# Strategies to Mitigate Risks Associated to Wind Loads in Trackers Compatible with Large-Format Modules

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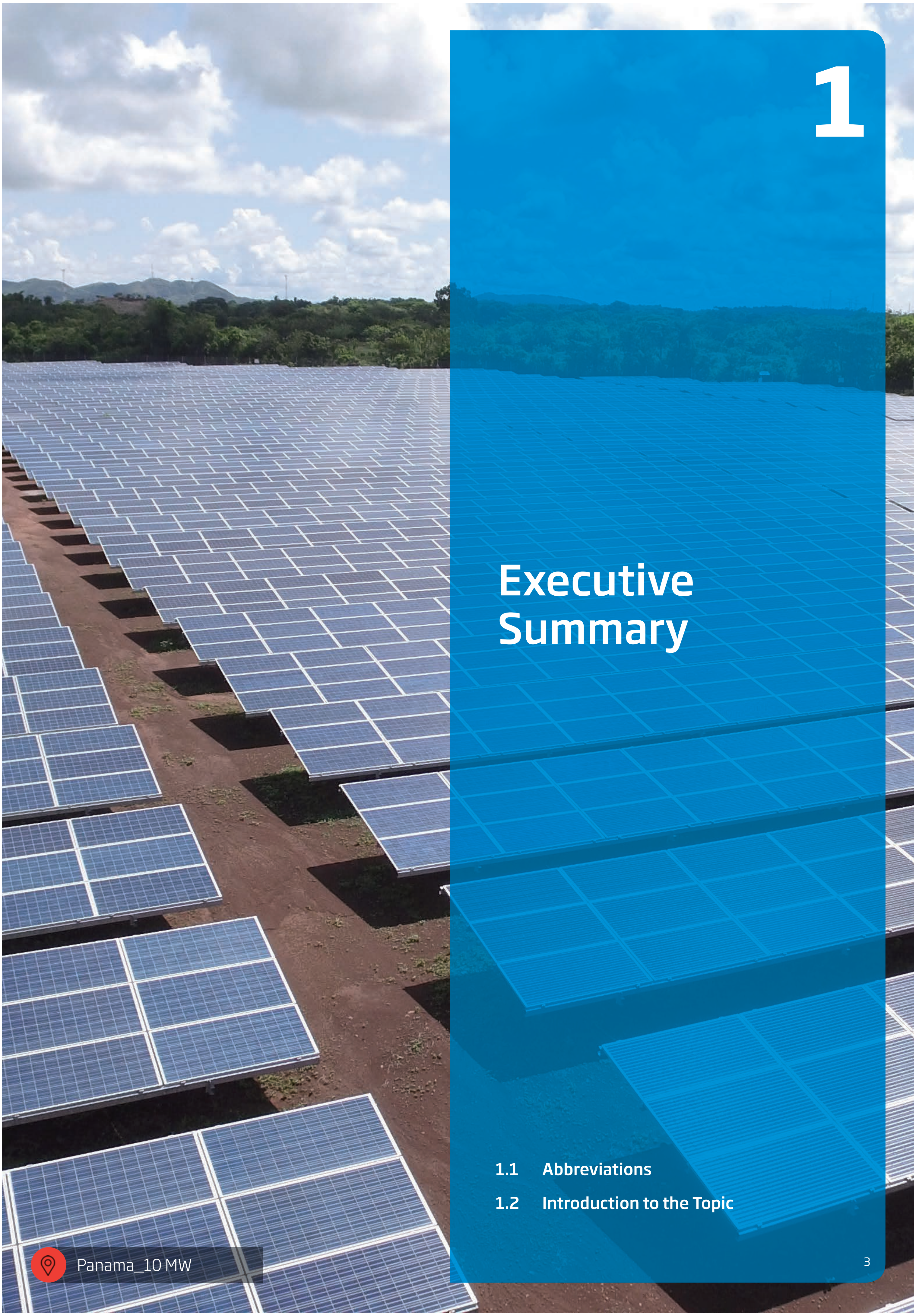
TrinaTracker

# Content



TrinaTracker



Panama_10 MW

# 1

# Executive Summary

# 1.1 Abbreviations

| | |
|---|---|
| **BOS** | Balance of System (cost of all components of a PV system other than the modules) |
| **W** | Watt |
| **RWDI** | Rowan Williams Davies & Irwin Inc. (wind consulting engineering firm) |
| **CPP** | Cermak Peterka Petersen Inc. (wind engineering consultants) |
| **DOE** | Design of Experiments |
| **IEC** | International Electrotechnical Commission |
| **UL** | Underwriters Laboratories |
| **P** | Portrait |
| **PV** | Photovoltaic |
| **DAF** | Dynamic Amplification Factor |
| **GCN** | (external) Gust (pressure) Coefficient Net |
| **O&M** | Operation and Management |
| **FEM** | Finite Element Method |
| **NCU** | Network Computer Unit |
| **R&D** | Research and Development |
| **AMFE** | Feature and Design Model Analysis |
| **SCRA** | Sign, Cause, Remedy, Action |
| **NPR** | Risk Priority Number |
| **LCOE** | Leverage Cost of Energy |
| **WTT** | Wind Tunnel Test |

# 1.2 Introduction to the Topic

**The photovoltaic industry has experienced a tremendous evolution over the past two years, leading to higher energy production and lower installation costs.**

**The solar business has entered into a new-module-era characterised by the production of the 600W + large-format modules, which leads to a considerable increase in yield generation and a BOS reduction.**

**The design of large modules requires new geometrical and electrical features to incorporate bigger wafers and a configuration of lower open-circuit voltage, higher short circuit current, and a new string design.**

**The most critical challenge of the photovoltaic installation in this new era is the reconfiguration of the trackers' design. The accommodation of 600W + involves a higher pressure of wind load on the system that affects the trackers' stability and reliability.**

Therefore, the most critical challenge of the photovoltaic installation in this new era is the reconfiguration of the trackers' design, since the accommodation of 600W + involves a higher pressure of wind load on the system that affects the trackers' **stability** and **reliability.**

TrinaTracker has focused its research and engineering resources to accomplish an optimum adaptation of the trackers' design parameters to solve any issue originated from the large measurements of panels, like the impact of **higher wind pressure** on the modules. TrinaTracker, in collaboration with leading wind engineering experts, **RWDI** and **CPP**, has accurately adapted the trackers' design to mitigate risks and guarantee optimum energy production and system's reliability.

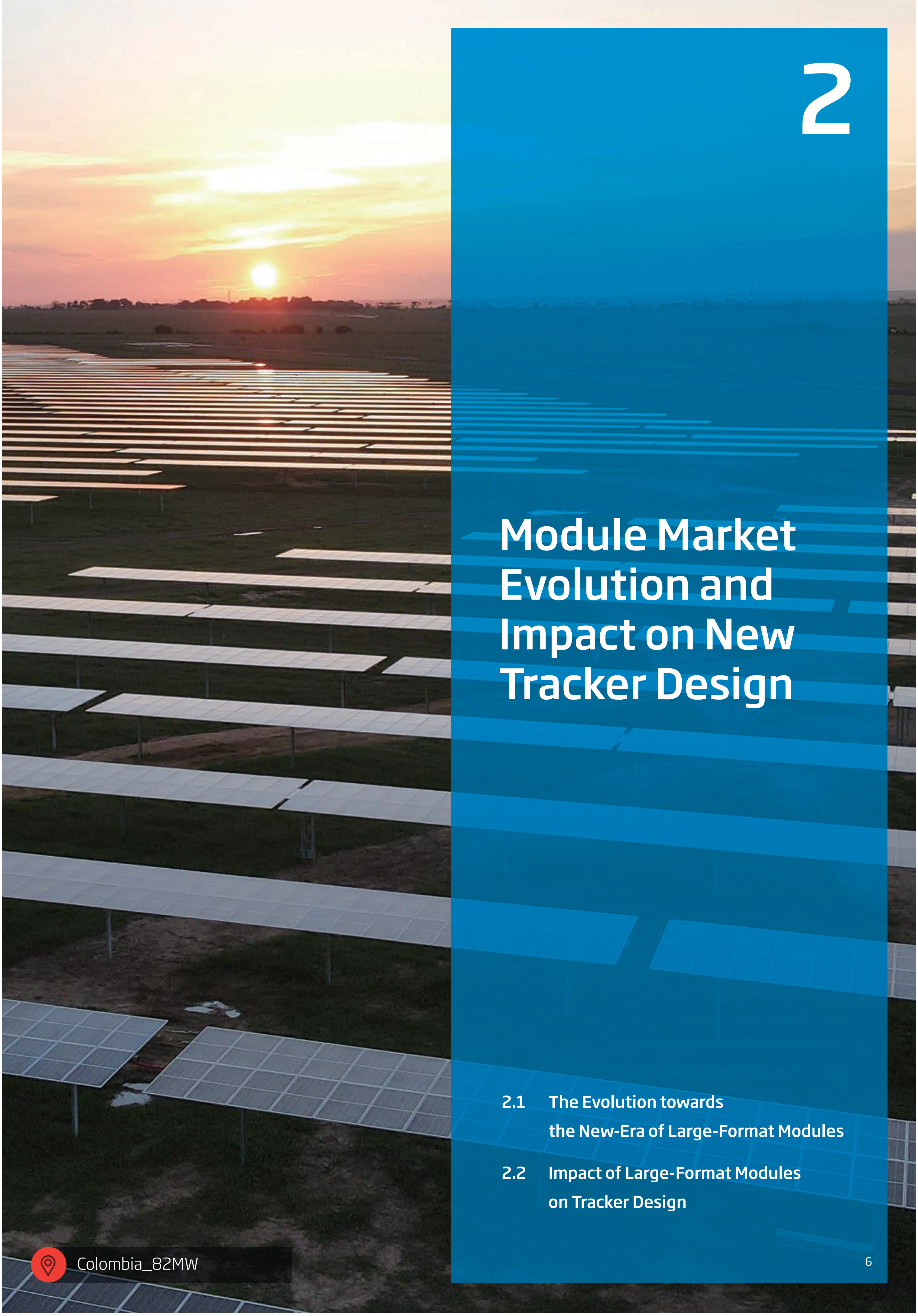
**Dynamic** and **aeroelastic** effects and analysis of external wind load represents crucial factors in the design of trackers compatible with large-format modules.

