designed with W shapped piles reducing failure rate associated with motors and bearings.
- New W shapped piles prove to have more stiffness while more robust, improving final result of pile driving process and reducing the quantity of "out-of-tolerance" piles.
- C shaped piles installed in previous 2P tracker model were:
  - Highly deformable both, bottom side, while penetrating in the ground and top side, because of ramming bumping process
  - Source of defective unions with Bearing Supports due to out of tolerance (twisting & plumbness) results after ramming process, producing failure subsequently.
  - Source of motor overconsumption and lifetime reduction due to extra-power used for sun tracking. This is due to piles out of tolerance (twisting & plumbness).
  - Source of undesirable noises whilst tracking, in operational phase.

Optimized Spherical Bearings and Bearing Joints

Vanguard 2P upgraded bearing design:

- **TrinaTracker** patented three-dimensional spherical bearing has proved its realiability by having reported no failure rates since it was first installed nearly one a half decades ago in the 11MW plant in Zuera, Zaragoza. Moreover, spherical bearings have been continuously optimised.
- Along with the changed of C shapped piles and directly associated to it, bearing supports and bearings were redesigned to make the joint more efficient, because activity is not always easily predictable and these joints required dedicated and continuous maintenance.
- The union of lower bearing support to W pile is designed with circular holes instead of slotted holes. Movement is restricted and durability of these unions much longer.
- Upper bearing support is designed as one single piece, reducing upper flange pieces and failure points.
- The component is made of polyamide with fiberglass, which rotation axis sliding while selflubricating when trackers move.
- **TrinaTracker spherical bearing** it self-maintenance. It reduces the number of **O&M** tasks and cost during the operation phase of the plant.



Video 1: Spherical bearing movement on three axis

Image 4: Previous Spherical Bearing

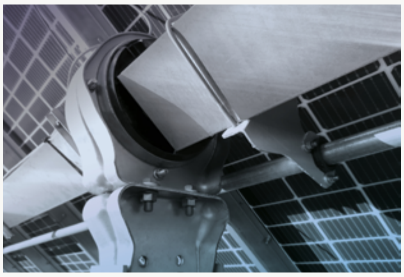


Image 5: New Spherical Bearing

Torque Tube

- Larger modules mean higher torsional moments on the tracker rotational axis. The torque tube of the upgraded tracker includes a larger cross-section, increased thickness and strength. A sturdy torque tube brings higher natural frequencies to the system avoiding dynamic effects. The new design **increases the torque tube dimensions by 28%**.
- The design of the most complex elements of the tracker is configured with the implementation of **"The Finite Element Method."** This analysis identifies those areas of stress concentration that need a change in thickness or reinforcement.
- The Finite Element analysis is not sufficient to validate the modifications made in the trackers since **FEM calculations** are often done over an isolated part of the system.
- Therefore, the results that represent the impact of deformations in the other parts of the structure exposed to loads are not 100% realistic. Consequently **full-size load tests** are performed to obtain this type of data.

Multi-Drive System

- The torsional locks and the torque tube in **Vanguard 2P** reduce torsional spans, increase natural frequencies and damping and prevent torque tubes from twisting. Longer trackers with 1P and 2P configurations lower torsional stiffness. Therefore, **multi-drive systems** are adopted to effectively reduce **torsional loads** from **buffeting**.
- TrinaTracker' assembles experimental trackers in its **own facilities** to verify the adequate performance of the system, test multi-actuators, and ensure that energy consumption and load tests are performed under different conditions.

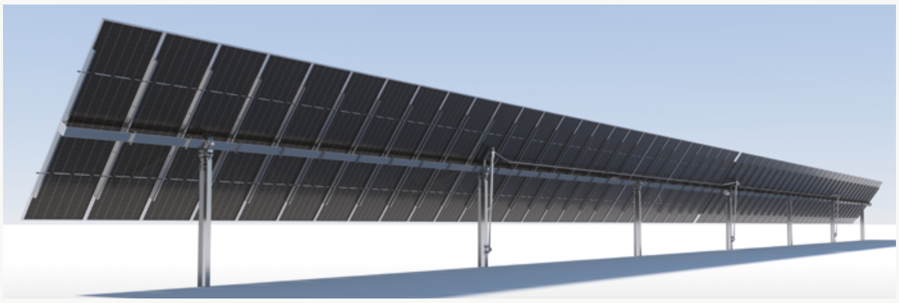


Image 6: Vanguard 2P with multi-drive system

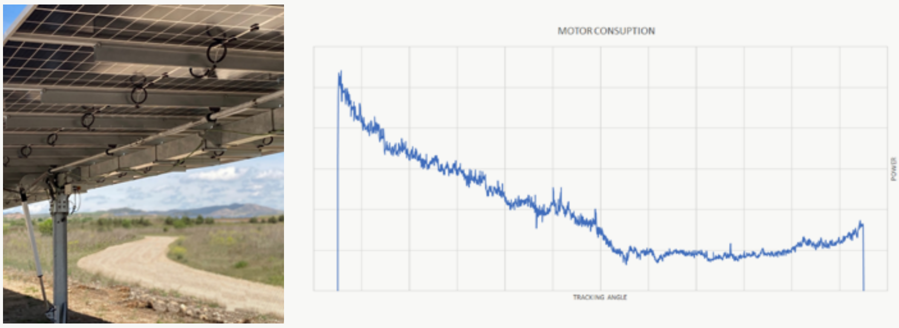


Image 7: Tracker testing under beta site conditions

Optimized Purlins

- Critical challenges in pv installations include achieving optimal combinations between mechanical loading and large-format modules.
- The use of **purlins** in solar trackers provides **extra rigidity** to the modules. With the introduction of large-format modules purlins are redesigned to **optimize steel usage** in **Varguard 2P**.
- Dynamic effects are also well known for causing purlin fastenings to torque tubes to become loose due to vibrations. **Sturdy purlins** prevent modules from micro-cracking and loosening.

Image 8: Reinforced purlin design

Control Units

Agile 1P and **Vanguard 2P** include high-tech control units

The **TrinaTracker**'s components associated with communications are continuously evolving to accommodate the latest industry trends.

TrinaTracker new **"SuperTrack"** algorithm increases yield generation up to 8%.

- Maintenance is currently very low and only simple checking is needed.
- Software updates and the most frequent problems affecting TCUs can be solved remotely, resulting in an enormous operational cost savings.

These devices are moving towards higher efficiency, and in the near future, it might be worth replacing old component in older generation trackers installed in plants. The cost of replacing the components will be offset by higher energy production.

5

Preventive Design, validation & Quality Control

5.1 Product Design and Validation Methodology

Agile 1P and **Vanguard 2P** components are validated by **TrinaTracker** Research and Development Department (R&D). Prior to validation, controllers, drive systems and structural components are tested and evaluated following a **strict methodology** to meet internal and external quality standards, support loads and operate efficiently.

Preventive Design

Design

The components are designed by **TrinaTracker** must fulfil internal quality requirement, third party validations and industry standards. **TrinaTracker**'s engineers design the tracker's elements using advanced "**CAD**" (Computer-Aided Design) advanced software extensively used for mechanical design.

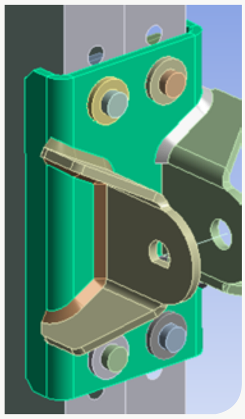


Image 9: Graph designed with CAD

Methodology to Validate Structural Components

FEM (Finite Element Method) Calculation

When the design is approved, it has to be also subjected to an **FEM** study, where engineers apply the loads obtained from different calculations to simulate the real and specific conditions that the tracker will encounter at the site.

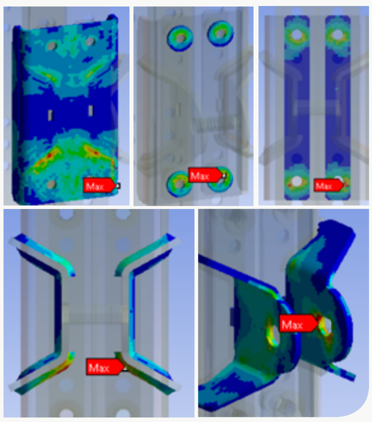


Image 10 (1, 2, 3, 4, 5): Example of FEM calculation

Joints Calculations

All joints in the trackers are calculated to meet the UNE-EN 1993-1-8:2013 standards.

