# ORUGA® software
# *PERFORMANCE MODULE*

**November 25, 2022**

## 0. EXECUTIVE SUMMARY

ORUGA® software – *Certified by a Technical Advisor* – calculates accurately the Annual Electricity Production of PV plants in complex orography terrains for any tracker model, applying Flat *Backtracking* or Sener proprietary 3D *Backtracking* strategy.

ORUGA® therefore overcomes the limitations of the Software considered as the Reference in the Market (SRM) for commercial plants (>1 MWp) in complex orography terrains. This new feature can positively reduce the uncertainties associated to complex orography in PV projects at all levels: Development, EPC and Operation.

The decrease in annual electricity production when moving from a flat terrain to a complex one typically varies between 0 and 10%. The specific value depends on the complexity of the terrain in each case.

The new software has been developed by Sener based on their experience in the field of performance simulation for CSP technology, an order of magnitude more complex than PV technology. This knowledge in CSP has made possible giving bankable annual production guarantees in 19 projects since 2006.

## 1. THE PROBLEM

**Calculating the annual electricity production of a PV plant in a complex orography terrain is a problem with no commercial solution today.**

The Software considered as the Reference in the Market (hereafter SRM) for Banks, Technical Advisors and Engineering firms – ***extremely accurate and detailed for flat terrains*** – presents an important limitation (published on their web page): "the *Module Layout* – where modules I-V curves are considered – is only useable with systems of the order of some few MWp at most". "SRM fixes a "reasonable" limit of around 1 MWp, and an upper limit of 5 MWp".

The above is due to the calculation time, which would be prohibitive in such case. However, in complex orography terrains, where shading losses between trackers are considerable, this is the only valid alternative to accurately calculate plant production.

Hence, SRM leaves 2 options for plants larger than 5 MWp:

1. *Linear shadings*, considering only irradiance deficit, not electrical shadings
   **>>> yield is overestimated**
2. *According to Module Strings*, assuming that, when one string is touched by a shadow, it is considered inactive (affection regulated by a factor)
   **>>> yield is underestimated**

**The decrease in annual electricity production when moving from a flat terrain to a complex one typically varies between 0 and 10%**. The specific value depends on the complexity of the terrain in each case.

## 2. THE CONSEQUENCES

The inability of calculating accurately and reliably a bankable electricity production for a PV plant located on a complex orography terrain **considerably increases the uncertainty and the risks in each and every project phase**. The following questions arise to our Clients (see ANNEX 2):

- As ***Project Developer,*** ¿can I offer a reliable energy price (USD/MWh), assuring long term profitability of my project?, ¿is the *Business Model* realistic?, ¿will the Technical Advisor for the Lenders accept the yield I considered?
- As ***EPC Contractor***, ¿can I guarantee the electricity production the Developer is requiring or is it unachievable?, ¿can I offer a higher yield to the Developer using another tracker model for this terrain?, ¿is this yield increase the tracker supplier is claiming for via his 3D *Backtracking* achievable?
- As ***Plant Operator***, ¿can I quantify the energy loss due to row-to-row shadowing in my plant?, ¿can I increase my annual production implementing a 3D *Backtracking* strategy?

## 3. THE SOLUTION

**ORUGA® replicates the calculation of power output of SRM for flat terrains not only at annual level, but also hour by hour, with a very reduced deviation**: in case study #1 (section 5), the deviation in annual production is +0.2%, being the RMS of the hourly deviation in power output 0.7%. In case study #2 (section 6), these figures are 0% (annual) and 2.2% (hourly RMS).

Furthermore, **ORUGA® overcomes the limitations of SRM for plants larger than 5 MWp**. ORUGA® can, for any plant size…

1. Consider I-V curves of modules
2. Simulate any tracker in the market: single-row, multi-row, fixed or variable length, adaptable to terrain profile…
3. Use ray-tracing methods to compute accurately shadowing between trackers and those from the objects defined in 3D (trees, mountains, buildings…)
4. Implement 2D *Backtracking* (Flat) and 3D *Backtracking* (Sener proprietary)
5. Analyse and compare different *Backtracking* strategies from Third Parties
6. Calculate in 1 minute time-steps
7. Admit user-defined inputs, such as IAM matrix and Inverter efficiency

*ORUGA® has been verified by a Technical Advisor for several case studies on different terrains (flat and 3D) and with monofacial and bifacial modules, as per the request of a Client that has used ORUGA® in several of his projects in order to mitigate the risks associated to the complex orography of the sites.*

*This Audit process has taken 6 months. The resulting* ***certificate*** *is available for potential Sener Clients interested in the use of ORUGA®.*

## 4. BACKGROUND: a much more complex technology

**Sener is a pioneer in CSP technology (Concentrating Solar Power or Solar Thermal), where performance simulation is an order of magnitude more complex than PV technology**. Sener has designed, constructed, commissioned and operated 29 CSP projects all over the world, closing bankable annual production guarantees in 19 projects since 2006.

Out of these 29 plants, all of them operational today, it is worth mentioning Gemasolar (19.9 MW) – 1st world commercial plant using molten salt tower technology with 15 hours of storage – and Noor III (150 MW) – the world largest tower plant in operation.

**Fig. 1: Ouarzazate CSP complex; from left to right: Noor III, Noor II and Noor I**

*Specifically in Noor III, there are 7400 heliostats (as far as 1.6 km from the tower), which track the Sun in 2 axes during the whole day, changing their target position each 30 seconds. These 7400 "2 axes trackers" must reflect Sun's rays to a receiver located on top of a 250 m high tower.*

*Because peak energy concentration on receiver surface may reach 2000 to 1 and this component only supports nominally half of this figure (1000 to 1), the heliostat field aiming strategy must be extremely precise to respect receiver limitations in all operating conditions (start up/shutdown, ramping up/down, nominal output, cloudy periods…). This means,* inter alia*, distribute the 7400 aiming points all over receiver surface with an accuracy <0.1º, considering a list of parameters for each control point on receiver surface (>300 points) and other data received from plant control system and from operation staff:*

- *Temperature and flow of molten salts*
- *Outer and inner temperature of receiver tubes*
- *Solar radiation, wind speed, ambient temperature and relative humidity*
- *Availability and cleanliness factor of each heliostat*
- *Weather forecast*
- *Storage level*
- *Turbine status (starting up, shutting down, in operation) and power level*
- *Electricity production planning*