Comprehensive DOE and module pressure testing activities are conducted to provide **State-of-Art** design engineering solutions and validate the effect of wind loads on modules and trackers while complying with IEC and UL standards.

Thereby, TrinaTracker's **Vanguard 2P** and **Agile 1P** series, compatible with 600W + modules have been upgraded according to the results gathered from the multiple tests and calculations performed on the systems to guarantee optimum energy production, excellent performance and minimum O&M services.

1P and 2P trackers adopts an individual design approach due to architectural differences, being the aeroelastic instability and wind pressure analysis on modules critical factors in the systems' design.

The data gathered from wind analysis and tests notoriously improve the calculation methodology that defines the requirements to upgrade the trackers' design. The key elements of the new design are the introduction to a new **multi-drive system** for 2P structure to increase the torsional stiffness and the definition of **new stow position** established for 1P trackers.




# 2

# Module Market Evolution and Impact on New Tracker Design

# 2.1 The Evolution towards the New-Era of Large-Format Modules

The module industry experienced some substantial changes from the beginning of the millennium to 2014. However, the arrival of **bifacial** modules in 2018 represented a significant technological milestone, which was followed in 2019 by the production of large-format modules to accommodate broad wafers (M10:182x182mm and M12: 210x210mm).

The massive availability of large-format modules and the increase of energy generation drive a significant **reduction in system cost**. Besides, there is a need of accommodating technology changes in the pv systems, since large-format modules add significant weigh and require mechanical and electrical **adaptations** in trackers, to guarantee the optimum yield and efficiency.

**Trina Solar**, a leading module manufacturer and system solution provider with a profound experience in module R&D, engineering and tracker design, prioritise aeroelastic stability and module compatibility in the process to create a tracker design that guarantees energy production and system reliability when accommodating large-format modules.

**Large-format modules add significant weigh and require mechanical and electrical adaptations in trackers**

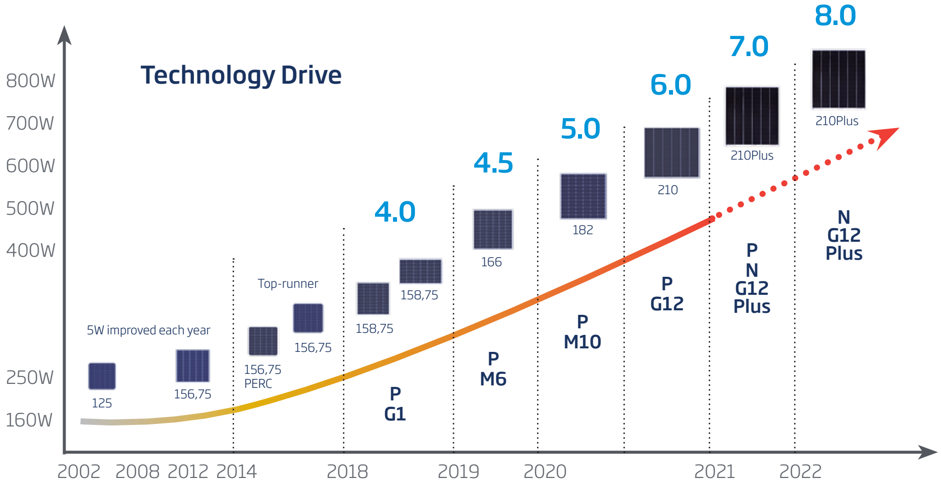



**Image 1 - Chart:** PV cell technology roadmap from 2002 to 2022

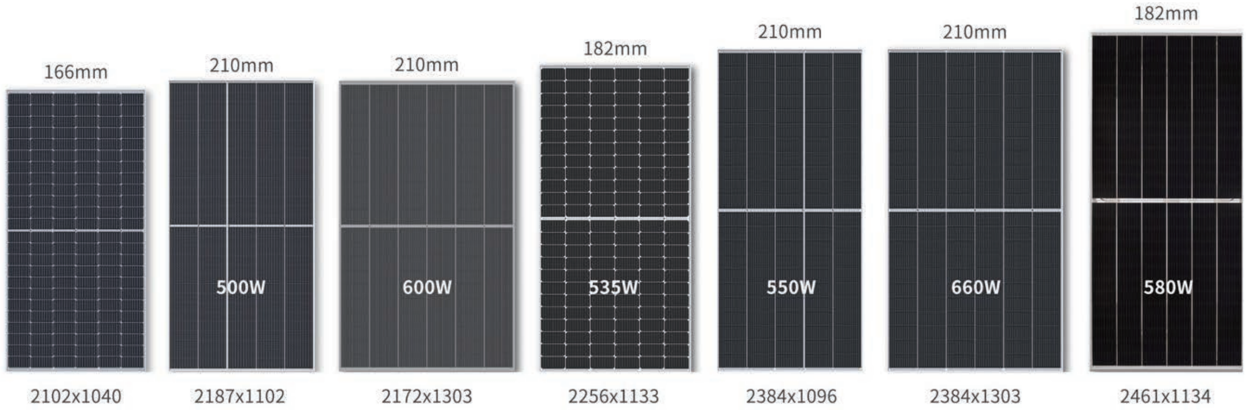



**Image 2:** PV module size change

## Change Of Module Parametres 2018 - 2021

| Timeline | | 2018 | 2019H1 | 2019H2 | 2020H1 | 2020H2 | | 2021H1 | 2021H2 |
|---|---|---|---|---|---|---|---|---|---|
| Power (Watt) | | 370 | 400 | 450 | 500 | 550 | | 600 | 660 |
| Wafer Type | | 157mm | 158mm | 182mm | 210mm | 182mm | 210mm | 210mm | 210mm |
| Frame Thickness (mm) | | 35 | 30 | 35 | 35 | 35 | 35 | 35 | 35 |
| Electrical | VOC (V) | 48.3 | 49.9 | 49.3 | 51.5 | 49.5 | 38.1 | 41.7 | 45.9 |
| | ISC (A) | 9.83 | 10.39 | 11.6 | 12.13 | 13.85 | 18.39 | 18.42 | 18.45 |
| | Toc* (%/°C) | -0.29 | -0.25 | -0.27 | -0.25 | -0.28 | -0.25 | -0.25 | -0.25 |
| Mechanical | Size (mm) | 1960x992x35 | 2024x1002x30 | 2094x1038x35 | 2187x1102x35 | 2256x1133x35 | 2384x1096x35 | 2172x1303x35 | 2384x1303x35 |
| | Size increase % | base | 4.3 | 11.8 | 23.9 | 31.5 | 34.4 | 45.6 | 59.8 |
| | Weight (Kg) | 21.5 | 26 | 23.3 | 30.1 | 32.3 | 32.6 | 35.3 | 38.7 |

**Image 3 - Table:** Module technology roadmap

## 2.2 Impact of Large-Format Modules on Tracker Design

The design and configuration of solar trackers are closely related to the dimensions of the photovoltaic panel.

The installation of large-format modules implies suffering different dynamic behaviors in the tracker' structure, including heavier loads.

**The installation large-format modules implies suffering different dynamic behaviors in the tracker structure, including heavier loads.**

The use of large-format modules requires longer chord, more extensive rows, stronger structures and, overall, more robust cross-sections to support the **extra weight** and keep stability against **wind effects**.

The electrical configuration of the tracker is also affected by the accommodation of large-format modules due to the change the in the number of strings (modules connected in series) assembled in a row.