$F_{v,Rd}$	60288	N
a_v	0,6	
f_{ub}	800	
A_s	157	
Y_{M2}	1.25	
Bolt metric	16	
Bolt grade	8.8	
% use	42%	

Failure mode	Bolts	Rivets
Shear resistance per shear plane	$F_{v,Rd} = \frac{a_v \ f_{ub} \ A}{Y_{M2}}$ - Where the shear plane passes through the threaded portion of the bolt (*A* is the tensile stress area of the bolt A_s): • for classes 4.6, 5.6 and 8.8: a_v=o,6 • for classes 4.8, 5.8 and 10.9: a_v=o,5 - Where the shear plane passes through the unthreaded portion of the bolt (*A* is the gross cross section of the bolt): a_v=o,6	$F_{v,Rd} = \frac{0{,}6 \ f_{ur} \ A_o}{Y_{M2}}$

Stow Strategy Definition

Different stow management strategies are defined, taking into consideration the configuration of the tracker, location of the project or meteorological conditions of the site.

Wind Stow Strategy to Mitigate Negative Pressure on Module

In the 1P configuration, the stow position at high tilt angle has been chosen.

This position **minimises the dynamic effects** despite high wind pressure on modules.

In the 2P configuration the stow position is set at a low tilt angle. In this position the dynamic behaviour governs the design and the maximum pressure on the PV panels is minimized. To avoid any aeroelastic instability, **multi-drive system** is installed.

The multi-drive system fixes the torque tube in different points multiplying the torsional frequency by three compared to the traditional one-fixed point 2P configuration.

Image 11: Snow load

Video 2: Snow Storm

Snow Stow Strategy to Mitigate Positive Pressure on Module

Solar installations are expanding in areas where snow in abundant and frequent for several months of the year, like, for example, the regions located in Northern Europe and the American North.

Therefore, snow load pressure on modules becomes the greater challenge to overcome and a critical factor that defines tracker design.

Potential issues triggered by snow loads are mitigated with the integration of snow sensors as part of the sensor package which, connected to the NCU, governs tracker behavioiur and movement toward the stow position when any of the snow sensor is activated due to severe weather conditions, avoiding unnecesary risks for the system.

In the case of snow cumulation detection by snow sensors, the alarm will be activated and trackers will rotate accordingly to avoid snow accumulation.

The strategies are focused on the correct rotation of the trackers to avoid snow accumulation.

Hail Stow Strategy to Mitigate Damages

The impact of hailstorms on modules becomes a significant problem in certain regions in China and the US, for example. The consequences of hailstorms could be detrimental to PV installations.

Alarm systems are integrated in the project designs.

Testing

Actual prototypes of the components are physically reproduced and subjected to the loads the systems will support when they are installed.

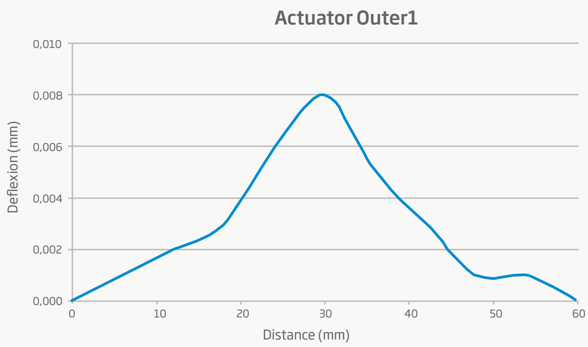


Image 12 (Photo & Graph): Prototype tested and results

Validation and Documentation

The tracker components receive their validation and documentation only after they successfully pass the required high standard laboratory tests, trials and mock-ups.

Wind Tunnel Test

To validate the tracker stability, **Vanguard 2P and Agile 1P** scale prototypes were reproduced and subjected to static, aeroelastic, and dynamic loads via wind tunnel tests performed by wind engineering con-sultancy firms CPP and RWDI.

These tests comprised **Pressure Model Wind Tunnel Research, 2D Sectional Model Test & Numerical Models**, and an additional Full Aeroelastic Model Test.

The **Pressure Model Test** made it possible to obtain a more accurate definition of the static coefficients for different distance between rows, ground clearance, pile separation or tracker length. Further-more, by adding data obtained from the Modal Analysis (natural frequencies) and the Free Vibration test (damping ratios) the DAF (Dynamic Amplification Factor) was attained.

The **2D Sectional Model** enabled Aerodynamic Stability Analysis and Buffeting Response Analysis to be carried out using Numerical Models. The advantage of the data gained from the 2D sectional model is that the results were applied to a wide range of tracker dimensions.

The **Numerical Models'** output was verified by comparing the results in the numerical model and the results in the full aeroelastic wind tunnel test.

The wind tunnel tests evaluated the reactions of the main structural elements (piles, torque tube and purlin) and con-necting components (bearings and drives) to the wind loads.

With results from the wind tunnel tests, the company determined the wind loads of the main structural elements (piles, torque tube and purlin) and connect-ing components (bearings and drives) and provided the output to upgrade the tracker designs and achieve more accurate adaptability to the sites.

SBP ratified the calculation procedures that TrinaTracker adopted, with the output gathered from the wind tunnel tests.

Upon these tests, the tracker series was optimized to ensure reliability and adaptability of all the system components.

The designs were reviewed and included more robust piles, purlins that add rigidity to the modules, stiffer torque tube, different stow strategies for 1P and 2P configurations, tailored tracker layout, and multi-drive systems.

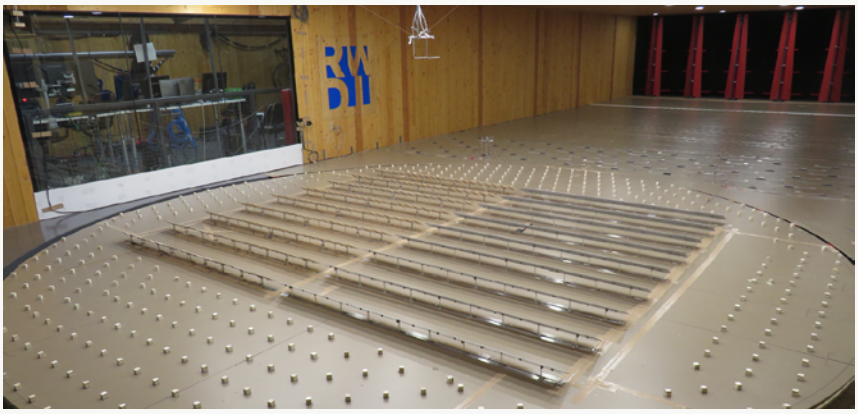


Image 13: Full aeroelastic model test

Tracker Control Unit

Control components and their functions are tested internally to ensure reliability and mitigate dysfunctional risks and they also must comply with industry standards and certifications

IEC 6100

- Conducted radio-electric emissions.
- Electrostatic discharge immunity
- Radiated, radio-frequency and electromagnetic field immunity
- Electrical fast transient/burst immunity
- Surge immunity (class 3)
- Immunity to conducted disturbances and induced radiofrequency fields
- Immunity for industrial environments

Photovoltaic Systems

- Design qualification of solar trackers

Saline mist accelerated corrosion

- 450 hours in accelerated test

CE Mark

IEC 61010

- Safety Requirements for Electrical Equipment for measurement, control and laboratory

Enclosure Testing

- Water/dust ingress category
- Impact category2

Image 14: Tracker control unit

Slewing Drive Test

TrinaTracker always runs slewing drive testing combining the drive with all of the components in relation to all the rest of the tracker elements, ensuring optimum operation of the system under extreme conditions.

Datasheet Specifications

- Slewing drive + motor requirements sheet
- IP Class 65
- -40°C ~+80°C

IEC Testing Requirements

Environmental Test

The tests are performed in a chamber with extreme temperatures. Life cycles are carried out to guarantee operation efficiency.