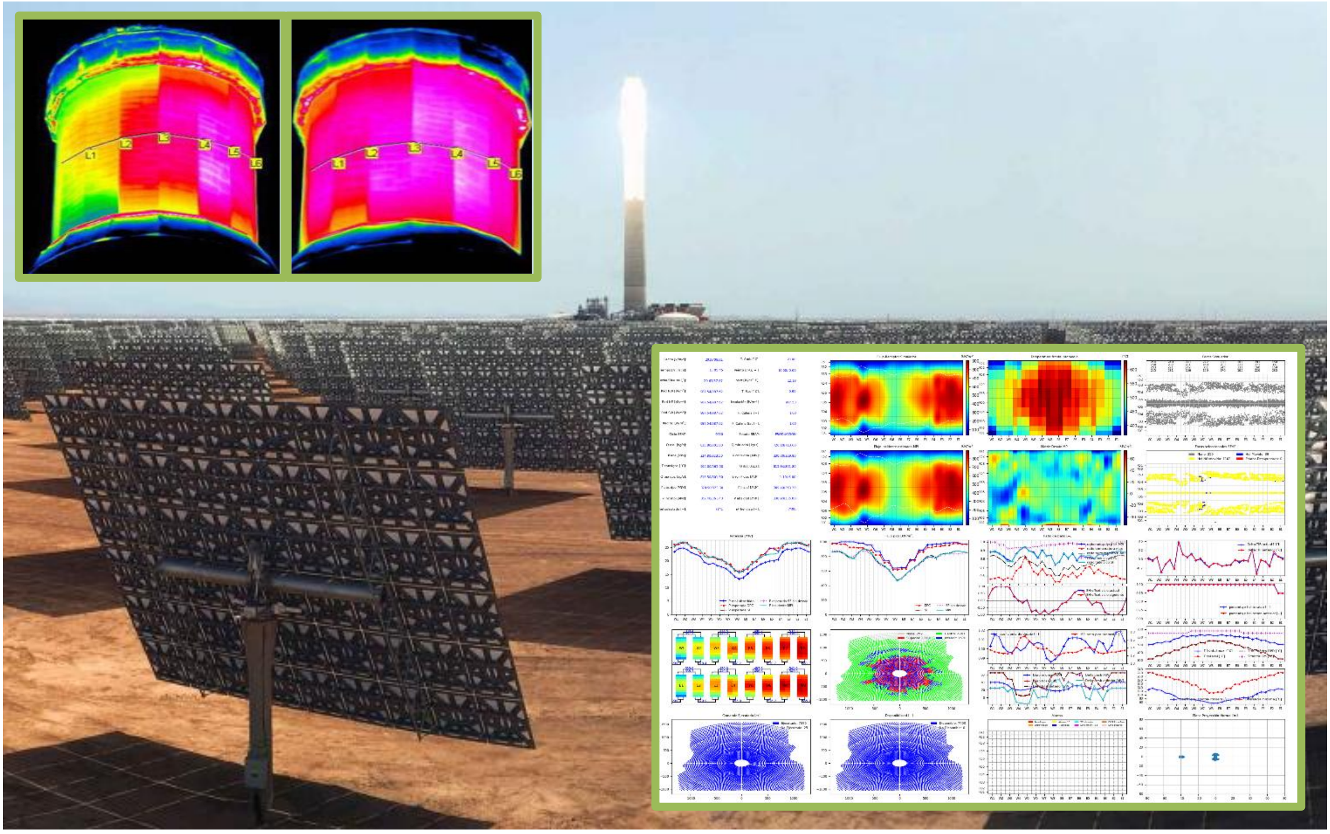


**Fig. 2: Noor III solar field in operation. Superimposed: receiver thermography (top left) and aiming control system (bottom right)**

In summary, the aiming control system in a tower plant manages millions of signals to control the actuation of 7400 "trackers" spread over a 6 $km^2$ area, which change their target position each 30 seconds with an accuracy <0.1º to always assure a peak energy concentration lower than 1000 to 1 on the receiver. The excellence required for this process is outstanding, considering that deviations in peak concentration w.r.t. the limit at each point of the receiver surface would damage this.

*The basis for this control system is a precise optical model of the solar field, which is used to predict the energy that the receiver is going to collect at each moment over its panels. Without this model, it would not be possible to actually have a solar field control system in a tower plant.*

*Such a detailed model of the solar field optical behaviour is performed by the Technological Solutions Department at Sener, the very same responsible of ORUGA®.*

## 5. REAL CASE STUDY #1

In 2022, **a Developer – in charge also of project O&M – ordered a Performance Report to Sener for an <u>operational PV plant</u> on a terrain with a very complex orography**. The plant has 50 MWp approx., 2P trackers and monofacial modules. It is located in southern Europe.

This plant, since the beginning of operations, has an ***important problem of shadows between trackers in the mornings and afternoons***, decreasing electricity production below the expected value, thus compromising the achievement of plant guarantees.

*The Client wanted to 1) evaluate the impact of terrain on plant production – which could not be done with SRM (Software considered as the Reference in the Market) – and, furthermore, 2) evaluate the possibility of implementing ORUGA® 3D* Backtracking *in the plant to improve efficiency; because of these reasons, he ordered the Performance Report with ORUGA® to Sener.*

These are the steps followed:

0. Creation of a 3D model with the actual XYZ location of the trackers on the terrain, as well as the obstacles within site limits (electrical towers, transformation centres and elevated areas on the ground).
   *To this end, a topographical survey was carried out on site*
1. Plant simulation with SRM >>> Flat Terrain + 2D *Backtracking*
2. Plant simulation with ORUGA® >>> Flat Terrain + 2D *Backtracking*
3. Plant simulation with ORUGA® >>> 3D (real) Terrain + 2D *Backtracking*
4. Plant simulation with ORUGA® >>> 3D (real) Terrain + 3D *Backtracking*

**The terrain had important undulations, reaching values of North-South slope of ±15%**, as shown below:

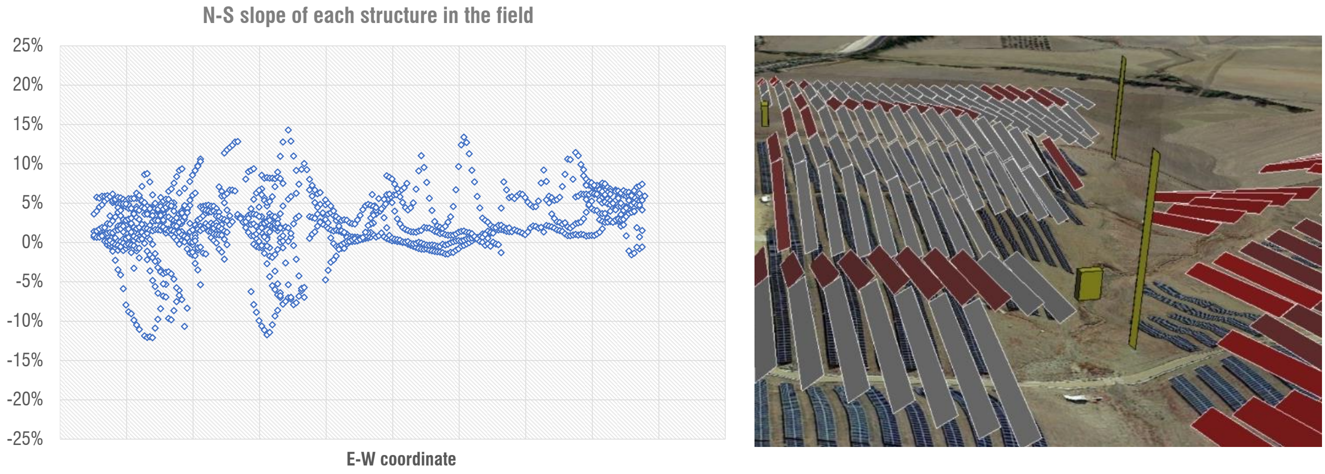



**Fig. 3: N-S slope distribution (left) and 3D detail of trackers and obstacles (right)**

The <u>**results**</u> of the study are as follows:

| CASE | SOFTWARE | TERRAIN | *BACKTRACKING* | ANNUAL PRODUCTION |
|---|---|---|---|---|
| 1 | Reference in the Market | Flat | 2D | 100.0% |
| 2 | ORUGA® | Flat | 2D | 100.2% |
| 3 | ORUGA® | 3D | 2D | 96.8% |
| 4 | ORUGA® | 3D | 3D | 100.1% |

