Coordinating and integRating state-of-the-art Earth Observation Activities in the regions of North Africa, Middle East, and Balkans and Developing Links with GEO related initiatives towards GEOSS

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Executive Summary

GEO-CRADLE introduced the Solar Energy Nowcasting SystEm (SENSE) pilot in order to coordinate, improve and support the regional EO infrastructures and capabilities related to ''access to energy''. The niche for this pilot is the operational, satellite-driven and real-time system for solar energy nowcasting and forecasting. SENSE was intended to be a starting point for energy related short future investments towards and beyond the implementation of GEO, GEOSS and Copernicus Energy activities and visioning innovative high-end applications and technologies. Towards this direction, the SENSE's objectives were:

- Effective dissemination of the high precision and resolution nowcasting and forecasting solar energy services for the fulfillment of the regional needs taking advantage of the nowadays satellite data, efficient envision of new but crucial model inputs and state-of-the-art real time solar energy calculating system capabilities.
- Development of reliable, high resolution solar Atlases and broader climatology studies for the RoI.
- Engraving strategy methods of how to integrate such a solar energy nowcasting system into a wider GEOSS driven system in the international scale, making the whole effort of the participating partners ''a possession for all time''.

In the framework of the GEO-CRADLE project, the PMOD/WRC (Switzerland) in collaboration with NOA (Greece) are responsible for the SENSE pilot, its effective dissemination for the fulfilment of the regional needs taking advantage of the current satellite data availability, efficient envision of new but crucial model inputs and state-of-the-art real time solar energy calculating system capabilities. During this HORIZON 2020 project SENSE pilot developed reliable, high resolution solar Atlases and broader climatology studies for the Region of Interest, while it engraved strategy methods of how to integrate such a solar energy nowcasting system into a wider GEOSS driven system in the international scale with multifarious collaborations and carefully selected end-users. We succeeded in stimulating the interest of relevant energy stakeholders and decision makers like Ministries of Electricity and Renewable Energies (Egypt), Electric Power Transmission Operators (Greece) and Solar Energy investors from the private sector (Attica Group).

SENSE pilot established closer collaboration and extension of cooperation with the following end-users:

- Egyptian Ministry of Electricity and Renewable Energy: We developed a common website in which we disseminate the real-time and climatological solar energy products of SENSE and running on the official ministry website. Moreover, we published an analytical Egyptian Solar Atlas Book.

- The Greek National Independent Power Transmission Operator: We started a close collaboration in order to update their nowcasting and forecasting power systems with the SENSE's state-of-the-art methods and techniques. They exploit the real-time solar energy maps and data (60K pixels/integrated energy values every 15-minutes) by comparing them with real solar farms and controlling the local energy demands.
- Pre-tect campaign: We provided the solar energy maps of Crete in real-time for the purposes of the campaign (April 2017) and we made spectral comparisons with a high precision solar spectroradiometer (PSR) in order to further validate the SENSE under high-aerosol loads.
- Attica Group with Bluestar and Superfast Ferries: For the pilot period they attracted relevant ads in order to efficiently advertise the real-time UV-index service from SENSE through the monitors of their ships with routes to the Aegean and the Adriatic sea.
- The National and Kapodistrian University of Athens (NKUA): We provided the mean hourly Photosynthetically Active Radiation (PAR) for all months of 2016 in order to estimate the magnitude of Non-Methane Volatile Organic Compounds emissions emitted by vegetation over Greece.

Results of SENSE have been documented in four scientific peer review publications [1, 2, 3, 4], five scientific conferences [5, 6, 7, 8, 9], one book [10] and nine project workshops, forums and invited talks [11, 12, 13, 14, 15, 16, 17, 18, 19] from October 2016 till January 2018.

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1	National Observatory of Athens (NOA) - **Coordinator**	Greece	
2	Interbalkan Environment Center (IBEC)	Greece	
3	Center for Environment and development for the Arab Region and Europe (CEDARE)	Egypt	
4	Research and Studies Telecommunications Centre (CERT)	Tunisia	
5	Tel Aviv University (TAU)	Israel	
6	Cyprus University of Technology (CUT)	Cyprus	
7	TUBITAK UZAY Space Technologies Research Institute (UZAY)	Turkey	
8	Space research and technology institute (SRTI)	Bulgaria	
9	National Institute of R&D for Optoelectronics (INOE)	Romania	
10	University of Ss Cyril and Methodius (USCM)	FYROM	
11	Institute for Nature Conservation in Albania (INCA)	Albania	
12	Institute of Physics Belgrade (IPB)	Serbia	
13	CIMA Research Foundation (CIMA)	Italy	
14	Academy of Athens (AOA)	Greece	
15	INOSENS (INS)	Serbia	
16	European Association of Remote Sensing Companies (EARSC)	EU	
17	EURISY	EU	
18	EuroGeoSurveys (EGS)	EU	
19	World Radiation Center (PMOD/WRC)*	Switzerland	

*Note: Switzerland is not requesting financial contribution from the EC

Contents

Acronyms and Abbreviations 6

List of Tables 7

1. Sense pilot 2

1.1. Introduction to the Sense hierarchy 2

1.2. Sense validation activities 4

2. Link of Sense with the output of the Inventory of capacities and user needs and the analysis, indicators and regional priorities 15

3. Pilot applications 20

3.1. IPTO 20

3.1.1. Objectives and expected results 20

3.1.2. Methodology, methods of implementation 22

3.1.3. Main activities and results of the pilot analysis 24

3.1.4. Sustainability 26

3.2. Egypt 27

3.2.1. Objectives and expected results 27

3.2.2. Methodology, methods of implementation 29

3.2.3. Main activities and results of the pilot analysis 31

3.2.4. Sustainability 41

3.3. Shipping companies 44

3.3.1. Objectives and expected results 44

3.3.2. Methodology, methods of implementation 46

3.3.3. Main activities and results of the pilot analysis 47

3.3.4. Sustainability 49

3.4. PRE-TECT 50

3.4.1. Objectives and expected results 50
3.4.2. Methodology, methods of implementation........ 51
3.4.3. Main activities and results of the pilot analysis 52
3.4.4. Sustainability 54
3.5. Air quality 55
3.5.1. Objectives and expected results 55
3.5.2. Methodology, methods of implementation........ 56
3.5.3. Main activities and results of the pilot analysis 56
3.5.4. Sustainability 57
4. Key recommendations and next steps 59
References........ 61

