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Philippe Blanc, Maroun Nemer

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## GLOBAL SENSITIVITY ANALYSIS: RATING THE INFLUENCE OF PARAMETERS IN A PV PERFORMANCE TOOL

Katherine Alvino<sup>1,2</sup>, Nicolas Zalachas<sup>2</sup>, Rodrigo Amaro e Silva<sup>3</sup>, Philippe Blanc<sup>3</sup>, Maroun Nemer<sup>1</sup>  
<sup>1</sup> Mines Paris, Centre Efficacité Énergétique des Systèmes, 5 rue Léon Blum, 91120 Palaiseau, France  
<sup>2</sup> BBS Slama, 23 Rue du Mont Mouchet, 63000 Clermont-Ferrand, France  
<sup>3</sup> Mines Paris, Centre Observation, Impacts, Énergie, 1 Rue Claude Daunesse, 06560 Valbonne, France  
 katherine.alvino@minesparis.psl.eu

**ABSTRACT:** We applied a global sensitivity analysis (GSA) to a PV performance tool to describe the influence of four parameters (orientation, tilt, distance between rows and albedo, along with the interaction effects between them) on two intermediary results of the estimation: yearly effective irradiance and yearly energy generation.

In the case of yearly effective irradiance, the most influential factors were orientation, distance between rows and tilt, in order of influence, followed by two interaction effects between them. For the yearly energy output, the most influential factors were distance between rows, orientation and tilt, with the first parameter noticeably exceeding the rest of influence sources. We underlined the importance of using this information to obtain relevant visual representations of the model's behaviour.

**Keywords:** PV performance tools, global sensitivity analysis (GSA), Sobol', optimisation

### 1 INTRODUCTION

Photovoltaic (PV) project developers increasingly use optimisation tools for planning, sometimes without knowing neither the most influential parameters nor the interaction effects between them. But, do these tools point out the most influential parameters or the interaction effects that can occur between them? And, why would this information be useful?

Global sensitivity analysis (GSA) is a tool to enhance the knowledge of not only individual parameters but also of the interactions between them. When optimising a configuration, GSA detects the most influential parameters and describes their effect, allowing to prioritise the most important factors.

A few articles entailing sensitivity analysis applied to photovoltaics are found in the literature. Andrei et al. [1] studied in 2012 the first-order derivative sensitivity of six output variables: short circuit current ( $I_{sc}$ ), open circuit voltage ( $V_{oc}$ ) and maximum power point ( $P_{MPP}$ ,  $V_{MPP}$ ,  $I_{MPP}$ ), to the temperature and irradiance factors, using them to produce and validate a set of analytical relations. In 2013, Li-nan et al. [2] applied static (the research object is time-independent) and trajectory (dynamic) sensitivity methods for parameter identification of grid-connected photovoltaic inverters. In a third study published in 2015, Hansen et al [4] performed a sensitivity analysis by means of scatterplots to evaluate the uncertainty of the output to the model choice. More recently, Zhang et al.[3] applied a Sobol algorithm in order to study the influence of three input factors, yielding to similar first-order and global sensitivity values for each parameter and obtaining a ranking of sensitivities ( $S$ ):  $S_{irradiance} \gg S_{module\ temperature} > S_{air\ rel.\ humidity}$ .

Generally, most sensitivity analyses within the field of earth sciences apply a local approach [5]. Global methods evaluate more than one factor simultaneously, thus providing the added capacity to evaluate whether there are interaction effects between two or more input parameters, besides of the perturbation of each parameter individually. That is a particularly useful feature for PV applications since the optimal positioning of solar modules cannot be made considering each parameter individually. With this in mind, the focus of this research work will be to evaluate

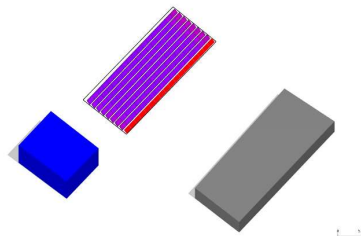
the influence of parameters related to the physical configuration on two steps of the energy estimation. Which parameters among orientation, inclination, distance between rows and albedo influence the most the energy output? What are the interaction effects between them? How can we apply this knowledge in the development of tools?