**Table 1: Results of the study**

Table above shows that…

- **ORUGA® calculates a slightly (+0.2%) higher production on a flat terrain than SRM:**
  *[case 2 vs case 1]*
- **The terrain where the trackers are positioned is causing a decrease of 3.4% w.r.t. the calculation on a flat terrain:**
  *[case 3 vs case 2]*
- **ORUGA® 3D *Backtracking* would take plant production up to a level almost equal to the flat terrain case:**
  *[case 4 vs cases 3 and 2]*

The graph in the next page (Fig. 4) shows, for several days in the year, the power output calculated in the 4 cases of Table 1 above. <u>Fig. 5 contains exclusively the comparison between cases 1 (SRM) and 2 (ORUGA®) on a flat terrain</u>.

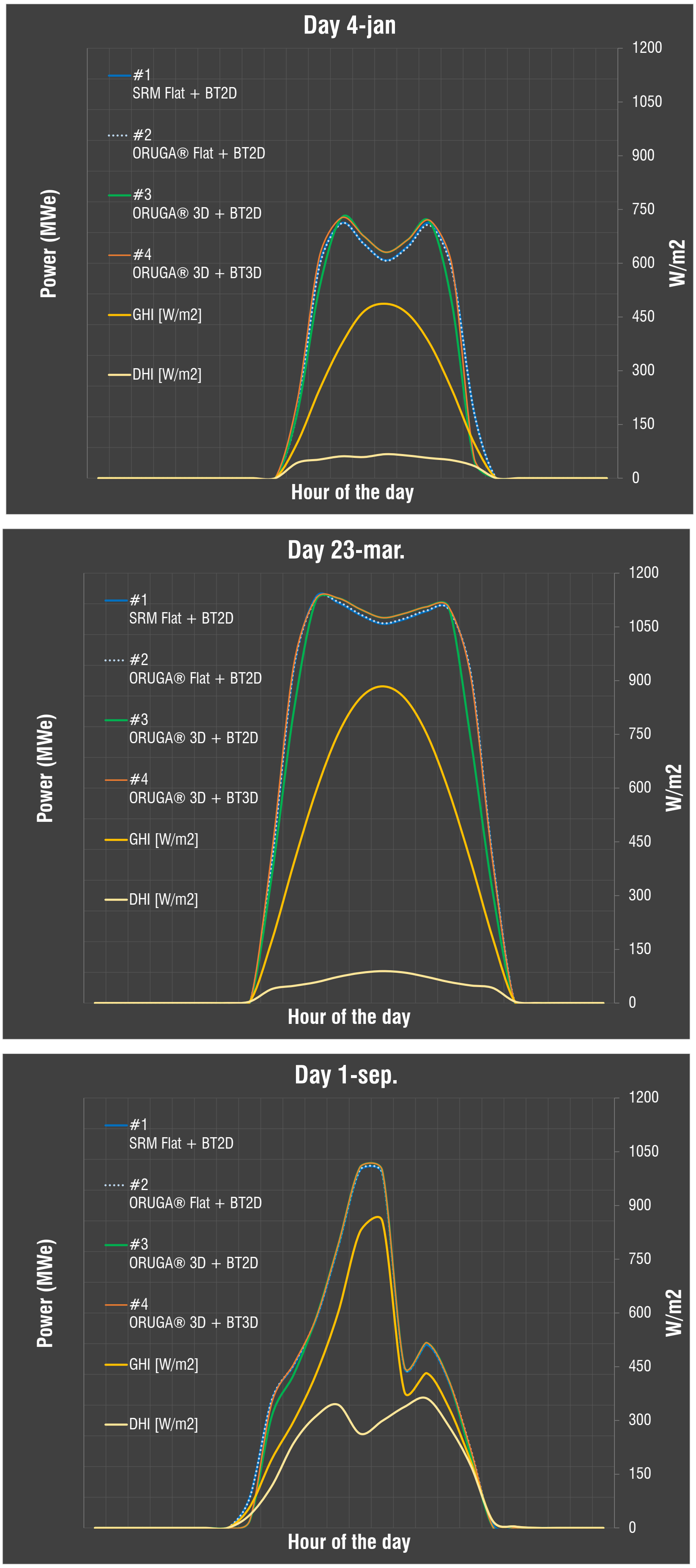



**Fig. 4: Power output and solar radiation for different days in the year (cases 1 to 4)**

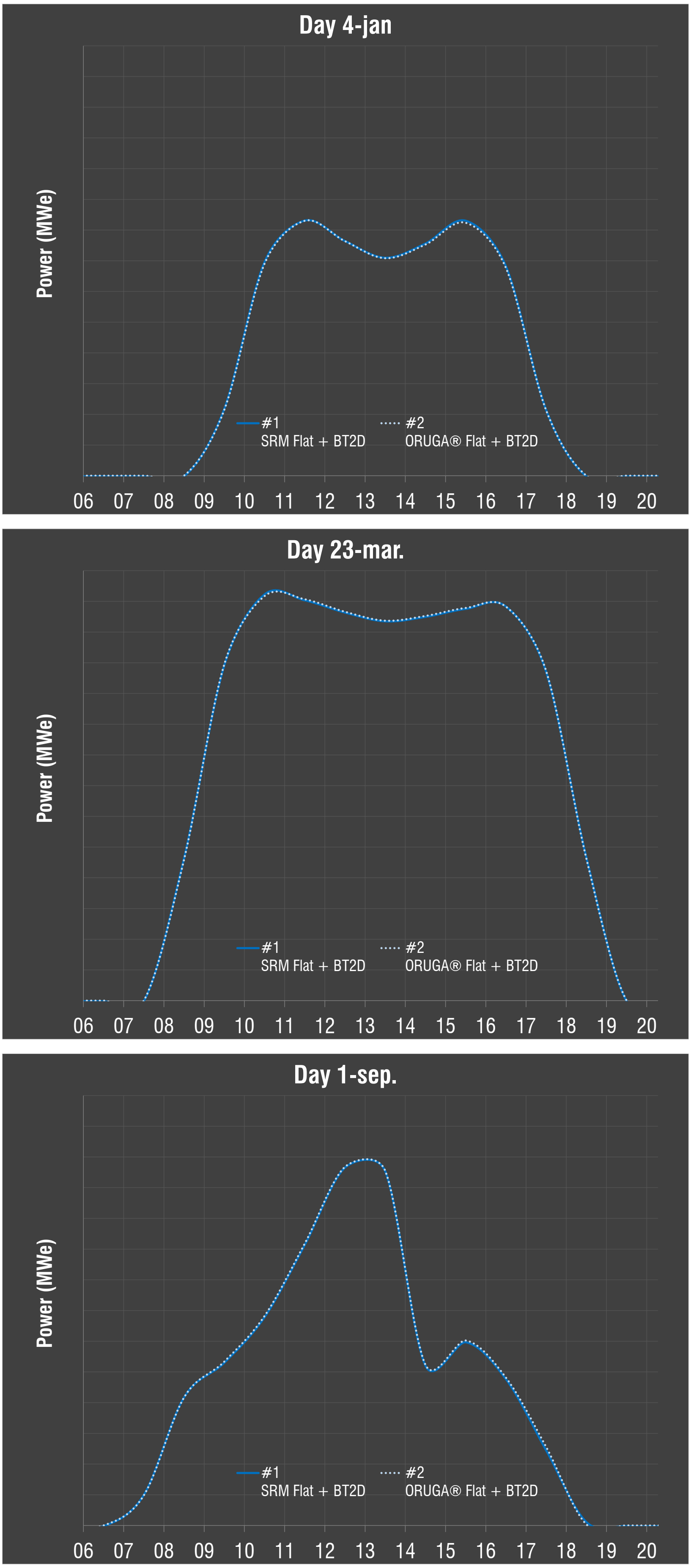



**Fig. 5: Power output for different days in the year. SRM vs ORUGA® (cases 1 and 2)**

The 2 graphs below (Fig. 6) show the deviation in power output calculation when ORUGA® is compared to SRM (considering only datapoints with Power > 5 MWac).

In line with Fig. 5, **the deviation for each time step** (hourly, as SRM has this limitation) **is concentrated in a ±1% interval, being the RMS of all datapoints 0.7%**. The deviation in annual production is +0.2% in this case (see Table 1).

