

# CAPACITATI

## Final Scientific and Technical Report

**Project title:** Effect of clouds on solar irradiance (ECSOL – PROGNOSIS)

**Contract no.:** 765 / 30.04.2014

**Completion year:** 31.12.2015

**Duration of the bilateral project:** 18 months

**Romanian partner:** Universitatea Transilvania din Braşov - prof.dr.ing. Ioan Vasile ABRUDAN

**Project manager:** ş.l.dr.ing. Bogdan Gabriel BURDUHOS

**Foreign partners:** Cyprus University of Technology - ş.l.dr.ing. Alexandros CHARALAMBIDES

### **General objectives**

The objectives of the project are: a) to establish bilateral cooperation between the partners in the R&D field and to exchange knowledge by organizing technical visits which allow getting used with the equipment of the partners and by participating in international events; b) to match the needs of the research project to the ones of the field industry; c) to identify models / algorithms for classifying clouds and estimating available solar irradiance based on sky photos.

### **Description of the technical and scientific results and the degree of the objectives' achievement**

#### **WP1. project Management**

1. An optimal framework for effective communication between the partners was ensured, which allowed an effective exchange of information and records via electronic mail, videoconferencing and *Dropbox* application.
2. A good project team management and reporting of results to the financing authority was ensured.
3. All 4 technical visits were organized, in: Brasov, Bucharest, Romania and Limassol, Cyprus.
4. New topics for future common projects have been identified by the team members.

#### **WP2. Dissemination of results**

The results were disseminated by participating in 4 international conferences:

1. Tapakis, R., Charalambides, A.G., Moldovan, M.D., Burduhos, B.G., *Cloudy sky irradiance model using sky images*, 14th World Renewable Energy Congress 2015 (<http://www.wrec.ro>), Bucharest, Romania, paper number S10\_13, (paper accepted in **Journal of Physics: Conference Series**).
2. Burduhos, B.G., Moldovan, M.D., Neagoe, M., Bizu, A.M., Tapakis, R., Charalambides, A.G., *Novel solar irradiance prediction model adjusted based on infield data*, 14th World Renewable Energy Congress 2015 (<http://www.wrec.ro>), Bucharest, Romania, paper number S10\_12.
3. Tapakis, R., Charalambides, A.G., Moldovan, M.D., Burduhos, B.G., *A multi-dimensional criteria algorithm for cloud detection in the circumsolar area*, 3rd International Conference Energy & Meteorology 2015 (<http://icem2015.org>), Boulder, Colorado, USA.
4. Tapakis, R., Charalambides, A.G., Moldovan, M.D., Burduhos, B.G., *Effect of clouds inside the circumsolar area*, ISES Solar World Congress SWC 2015 (<http://www.swc2015.org>), Daegu, Korea, paper number ABS-T02-T01-0251.

A website for the presenting the project results in all 3 languages of the project (English, Greek and Romanian) was developed and maintained, (<http://www.unitbv.ro/ecsol-prognosis>).

The project idea was promoted in the European *CleanLaunchPad* competition, Cyprus-Greece finals (<http://cleanlaunchpad.eu/events/final-cyprus-greece>), held in Nicossia on 17/10/2014, in order to identify opportunities for exploitation the project results.

The objectives, used infrastructure and the results of the project were disseminated by members of both teams to students from the *Department of Environmental Sciences and Technology*, Cyprus University of Technology by organizing two seminars on the 22/10/2014 and 28/09/2015.

#### **WP3. Experimental measurements of solar irradiance and taking pictures of the sky**

Images of the sky were taken in Brasov with a high-resolution wide-view-angle camera, type GoPro Hero 2 (installed on the Kipp & Zonen, Solys2 tracking system, from the L7-ICDT terrace

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laboratory of the Research Centre for *Renewable Energy Systems and Recycling* in Braşov); in Limassol, Cyprus an all-sky camera CMS CloudCam II was used.

In Brasov, during the period July 2014 - December 2015 approx. 7800 images of the sky were taken, on 56 days with varying degrees of cloudiness, according to a schedule agreed with the partners.

On the same days the available solar irradiance (direct, diffuse, global) was recorded using the equipment Kipp & Zonen, Solys2 equipment of research department.

They distortions between the images taken with GoPro Hero2 camera and reality were identified.

## WP4. Detection and classification of clouds

Sets of 2 consecutive images (normal exposed and under-exposed) were taken by the CMS CloudCam II camera and processed using software tools such as Fiji, ImageJ and OpenCV; their decomposition based on RGB (Red, Green, Blue) and HSV (Hue, Saturation, Value) components and the identification of several thresholds / levels allowed the identification of 4 zone types in each picture: sun, blue sky, thin clouds and thick clouds.