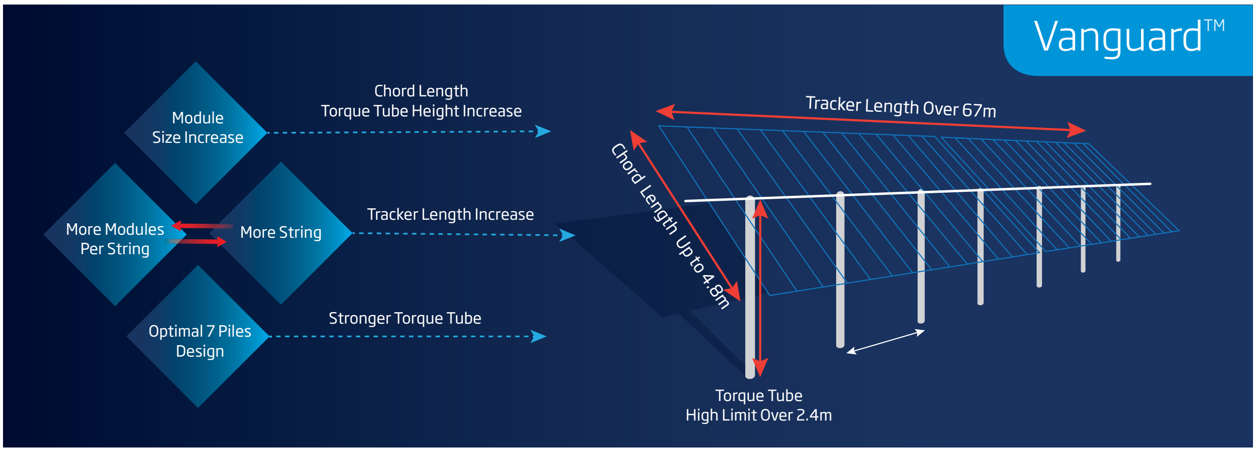



**Image 4:** Impact of large-format modules on the tracker's structure

The accommodation of large-format modules means that the **central mass** of the module is located further away from the torsional centre of the tracker. Therefore, the torque tube will have lower torsional natural frequencies for the same configuration.

Usually, more weigh moved further away from the torsional centre of the tracker implies **lower natural frequencies** and **damping changes**; hence, the use of more extended chords requires more refined aeroelastic calculation.

Large-format modules requires longer trackers to be accommodated for the same number of panels

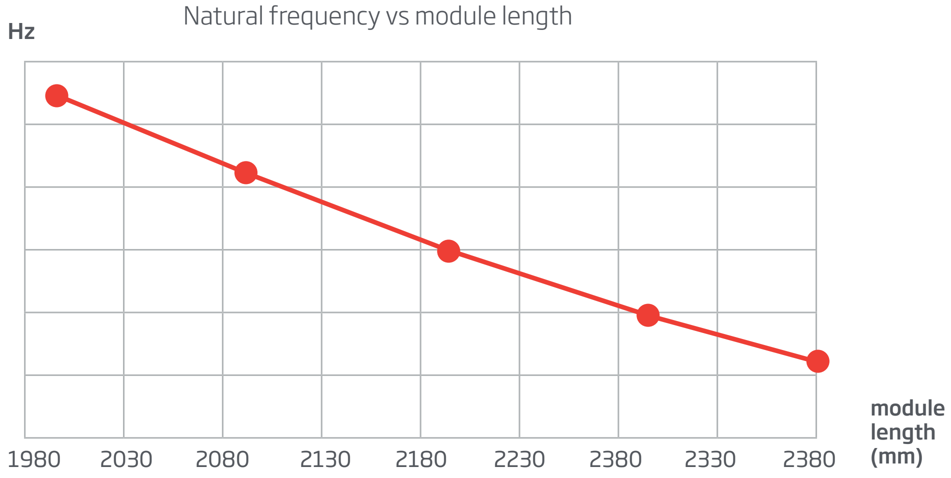



**Image 5 - Chart:** Natural frequency vs module length

Large-format modules requires **longer trackers** to be accommodated for the same number of panels. The installation of longer trackers involves a higher risk of motions and the challenge to deal with **higher torsional deflections**.

The solution to this issue includes the installation of **stiffer torque tubes** or **torsional locks** along the length of the tracker or combining both structural elements. Additionally, longer tracker means lower frequencies if the traditional central drive is kept.

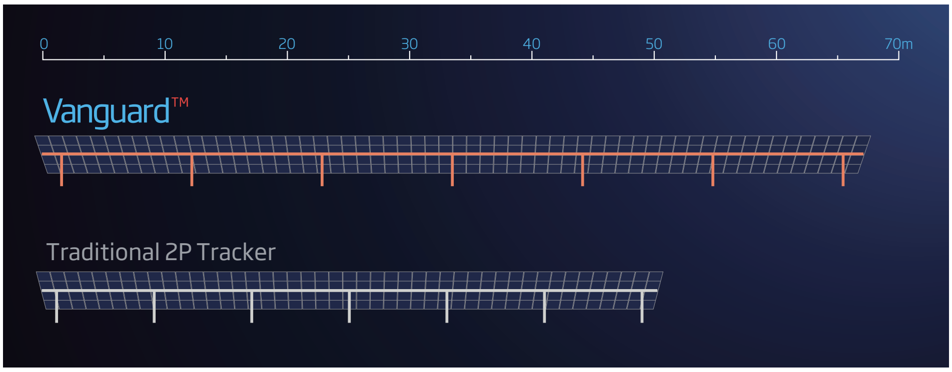



**Image 6:** Impact of large-format modules on the tracker's structure

Higher load pressure on modules involves **higher foundation reactions** for the same number of piles. Foundation reactions are one of the reasons why **TrinaTracker** define a low tilt angles stow position for the 2P configuration trackers.

The following table summarises the crucial modifications performed in solar trackers to embrace large-format modules and keep the system's reliability.

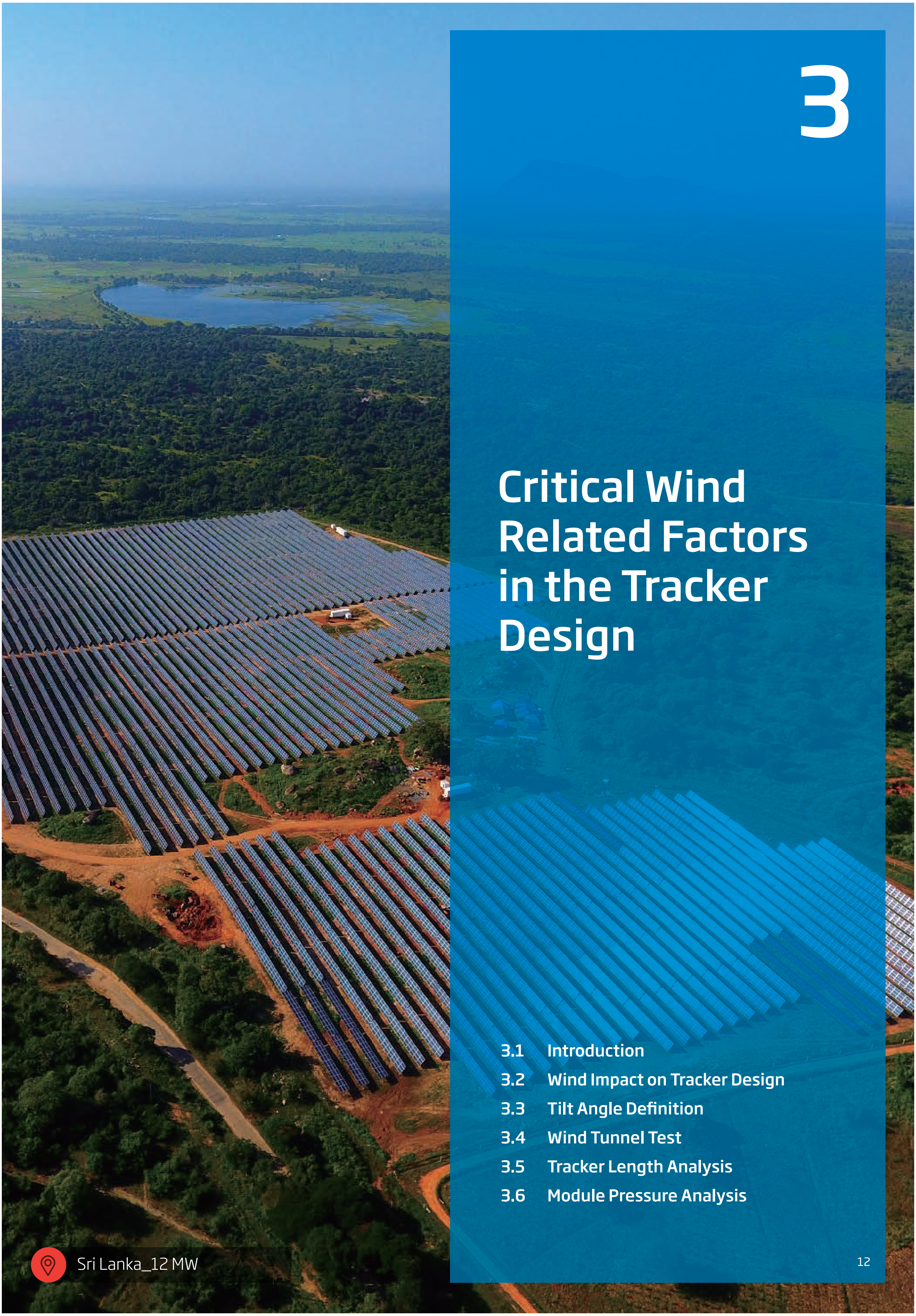
| Module Changes | Changes in Tracker Stiffness and Stability | Impact on Tracker/Components Design |
|---|---|---|
| Length increase | Chord increase<br>High effect on aeroelastic critical wind speed | Higher structures<br>Adjusted stow strategy |
| Width increase | Longer rows<br>Lower torsional stiffness | Improved drive system |
| Surface increase | Higher wind load on module surface<br>Higher torque on lock systems<br>Higher foundation reactions | Bigger tracker surface<br>Stiffer purlin<br>Strengthened tube<br>Higher post |
| Mass increase | Lower natural frequency<br>Changes in damping<br>High effect on aeroelastic critical wind speed | Improved drive system<br>Adjusted stow strategy |

**Image 7 - Table:** Most important changes in solar trackers to accommodate large-format modules

# 3

# Critical Wind Related Factors in the Tracker Design





Sri Lanka_12 MW

## 3.1 Introduction

The tracker design and the quantitative impact on stiffness and stability are defined by the parameters resulted from the analysis of the wind effect on the tracker design, the definition of tilt angles, wind tunnel test, length of the tracker and the study of the module pressure.