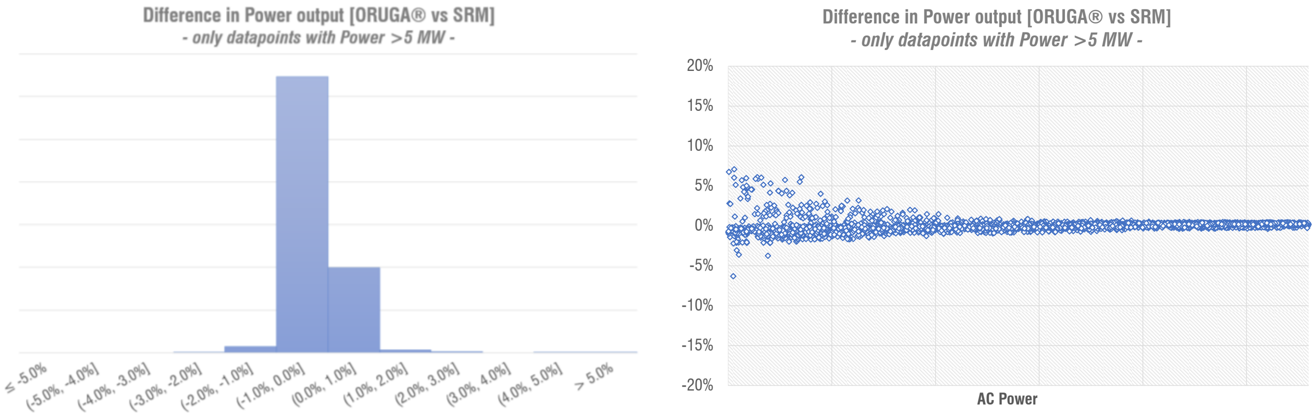



**Fig. 6: Comparison of ORUGA® vs SRM for all datapoints with Power > 5 MW**

Images below illustrate the shadows between trackers for Case 3 (2D *Backtracking*) and Case 4 (ORUGA® 3D *Backtracking*). Time stamp is December 21 – 6 PM.

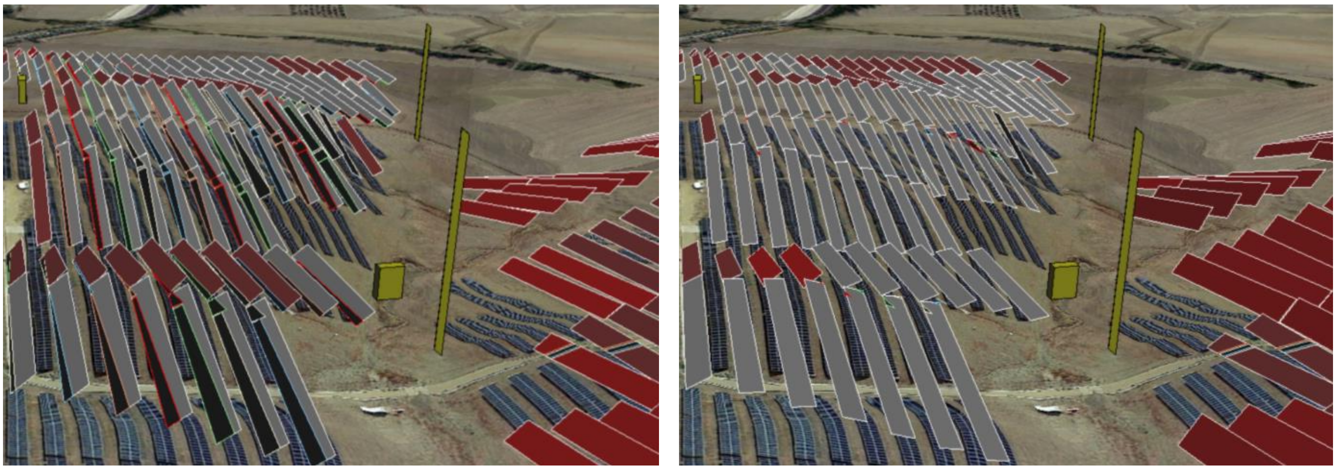


**Fig. 7: Shadows between trackers: Case 3 (BT2D, left) vs Case 4 (ORUGA® BT3D, right)**

## ¿What is the effect of ORUGA® 3D *Backtracking*?

This can be easily observed in the following table, which shows part of the internal calculations of plant production:

| CASE | Global incident in coll. plane | IAM factor on global | Near Shadings: irradiance loss | Electrical Shadings |
|---|---|---|---|---|
| 2 | 28.0% | -1.3% | -1.2% | 0.0% |
| 3 | 28.8% | -1.3% | -1.9% | -3.4% |
| 4 | 28.0% | -1.4% | -1.2% | 0.0% |

**Table 2: Effect of ORUGA® 3D *Backtracking***

ORUGA® 3D *Backtracking* (case 4) regulates the tilt angle of the trackers in a way that minimizes linear shadings and, at the same time, the corresponding electrical shading when compared to Flat *Backtracking* (case 3). In this process, incident radiation decreases, but this is widely compensated by the lower shadowing (linear and electric).