### 2 SCIENTIFIC OBJECTIVES

To give an answer to the previously exposed questions, we explored the application of global sensitivity analysis to analyse PV performance methods and propose a methodological framework to identify parameter influences and their interaction effects.

### 3 EXPERIMENTAL SETUP AND METHODOLOGY

We simulated a PV system that explores a surface of 378 m<sup>2</sup> (limited by the dark grey contour enclosing the panels in Figure 1), located in Marseille, France (43.3°, 5.37°). The weather database (year 2005) was obtained from Meteonorm 7. Two buildings are placed nearby, from which the blue one is 5 m tall and placed to the west, while the grey building is 3 m tall, due south.



**Figure 1:** PV installation with nine (18x1) rows of modules with two nearby buildings

We chose to assess four parameters: orientation, tilt, distance between rows and albedo, along with their intervals of variability (see Table I). Then, the sensitivity analysis was performed in three steps (see Figure 2): first, we applied the quasi-random Sobol' method to generate

over 40000 combinations of the parameters, using the library SaLib in Python [7], [8]. Then, we evaluated all the scenarios with the PV Prod tool. Finally, we performed a Sobol' GSA by using two tools developed by the *Centre OIE (Observation, Impacts, Énergie)*. The first algorithm is based in MATLAB and the second one in Python.

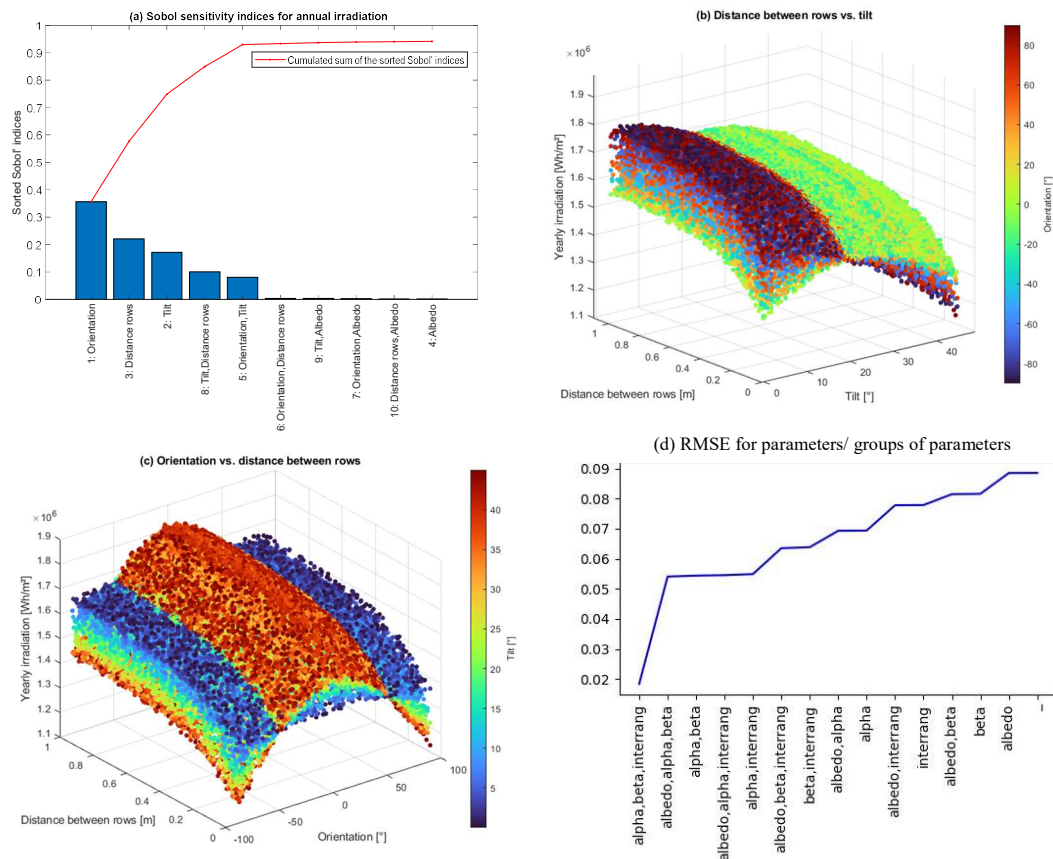
**Table I:** Parameter variabilities for optimisation case