# 3.2 Wind Impact on Tracker Design

**The most critical wind impact on trackers is the torsional motion which occurs when wind speed exceeds the limit allowed by the tracker's structure. The resulting effect is an uncontrollable torsional vibration that caused instability in solar trackers.**

Tracker structures comprise a **central torque** tube with piles evenly distributed in between.

Tracker structures that accommodate large-format modules are prone to different **torsional aerodynamic instabilities**, depending on their geometry and dynamic properties (frequency, damping).

The most critical wind impact on trackers is the torsional motion which occurs when **wind speed** exceeds the limit allowed by the tracker's structure. The resulting effect is an uncontrollable torsional vibration that cause instability in solar trackers.

The static torsional loads resulted from lower wind speed are also considered when designing the tracker's structure.

Instability is avoided by calculating the critical wind speed, and then, taking the result into consideration when defining the tracker's design.

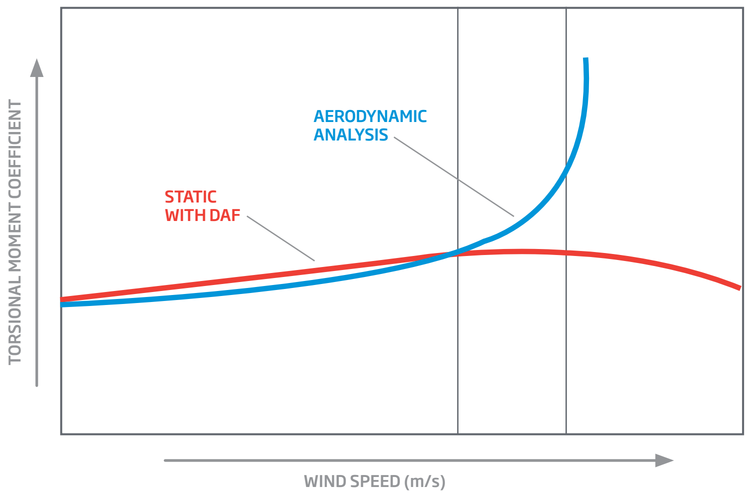



**Image 8 - Chart:** Static torsional and aerodynamic loads

The two tracker configurations addressed in this paper (1P & 2P) require two **different design approaches**. **TrinaTracker** follows different design criteria depending on the system's features of the tracker, and the resulted insights gathered from the tunnel tests performed in collaboration with the leading engineering wind consultancy firms in the market: **RWDI** and **CPP**.

# 3.3 Tilt Angle Definition

Advanced analysis show that different design criteria must be adopted to define the tilt angles of the structure.

As result, **high tilt angles** are governed by **static loads**, while **stiffness** defines the design at **low tilt angles**.

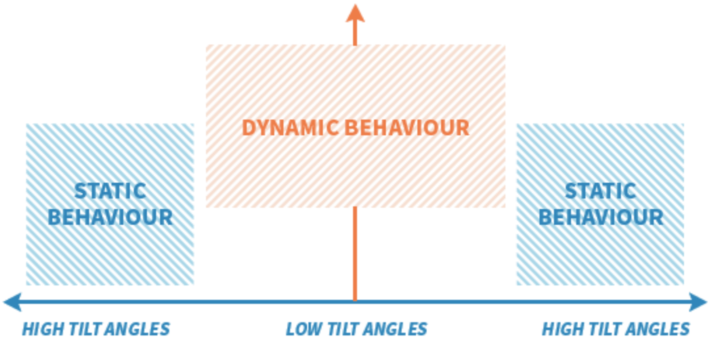



**Image 9 - Chart:** Tilt angles and dynamic & static behavior

## STATIC BEHAVIOR

Static loads, both pressure coefficients alongside with dynamic amplification factors govern the design at high tilt angles.

Critical structure pieces and components are designed according to the data resulted from static and **torsional loads analysis**.

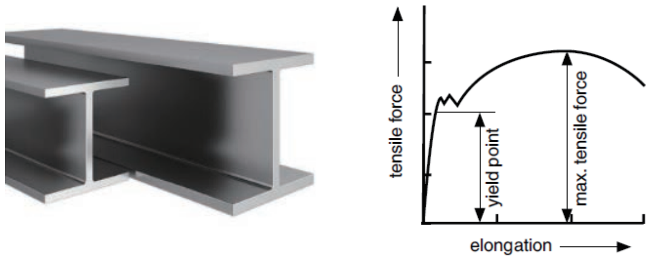



**Image 10 (1&2):** Loads and structure design

## DYNAMIC BEHAVIOR

Aerodynamic loads define the tracker design at low tilt angles. Stiffness and damping parameters are fundamental inputs for this scope. The structure's stiffness can be increased by including a multi-actuator system and/or robust design that allows effective wind mitigation at low tilt angles.

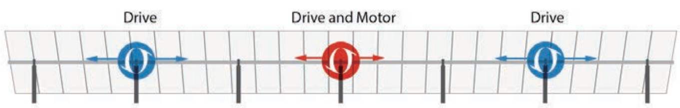



**Image 11:** Multi-drive system

# 3.4 Wind Tunnel Test

Wind pressure analysis resulted from tunnel test along with module pressure must be studied to understand the **quantitative impact of wind loads** on the trackers' stiffness and stability and therefore configurate a design according to these parameters.

Tracker length is established since it depends on the clients' requirements.

## STATIC WIND LOAD COEFFICIENTS & DYNAMIC WIND LOAD FACTORS (DAF):

Analysis to obtain full-scale peak responses by combining the effects of wind loads, gust wind loads, and the inertial wind loads to increase the provided equivalent static wind load.

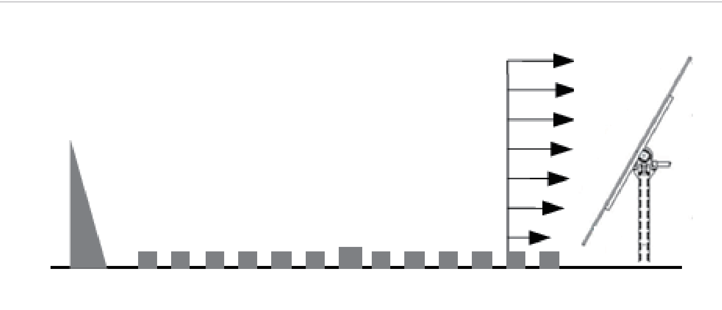
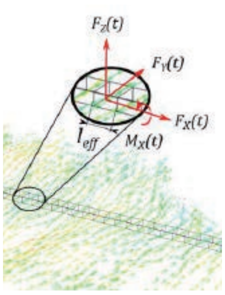



**Image 12 (1 & 2):** Prototype test for static coefficients and DAF factors

## 2D SECTIONAL MODEL & NUMERICAL MODELS

This test called **"Recogn Methodology"**, was appointed by **RWDI** to be performed exclusively on the **Vanguard 2P** series.

The test is implemented to define the tracker's **self-excited forces** by measuring aerodynamic derivatives, static aerodynamic forces and moment coefficients. These parameters are critical to execute the 3D Flutter Analysis and the 3D Buffeting Response Analysis to calculate wind loads.




The motion equation of a body subjected to the dynamic action of wind is given by:

$$[M]\{Z\} + [C]\{\dot{Z}\} + [K]\{Z\} = \{F\}_{SE} + \{F\}_{BUFF}$$

Vector $[M]$, $[C]$ and $[K]$ correspond with the mass, damping and stiffness matrix of the system, and $\{F\}_{SE}$ & $\{F\}_{BUFF}$ represent the self-excited and the buffeting forces.

**Image 13:** Loads resulted from 2D sectional model test

**Image 14:** Prototype for the 2D sectional model test

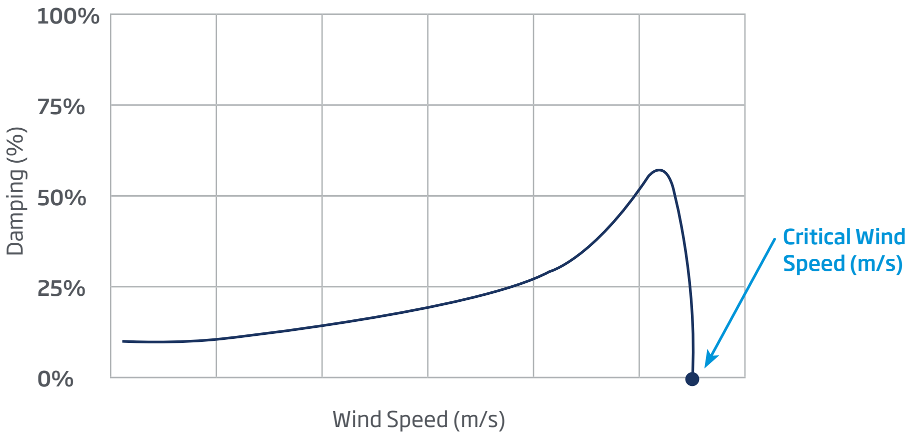



**Image 15 - Chart:** Critical wind speed according to the damping ratio

The tracker's instability is assessed at each of the tilt angles by implementing **aerodynamic derivatives**. The use of numerical methods defines the chord length and the natural frequency of the tracker. **Critical wind speed** occurs when the damping is negative.