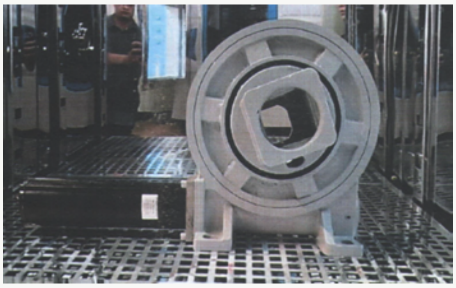


Image 15: Environmental test

Static Maximum Holding Torque

This test verifies the drive's static load performance (holding torque and safe factor. When thrusting with a hydraulic oil cylinder 1.5m away from the center of the slewing drive and the sensor shows a thrust force to 2,600KG, the actual holding torque is raised to a maximum. This situation must be maintained for one minute and repeated 3 times.

Image 16: Static maximum holding test

Slewing Drive Test

Dynamic Maximum Load Test

The tracker motor consumption is logged with and without extra weight during tracking rotation to obtain different parameters, including power consumptions relationship, efficiency and speed influences.

Image 17: Dynamic maximum load test

Maintenance

TrinaTracker products have been injected with sufficient grease before they leave the factory. Temperature is -4°C~+80°C

- Lubrication must be checked every five or six years when the plan is operating
- Lubrication must be applied after 10 years and according to the product condition
- Grease must be continuously injected through the plug hole while the slewing drive is rotating
- The actuator could be damaged or have its lifespan reduced if sufficient lubrication is not applied.

Functional Tests Performed on the TCU + Mechanical Drive

Functional Test Performed on the TCU + Mechanical Drive

To verify the correct operation of the tracker it is necessary to perform some tests to see the strong compatibility between the different TCU and Slewing drive.

IEC 62817 Testing Requirements

In the part that refers to the tracker structure, only some of the different tests referred to in the regulations need to be performed:

Tracker Accuracy Measurement

Tracker Accuracy Calculation

Visual inspection

Validation of Functional Tests

- Verification of tracking limits
- Limit switch operation
- Automatic sun tracking after a power outage and shadow on the feedback sensor
- Manual Operation
- Emergency stop
- Maintenance mode
- Operating temperature range
- Flag wind, snow, hail and stow

Performance Test

- Daily energy and peak power consumed.
- Flag time, flag energy and maximum power

Mechanical Tests

- Repeatability test of the aiming control of the pointing system drive
- Deformation under the static load test
- Torsional stiffness, mechanical displacement, engine torque, and backlash tests
- Moment under extreme wind load

Mechanical Tests

Accelerated Mechanical Cycles

Accelerated life tests are carried out on prototypes with the conditions of 10-year operating trackers and 3,650 cycles. All data is recorded, and all components are checked periodically.

Image 18: Accelerated mechanical cycles

5.2 Quality Control

TrinaTracker ccontinuously evaluates and measures the quality of the components over the entire product **lifetime** of the system. Failure rates are established in the first stage of product design (e.g. the failure rate related to the motor, control box, driving system, battery and bearing).

This approach aims to mitigate failure risks before the commissioning of the solar installation plant.

Additionally, TrinaTracker's critical factor to ensure efficient performance and minimum service maintenance is to establish a minimum required **quality level** for the tracker components. TrinaTracker carries out in-house and external inspections to ensure that all components meet the agreed quality standards.

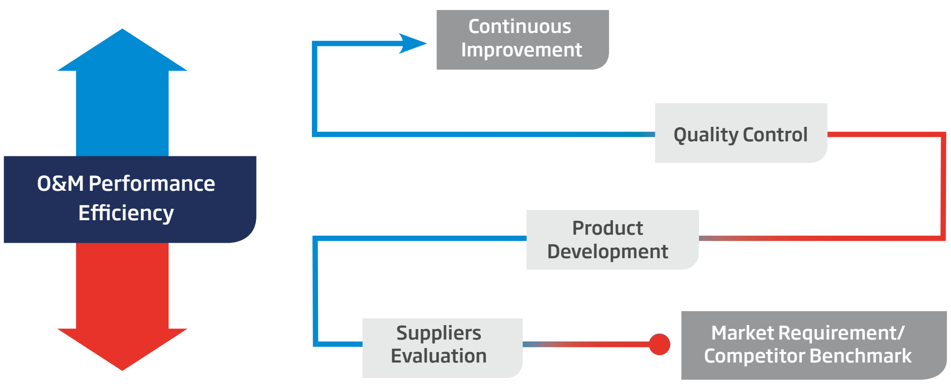
The main components inspected are:

Main Inspected Components

Piles (W)	Made of S355JR carbon steel, suitable for hot-dip galvanizing, or another steel quality suitable for subsequent treatment for protecting it against corrosion. W profiles in the U.S. must be manufactured and inspected according to the dimensional tolerances established in the standard ASTM A6/A 6M. The galvanizing coating must comply with the standard UNE EN ISO 1461 or ASTM A 123.
Torque Tubes	Made of S355JR carbon steel, suitable for hot dip galvanizing, or another quality of steel appropriated for a subsequent protecting treatment to avoid corrosion. They are manufactured and inspected according to the dimensional tolerances reflected in the standard: UNE EN ISO 10219. The galvanizing coating comply with the standard: UNE EN ISO 1461 or ASTM A 123. In specific project, due to terrain characteristics or due to contractual agreements, corrosion protection other than hot dip galvanizing may be used, for example regalvanization. In this case, the coating must conform to the standard: UNE EN ISO 10346.
Purlins	Made of carbon steel suitable for Zinc-Magnesium (ZM) alloy coating against corrosion, usually S350GD steel. They must be manufactured and inspected according with the dimensional tolerances reflected in the standard: UNE EN ISO 10162. The ZM coating must comply with the standard UNE EN ISO 10346.

Screw	Made of carbon steel. They must be manufactured and inspected according to the dimensional tolerances stated in the standard: UNE EN ISO 4759. Carbon steel screw needs additional coatings for protect them against the corrosion: Zinc-Nickel coating + seal, according to the standard: UNE EN ISO 4042.
Bolts	Made of type 8.8 carbon steel, according with the standard UNE EN ISO 898-1. Mechanical and chemical properties must meet requirements established at UNE EN ISO 898-1.
Nuts	Made of type 8 carbon steel class, according to the standard: UNE EN ISO 898-2. Mechanical properties meet requirements in: UNE EN ISO 898-2. Chemical properties comply with standard DIN 267-4.
Washers	Made of type A carbon steel. Mechanical properties meet requirements stated in: UNE EN ISO 7089 and UNE EN ISO 7090. Chemical properties comply with the standard: DIN 267-26 and DIN 17221.
Mechanical Parts	Usually made from S275JR, S355JR or greater carbon steel, suitable for hot dip galvanizing, centrifuged, or made for carbon steel suitable for Zinc-Magnesium (ZM) alloy coating against the corrosion, usually S350GD steel. They are manufactured and inspected according with the dimensional tolerances stated in the standard: UNE EN ISO 22768. Hot dip galvanizing coating must comply with the standard: UNE EN ISO 1461 or ASTM A 123. The ZM coating fulfils the requirements established in the standard UNE EN ISO 10346.
Trina Clamp	A component specially designed by TrinaTracker. This element improves the tracker performance and decreases failure rate, reducing operation and maintenance services during the lifetime of the installation, and subsequently lowering costs.

TrinaTracker's preventive maintenance methodology and quality control reduces the failure rate of components and therefore the required operation and maintenance services and costs during the lifetime of the installation.