Acronyms and Abbreviations

Acronym	Description
AERONET	Aerosol Robotic Network
AOD	Aerosol Optical Depth
BSRN	Baseline Surface Radiation Network
CAMS	Copernicus Atmosphere Monitoring Service
CM SAF	Satellite Application Facility on Climate Monitoring
COT	Cloud Optical Thickness
CSP	Concentrated Solar Power plant
CT	Cloud Type
DNI	Direct Normal Irradiance
DSO	Distribution System Operator
EM	Eastern Mediterranean
EO	Earth Observation
EUMETSAT	EUropean organisation for the exploitation of METeorological SATellites
GAW	Global Atmosphere Watch
GHG	Green House Gases
GHI	Global Horizontal Irradiance
IPTO	Independent Power Transmission Operator
LUT	Look Up Table
MACC	Monitoring Atmospheric Composition and Climate
MBE	Mean Bias Error
MENA	Middle East and North Africa
MODIS	MODerate resolution Imaging Spectroradiometer
MOEE	Ministry of Electricity and renewable energy of Egypt
MRF	Multi-Regression Function
MSG	Meteosat Second Generation
NN	Neural Network
NNS	Spectral Neural Network
NREA	New and Renewable Energy Authority
OMI	Ozone Monitoring Instrument
PAR	Photosynthetically Active Radiation
PFR	Precision Filter Radiometer
PV	Photovoltaic
RMSE	Root Mean Square Errror
RTM	Radiative Transfer Model
SARAH	Solar surfAce RAdiation Heliosat
SENSE	Solar Energy Nowcasting SystEm
SEVIRI	Spinning Enhanced Visible and InfRared Imager
SIS	Surface Incoming Solar radiation
SOLEA	SOLar Energy Applications
SSR	Surface Solar Radiation
SZA	Solar Zenith Angle
TOC	Total Ozone Column
TSO	Transmission System Operator
UV	Ultraviolet

List of Tables

Table 1: Coordinates (degrees) and height (meters above sea level) of the BSRN stations used for the validation....4

Table 2: The SENSE pilot Timetable....15

Table 3: The photovoltaics and concentrated solar plants in Greece....15

Table 4: The definition of the specific pilot sites....18

Table 5: Mean solar power and energy for Egypt and the three sub-regions....37

Table 6: The analytical annual solar energy results for the 29 specific locations together with the expected energy output to the electricity grid based on the specific exploitation area of each NREA devoted location. More information on the specific...40

List of Figures

Fig. 1: An example of the SENSE's output maps. Here is the GHI for the 15 April 2015 at 12:00 UTC....3

Fig. 2: The mean GHI in W/m^2 of the real time modelling techniques as compared to the RTM simulations for all ground stations (left), and the mean GHI of all models as compared to the BSRN measurements (right)....5

Fig. 3: Mean GHI differences in W/m^2 derived by MRF as compared to the BSRN stations for each time horizon. The boxes represent the 25th and 75th percentiles, while the in-box lines represent the median of the difference of each station. The upper and lower whiskers represent the minimum and maximum error values....6

Fig. 4: Seasonal relative RMSE values of the GHI estimations produced by the real time techniques as compared to the BSRN measurements....7

Fig. 5: Scatterplots in terms of sky condition reliability of the real time (MRF and NN) and RTM simulated GHI in W/m^2 as compared to the BSRN measurements for all stations under clear sky (upper plot) and all sky (clear sky and cloudy) (lower plot) conditions....9

Fig. 6: Mean percentage difference (blue) and standard deviation (red) of the 15-min GHI produced from the MRF technique as compared to ground-based measurements from all stations as a function of the COT....10

Fig. 7: Frequency histogram of differences between the CAMS and the PFR AOD at the Izaña station together with the mean absolute difference and standard deviation metrics....11

Fig. 8: Absolute differences in GHI (in W/m^2) derived by the MRF technique from the ground-based measurements at Izaña (BSRN pyranometer), as a function of differences in AOD from CAMS and PFR....11

Fig. 9: (left plots) AOD from MODIS level 3 and the CAMS 1-day ahead forecast. (middle plots) RTM simulations at local noon on the day of the incursion on 1 Feb 2015 for GHI and DNI. GHI0 and DNI0 represent the simulations without dust (with only the effects of SZA). (right plots) The energy impact in terms of percentage attenuation relative to the dust-free simulations for GHI and DNI under MODIS- and CAMS-based AODs. For the GHI, the attenuation is about 30 – 70 % for MODIS and about 30 - 60 % for CAMS. For the DNI, the attenuation is about 70 – 100 % for MODIS and about 60 - 90 % for CAMS....13

Fig. 10: The solar energy production from PV and CSP in Greece....15

Fig. 11: The energy consumption in North Africa and Middle East (left figure) and the expected future energy status in Egypt (right figure)....16

Fig. 12: The expected evolution of peak demands (from 2009 to 2030)....17

Fig. 13: Energy related partner capacities, regional needs and maturity indicators....18

Fig. 14: The Independent Power Transmission Operator (IPTO or ADMIE) for Greece. It controls the energy demands and the effects of implementing demand-side management strategies on the daily demand curve.Here is the IPTO's area of operations....21

Figure 15: Flowchart illustration of the modelling techniques scheme. The initial pixel classification followed by the clear or cloudy sky inputs to the real-time solver resulting the spectral (NNS) and integrated (MRF and NN) SSR-related outputs....23

Fig. 16: Example of the effect of implementing Demand-Side Management Strategies

on the daily demand curve....24

Fig. 17: Time-step example maps from the SENSE nowcasting service for the Greek IPTO....25

Fig. 18: The solar energy potential in Egypt in kWh/m^2 together with the MSG pixel-based specific location of Aswan (longitude: 32.90^o and latitude: 24.09^o)....30

Fig. 19: Monthly mean GHI (in W/m^2) in Egypt derived from the EUMETSAT's Satellite Application Facility on Climate Monitoring (CM SAF) for the period 1999 - 2013....32

Fig. 20: Monthly mean DNI (in W/m^2) in Egypt derived from the EUMETSAT's Satellite Application Facility on Climate Monitoring (CM SAF) for the period 1999 - 2013....32