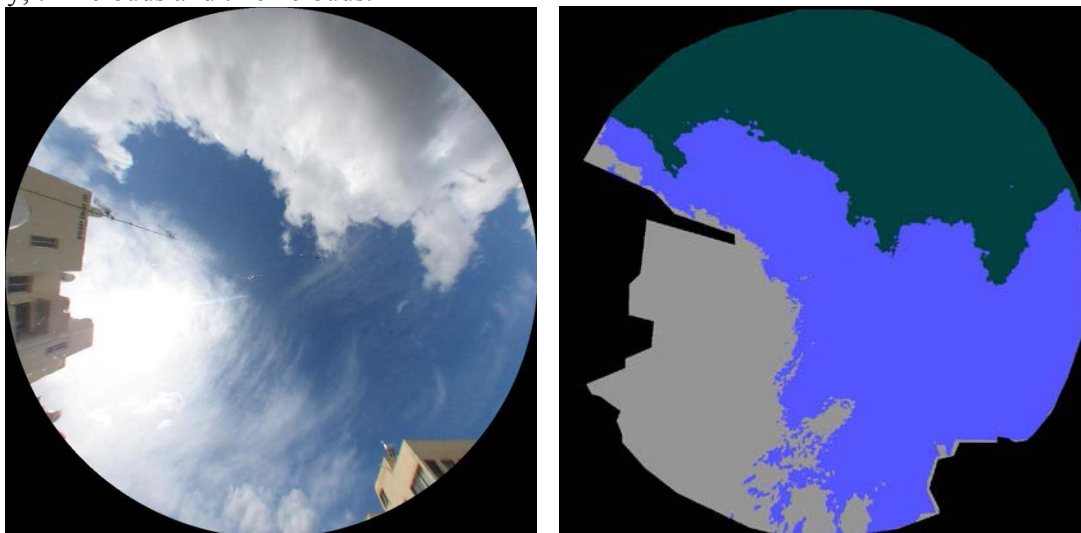


Fig. 1. Example of classifying clouds in a sky image.

## WP5. Modeling solar irradiance

The images taken by the GoPro Hero2 camera were correlated with the experimental records of solar irradiance available in Brasov, Romania.

The analysis of the main references in the field of solar irradiance modeling confirmed that the Meliss model is optimal; this model was adapted to match the requirement of estimating solar irradiance based on the number of pixels of different colors in the taken / processed sky images. The model indicates a good correlation between measured and estimated values of solar irradiance ( $MBE = -0.6 \text{ W/m}^2$  and  $R^2 = 95.5\%$ ).

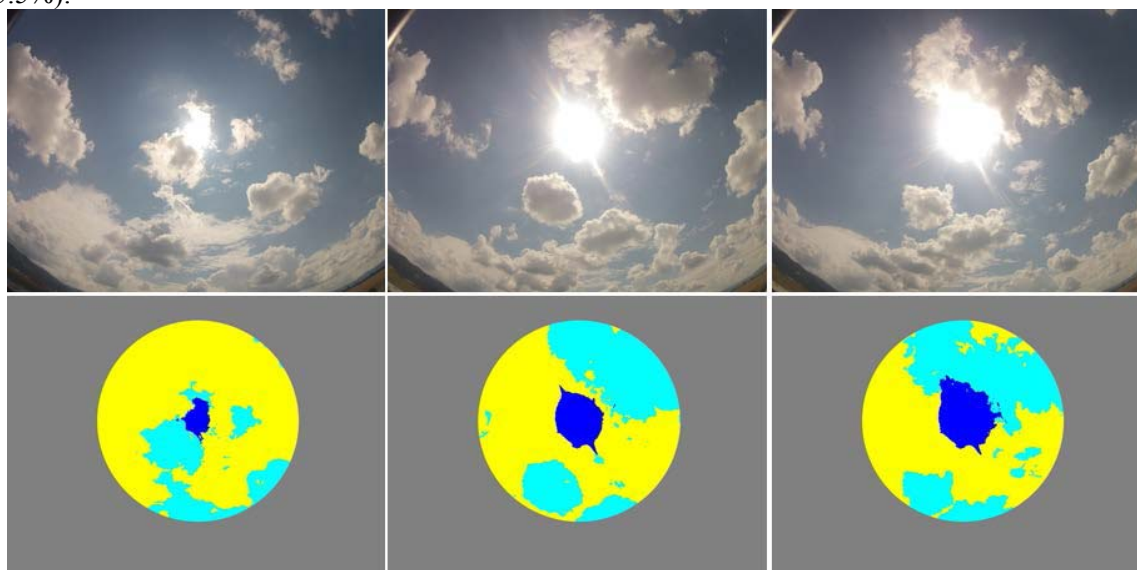


Fig. 2. Image processing of sky images in order to count 3 types of pixels (sun, cloud, sky blue).