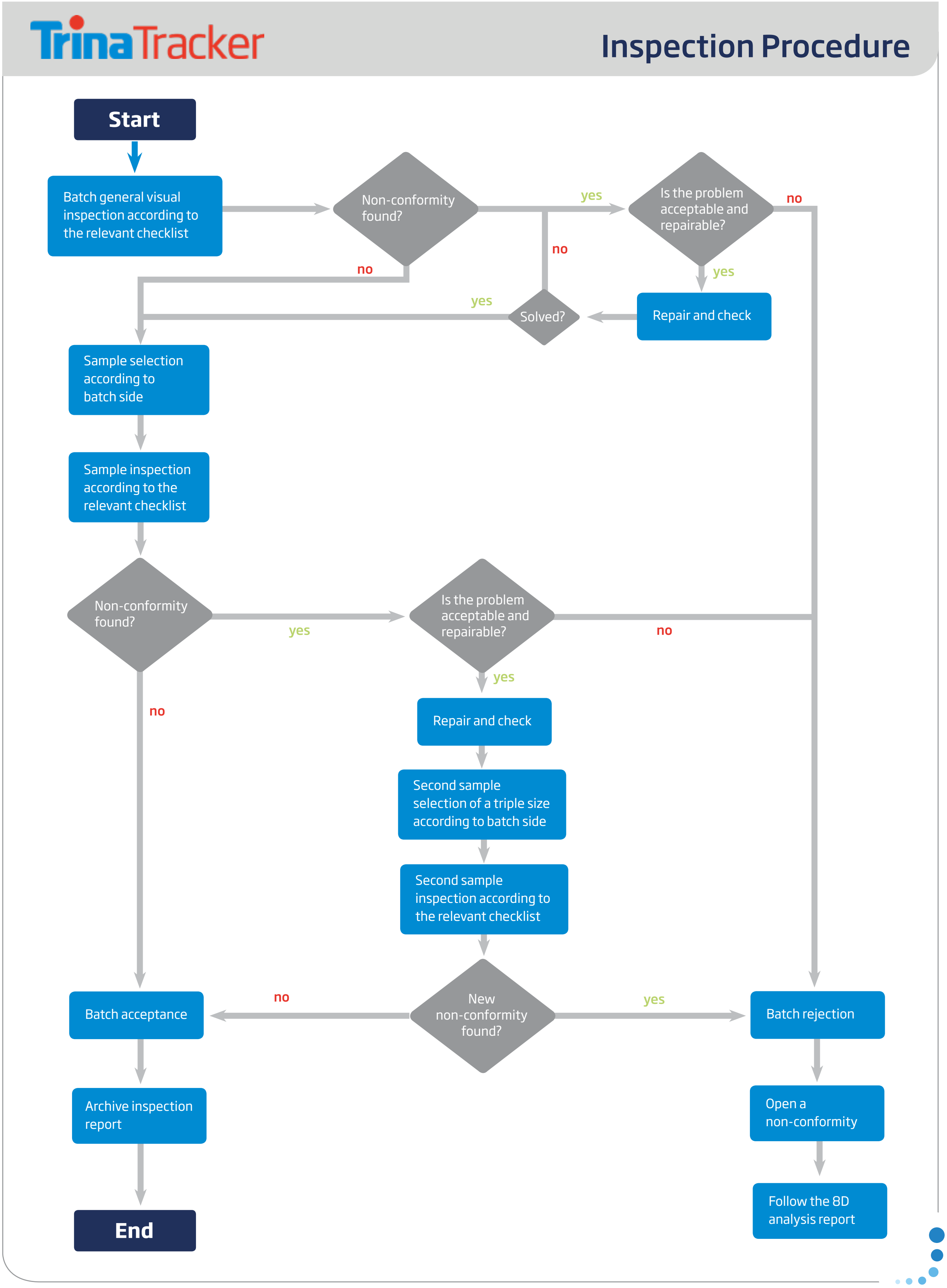


Image 19: TrinaTracker Inspection Procedure

6

Operation and Maintenance Costs Reduction and Lifetime Reliability

6.1 Lowering Failure Rates

The failure ratio (FR) is an indicator that reflects **corrective O&M costs**. **TrinaTracker** always focuses on lower LCOE, directing its resources to reduce product failures, continuously achieving optimum energy production.

It is not surprising that **Trina Solar**, as one of the world's leading solar solutions providers, offers the new advanced trackers **Agile 1P** and **Vanguard 2P**, that apart from being compatible with large-format modules, have remarkably low failure rates, requiring easy and limited operation and maintenance.

In addition, **TrinaTracker** implements new, stricter quality control procedures inherited from **Trina Solar** to ensure product reliability. The company's control methodology is rigorously applied to critical factors, including supplier, quality, product design accuracy and validation, and risk mitigation.

Furthermore, **TrinaTracker**, in collaboration with **CPP** and **RWDI**, two leading wind consulting companies in the industry, has subjected **Agile 1P** and **Vanguard 2P** to wind-tunnel tests, obtaining accurate data that was applied to the tracker's design to increase the trackers' reliability and lower failure rates. This means that both trackers have low failure rates, even when accommodating large-format modules and when installed in adverse terrain and/or extreme weather conditions.

Reducing the number of components in the **Agile 1P** and **Vanguard 2P** series helped to achieve low failure rates.

The failure rates shown below were estimated taking into account the average failure reported for **Agile 1P** and **Vanguard 2P** previous tracker models (SP160 and single row 1P); the reduction of components in the new trackers design and the accommodation of large-format modules.

Warranty	Component name	Units per Tracker (N°)	Units per 100 MWp (N°)	Unplanned O&M Time (hr/year)
5 years	Slewing Drive Base	2.0	3,190	2.33
5 years	Slewing Drive Motor	1.0	1,595	0.00
5 years	Bearing	16.0	25,520	1.60
5 years	Tracker Control Unit (TCU)	1.0	1,595	0.65
5 years	Self-powered Module	2.0	3,190	0.20
5 years	NCU	0.0083	13	0.38
5 years	Battery	1.0	1,595	0.00
5 years	Anemometer	0.0083	13	0.10

Table 5: Example of Agile P1 failure rate from components perspective

Warranty	Component name	Units per Tracker (N°)	Units per 100 MWp (N°)	Unplanned O&M Time (hr/year)
5 years	Actuator (Motorized & Non-Motorized)	3.3	5,359	0.77
5 years	Actuator Motor (Motorized)	1.0	1,624	0.00
5 years	Bearing	8.2	13,317	6.66
5 years	Tracker Control Unit (TCU)	1.0	1,614	0.34
5 years	Self-powered Module	2.0	3,248	0.21
5 years	NCU	0.0083	14	0.09
5 years	Battery	1.0	1,624	0.03
5 years	Anemometer	0.0083	14	0.06
5 years	Slewing Drive Base	0.0	0	0.00
5 years	Slewing Drive Motor	0.0	0	0.00

Table 6: Example of Vanguard P2 failure rate from components perspective

6.2 Lifetime Availability

TrinaTracker provides a monitoring system allowing DAS checks of the photovoltaic plants. Alarms and events are also monitored and recorded with the system. This solution improves the availability as well as allowing quick implementation of corrective actions.

The high availability of the **TrinaTracker** is due to the reduction of components, detailed product design and validation, together with rigorous quality control.

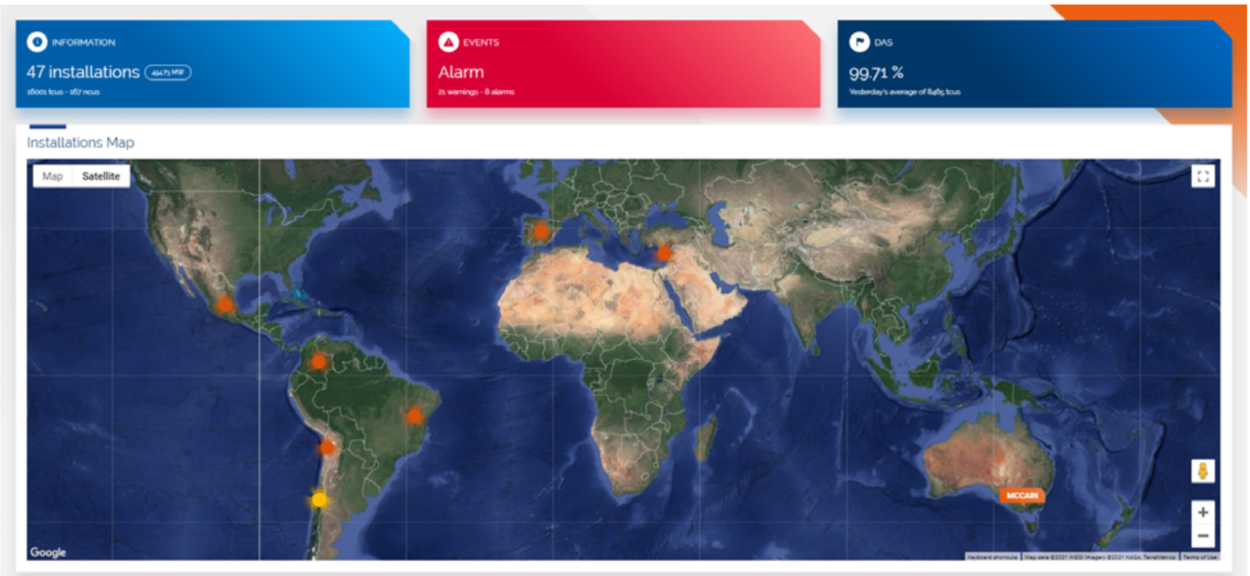


Image 20: Daily Availability Score (DAS) of some **TrinaTracker** installations around the world

