

# Web tools for performance analysis and planning support for solar energy plants (PV, CSP, CPV) starting from remotely sensed optical images

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## Abstract

We present new services, developed also under the GMES ENDORSE (ENergy DOWnstream SErvices) project, for the performance analysis and the support in the planning of solar plants (photovoltaic, CSP, CPV) that combine a detailed model of each part of the plant (solar field, thermal storage system, electrical power system and inverters) and the near real-time remote sensing of the global (or direct component) of solar irradiance incident on the plane normal to sun rays (DNI) at ground level. Starting from temporal series of satellite Meteosat Second Generation (MSG) optical images, elaborated via the Heliosat algorithm (MACC Core Service), we obtain firstly the solar global horizontal irradiance (GHI) and then the GTI or the BNI using a model to derive irradiance on tilted planes from GHI. Combining these parameters with the model and technical features of the solar power plant, using also air temperature values (measured in-situ), we can assess in near-real-time the daily evolution of the alternate current power coming from the plant and then, using a temporal integration, we can finally obtain the expected daily energy yield by the plant. We are therefore able to compare this energy yield based on satellite measurements with the measured one and, consequently, to readily detect any possible malfunctions and to evaluate the performances of the plant. This method has been successfully applied for the performance analysis of several test solar plants, showing always a precision less than 15% with respect to the measured values of energy yield by a well-functioning plant.

## 1. Introduction

### 1.1 The Endorse project

The project ENDORSE aims at a user-driven development of downstream services in renewable energies by exploiting the GMES Core Services (MACC, SAFER and Geoland 2) together with other EO/in-situ data and modelling. The service is provided for the following renewable power plants: CSP (Concentrating Solar Power plants) and CPV (Concentrating Photo-Voltaic plants). The service provided is based on the evaluation of the solar irradiance on the Earth surface. This physical entity is of fundamental importance in the planning of new power plants and in the monitoring of existing plants, both for the CSP and for the CPV cases. In the near future, the project will use data from MSG (SEVIRI) satellite and MIOSAT and PRISMA sensors to improve the service performances.

### 1.2 Context

An increasing energy demand has been predicted for the following 10-20 years. The total energy need will be superior to the increase rate of the energy production coming from fossil combustible materials (gas, oil, coal) representing, together, about the 80% of the total energy production nowadays. One of the major

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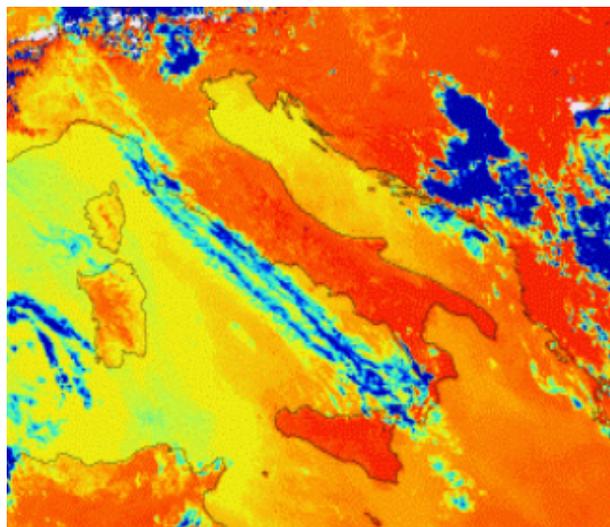
challenge in the near future is how to provide energy in abundance, and to be able to provide this energy from sources with a limited impact on the environment.

An effective and tangible approach to solve the energy production problem, used in Italy and in other countries, involves an improvement of the use of the renewable energy solution. This is also favoured by the introduction of specific laws. The solar energy production potentialities are well known, but they have begun to be fully developed only in recent years. Given the large variability, non easily predictable, of the solar source, the planning and installation of new power plants require a careful a priori analysis. Therefore, the presence of services able to provide an accurate estimation of available energy sources is extremely important for the investors, that are given the possibility to evaluate the repayment plan when planning new plants. A service providing this kind of information can use standard techniques, such as in-situ measurements of the solar energy available in a certain location; this kind of approach can be significantly expensive. On the contrary, cost reductions can be the strength of alternative approaches, such as monitoring system using data measurement from satellite.

Furthermore, when the energy plant begins its activity, a service able to monitor the productivity of the plant so to improve it and increase the efficiency is necessary for cost reductions. An effective and low-cost approach is to use a service able to compare the power actual produced with the power predicted by a model. The model uses data from satellite to evaluate the environmental parameters needed to predict the power production.