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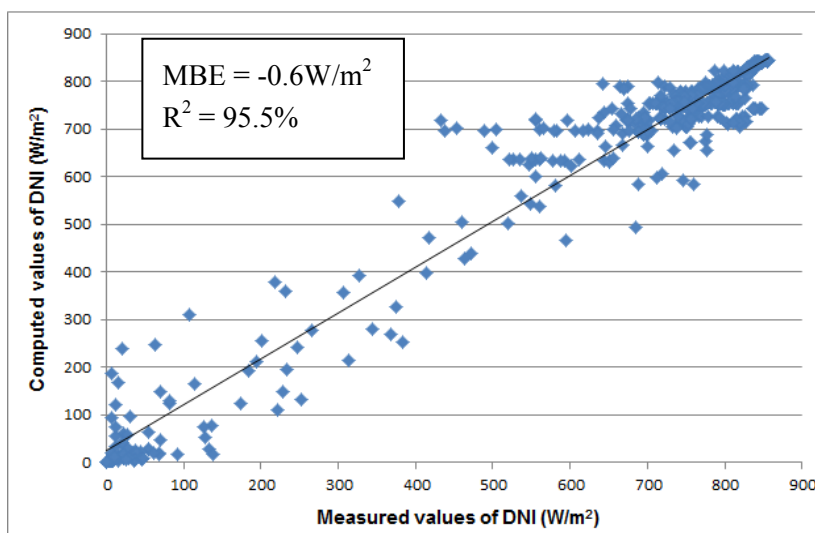


Fig. 3. Correlation between measured and estimated solar irradiance.

## **Technical visits during the bilateral project**

During the project all the 4 proposed visits were organized. The first visit (Brasov, 30.06 - 02.07.2014) aimed at the reciprocal knowledge of the two team members, familiarizing with research equipment used in the project and establishing rules / timing for taking sky images.

The second visit (Limassol, 13 - 25.10.2014) allowed verifying and discussion on the already taken sky images, finding image processing solutions using different software, familiarizing with the equipment used in Cyprus and the promoting of the project in the *CleanLaunchPad* European competition and at the *Cyprus University of Technology*.

During the third visit (Bucharest, 08-12.06.2015) the research stage was analyzed and a plan was established for completing all objectives of the project.

The last technical visit (Limassol, 14 - 29.09.2015) allowed: the validation of records made, the tune-up of the proposed models for cloud detection / classification and solar irradiance estimation; writing the article accepted in the *Journal of Physics: Conference Series* and the presentation of the project results in a final seminar at the *University of Technology in Cyprus*.

## **Possibilities for economic use of the obtained results**

The possibility of economic exploitation of the project results was pursued in all international scientific events where the team members participated (*Simpozionul Național AGIR București, sucursala Avrig*, cu titlul *Regiunea SMART Avrig – catalizator al dezvoltării durabile*; *World Renewable Energy Congress WREC 2015*; *ISES Solar World Congress SWC 2015* și *3rd International Conference Energy & Meteorology 2015*). At these conferences discussions took place with researchers and public authorities interested in implementing Renewable Energy Systems and the project results.

The project results were presented to a solar PV park developer in Cyprus (Mr. Memnon Papageorgiou; Memira company Genesis Ltd), who expressed interest in using them to estimate the electricity produced by photovoltaic parks. Some results have been tested on the 1.2 MW photovoltaic park developed by this company in the area of Avgorou, Cyprus (near Larnaca).

The main directions for economic exploitation of the results identified by the project members are: forecasting the electricity produced by photovoltaic installations, increasing the adaptability of smart electricity grids and optimizing the operation of water desalination plants in Cyprus.

The project manager brings special thanks to the UEFISCDI officer (Mrs. Cristina Claudia MUREA), which responded promptly and competently to all questions raised during the project, thus supporting its optimal implementation, including from the managerial point of view.

**The analysis of the data summarized in this report show that all objectives and proposed results of this project were fulfilled.**

02.12.2015

Director proiect,  
ș.l.dr.ing. Bogdan Gabriel BURDUHOS

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Anexa 1 – RST - Final

## Indicatori de realizare ai proiectului

Nr. crt.	Indicatori	UM
1.	Număr de publicații în reviste: Co-editate internațional - Indexate ISI - Incluse în alte baze de date internaționale recunoscute	- 1 acceptat
2.	Articole publicate în cărți, atlase, dicționare și alte produse cu caracter științific publicate anual (în țară și în străinătate)	-
3.	Participări la conferințe organizate, dintre care internaționale	4/4
4.	Evenimente organizate dintre care internaționale	2/2
5.	Pliante, broșuri, postere pentru diseminare de informații	1
6.	Proiecte de comunicare științifică	-
7.	Proiecte de studii prospective	-
8.	Proiecte / participanți în proiecte internaționale finanțate	-