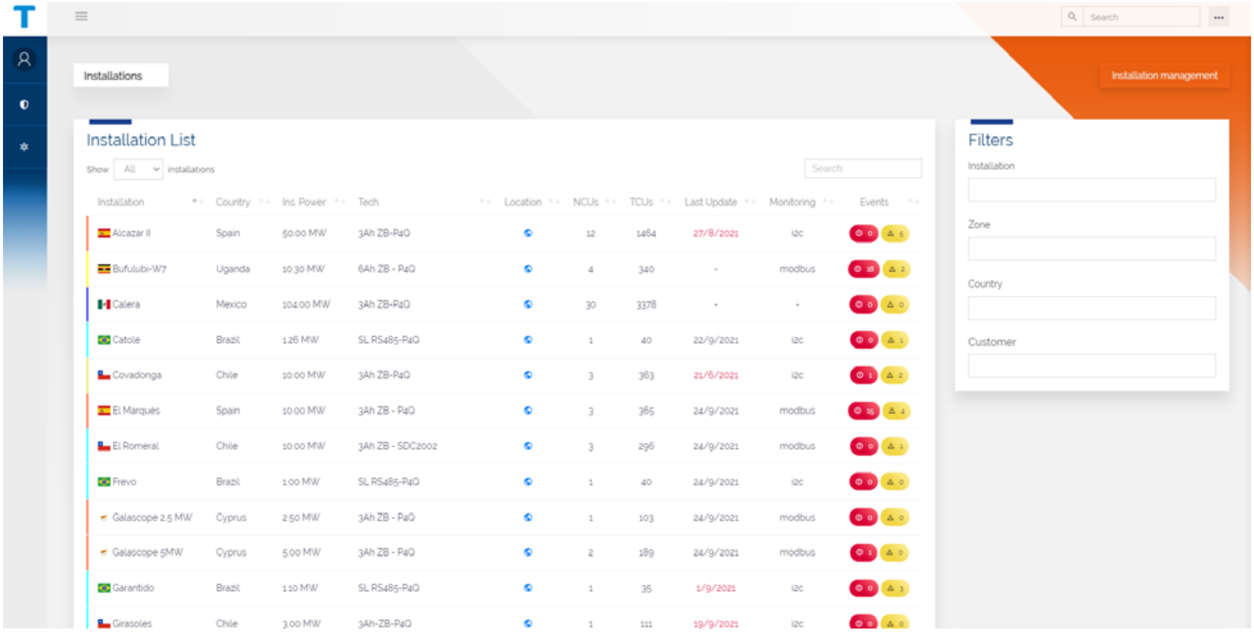


Image 21:	Installation list

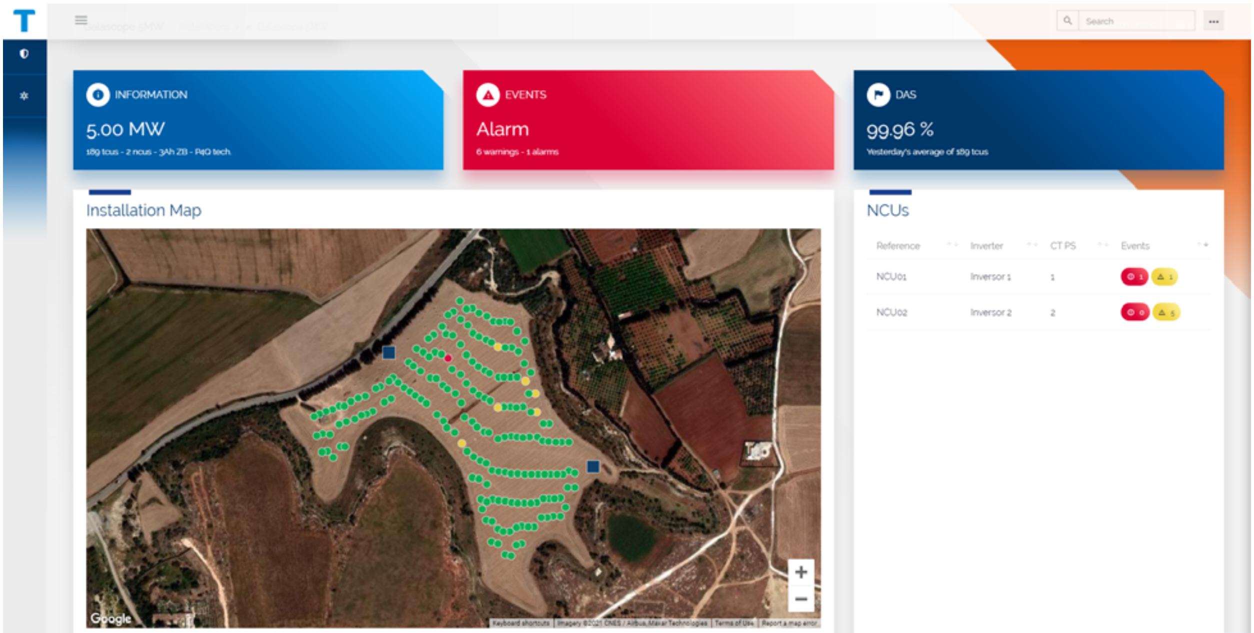
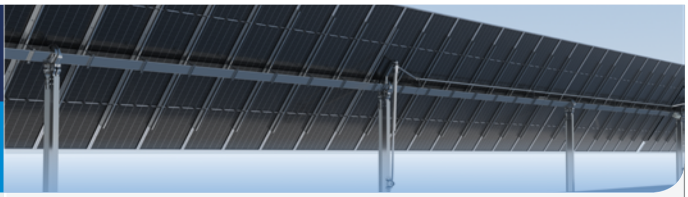


Image 22:	Installation information

6.3 Tracker Operation and Maintenance Cost Reduction

Estimated O&M Cost

Vanguard 2P



The **preventive O&M** cost was calculated according to the tracker's O&M manual, for an estimated cost of **98,968.57 $ / 100 MWp**.

The **corrective O&M** cost (unplanned) of the tracker was estimated according to **Vanguard 2P** at **13,539.89 $ / 100 MWp**.

Total estimated **O&M** cost for **TrinaTracker Vanguard 2P**:

112,508 $ / 100 MWp (0.0011$/ Wp $ / Wp)

The estimated **O&M** cost reduction achieved with **TrinaTracker Vanguard 2P** with regards to the previous 2P tracker model, is **-33%**