### 1.3 Solar irradiance estimation at the surface

The use of data from the Earth for the estimation of the solar radiation at the ground is the subject of study of many researches. One of the methodologies developed in such a frame is called Heliosat. The Heliosat technique for the analysis of satellite data was introduced by Cano (Cano et al., 1986) and over the years was successfully improved (new algorithms to calculate the cloudiness indexes, clear sky and horizontal global irradiance in the clear-sky case), making the Heliosat a standard and reliable methodology.



*Figure 1 –Map of solar irradiance from Heliosat and MSG satellite*

The key points are:

- the ability to convert an image from satellite to a matrix of “cloudiness index”;
- the ability to convert the “cloudiness index” into a “clear-sky index”;
- the model able to evaluate the global horizontal irradiance in clear-sky conditions.

The cloudiness index indicates the fact that the solar radiation, passing through the Earth atmosphere, undergoes different interactions with the atmosphere components, resulting in an attenuation of the radiation intensity. To evaluate this index, temporal series of data from satellite are necessary, including the corresponding info (“Cloud Mask”) about the presence or absence of clouds in the moment of the measurement made by the sensor pixel. Thus, the cloudiness index is linearly related to the clear-sky index representing the ratio between the global horizontal irradiance (the unknown quantity) and the global horizontal irradiance in clear-sky conditions. An evaluation of the global horizontal irradiance in clearsky conditions can be obtained using a model of atmosphere without clouds (Rigollier, 2000). Therefore using all the information, it is possible to evaluate the global horizontal irradiance.

This method is applied to image from geostationary meteorological satellite, such as Meteosat (Eumetsat), GOES (NASA) and GMS (NASDA). This methodology can be also applied to the PRISMA system that will implement a hyper-spectral sensor detecting the radiation between 0.4 and 2.5  $\mu\text{m}$ , with a resolution of 20 - 30 m. Among the level 1 products PRISMA will offer the “Cloud Mask”. An application of this methodology can be done also using data from the MIOSAT sensor.

## 2. Model of the plants

The power plant production can be estimated by using satellite EO data, evaluating the environmental needed parameters and an accurate model of the plant behavior.

### 2.1 CSP plants

A thermodynamic solar plant uses the direct solar radiation by reflecting it towards a concentrating point where a fluid is heated. The radiation intensity is hence a fundamental parameter for the plant planning and for its the financial evaluation, but it is also a critical information in the operational mode of the plant, since it allows an accurate analysis of the plant performances.

The necessary data for the model are:

- the temperature and the flow rate of the heat-transfer fluid;
- the direct solar irradiance incident on the plane normal to sun rays (DNI) at ground level;
- the environmental temperature.

The algorithm analyzes the balance between the power absorbed by the fluid and the overall power losses, so the outputs of the whole modeling will be the following:

- The fluid temperature;
- The absorbed power;
- The power losses
- The instantaneous efficiency

Other important aspects in the model are:

- Mirrors optical characteristics (shape, reflecting properties);
- The film applied to the surface of the heat-concentrating pipe

## 2.2 CPV plants

This kind of plants are typically comprised by:

- Reflecting mirrors or lenses concentrating the solar radiation on photovoltaic modules;
- Sun-tracking system.

This kind of photovoltaic systems are usually divided into three categories: low, medium and high concentration, based on the ratio between the effective area of the surface absorbing the solar radiation and the area of the modules where the radiation is concentrated. The photovoltaic systems with low concentration are the most used ones.

Similarly to the CSP systems, the only solar radiation components that can be concentrated is the component direct incident on the plane normal to sun rays; the knowledge of this quantity is fundamental for planning and for financial evaluation of the costs, but is also a critical information in the operational mode of the plant, since it allows an accurate analysis of the plant performances.

The other two important aspects in the CPV plants are:

- the mirrors shape;
- the photovoltaic modules.

The modules are typically the same as the ones used in traditional PV systems; thus, they can be modeled using standard well known techniques such as the one used in the SolarSAT PV-Controller service. This technique models the photovoltaic module using an equivalent circuit with a (photovoltaic) current generator, connected in series with a resistance and in parallel with a diode and another resistance.

## 3. First results of the test

The first results from the tests performed using the above methodologies were good: we compared the DNI at ground level from both the said satellite-based methodology and from in-situ measurements. The discrepancies observed were below 10%, i.e. within the typical end users expectations, thus representing a good baseline for the monitoring of AC power produced by the plants and for a further development of a web service.

## Bibliography

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