## FULL AEROELASTIC MODEL TEST

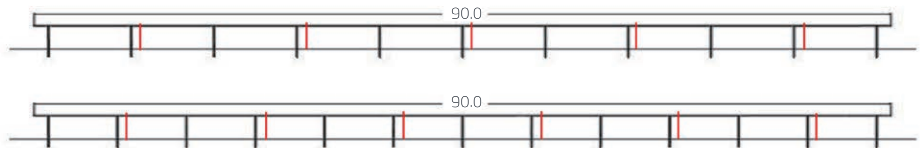
The full aeroelastic model test is performed on 1P and 2P trackers. With regards to 2P configuration, the full aeroelastic test confirms the 2D sectional model test results. On the other hand, the same test is executed to define the stow position strategy for 1P trackers.

**Image 16:** Prototype for full aeroelastic model test
Source: RWDI Lab

# 3.5 Tracker Length **Analysis**

The tracker length is defined by the number of modules assembled in a row, which depends on the number of strings that can be fitted in one tracker.

According to these data, a hypothetical configuration structure is usually drafted, like the one in the example showed below. However, a risk analysis of the structure must be developed to validate the final design. The no consideration of risks can be detrimental to the project stability and yied production.




| | | | | | |
|---|---|---|---|---|---|
| OUTER | Vanguard | 4 strings | 90m | 13 piles | 6 linear actuators |
| INNER | Vanguard | 4 strings | 90m | 11 piles | 5 linear actuators |

**Image 17:** Hypothetical components strategy for a 90m tracker length configuration

The following risks were encountered, after analysing the wind impact on an alternative TrinaTraker 2P configuration structure, with 90 meters of length. The potential threats, resulted fom the analisys, confirm that a longer design is not always the most efficient solution to ensure realibility and optimun energy production.

### Dynamic Issues

Longer trackers are inherently more unstable when supporting dynamic loads. They require extra reinforcement which results in an increased in the structure cost. The awareness of this issue create the need in TrinaTracker's engineering department of optimised the system design from a cost perspective.

### Lower Installation Tolerances

Longer spans traversing changes of slope on-site increases construction cost and involves higher risks. High slopes involve larger lateral forces pushing the piles. This matter is solved by using larger gauge piles, which consequently increase foundation cost significantly.

### Vibration

Longer trackers are prone to higher wind load pressure, which can loosen fixings. 90m long trackers require more frequent torque checking in O&M services.

### Land Utilisation

Longer trackers required a larger area of land, as result, the installation capacity can be reduced due to limited land extension.

### Energy Power

Longer and heavier components require more energy consumption by the system's motors.

Strengthening the tracker's structure increased the system's cost, since the solution includes the installation of a **larger quantity of components** and adding **more weight** to the tracker.

# 3.6 Module Pressure Analysis

The wind pressure coefficients applied to the module surface is increased with tilt angles and affect the stow strategy of the tracker.

Large-format modules might result in lower mechanical tracker performance. The **stow strategy** of the system is critical to this aspect. Primarily 1P, but also 2P trackers might suffer an increase of pressure on modules due to a high tilt angle at stow position.

Higher allowable pressures are guaranteed for 2P at low tilt angles and 1P at high tilt angles for extreme wind conditions. Trackers experience **higher external dynamic loads** from modules exposed to significant wind pressure at a high tilt angle. Meanwhile, they also encounter **less aeroelastic instability** due to torsional vibration.

Therefore, the most challenging aspect of tracker designing is to balance dynamic loads and aeroelastic instability.

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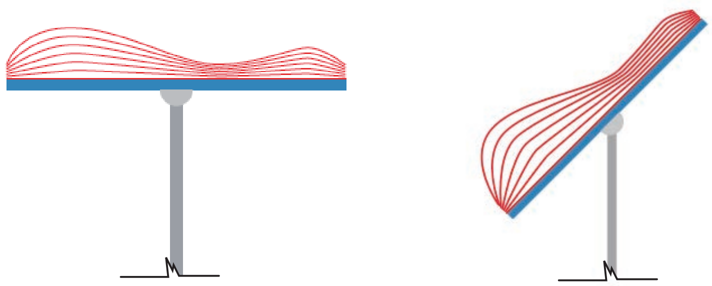


**Image 18:** Pressure on modules at different tile angles

**Image 19:** Agile 1P (left) and Vanguard 2P (right) stow angles postitions

**Wind load pressure** on the module's surface is calculated when multiplying wind tunnel pressure coefficients by the standard wind pressure already calculated in the project.

The pressure assumption of the module upper surface is obtained by considering snow pressure parameters. On the other hand, the snow factor can be excluded in the pressure assumption of the lower surface of the module.

In order to define **allowable module pressures**, various calculations are performed, following procedures described below:

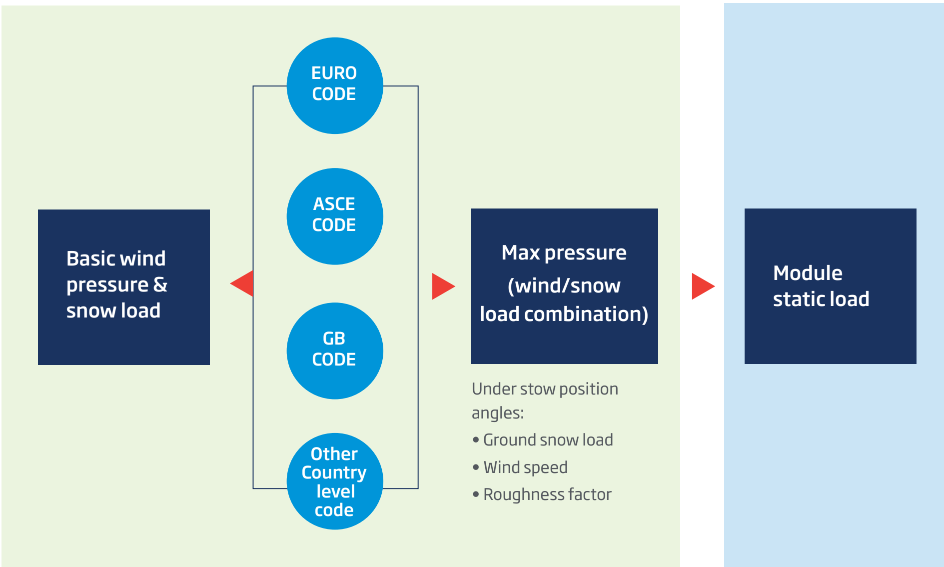



**Image 20:** Procedures of converting basic wind/snow load pressure to design load on module

The "triangular" pressure distribution for the 1P configuration divides the PV module into **4 zones** with different pressures.

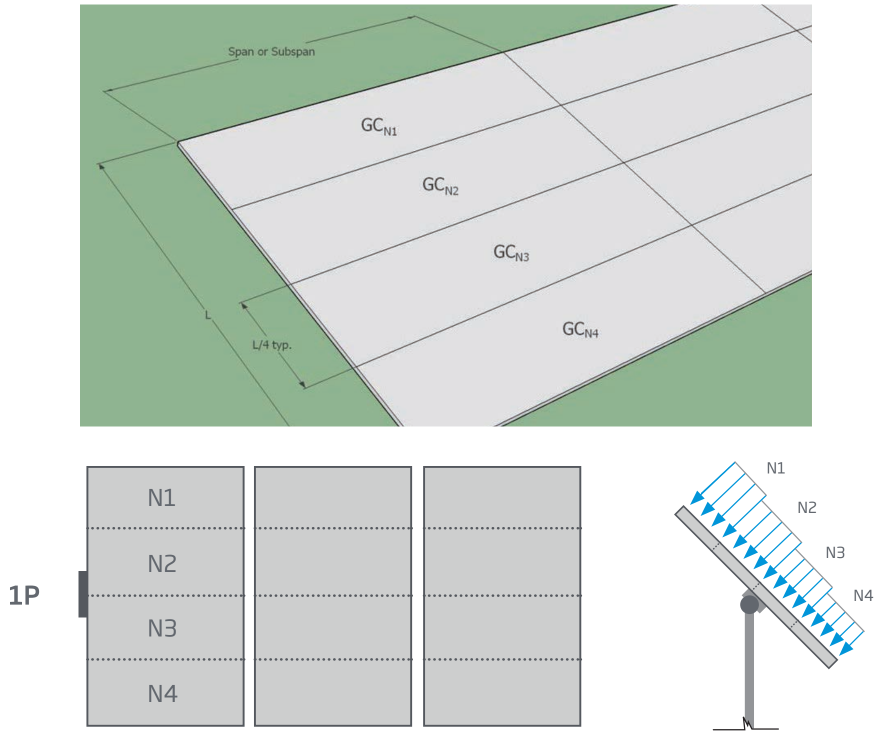



**Image 21 (1&2):** Wind pressure distribution over module in 1P configuration

The pressure distribution on the PV module in 2P trackers is rectangular.