Fig. 21: Upper plot: The GHI Solar Atlas 1999-2013. Lower plot: The DNI Solar Atlas 1999-2013....33

Fig. 22: The mean DNI in Egypt together with the three specific locations studied (greater Alexandria region, greater Cairo region covering the lower Nile's delta, and the southern region covering the greater regions of Aswan and Luxor)....34

Fig. 23: Mean DNI (a, b and c panels) and GHI (d, e and f panels) for the three sub-locations (a and d the greater Alexandria region, b and e the greater Cairo region, and c and f the southern region)....35

Fig. 24: Mean inter annual curves of GHI and DNI for Egypt and the three sub locations....36

Fig. 25: The expected future energy status in Egypt....37

Fig. 26: The mean inter annual solar energy potential in the 29 specific locations for PV (upper plot) and CSP (lower plot) exploitation....39

Fig. 27: One of the proposed locations for the development and exploitation of a solar farm. Here is the case study location of solar station for Dr. Magdy Yacoub Medical Center in Aswan. Contour plots of the analytical monthly mean energy production distribution in Aswan from a 12MW PV and a CSP system....41

Fig. 28: The SENSE pilot on the official website of the Egyptian Ministry of Electricity and Renewable Energy....42

Fig. 29: User testimonies from the SENSE pilot in Egypt....43

Fig. 30: The Superfast and Bluestar lines to the Aegean and Adriatic sea....44

Fig. 31: The onboard digital signage monitors of Superfast and Bluestar ferries....45

Fig. 32: A time-step visualization from the SENSE UV-index nowcasting service for the Superfast and Bluestar Ferries. Here is an example for the Aegean sea lines....48

Fig. 33: An example of the corresponding UV-index map for the Adriatic sea lines....49

Fig. 34: An example of the SENSE spectral product for the PRE-TECT campaign....51

Fig. 35: The online SENSE pilot service for the PRE-TECT campagn (April 2017)....52

Figure 36: Mean monthly GHI and DNI percentage attenuation in Athens as a function of solar zenith angle and AOD (a) together with the mean monthly range of AOD (b), the percentage attenuation range for GHI (c) and DNI (d). The red-shaded insets shows the corresponding median values and ranges at the peak of the strong dust incursion over the region on 1 Feb 2015....53

Fig. 37: The mean monthly climatological PAR of April over Greece as calculated by SENSE pilot....57

Fig. 38: SENSE's analytical inter-annual hourly mean PAR per month for the region of Greece....58

I. SENSE pilot results

1. Sense pilot

1.1. Introduction to the Sense hierarchy

Europe, North Africa and Middle East present an important solar energy potential and its exploitation is critical for the regional sustainable development through an efficient energy planning and a gradual independence from fossil fuels. Equitable access to energy is a basic requisite for economic development and an important condition to galvanize economic activity. The energy demand in the above regions is growing and will continue to do so for the next decades to come. The International Energy Agency has estimated that global primary energy demand will increase by 40-50% from 2003 to 2030. Since energy production, transportation and consumption put considerable pressure on the environment, there is serious concern regarding the sustainability of energy consumption. Energy security is critical for the growth and prosperity of MENA and European economies. EO-based systems and relevant services already play an important role in the commercial sectors of the energy industry. However, there is still a significant potential for increase. Space services have applications in renewable energy sources such as solar energy. Such services can deliver benefits throughout all the phases of energy production and supply. Their contribution ranges from identifying reservoirs and locations with solar energy potential, to controlling and monitoring of the distribution networks across Europe, North Africa and Middle East. They also could provide support to policy formulation and enforcement.

The need for improved solar energy forecasting is increasing as more solar farms (PV installations) and Concentrated Solar Power plants (CSP) come online worldwide. With an increasing share of the energy portfolio for many electrical utility companies, incorporating the highly variable power output from solar arrays into the grid is becoming increasingly difficult. Accurate predictions of the irradiance received at individual PV (where Global Horizontal Irradiance (GHI) is needed) or CSP installations (where Direct Normal Irradiance (DNI) is needed) are vital. At the same time spectrally weighted products like the UV-index, the Vitamin D effective dose or the photosynthetically active radiation (PAR) are critical for numerous vulnerable population groups and αgricultural production sectors. Utilities require these predictions in the nowcasting (minutes to 1-2 hours ahead) and forecasting (1-2 days ahead) time scales with real-time high temporal frequency (every 5-15 minutes) in order to perform load balancing properly. Such long- and short-term forecasting services are very important for grid operators in order to guarantee the grid stability and for those power plants that can be considered manageable, such as CSPs. Since the launch of Earth observing (EO) satellites, such as Meteosat Second Generation (MSG), and Sentinel satellite series, nowcasting techniques have also been developed from an image processing point of view. The main advantage of these techniques is the possibility to monitor a lot of meteorological information in almost real time. This high value information is used as input to radiative transfer models based on image processing techniques that in the end calculates solar radiation related parameters.

For the above energy forecast requirements we introduce the Solar Energy Nowcasting SystEm (SENSE; www.solea.gr), which produces state-of-the-art solar energy applications and is based on the synergy of Neural Networks (NN), Multi-Regression Functions (MRF), Radiative Transfer (RT) simulations and real-time satellite (clouds movement) and Copernicus Atmosphere Monitoring Service (CAMS) based retrievals (aerosol forecast). A NN is trained on a large-scale (2.5 million record) look-up table (LUT) of radiative transfer simulations to convert satellite cloud and aerosol products directly into solar radiation spectra. The developed and applied real-time modelling techniques are the integrated NN, the NN that produces spectral irradiances (NNS), and the MRF technique (for more information on these techniques see [2]. As a result, SENSE is capable of producing high resolution maps (1nm, 0.05 x 0.05 degrees, 15 min), databases and time series of spectrally-integrated irradiances of the order of 1 million pixels within 1 minute. Figure 1 shows an SENSE's application example covering the Earth disk MSG3's view. The SENSE comes to unite the multifarious local and regional solar energy needs and sustainable development policies with the nowadays available capacities and state-of-the-art technologies. As a result, we aim to fulfill these regional needs for optimum solar energy exploitation and for active and effective integration of these technologies to the national sustainable development economies and strategies. The quantification of the clouds' and aerosols' impact on the solar energy potential guarantees the reliability of the real-time, nowcasting and forecasting energy results. With the use of input data from CAMS for aerosols impact and from Spinning Enhanced Visible and InfRared Imager (SEVIRI) onboard the MSG for clouds impact, (and in a future version data from S-2, S-3, and S-4 missions), we provide state-of-the-art EO real time and climatology services, products and data bases, while SENSE is proven able to stimulate the interest of relevant stakeholders and decision makers like Ministries of Electricity and Renewable Energies, Electric Power Transmission Operators and Solar Energy investors from the private sector.