Parameter	Distribution	Boundaries
Orientation of modules	Uniform	-90° to 90°
Tilt of the modules	Uniform	0° to 45°
Distance between rows	Uniform	0 to 1 m
Ground albedo	Uniform	0.1– 0.3



**Figure 2:** Steps of the estimation of the Sobol' indices

We also confirmed the sufficiency of data for the sensitivity results.



**Figure 3:** a) Sobol' indices, b) and c) dependency on the four parameters of the effective yearly irradiation; d) part of the RMSE caused by each parameter/group of parameters.

Figure 3b presents a green layer of points corresponding to a south orientation, showing that, the further the panels are, generally the irradiation per square meter increases, which is not so true when the tilt is zero or when the modules are oriented away from the equator, as is shown by the red and blue points. An intersection of points occurs when the tilt is equivalent to around 20°. Fig. 3d follows similar characteristics, only differing in the fact

## 4 RESULTS

The GSA has been applied for two steps of the method (outputs of interest): yearly irradiation first, followed by yearly energy output.

We used another python-based tool from the OIE group that confirmed the results of the sensitivity analysis, and additionally we obtained the RMSD values to explain the part of RMSE that corresponds to using a function that only considers the indicated parameters.

### 4.1 Yearly irradiation

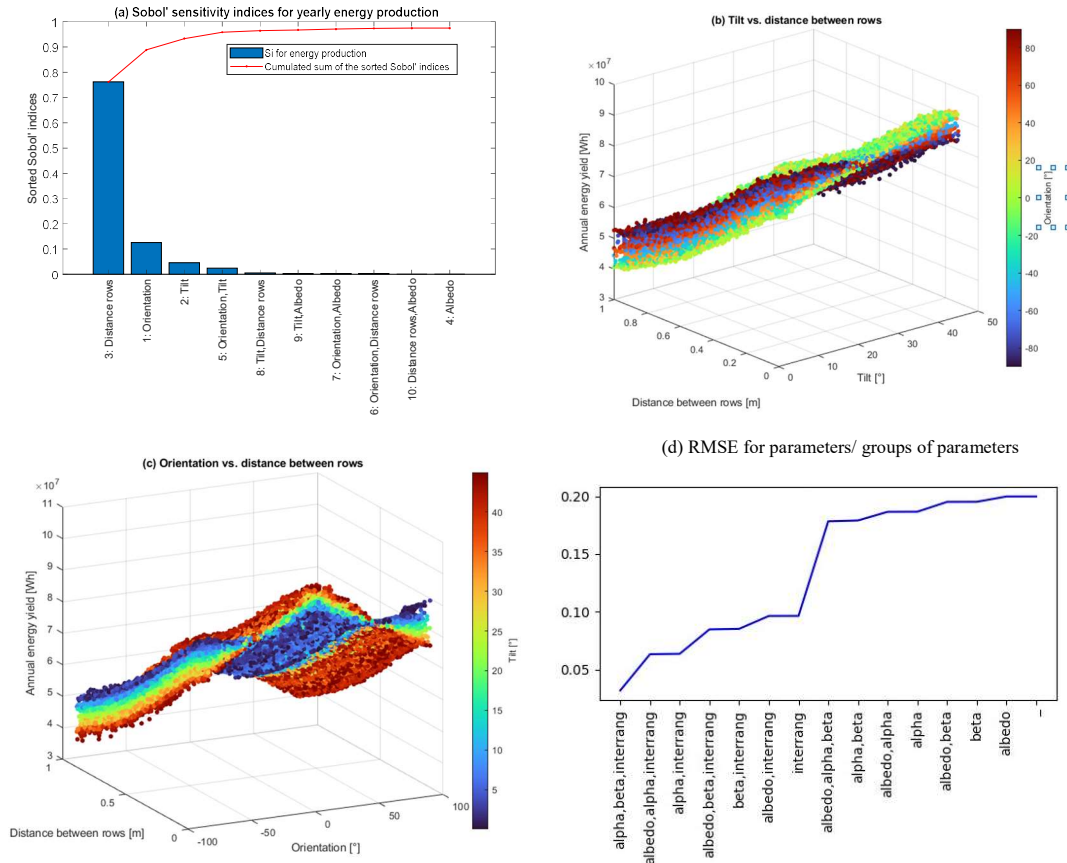
The modules orientation is by far the most influential factor (See Figure 3a), followed by the distance between rows and module tilt. The most important interaction effects come after them and albedo comes only at the seventh place of importance, almost with no addition to the cumulated effects. Note that the sum of the first-order indices, those corresponding to the four parameters, is less than one. Thus, we can consider that the method is a non-additive model.