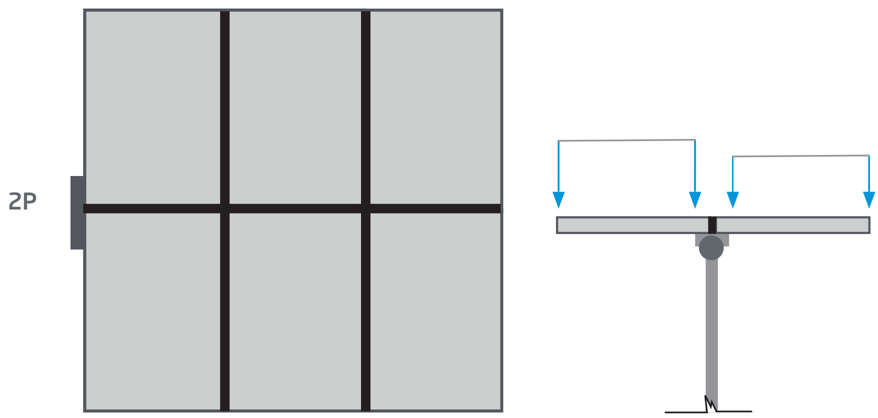



**Image 22:** Wind pressure distribution over module in 2P configuration

Uruguay_65MW

# 4

# Strategic Design Solutions

# 4.1 Structure Design & Validation

**Upgrading trackers to accommodate large format modules requires numerous structural design adaptations to achieve system's reliability and optimum energy generation at all wind speeds**

The described static, dynamic and aeroelastic analysis alongside with the module pressure analysis provide multiple calculations with various coefficients (including "DAF") , that allow the systems to comply with **EURO CODE or ASCE Standards**. Forces and torsions data are essential to define the tracker's design.

Therefore, upgrading trackers to accommodate large format modules requires numerous structural design adaptations to achieve system's reliability and optimum energy generation at all wind speeds.

The upgrading of tracker design considers several **strategic solutions**:

## STIFFER 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, increase 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 12%**.

When the area is defined, the rest of the components that require modifications are redesigned by using the software: **"CAD"**

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 executed to obtain this type of data.

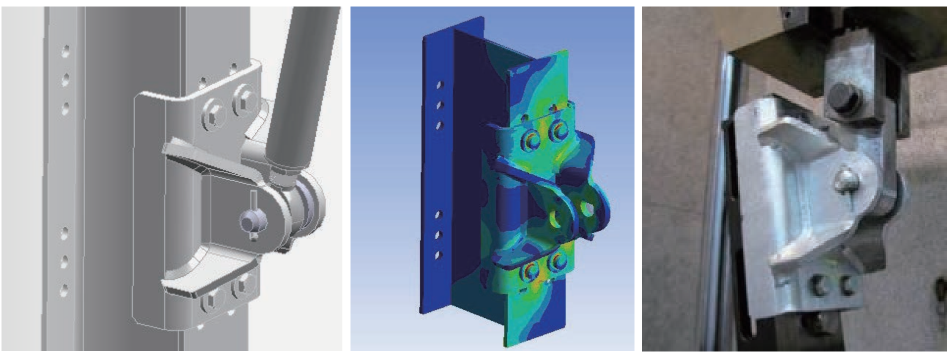


**Image 23 (1,2 &3):** Linear actuator base

## MULTI-DRIVE SYSTEM

The torsional locks and the torque tube in 2P configuration reduce torsional spans, increase natural frequencies and damping and restrict torque tube twist. Longer trackers with 1P and 2P configurations lower the torsional stiffness. Therefore, **multi-drive systems** are adopted to effectively reduce the **torsional loads** from **buffeting**.

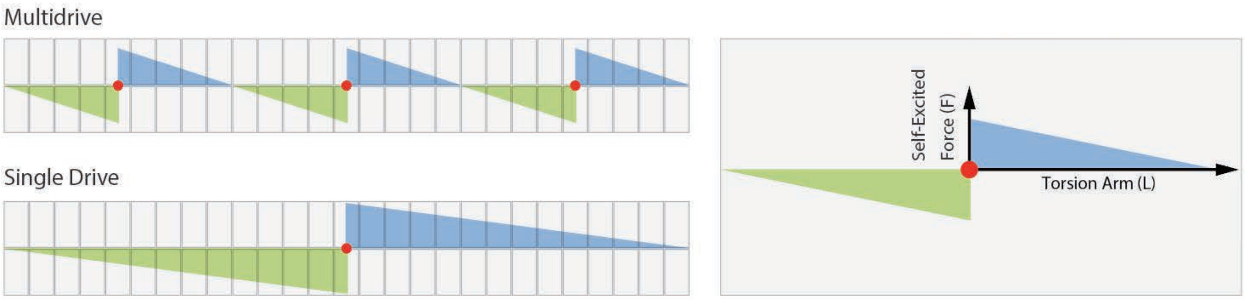



**Image 24 (Chart):** Agile 1P design overview

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.

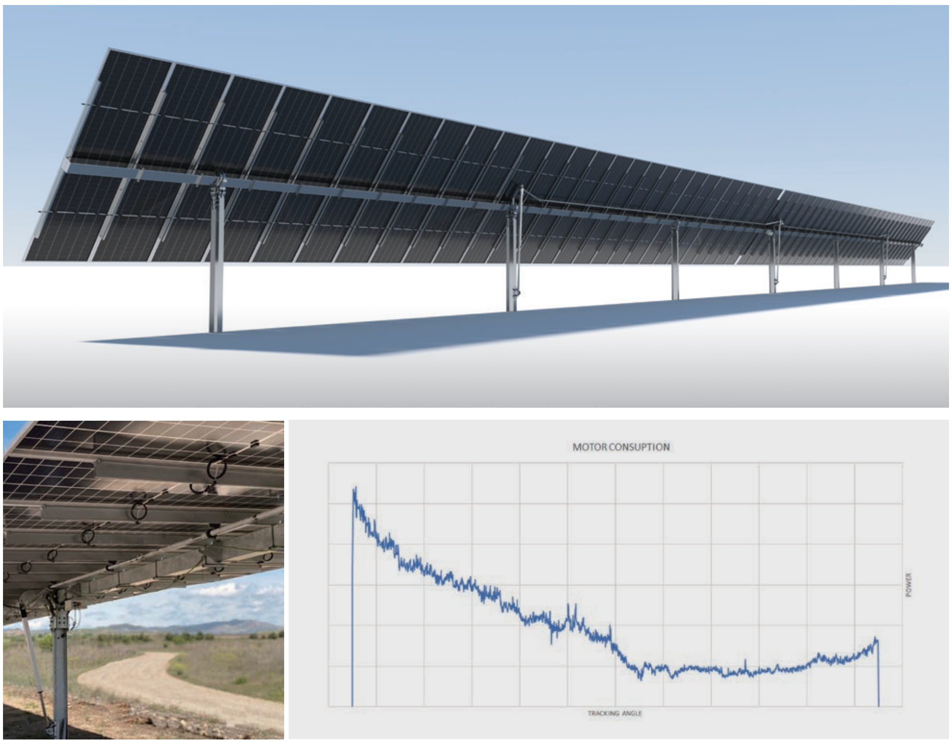



**Image 25:** Tracker testing under beta site conditions

## OPTIMIZED PURLINS

Critical challenges in the pv installations include achieving optimal combinations between mechanical loading and large-format modules.

The use of **purlins** in solar trackers provide **extra rigidity** to the modules. With the introduction of large-format modules and 2P configurations, purlins are redesigned to **optimize steel usage**.

Dynamic effects are also well known for untightening purlin fixation to torque tube due to vibrations. **Sturdy purlins** prevent modules from micro-cracking and losing.

**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.**

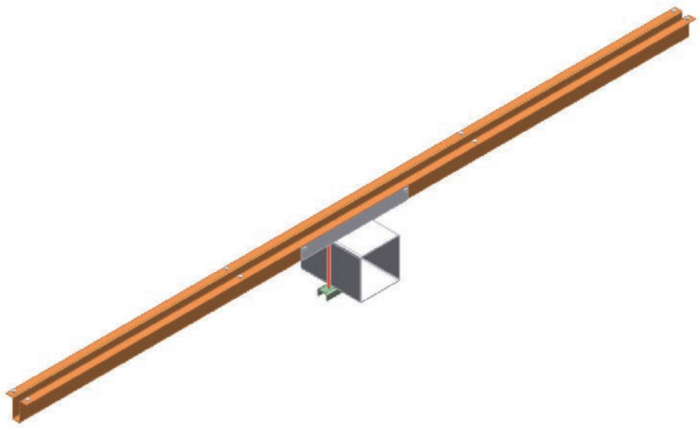


**Image 26:** Reinforced purlin design

## OPTIMISED POST

1P and 2P tracker components are optimised to reduce the number of posts installed per tracker. The posts used in upgraded trackers are designed with **larger cross-sections** to avoid problems caused by ramming, such as local bumps or twisting. A reduction in number of poles per tracker minimises the risk of **soil-related issues**.

## MODULE TESTING

Module resistance is tested to justify the pressure supported by modules under different tilt angles and comply with **IEC 61215-2 Standard**. Critical input is gathered from the pressure and suction hypothesis.

# 4.2 Stow Strategic Solutions

Different stow strategies are defined, considering the tracker's configuration, location of the project or meteorological conditions of the site.