Looking deeper into the effect of 3D *Backtracking* in this plant, next table shows a **breakdown of the increase in production throughout the year** w.r.t. Flat *Backtracking* (figures in MWh, relative to annual total):

| [MWh] Case 4-Case 3 | MONTH | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HOUR | January | February | March | April | May | June | July | August | September | October | November | December | |
| 0 | | | | | | | | | | | | | |
| 1 | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | |
| 7 | | | | 0.2% | 1.2% | 1.3% | 1.4% | 0.4% | | | | | 5% |
| 8 | | | 0.9% | 1.7% | 2.8% | 2.6% | 3.1% | 2.3% | 1.5% | 0.9% | 0.0% | | 16% |
| 9 | 1.0% | 1.1% | 2.6% | 1.5% | 0.1% | | 0.3% | 1.6% | 2.8% | 2.3% | 1.5% | 0.8% | 16% |
| 10 | 2.5% | 1.5% | 0.1% | 0.0% | | | | | | | 0.7% | 1.8% | 7% |
| 11 | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | |
| 13 | | | | | | | | | | | | | |
| 14 | | | | | | | | | | | | | |
| 15 | 0.0% | | | | | | | | | | 0.2% | 0.2% | 0% |
| 16 | 2.6% | 0.9% | 0.1% | | | | | | 0.3% | 2.6% | 2.8% | 2.3% | 12% |
| 17 | 1.2% | 2.1% | 3.7% | 3.3% | 2.0% | 0.3% | 0.3% | 2.7% | 3.1% | 1.9% | 0.1% | 0.0% | 21% |
| 18 | | 0.2% | 1.6% | 2.0% | 3.4% | 3.9% | 4.6% | 3.1% | 1.2% | 0.0% | | | 20% |
| 19 | | | | 0.0% | 1.0% | 1.6% | 1.8% | 0.5% | | | | | 5% |
| 20 | | | | | | | | | | | | | |
| 21 | | | | | | | | | | | | | |
| 22 | | | | | | | | | | | | | |
| 23 | | | | | | | | | | | | | |
| Total | 7% | 6% | 9% | 9% | 11% | 10% | 11% | 11% | 9% | 8% | 5% | 5% | 100% |

Table 3: Annual breakdown of the effect of ORUGA® 3D *Backtracking*

It is clear how the production gain occurs only in the mornings and in the afternoons (see also Fig. 8), since **ORUGA® 3D *Backtracking* is focused on increasing plant production through a reduction of shadows between trackers**. Sener has also developed an alternative 3D *Backtracking* that, in addition to the reduction of shadowing, maximizes the reception of diffuse radiation providing that this leads to an increase in electricity generation[1].

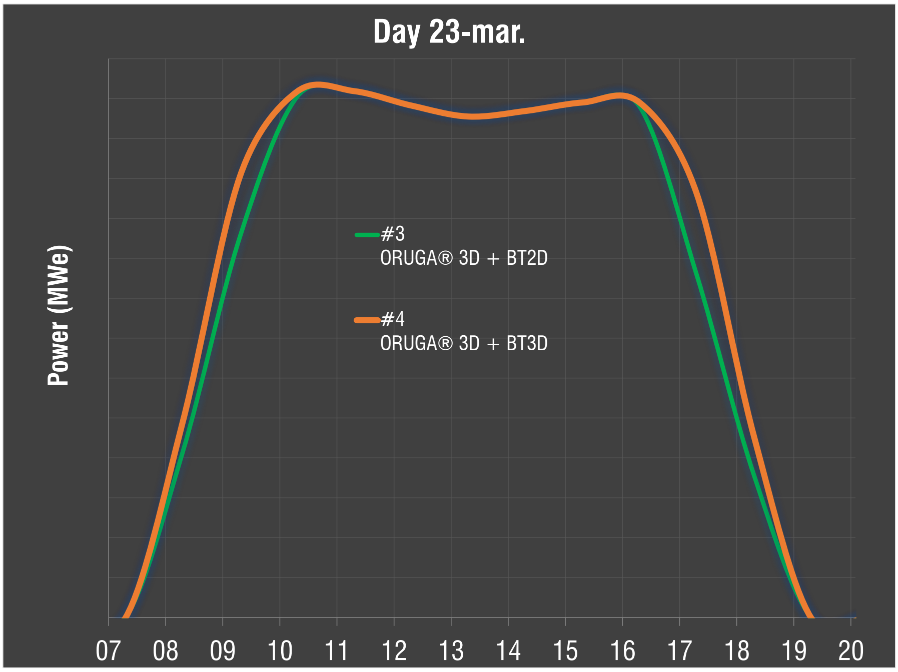



Fig. 8: Effect of ORUGA® 3D *Backtracking*. Sunny day

## Implementation of ORUGA® 3D *Backtracking* in the plant

The supplier of plant control system has already provided a technical solution, very fast to implement, and with a minor economic impact on the project. This solution would also allow the use of the current *Backtracking* strategy (Flat), if desired.

[1] This alternative 3D *Backtracking* will be discussed in future articles

## 6. REAL CASE STUDY #2

Recently, **a Developer ordered a Performance Report to Sener for a PV plant on a site with a very complex orography**. The plant has 10 MWp approx., 2P trackers and bifacial modules. It is located in southern Europe.

> *The tracker model is relatively new to the market, and it allows the aggrupation a variable number of structures along the North-South axis on each site zone, producing a lay out with 8 different types of trackers in this case (8 different lengths).*
>
> *Each tracker type, regardless its length, is actuated by the same actuation and control system. This has the potential of reducing the cost per installed Wp but, at the same time, restricts the independent actuation of each structure, thus reducing the capacity of production recovery when implementing a 3D* Backtracking.

*The Client needed certainty on the annual electricity production of the plant before elaborating the* Business Model *and initiating the selection process of the EPC Contractor. He could not calculate the annual electricity production with SRM (Software considered as the Reference in the Market) and therefore he ordered the Performance Report with ORUGA® to Sener.*

These are the steps followed:

0. Creation of a 3D model with the actual XYZ location of the trackers on the terrain
1. Plant simulation with SRM >>> Flat Terrain + 2D *Backtracking*
2. Plant simulation with ORUGA® >>> Flat Terrain + 2D *Backtracking*
3. Plant simulation with ORUGA® >>> 3D (real) Terrain + 2D *Backtracking*
4. Plant simulation with ORUGA® >>> 3D (real) Terrain + 3D *Backtracking*