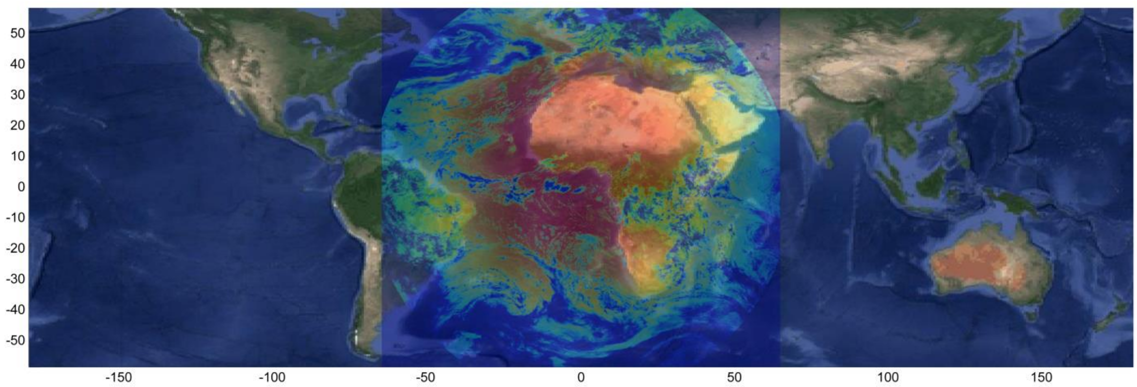


Fig. 1: An example of the SENSE's output maps. Here is the GHI for the 15 April 2015 at 12:00 UTC.

1.2. Sense validation activities

The SENSE pilot using real-time cloud and aerosol optical properties inputs from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) onboard the Meteosat Second Generation (MSG) satellite and the Copernicus Atmosphere Monitoring Service (CAMS), respectively, is capable of calculating SSR in high resolution (1 nm, 0.05 degrees, 15 min) that can be used for spectrally-integrated irradiance maps, databases and various applications related with energy exploitation. The SENSE's developed and applied surface solar radiation (SSR) real-time modelling techniques are validated against ground-based measurements from nine stations (Table 1) of the Baseline Surface Radiation Network (BSRN) equipped with Kipp and Zonen pyranometers (GHI measurements) and a Precision Filter Radiometer (PFR) at Izaña, Spain. This validation was performed in a temporal range varying from 15-min to monthly means, while a sensitivity analysis of the cloud and aerosol effects on SSR is performed to ensure reliability under different sky and climatological conditions.

Station	Country	Code	Latitude (°N)	Longitude (°E)	Height (m.a.s.l.)
Gobabeb	Namib Desert, Namibia	GOB	-23.5614	15.0420	407
Izaña	Tenerife, Spain	IZA	28.3094	-16.4993	2373
Tamanrasset	Algeria	TAM	22.7903	5.5292	1385
Cabauw	Netherlands	CAB	51.9711	4.9267	0
Camborne	United Kingdom	CAM	50.2167	-5.3167	88
Carpentras	France	CAR	44.0830	5.0590	100
Cener	Spain	CNR	42.8160	-1.6010	471
Lerwick	United Kingdom	LER	60.1389	-1.1847	80
Toravere	Estonia	TOR	58.2540	26.4620	70

Table 1: Coordinates (degrees) and height (meters above sea level) of the BSRN stations used for the validation

BSRN consists of high-quality ground based measurements of SSR and for the purposes of the comparisons made in this study, we used the dataset from July 2014 to June 2015. Table 1 presents the locations and the descriptions of the nine BSRN stations used for the reliability and accuracy of the SSR estimations made by the evaluated modelling techniques. The temporal resolution of the ground-based measurements is 1 per minute, so in order to match the 15-min resolution of the MSG cloud data (and hence the SSR outputs) we used only the 15-min interval of all the BSRN and PFR measurements. The selected BSRN stations represent a variety of climates, altitudes and aerosol sources in the field of view of MSG and as a result ensure the multifactorial performance tests for the real-time modelling techniques presented in this section.

We calculated the regression of the mean GHI between the ground measurements and the model outputs, shown in Fig. 2. We also show the intra-model regression compared to the initial RTM simulations (Fig. 2 left), in order to assess the NN and NNS included interpolations of the LUT outputs and the MRF performance. We found that the MRF technique presents identical values with the RTM, for all ground stations and under all climatological conditions. The NN and NNS show a quite good agreement too in terms of absolute values, as under all conditions, mean GHIs are less than 5% different from the BSRN measurements. In Fig. 2 (right) we confirmed the similarity of MRF with RTM and in some cases with the NN models, indicating the overall efficiency of all interpolation and multi-function techniques used. A slightly better performance was observed for higher mean GHIs proving the usefulness under high solar energy potential conditions.