**Different stow management strategies** are defined, considering the tracker's configuration, location of the project or meteorological conditions of the site.

## 4.2.1 Wind Stow Strategy to Mitigate Negative Pressure on Module

In the 1P configuration, high tilt angles stow position has been chosen. This position **minimises the dynamic effects** despite high wind pressure on modules.

In the 2P configuration stow position is set at a low tilt angles. In this position the dynamic behavior 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 compering to the traditional one-fixed point 2P configuration.

Image 27: Snow load

## 4.2.2 Snow Stow Strategy to Mitigate Positive Pressure on Module

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

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

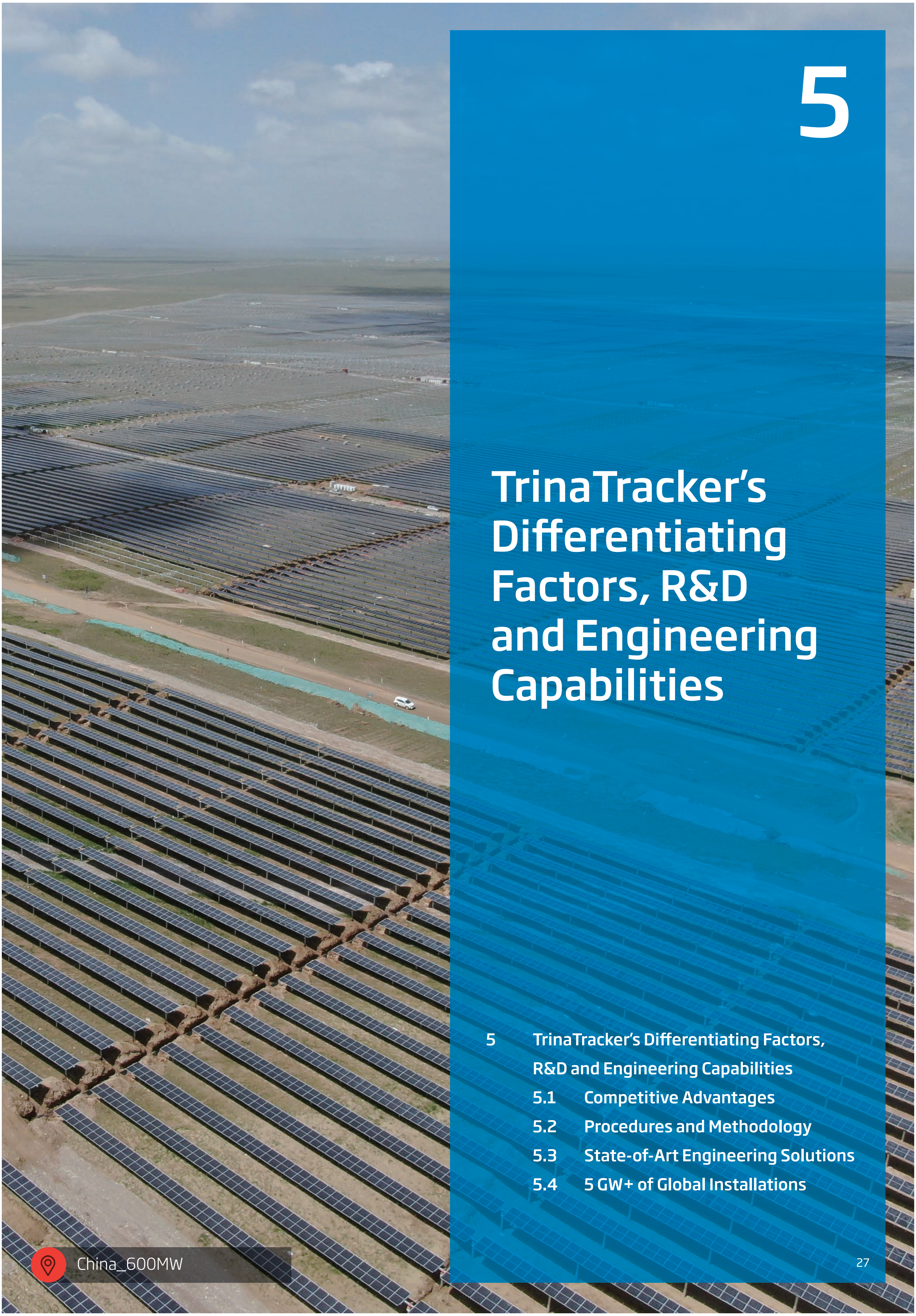
Potential issues triggered by snow loads are mitigated with the integration of an **alarm system**. The activation/devoid activation of the snow stow alarms are commanded by the **NCU sensors** and/or the operator **manual control**. The tracker will rotate accordingly to avoid snow accumulation.

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

## 4.2.3 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 can be detrimental for the **reliability and performance** of the pv installations.

New alarm systems are integrated into the project's design to mitigate risks. The **NCU** commands the activation of the hail alarm, which can also be activated at the **operator's criteria**. After the system's alarm is activated, the tracker rotation will reduce the direct impact of hail on the modules.



China_600MW

# 5

# TrinaTracker's Differentiating Factors, R&D and Engineering Capabilities

# 5.1 Competitive Advantages

**TrinaTracker** is a subsidiary company of **Trina Solar** (SHA:688599), a world leading pv and **smart energy solution provider.**

The company stands out in the solar sector for engaging in all activities integrated in the pv industry value chain: pv products, R&D, manufacture, sales, pv project development, EPC, O&M, smart micro-grid and multi-energy complementary systems development and sales as well as energy cloud performance operation.

Trina has recently maintained its **100% bankability** record with Bloomberg New Energy Finance for the 5th consecutive year.

## 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 the solar industry technology and markets
- **5 GW** of plants where trackers are tailor-made design to meet the site characteristics and clients' requirements
- Trackers installed in more than **40 countries**
- **In-house resources** to carry out the geotechnical design, structural design, FEM analysis, physical test, software and hardware design, project detailed design, research and development of products.
- **Work partnership** with leading wind engineering consultancy companies (RWDI and CPP)
- State of art **engineering** designed
- Designed technology that comply with the highest **European and US standards** (IEC62817 and UL3703 Certifications respectively)

# 5.2 Procedures and Methodology

**TrinaTracker** implements rigorous and meticulous **procedures and methodology** to guarantee a well-functioning of the trackers and avoid potential failures.

The company not only provides solutions to problems but take advantage to any issue by looking at it as an opportunity to add value to the trackers.

| PROBLEM WE SOLVE | Method | Value |
|---|---|---|
| How new tracker is compatible with big modules | Compatible design of module tracker | Reliable and bankable company and product |
| Complex terrain and harsh application environment | Unique spherical bearing & Multi-drive system | |
| Not bankable company balance sheet | Top and strict WTT Lab Tests | |
| | Solid company balance sheet | |
| PPA is declining fast | Intelligent Algorithm | Higher Power Generation |
| No efficient technology to improve yield | Shading mitigation engineering design | |
| PPA is declining, investors need to maintain IRR | Longer strings/less piles | Lower System Cost |
| System cost reduction slows down | Fast installations | |
| O & M costs are rising due to labor cost and complex Site & environment | SCADA O&M platform | Smarter O&M Platform |
| Traditional O & M efficiency is low | | |
| Delay of delivery due to non-integrated delivery | Integrated one-stop delivery of module and tracker | High delivery efficiency |

**Image 28-Table:** Reinforced purlin design

## FAILURE AND EFFECTS MODAL ANALYSIS (FEMA)

Failure mode and effects analysis is the process of reviewing as many components, assemblies, and solar tracker subsystems as possible to **identify potential failure modes** in a tracker system and their causes and effects. For each solar tracker component, the failure modes and their resulting effects on the rest of the system are recorded in a specific **FEMA worksheet**.

A successful FEMA activity helps us to identify potential failure modes based on experience with similar solar trackers produced in the past.

**DESIGN FEMA**

Trinasolar · TrinaTracker

Cod:
FEMA:
Date:
Sheet

Element: | Design responsible | By:
Customer: | Launchment date | Date 1st rev | Date 2nd rev
Analysis team:

| Function | Potential failure mode | Potencial failure effect | Severity | Potential failure cause | Ocurrency | Current controls | Detection | NPR | Corrective actions | Responsible and date | Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Submitted actions | Severity | Ocurrency | Detection | NPR |
| Function 01 | Failure in function 01 | Effects of the failure 01 | 8 | Cause of the failure 01 | 1 | Visual on site | 1 | 8 | | | | | | | |
| Function 02 | Failure in function 02 | Effects of the failure 02 | 8 | Cause of the failure 02 | 1 | Visual on expedition | 1 | 8 | | | | | | | |
| Function 03 | Failure in function 03 | Effects of the failure 03 | 8 | Cause of the failure 03 | 1 | Prototype test | 2 | 16 | | | | | | | |

**Image 29-Table:** Reinforced purlin design

## Factors of Failure to be Measured

### Severity

Severity considers the worst potential consequence of a failure, determined by the degree of injury, property damage, system damage and/or time lost to repair the failure.

### Occurrence

The likelihood of the failure occurring.

### Detection

Awareness of failure mode by maintainer, operator or built-in detection system, including estimated dormancy period (if applicable).

### NPR

Risk Priority Number.