**The terrain had many undulated areas, reaching values of North-South slope of ±20%**, as shown below:

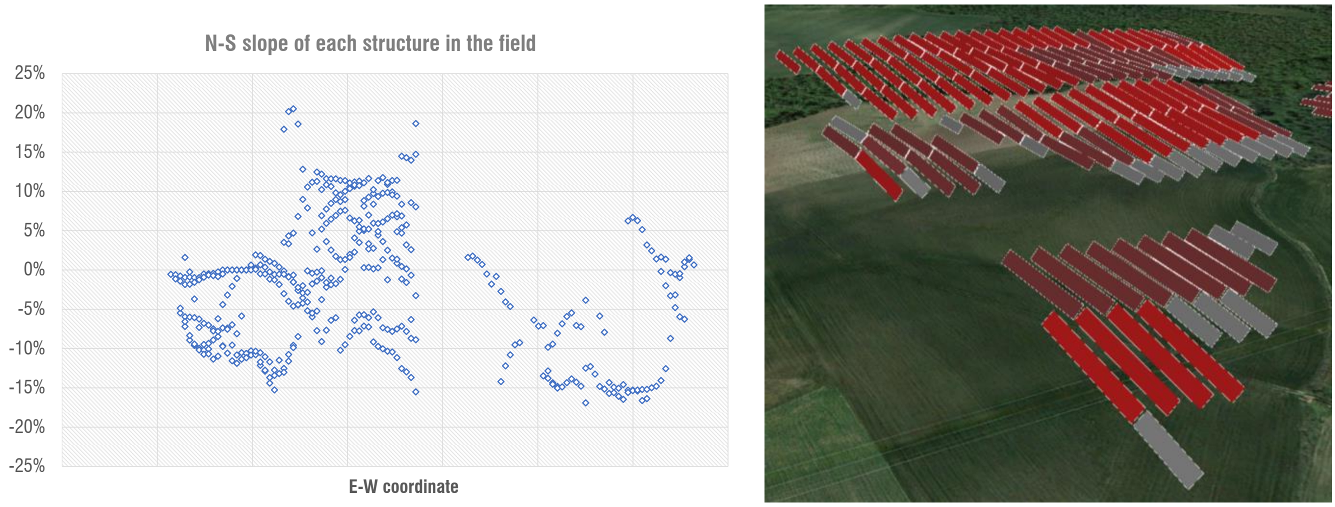



**Fig. 9: N-S slope distribution (left) and 3D detail of trackers (right)**

The **results** of the study are as follows:

| CASE | SOFTWARE | TERRAIN | *BACKTRACKING* | ANNUAL PRODUCTION |
|---|---|---|---|---|
| 1 | Reference in the Market | Flat | 2D | 100.0% |
| 2 | ORUGA® | Flat | 2D | 100.0% |
| 3 | ORUGA® | 3D | 2D | 95.3% |
| 4 | ORUGA® | 3D | 3D | 96.7% |

**Table 4: Results of the study**

Table above shows that…

- **ORUGA® calculates the same production on a flat terrain than SRM:**
  *[case 2 vs case 1]*
- **The terrain where the trackers are positioned is causing a decrease of 4.7% w.r.t. the calculation on a flat terrain:**
  *[case 3 vs case 2]*
- **ORUGA® 3D *Backtracking* would recover 1.5% of the production, leaving the decrease above in 3.3%:**
  *[case 4 vs cases 3 and 2]*

The graph in the next page (Fig. 10) shows, for several days in the year, the power output calculated in the 4 cases of Table 4 above. Fig. 11 contains exclusively the comparison between cases 1 (SRM) and 2 (ORUGA®) on a flat terrain.

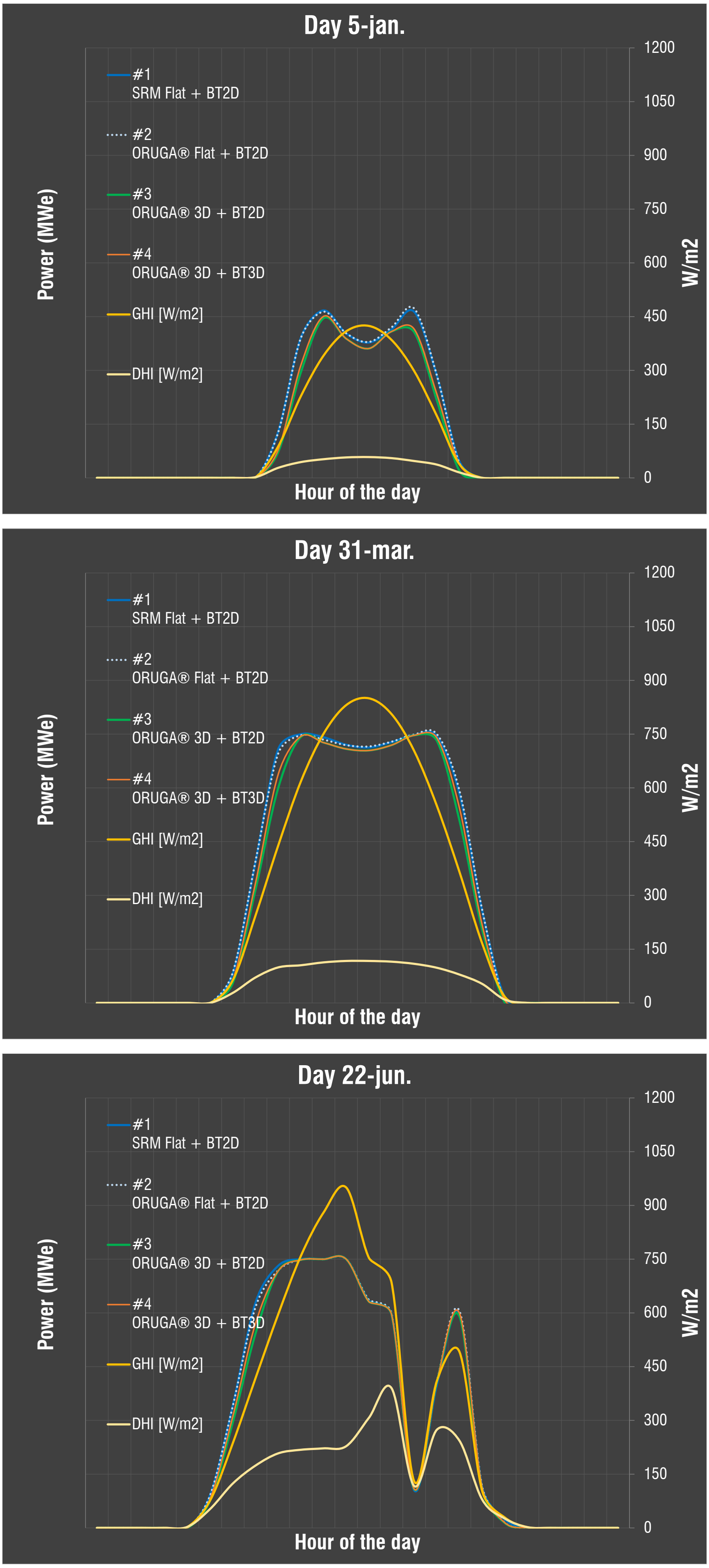



Fig. 10: Power output and solar radiation for different days in the year (cases 1 to 4)