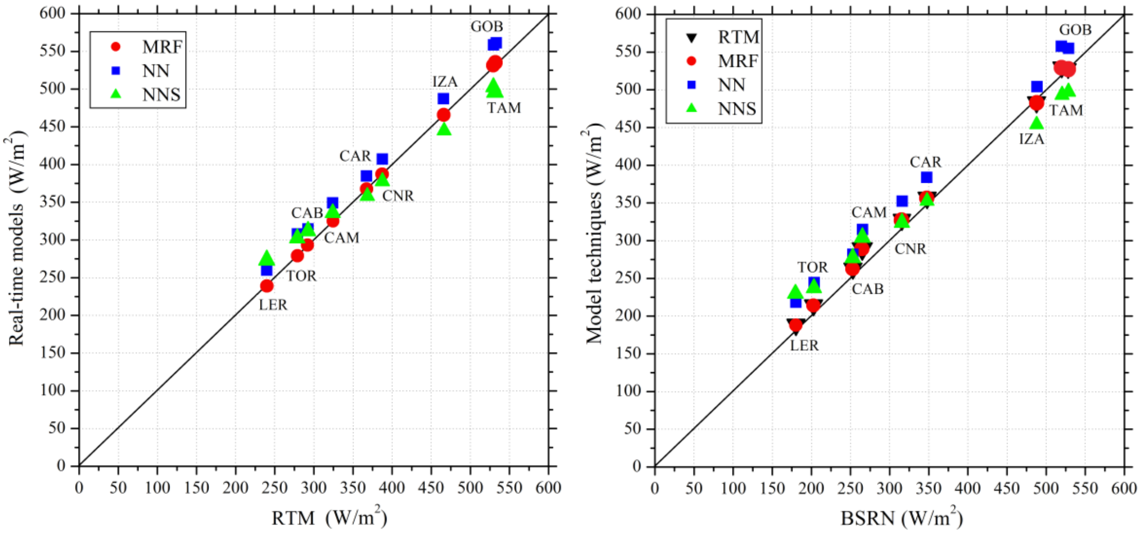


Fig. 2: The mean GHI in W/m^2 of the real time modelling techniques as compared to the RTM simulations for all ground stations (left), and the mean GHI of all models as compared to the BSRN measurements (right).

Figure 3 shows the accuracy of MRF, being the most reliable technique as presented in [2], with respect to the ground-based measurements, for various temporal integrations, starting from the (actual derived) 15-min to hourly, daily and monthly averages. The uncertainty range of the MRF simulations given as mean inter-quartile GHI differences is highest (from -100 to 40 W/m^2, depending on the station) for the 15-min resolution. It is reduced for hourly and daily averages (-70 to 40 W/m^2 and -40 to 30 W/m^2, respectively), and is minimized for the monthly averages (-20 to 20 W/m^2).

In particular, IZA and TAM showed the highest differences for all temporal retrievals, while LER and TOR presented minimum differences down to ±20 W/m^2 for the inter-quartile range of the 15-min averages. The median values are within 10 W/m^2 for the 15-min and hourly resolutions, while the corresponding minimum and maximum error values (represented in Fig. 3 as the upper and lower whiskers) extends from -200 to 100 W/m^2 for the aforementioned resolutions and are reduced to ±60 W/m^2 and ±40 W/m^2 for the daily and monthly averages, respectively.

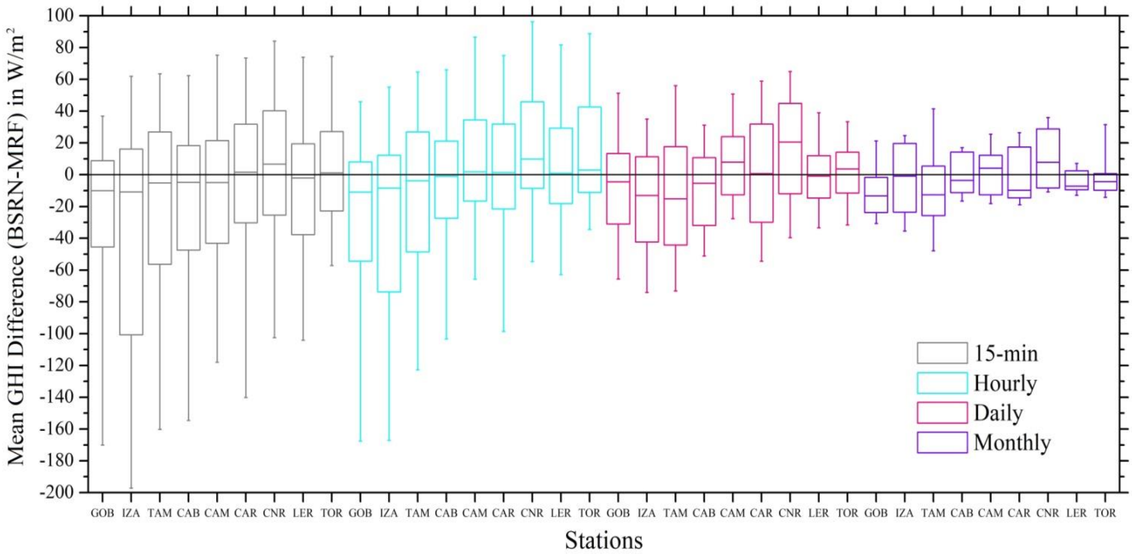


Fig. 3: Mean GHI differences in W/m^2 derived by MRF as compared to the BSRN stations for each time horizon. The boxes represent the 25th and 75th percentiles, while the in-box lines represent the median of the difference of each station. The upper and lower whiskers represent the minimum and maximum error values.

These results are comparable with similar model verification approaches and studies [20, 21, 22, 23, 24, 25]. Indicatively, [21] and [20] discussed the CM-SAF SARAH (Solar surfAce RAdiation Heliosat) data record, which are post processed data. They calculated a mean monthly error for GHI of 5.5 W/m^2 and a mean daily error of 12.1 W/m^2, with additional uncertainties in terms of spatial representativeness and measurements quality of about ±12 W/m^2, while they did not provide relevant information about the hourly or even higher time resolution.

The overall accuracy of all models was evaluated also with respect to seasonality. In Fig. 4 we present the seasonal rRMSE values of the GHI estimations produced by the MRF, NN and NNS models as compared to the BSRN 15-min intervals measurements. The rRMSE for MRF, ranges from 5 to 48% for GOB and TOR stations respectively, for NN the range is increasing to 6-60% and for NNS the corresponding range is 7-87%.

We need to highlight that the aforementioned large differences correspond to significantly low absolute GHI values indicating the impact under cloudy conditions mainly in the winter season, at stations with high mean cloudiness (LER, TOR, CAM and CAB).