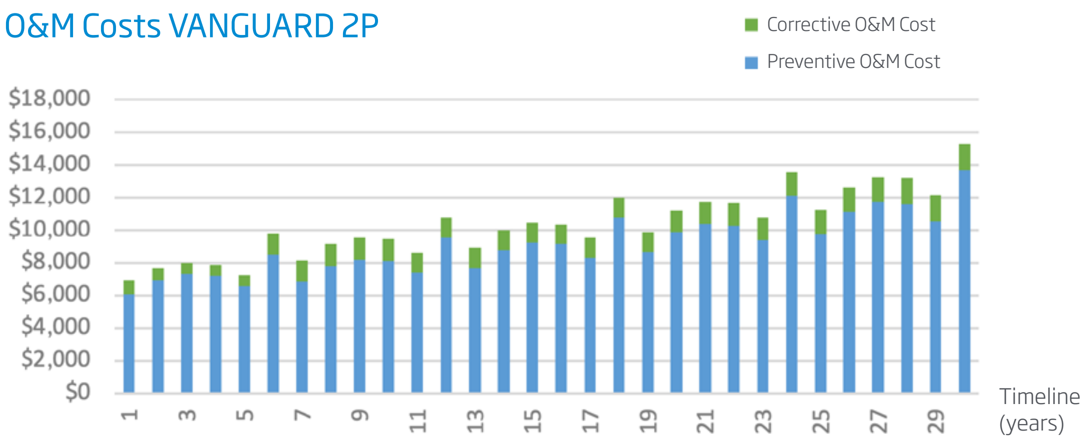


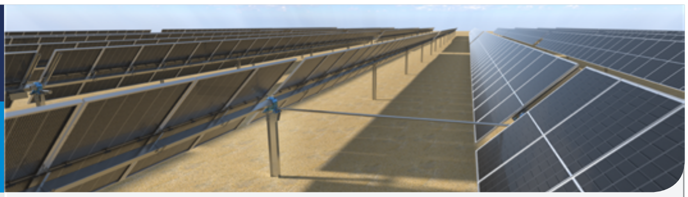
Chart 3: Estimated O&M cost - **Vanguard 2P** with module 550 Wp

Vanguard 2P	
Project Size (Mwp)	100
Module Power (Wp)	550
Modules per row	112
Rows/batteries per MWp project size	1,624
Labor Rate/Hr $	43
Annual Labor Inflation	2.0%
Discount Rate for NPV	8%

Table 7: Key assumptions - **Vanguard 2P** with module 550 Wp

Estimated O&M Cost

Agile 1P



The **preventive O&M** cost was calculated according to the tracker's **O&M** manual. The total estimated cost was **106,262 $ / 100 MWp**.

The **corrective** (unplanned) **O&M** cost of the tracker was estimated according to **Agile 1P** was **12,045 $ / 100 MWp**.

Total estimated **O&M** cost for **TrinaTracker Agile 1P**: **118,307 $/ 100 MWp** (0.0012 $ / Wp)

The estimated reduction of **O&M** costs achieved with **TrinaTracker Agile 1P** compared to previous dual-row model is **-25%**

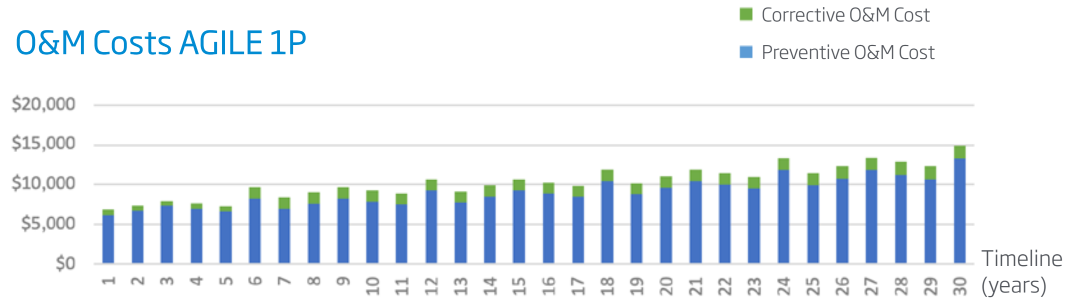


Chart 4: Estimated O&M cost - **Agile 1P** with module 550 Wp

Agile 1P	
Project Size (Mwp)	100
Module Power (Wp)	550
Modules per row	114
Rows/batteries per MWp project size	1,595
Labor Rate/Hr $	43
Annual Labor Inflation	2%
Discount Rate for NPV	8%

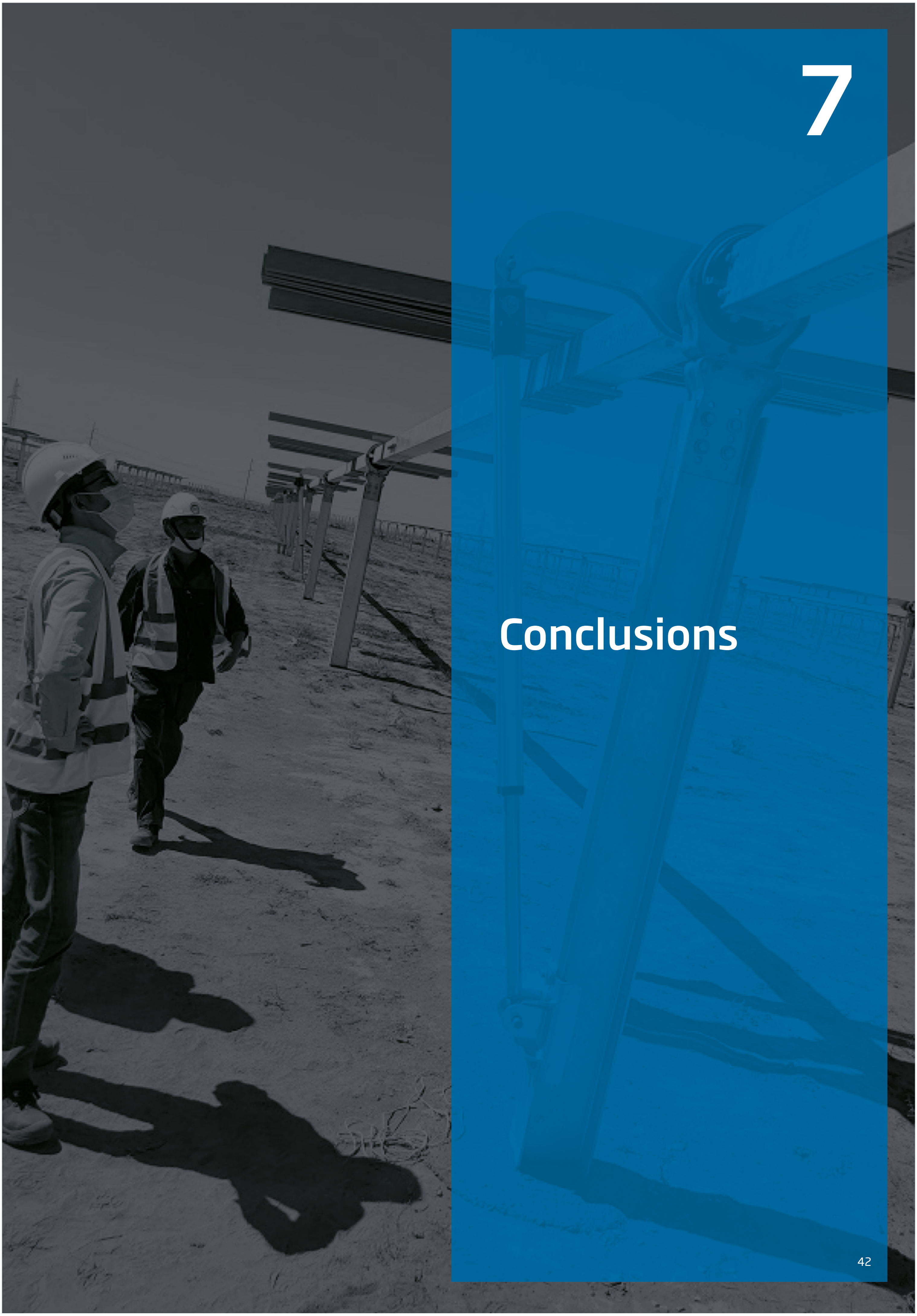
Table 8: Key assumptions - **Agile 1P** with module 550 Wp

Robot Cleaning

Item	Manual Cleaning	Robot Cleaning	Diference
Frequency	monthly	daily	+ 30 days
Equipment amount	0	350 €	+ 350 €
CAPEX	0	4,200 €	+ 4,200 €
OPEX (20 years)	14,400 €	9,815 €	- 4,585 €
Total investment	14,400 €	14.015 €	- 385 €
Energy gain vs. NON O&M	6%	18%	+ 12%
IRR vs. NON O&M	0.03%	0.36%	+ 0.33%

Table 9: Comparative cleaning costs for 20MW project

Accuracy of calculations and parameters is crucial in tracker design to minimise operation and maintenance services and costs.