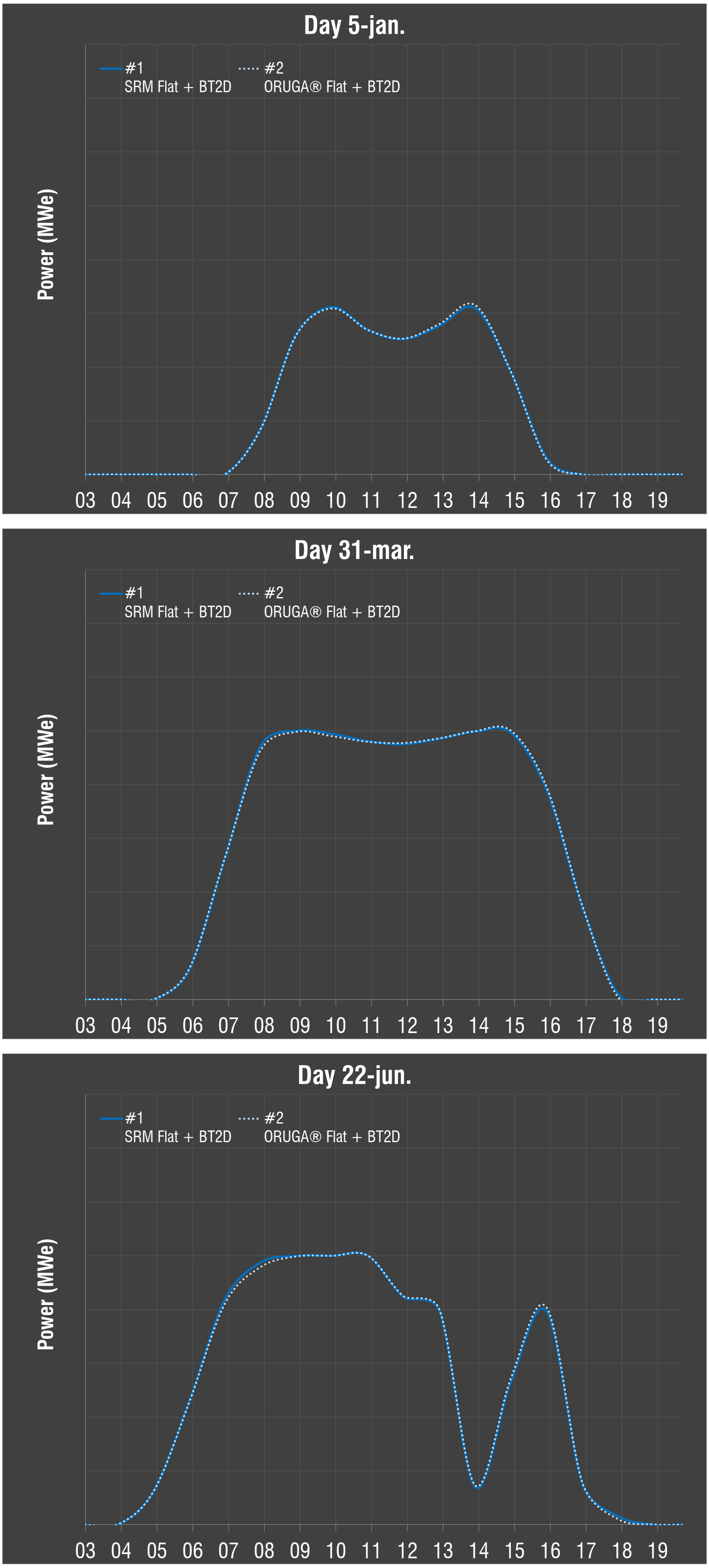
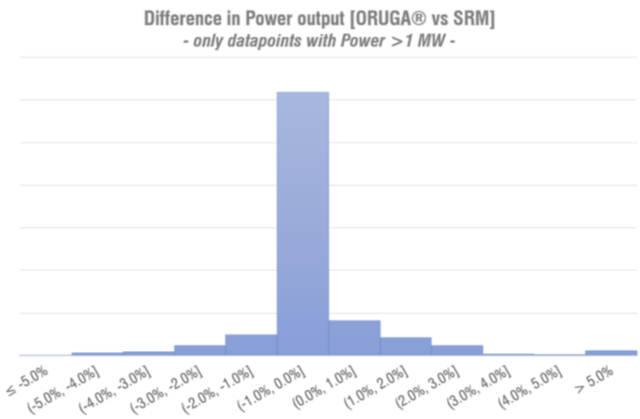



**Fig. 11: Power output for different days in the year. SRM vs ORUGA® (cases 1 and 2)**

The 2 graphs below (Fig. 12) show the deviation in power output calculation when ORUGA® is compared to SRM (considering only datapoints with Power > 1 MWac).

In line with Fig. 11, **the deviation for each time step** (hourly, as SRM has this limitation) **is concentrated in a ±2% interval, being the RMS of all datapoints 2.2%**. The deviation in annual production is 0 % in this case (see Table 4).



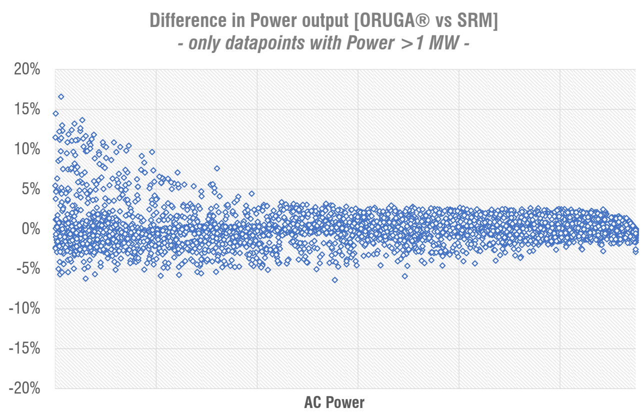
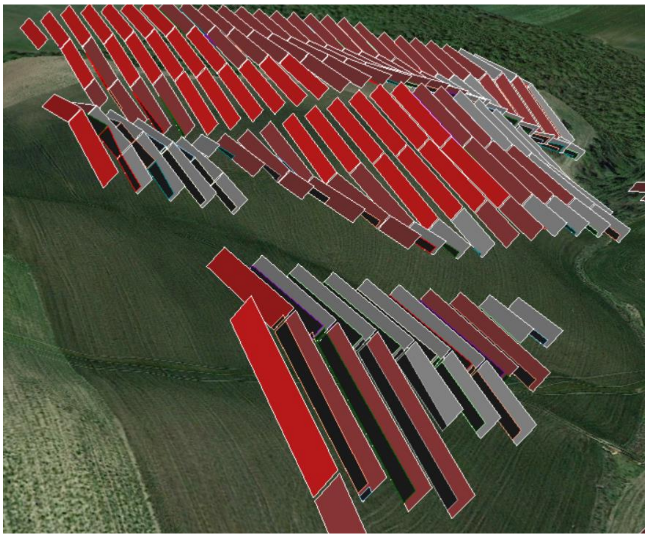




Fig. 12: Comparison of ORUGA® vs SRM for all datapoints with Power > 1 MW

Images below illustrate the shadows between trackers for Case 3 (2D *Backtracking*) and Case 4 (ORUGA® 3D *Backtracking*). Time stamp is March 21 – 9 AM.



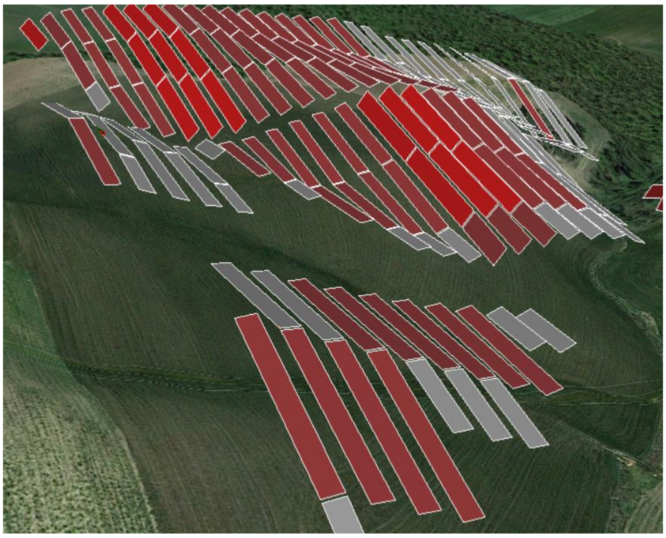


Fig. 13: Shadows between trackers: Case 3 (BT2D, left) vs Case 4 (ORUGA® BT3D, right)

## ANNEX 1 – INFORMATION ON ORUGA® SOFTWARE

ORUGA® software is a Sener proprietary tool conceived for the **3D Optimization of PV projects**, adding the best value in ***terrains with complex orography***.