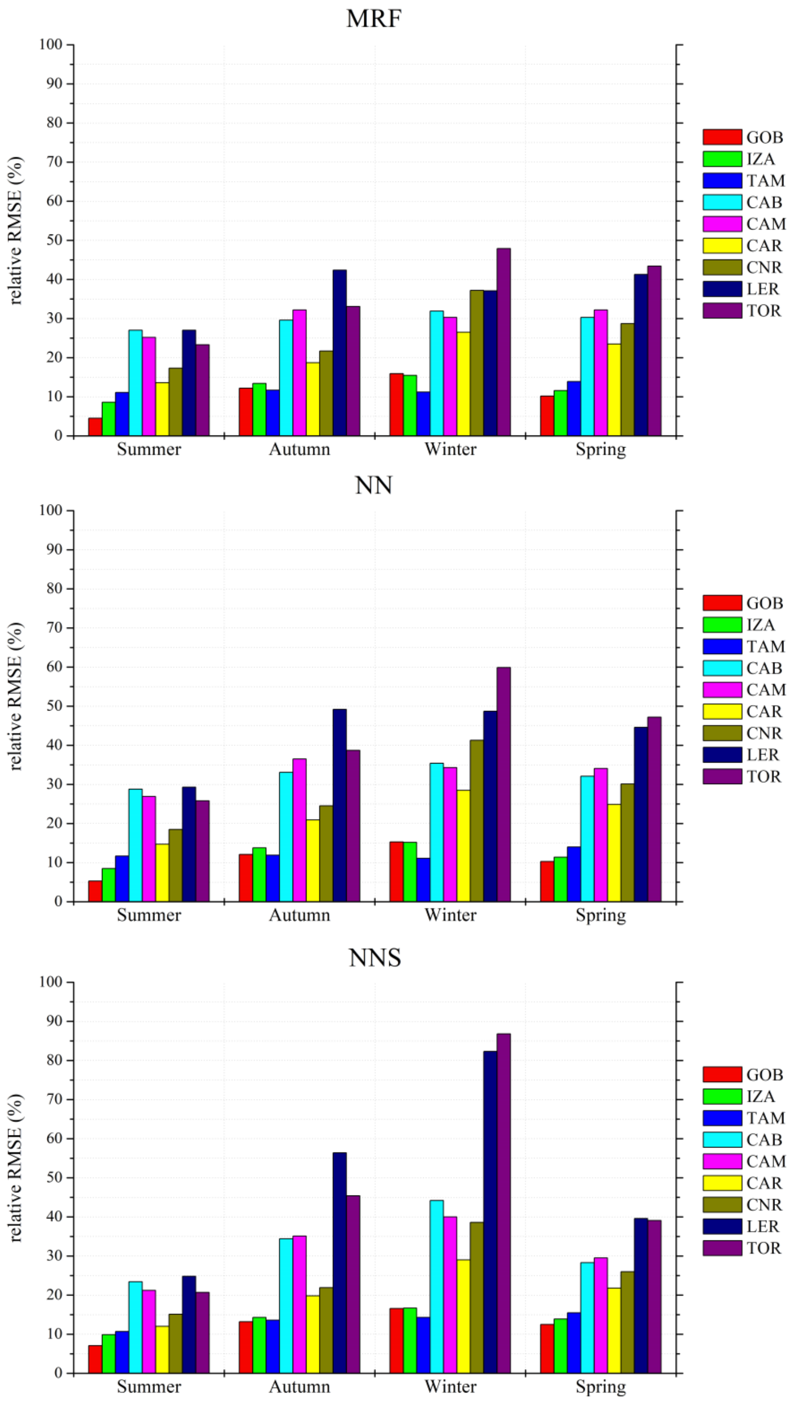


Fig. 4: Seasonal relative RMSE values of the GHI estimations produced by the real time techniques as compared to the BSRN measurements.

In the summer, results are better for all stations and for all models (5-29%), while GOB, IZA and TAM stations showed the lowest rRMSE values (5-12% in summer and 12-17% in winter), linked with their lower cloudiness. [24, 25] validated the HelioClim-3 database and the McClear model in Egypt and in the United Arab Emirates, and they found RMSE of 68.4-151.7 and 22-47 W/m^2, respectively (we found a range of 58.2-70.8 W/m^2). [22] validated the latest version of HelioClim-3 (v5) against BSRN and found rRMSE of 14.1-37.2% for the 15-min averages, which are directly comparable to our 15-min results (12-35.7%). In particular, for the LER, TOR, CAB, CAM, CAR and TAM stations they found rRMSE of 37.2, 33, 29.4, 25.9, 16.3 and 15.8%, while looking to our MRF performance evaluation results we observe 35.7, 35.6, 29.9, 30.3, 20.2 and 12.2% for the same stations. This indicates that the use of the suggested real-time modelling techniques enables the production of instantaneous, high resolution and quite accurate (as compared to the post-processed databases) GHI outputs that can be used for solar energy related applications and studies. A detailed presentation of results for all metrics and stations can be found in [2].

The cloud effect via the radiative transfer of solar radiation in the atmosphere, represents the greatest source of uncertainty in the simulation of SSR, while several models do not have the capability to deal with clouds coexisting with a radiatively active atmosphere [26]. Small changes in cloudiness and its optical properties can impact on GHI. The magnitude of the cloud effects on the model to BSRN comparison can be seen in Fig. 5.

Under clear-sky conditions (Fig. 5 upper plot), the regression of the 15-min modeled GHI values show very good agreement when compared with the BSRN measurements for both MRF and NN-based techniques. We plotted the RTM simulations as well in order to depict the corresponding regression. The distinct scatter shown under all-sky conditions (Fig. 5, lower plot) with the cloud cases linked with an underestimation of the modeled GHI in comparison to the BSRN values. This effect has to do with the MSG COT uncertainties and hence introduces errors to the outputs of the SSR techniques [27, 28]. In addition, comparison principles of a (point) station GHI measurements with a 0.05^o MSG cloud "picture" are responsible for part of the observed deviations. As an example, for instants that the MSG 0.05^o grid is partly cloudy, the BSRN GHI measurements could fluctuate more than 100%, depending on whether the sun is visible or if clouds attenuate the direct component of the solar irradiance. As a result, in the case of partly covered 0.05^o pixel and in the absence of clouds between the BSRN instrument and the sun, BSRN measured GHI would be much higher than the modeled one. Of course the opposite situation is feasible as well causing consequently an overestimation of the modeled GHI [29].