that albedo practically doesn't produce any change in the values.

Figure 3c presents that the yearly irradiation increases as the distance between rows decreases, while it reaches a maximum when the modules are facing a point around the south. As the inclination reduces (blue points), the orientation loses influence.

The highest irradiation point (1.8 Gh/m<sup>2</sup>/year)

corresponds to an orientation of  $-4.0^\circ$ , a distance between rows of 0.99 m, and a tilt equivalent to around  $35^\circ$ . The more straightforward way to find it is by observing Fig. 2c, which it describes graphically the relationship between the two most influential factors.



**Figure 4:** a) Sobol' indices; b) and c), dependency on the four parameters of the effective yearly irradiation; d) part of the RMSE caused by each parameter/groups of parameters.

We are no longer considering energy per square meter but the total energy provided, so the energy yield increases as the modules get closer, in opposition to the previous step.

The highest point, 0.1 GWh/year, corresponds to  $4^\circ$  of azimuth and 0 m of distance between rows, with a tilt around  $30^\circ$ , suggesting that we might need to take a look at the cost function instead of only maximising energy yield.

### 5 DISCUSSION

It is clear that Figs. 2c and 3c in both steps provided the clearest behaviours, making easy to visually identify the highest point since they consider the most influential factors. In contrast, figs. 2d and 3d do not provide the same facility.

We can observe that there is an overall symmetry between east and west orientations, since the obstacle in the scenario is 8m far and only 5m tall. Other applications with closer shading factors should be able to find a more visible asymmetry.

Soiling losses were not considered in this method, which should be taken into account afterwards. There exist issues to fix in our evaluation model and we aim to obtain

### 4.1 Yearly energy output [Wh/year]

In this step, the distance between rows is the most influential parameter (see Fig. 2a), since it strongly determines the number of modules that fit in a limited area.

more outputs to make further analyses (energy output, self-consumption, self-production rates or even performance ratio indicators).

Many other questions originate from these results. For example, how does this ranking vary for different locations and weather databases?

### 6 CONCLUSIONS

The Sobol GSA method was applied to a system with fixed-tilt, mono-facial modules confined in a rectangular area, in order to make a step-by-step optimisation.

The possibility to change the output of interest allows to study the dependencies of the final energy output, self-consumption, self-production rates or even performance ratio indicators. We underline the importance of analysing the relevant graphs and of being aware of the configuration compromises that can be taken, either for economic reasons or other constraints. It only takes to set the output of interest to rate the parameters according to their influence on it.

The number of parameters increases the difficulty to plot and to visually interpret them. There lies the benefit of using Sobol' to identify the parameters with the higher

sensitivity indices that will be useful in order to find an optimal point in a parsimonious way.

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