ORUGA® provides the **most profitable plant design for any given plot**, thanks to its differentiating features:

1. Accurate calculation of **Civil Works**, including Earthworks and Metallic Structure optimization
2. Precise determination of annual **Plant Performance – *certified by a Technical Advisor*** –, considering…
    a. Actual shadowing between trackers, via ray-tracing methods
    b. I-V curves behaviour of cells+modules+strings+inverters
    c. 3D *Backtracking* Algorithm that minimizes shadowing between trackers at all times
3. **Iterative mode** in order to manage thousands of design alternatives, evaluating CAPEX, OPEX, Production and, hence, LCOE of each one

**Sener provides advanced engineering services supported by ORUGA®. Basically, there are 3 options:**

A. Civil Works optimization, when PV plant lay out (XY) is defined
B. Plant performance calculation, when PV plant lay out (XYZ) is defined
C. Techno-Economical optimization, when there is room for design improvement

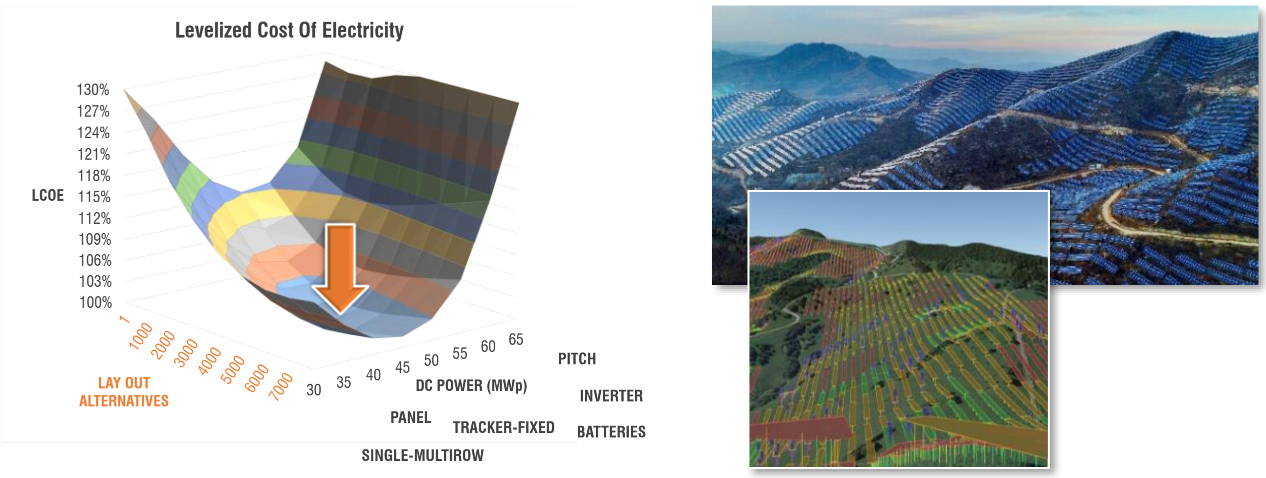



Fig. 14: 3D Design Optimization for the lowest LCOE in complex orography terrains

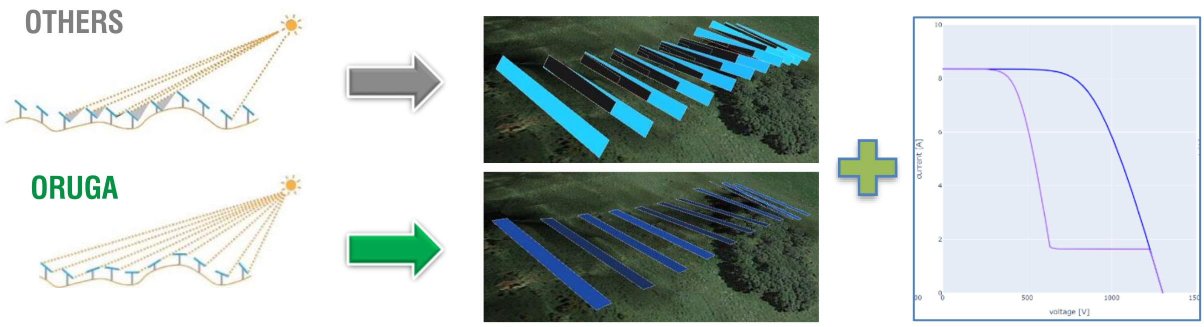



Fig. 15: 3D Backtracking Algorithm to enhance plant production and modules durability + I-V curves precise consideration

Fig. 16: Civil Works Optimization process

## ANNEX 2 – REFERENCES

The table below shows the projects in which ORUGA® has been applied so far:

| # | DATE | COMPANY (*) | POWER [MWp] | *OPTION ORDERED* | | | |
|---|---|---|---|---|---|---|---|
| | | | | Design Optimization BEST LCOE | Civil Works Optimization | Performance Calculation | Check of Civil Works & Performance |
| **1** | feb-20 | ACCIONA | 190 | X | | | |
| **2** | mar-20 | A&G RENOVABLES | 200 | X | | | |
| **3** | may-20 | ATA RENEWABLES | 100/63/63 | X | | | |
| **4** | dec-20 | ENFINITY | 116 | | X | | |
| **5** | apr-21 | ESPARITY SOLAR | 120 | X | | | |
| **6** | may-21 | FCC INDUSTRIAL | 50 | | X | | |
| **7** | jun-21 | GALP | 15 | X | | | |
| **8** | jul-21 | IGNIS | 70 | X | | | |
| **9** | aug-21 | IMASA | 30 | X | | | |
| **10** | aug-21 | NEOEN | 55 | X | | | |
| **11** | sep-21 | NEOEN | 100 | X | | | |
| **12** | oct-21 | NEOEN | 50 | | X | X | |
| **13** | jan-22 | NEOEN ECUADOR | 40 | X | | | |
| **14** | feb-22 | NEXTERA | 72 | X | | | X |
| **15** | feb-22 | OHL INDUSTRIAL | 72 | X | | | X |
| **16** | feb-22 | QAIR | 270 | X | | X | X |
| **17** | mar-22 | Q-ENERGY | 40 | | | X | |
| **18** | jul-22 | VINCI ENERGIES | 400 | X | | X | |
| **19** | sep-22 | X-ELIO | 166 | | X | | |
| **20** | sep-22 | X-ELIO | 16 | | | X | |
| **21** | oct-22 | X-ELIO | 528 | | X | | |
| | | | **2825** | | | | |

Table 5: ORUGA® references

NOTES:

1. Companies above are listed in alphabetical order – not chronologically as the rest of the columns – due to confidentiality issues
2. Performance calculation is also carried out in option *Design Optimization – BEST LCOE*

**Do you want further information on ORUGA® software?**

**Do you have a project on a complex terrain, and you think that it needs to be optimized?**

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