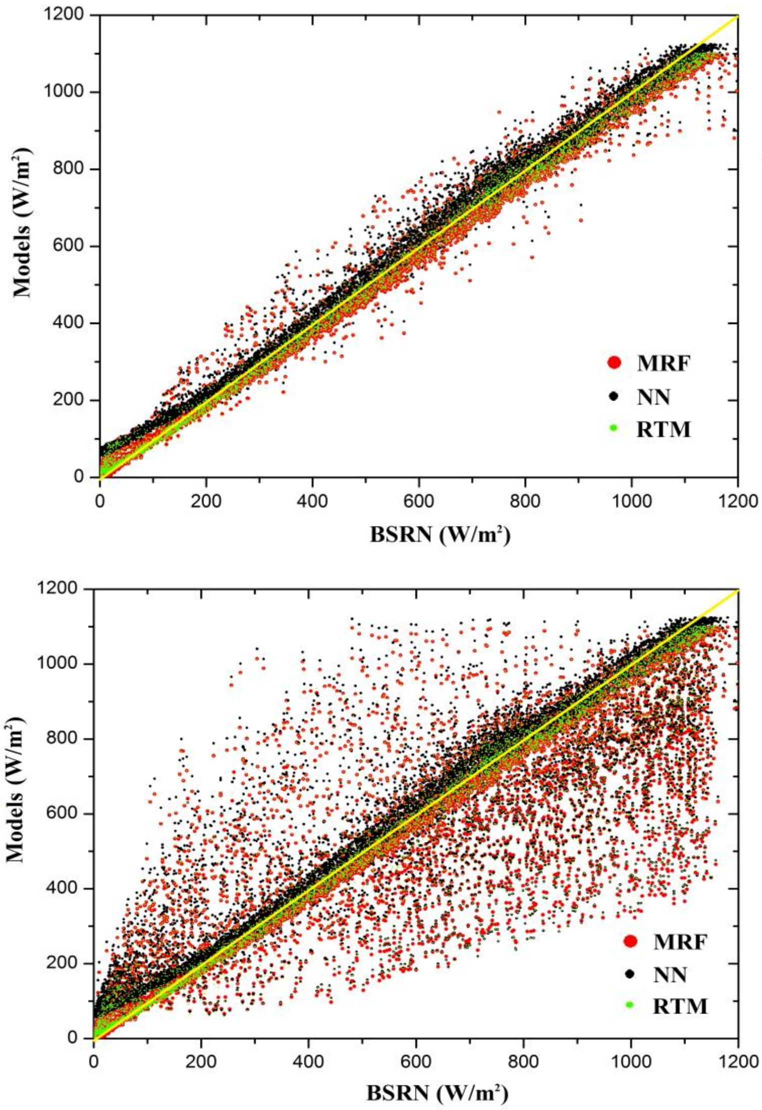


Fig. 5: Scatterplots in terms of sky condition reliability of the real time (MRF and NN) and RTM simulated GHI in W/m^2 as compared to the BSRN measurements for all stations under clear sky (upper plot) and all sky (clear sky and cloudy) (lower plot) conditions.

Figure 6 illustrates the mean percentage difference and standard deviation of the 15-min GHI produced by the MRF and the measured values by the BSRN stations (only instances with cloudy conditions were used for all stations) as a function of COT. For COT< 2, the MRF technique results higher GHI values than those actually measured, of 1-12%, while as the COT values get higher, the MRF underestimates the measurements by up to -60% for COT around 35. We note that under such high COT values the mean radiation values are much lower than 50 W/m^2. The standard deviation reaches its highest value of 43 W/m^2 for COT 14-16 while its lower value of 32 W/m^2 is found for COT 2.6.

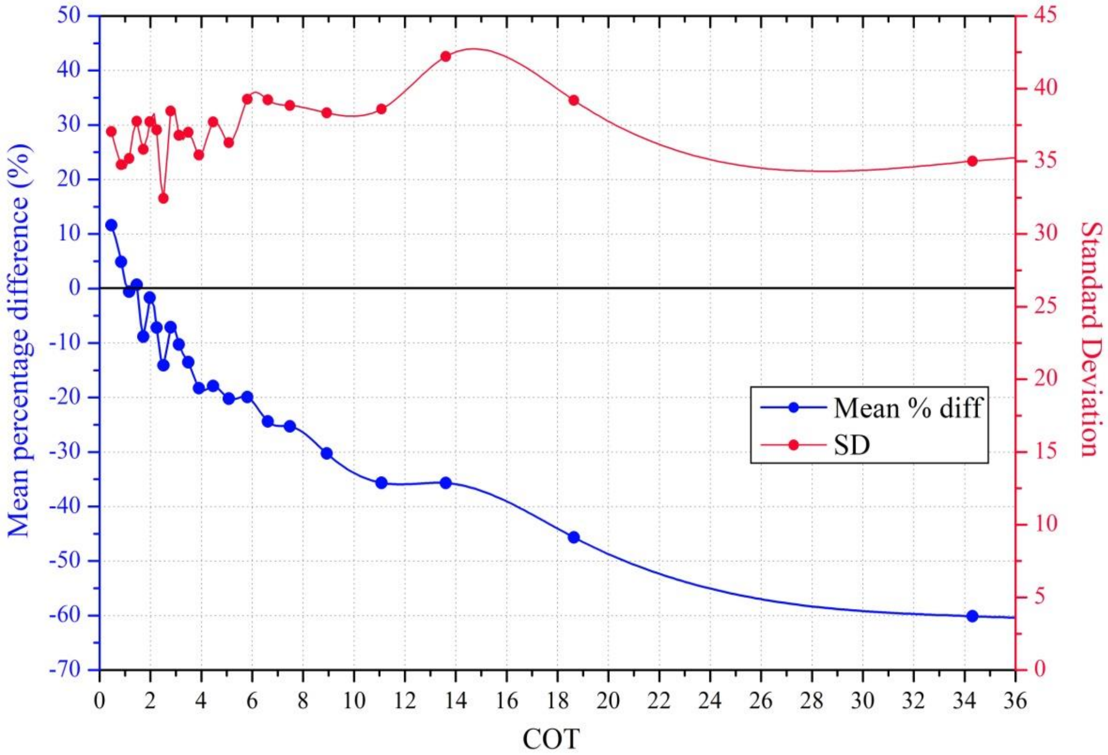


Fig. 6: Mean percentage difference (blue) and standard deviation (red) of the 15-min GHI produced from the MRF technique as compared to ground-based measurements from all stations as a function of the COT.