7

Conclusions

7 Conclusions

The components of the Agile 1P and Vanguard 2P systems are validated by TrinaTracker's Research and Development Department (R&D). Prior to validation, controllers, drive systems and structural elements are tested and evaluated following a strict methodology to meet internal and external quality standards, support loads and operate efficiently.

Solar energy investments have significant appeal because of their increasing **cost-competitiveness**. While the expected lifetime of utility-scale solar PV projects has increased over time, the anticipated **Operating Expenditures** (OpEx) have decreased significantly.

In addition to energy production optimization, **O&M costs** are a crucial when evaluating tracker purchases. Considering that the average lifetime of a solar installation is between 20 to 25 years, the absence of preventive activities, which leads to an increase of operation and maintenance services and costs, can be detrimental to obtain a low **LCOE**.

Trina Solar, as one of the world's leading solar solutions providers, offers the new **Agile 1P** and **Vanguard 2P** advanced trackers, compatible with large-format modules and with remarkably low failure rates, requiring easy operation and maintenance and limited corrective activities.

TrinaTracker has always focused on lowering **LCOE**, aiming its resources to continuously reduce product failure and achieve optimum energy production.

Therefore, **TrinaTracker**'s Research and Development Department has developed significant improvements in the design of trackers, increasing their reliability and decreasing failure rates.

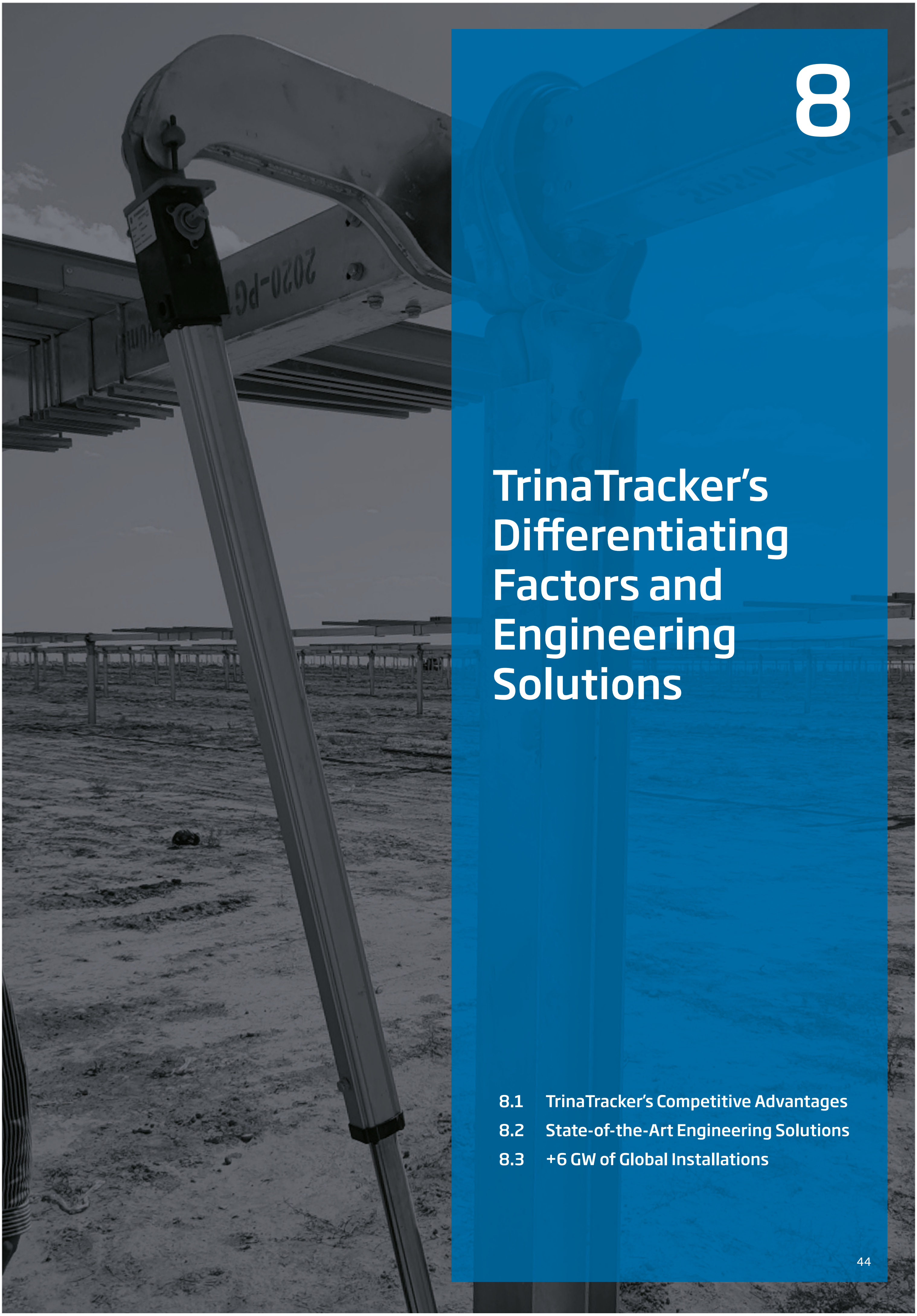
The components of the **Agile 1P** and **Vanguard 2P** systems are validated by **TrinaTracker**'s Research and Development Department (R&D). Prior to validation, controllers, drive systems and structural elements are tested and evaluated following a strict methodology to meet internal and external quality standards, support loads and operate efficiently. All these actions will help to improve the trackers' reliability and reduce potential failures.

TrinaTracker's critical factor for ensuring efficient performance and minimum service maintenance is to establish a minimum required quality level for tracker components. **TrinaTracker** carries out in-house and external inspections to ensure that all parts fulfil the agreed internal quality request, meet the industry standards and achieve third-party validations.

Furthermore, the number of components has been significantly reduced in the **Agile 1P** and **Vanguard 2P**, resulting in a decrease in the number of direct **O&M** activities required during the operation lifetime.

In conclusion, **TrinaTracker**'s planned preventive activities result in easy and limited operation and maintenance, reducing OPEX costs and **LCOE**, and potential power loss due to discontinue operation when implementing repairing and replacing tasks. Consequently preventive strategies lead to a reduction of OPEX costs and LCOE.

TrinaTracker's own internal validation methodology establishes strict testing to validate high component quality standards. The elements that make up the trackers do not receive internal validation until they demonstrate the targeted low failure rate established for each one.



8

TrinaTracker's Differentiating Factors and Engineering Solutions

8.1 TrinaTracker's Competitive Advantages

TrinaTracker, a business unit of **Trina Solar Ltd.** (SHA:688599), is a global solar tracker technology leader focused on providing "state-of-the-art" design solutions tailor-made to any terrain characteristics and weather conditions.

The company has more than 6GW of solar trackers deployed in 40 countries in which they accurately adapt the solar systems to each site's features. **TrinaTracker Agile 1P** and **Vanguard 2P** stand out in the market for their reliability, optimized design and minimal operation and maintenance requirements.

The trackers' compatibility with ultra-high power modules has been reported by **DNV**. Furthermore, **Agile 1P** and **Vanguard 2P** have been subjected to static, dynamic and aeroelastic loads through the most extensive tunnel test implemented in the solar industry and performed by leading wind engineering consultants, **CPP** and **RWDI**.

TrinaTracker is entirely focused on quality and innovation to provide its clients with high-technology solutions that achieve the highest energy yield and lowest **BOS** costs and **LCOE**.

About Trina Solar

Founded in 1997, **Trina Solar** is the world-leading PV and smart energy total solution provider. The company engages in PV products R&D, manufacture and sales; PV projects development, EPC, O&M; smart micro-grid and multi-energy complementary systems development and sales; and energy cloud-platform operation.

In 2018, **Trina Solar** launched the Energy IoT brand, established the Trina Energy IoT Industrial Development Alliance and leading enterprises and research institutes in China and around the world and founded the New Energy IoT Industrial Innovation Center. With these actions, **Trina Solar** is committed to working with its partners to build the energy IoT ecosystem and develop an innovation platform to explore New Energy IoT, as it strives to be a leader in global intelligent energy. In June 2020, **Trina Solar** was listed on the STAR Market of the Shanghai Stock Exchange.

For more information, please visit **www.trinasolar.com**.