## SIGN, CAUSE, REMEDY AND ACTION (SCRA)

**SCRA** is a **problem-solving** method that follows a logical **step-by-step** approach to identify the causes of the problem and propose actions to prevent recurrence.

### SCRA

**S — Sign**

**The 6 W's**: "what, who, when, where and how". Purpose: Establish the "focus" on the analysis.

**C — Cause**

**"why" Purpose**: Go into the root of the problem.

**R — Remedy**

**Search for all possible solutions** to the symptom. Purpose: Define corrective, preventive or even proactive measures.

**A — Action**

Relate the **"Remedies"** to more concrete actions, so that they can be planned, indicating a description of the measure **("what")**, the person responsible for implementing it **("who")** and the execution deadline **("when")**.

## QUALITY DESIGNING TOOLS

The company adopts crucial tools for **quality control** that enable efficient data communications and visual representation, leading to an accurate, assertive, and fluent decision-making process.

The tools operate vertically across all departments and business areas existing in the company.

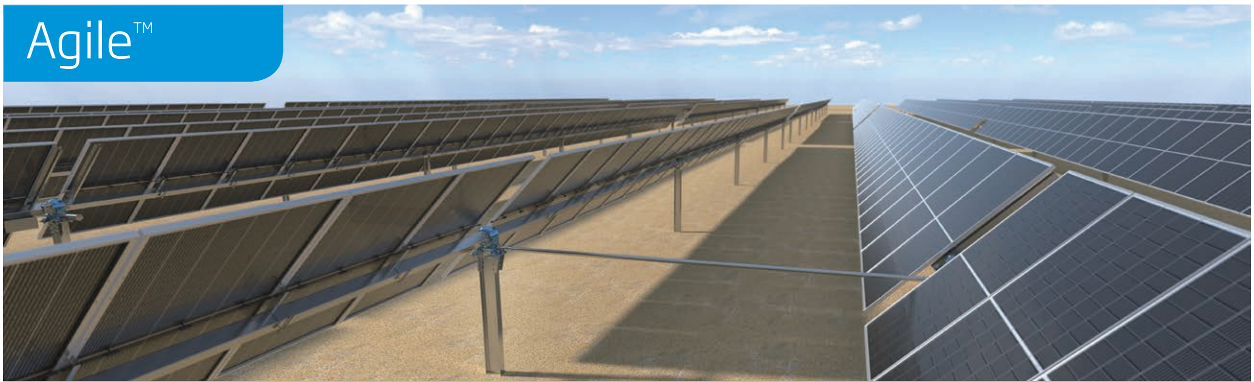

**Image 31:** 7 Tool's definitions

# 5.3 State-of-Art Engineering Solutions

## Vanguard™

- 2 in portrait, specifically engineered for large modules with multi point drive for stability.
- Up to 120 modules per tracker - optimized for Low Voltage up to 40 modules per string.
- Individual row actuation for optimum bifacial yield and wide unimpeded vehicle access every row (easiest O&M).
- Optimized slope tolerance up to 30% (15% standard).
- Lowest installed cost: 7 piles per table, <120 piles per MW.
- Best for Challenging sites: irregular/ constrained, geotech, undulating, flood plain.

## Agile™



- 1 in portrait, specifically engineered for large modules.
- Up to 120 modules per tracker - optimized for Low Voltage up to 40 modules per string.
- Dual row actuation for enhanced bifacial yield and wide vehicle access every other row (easy O&M).
- Fewest motors/controller/battery per MW (save capex & opex).
- Enhanced slope tolerance 20% N/S, 10% E/W.
- Best for less challenging sites.

# 5.4 5 GW+ of Global Installations


China_600MW


Kenia_96MW


Chile_33MW

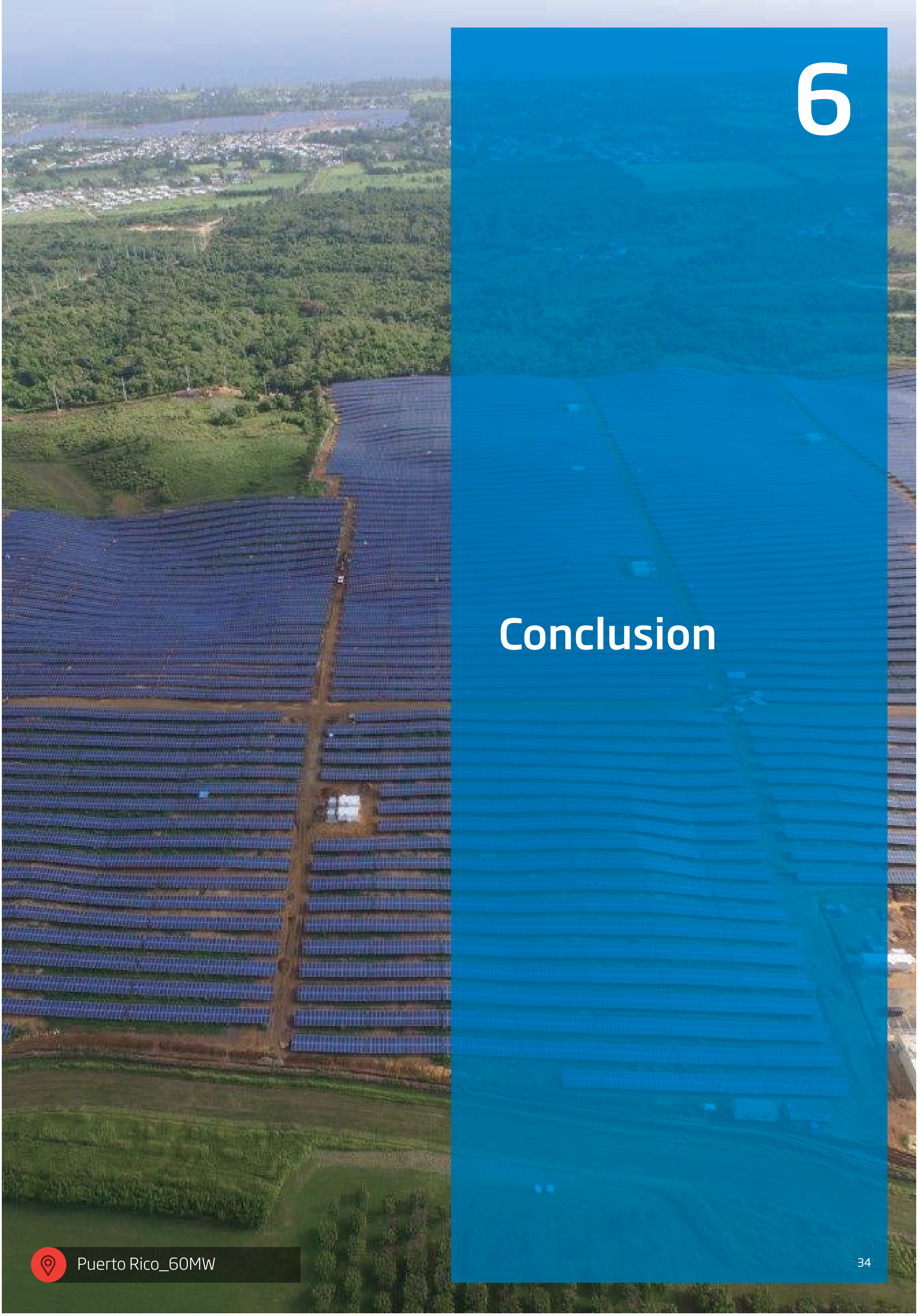

Argentina_32MW


Honduras_40MW


Spain_22MW

# 6

# Conclusion



# 6 Conclusion

**The accuracy of the information extracted from the test is critical to validate the strategic solutions adopted to mitigate wind-related risks and guarantee optimum yield generation and the trackers' reliability.**

The current massive availability of large-format module in the PV market represents a critical milestone in the solar industry that comes with new **technical challenges** for tracking structures.

Large-formal modules in pv plants benefit from higher energy production and require smaller size terrain for the same installed capacity. However, large-module areas also mean higher wind load pressure that can be detrimental to the **stability** and **durability** of the trackers.

Therefore, one of the most critical challenge in trackers' configuration, in this large-format-module-era is the mitigation of **wind-related risks**.

Trackers engineering companies need to react rapidly and efficiently to keep up with industry trends. Consequently, tracker designs need to be upgraded to accommodate large-format modules and reach compatibility.

The new parameters and calculations that define the upgraded designs are crucial to achieving optimum energy production and system reliability. Thus, **TrinaTracker**, in partnership with leading wind consultancy firms **RWDI** and **CPP**, has focused great deal of its engineering and development resources to perform **wind tunnel tests**. **The tests are implementing in the trackers** under the real and specific wind speed and load pressure existing in each of the installations' sites. The data resulted from the tests govern the systems´upgrade existing in the sites.

The accuracy of the information extracted from the test is critical to validate the strategic solutions adopted to mitigate wind-related risks and guarantee optimum **yield generation** and trackers' **reliability**.

The PV Industry on the way to **grid parity**, is on a permanent effort to optimise power output and systems' efficiency. Large-format module availability has become one essential factor to lower **BOS** cost and **LCOE**.

As the leading module and tracker manufacturer, Trina has been always well prepared for the technology changes. As part of our product roadmap, we will continuously optimize the tracker designs to achieve reliable, compatible, smarter solutions.


TrinaTracker

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