TrinaTracker

Competitive Factors

Own R&D & Engineering Department

Team of more than **50** experienced and highly qualified engineers

Consolidated expertise in modelling, calculation and engineering design

Extensive know-how of solar industry technology and markets

+6 GW of plants where tracker design is tailor-made to meet the site characteristics and clients' requirements

Trackers installed in more than **40 countries**

In-house resources to carry out geotechnical design, structural design, FEM analysis, physical testing, software and hardware design, detailed project design, research and development of products.

Work partnership with leading wind engineering consultancy companies (**RWDI** and **CPP**)

State-of-the-Art **engineering** design

Designed technology that complies with the highest **European and US standards** (IEC62817 and UL3703 Certifications respectively)

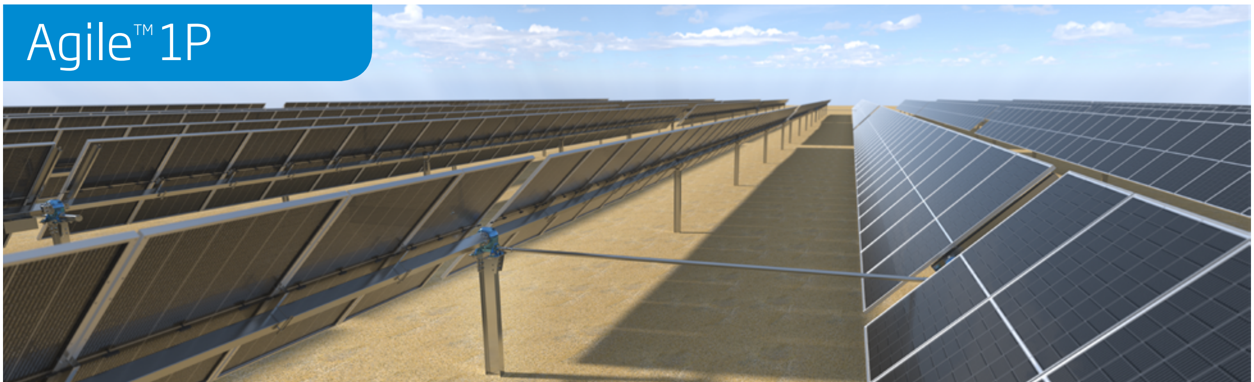
RWDI | cpp WIND ENGINEERING & AIR QUALITY CONSULTANTS | DNV | sbpsonne

8.2 State-of-the-Art Engineering Solutions

Vanguard™ 2P

- 2P configuration compatible with ultra-high power modules up to 210 mm wafer size.
- Multi-drive system that allows better wind tolerance, high adaptability and stability.
- 120 modules per tracker and up to 4 strings per row. Low voltage optimisation.
- Individual row actuator. Easy access for operation and manteinance activities.
- From 7 piles per row and less than 120 piles per MW.
- Global patented **Spherical Bearing** that allows up to 30% angle adaptability.
- **SuperTrack** algorithm that increses yield gain up to 8%.

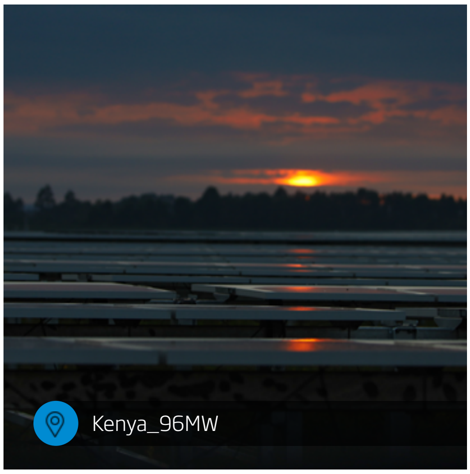
Agile™ 1P



- 1P configuration compatible with ultra-high power modules up to 210 mm wafer size.
- 120 modules per tracker and up to 4 strings per row. Low voltage optimisation.
- Dual row actuator. Easy access for operation and maintenance activities.
- Optimised number of components allows low operation and maintenance costs .
- High slope tolerance 20% N/S, 10% E/W.
- **Trina Clamp** reduces installation time and costs .
- **SuperTrack** algorithm that increses yield gain up to 8%.

8.3 + 6 GW of Global Installations


China_600MW

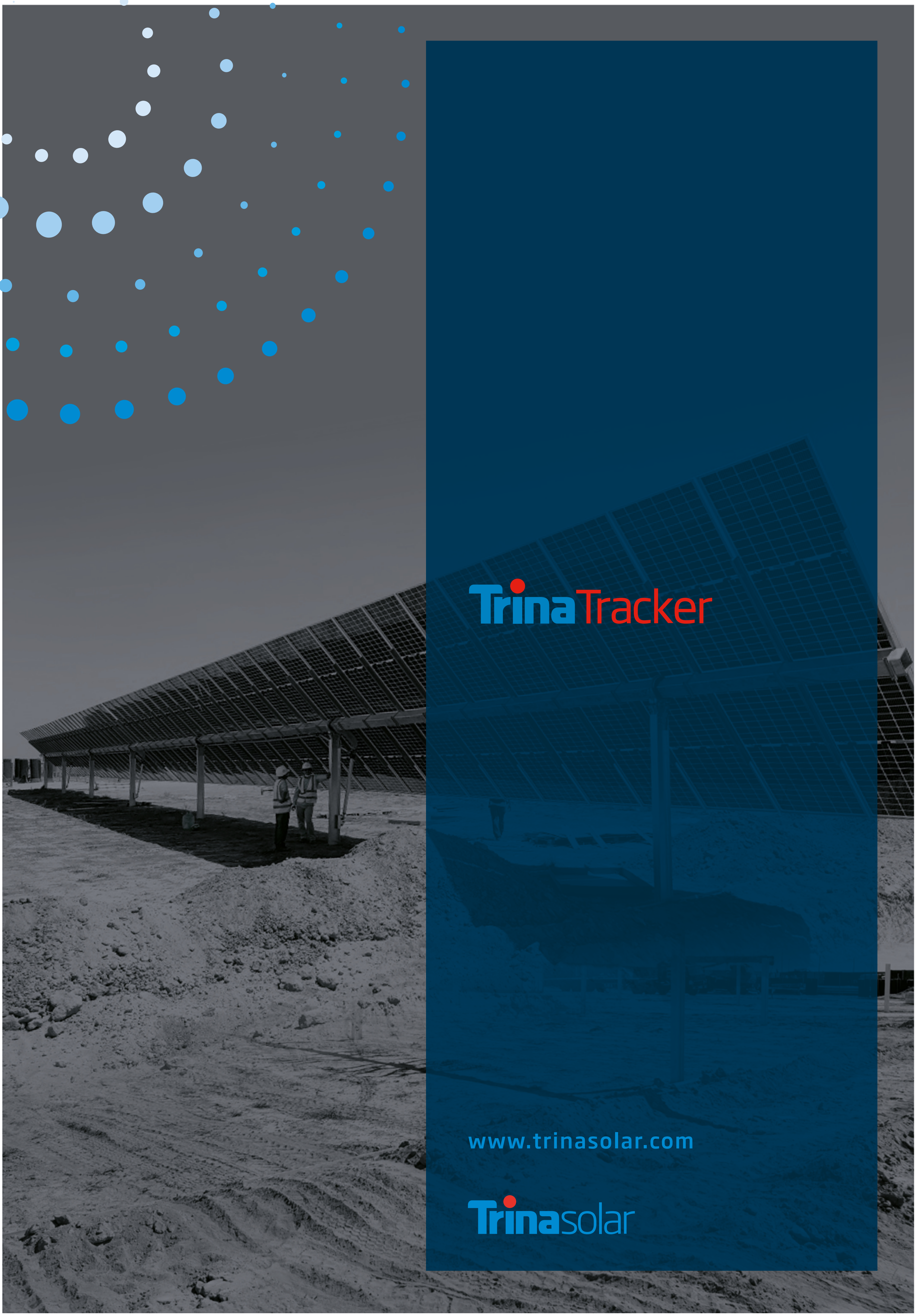

Kenya_96MW


Chile_33MW


Argentina_32MW


Honduras_40MW


Spain_22MW



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