In addition to the clouds, aerosols play an important role in the solar radiation transfer in the atmosphere. Especially in places with high solar energy potential, where cloud-free conditions prevail during the largest part of the year, significant aerosol sources could exist [30]. The aerosols effect is closely related to the aerosol optical properties and mostly AOD and as a consequence, the uncertainty in the model AOD input could result to significant errors in the assessment of SSR [31, 1]. For the purposes of this study we used the Global Atmosphere Watch (GAW-PFR) station of IZA, which is an internationally recognized test bed for aerosol remote sensing instruments [32], to quantify the AOD difference between the operational input from CAMS and a PFR instrument, under high altitude conditions [33].

In Fig. 7 we present the yearly frequency distribution of the differences between CAMS and PFR values for cloudless sky conditions. The majority of the AOD differences are lower than 0.2 with the maximum frequency encountered at zero AOD differences, indicating the overall good accuracy of CAMS-derived one-day forecasts of AOD. The mean absolute difference was found equal to 0.1075±0.1038 (1 sigma). This shows an overestimation of 0.1 for CAMS that could be lead to MRF GHI small underestimation of 2% compared with BSRN measured GHI.

Finally, in Fig. 8 a scatterplot of the CAMS-PFR differences in AOD is shown as a function of absolute differences in GHI derived between the MRF technique and the IZA measurements. The GHI differences are spread around zero independently of the AOD difference showing the negligible dependence of such small AOD differences to the GHI model calculations.

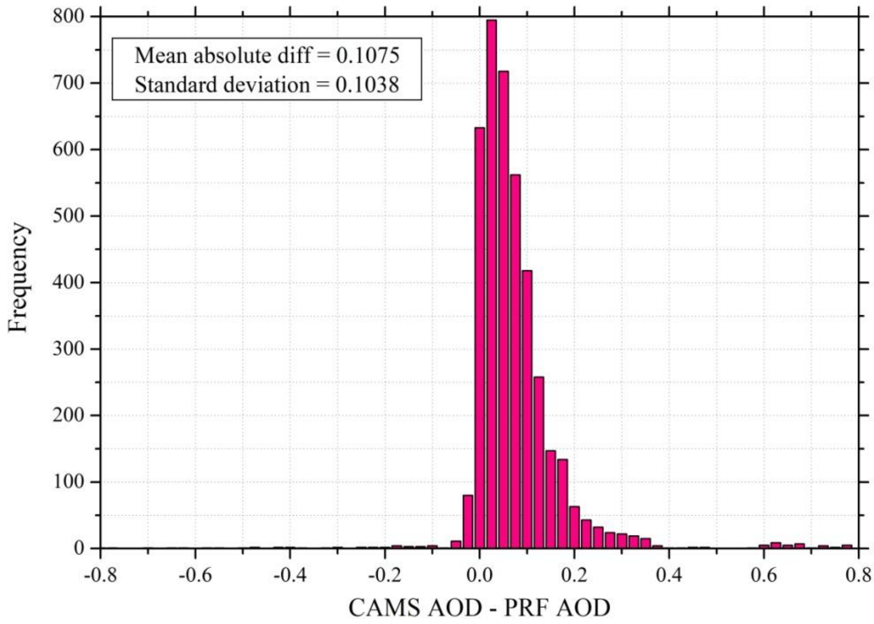


Fig. 7: Frequency histogram of differences between the CAMS and the PFR AOD at the Izaña station together with the mean absolute difference and standard deviation metrics.

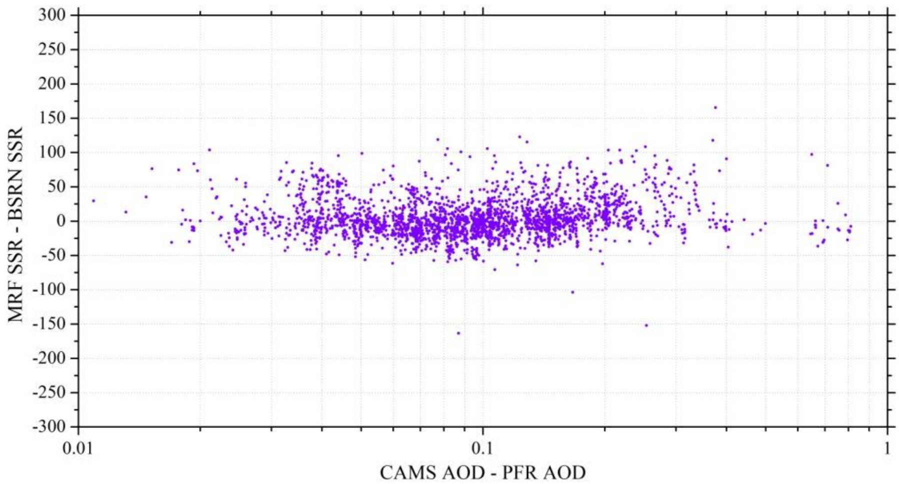


Fig. 8: Absolute differences in GHI (in W/m^2) derived by the MRF technique from the ground-based measurements at Izaña (BSRN pyranometer), as a function of differences in AOD from CAMS and PFR.

An additional SENSE validation activity concerning the dust impact, was performed for an exteme dust event that took place during the period 30 January to 3 February 2015. The intensity of the event was extremely high, with aerosol optical depth (AOD) reaching 3.5, and optical/microphysical properties suggesting aged dust. SENSE simulations were able to quantify the extent of dust impact on surface irradiances and reveal substantial reduction in solar energy exploitation capacity of PV and CSP installations, under this high aerosol load. We found that such an extreme dust event can result to Global Horizontal Irradiance (GHI) attenuation by as much as 40-50%, a much stronger Direct Normal Irradiance (DNI) decrease (80-90%), while spectrally this attenuation is distributed to 37% in the UV region, 33% to the visible and around 30% to the infrared. CAMS forecasts provided a reliable available energy assessment (accuracy within 10% of that obtained from MODIS).

Figure 9 presents the SENSE simulations using the CAMS AOD, as well as a direct comparison between the MODIS derived and simulated results with the CAMS 1 day-ahead forecasts. At Fig. 9 left plots we present the MODIS level 3 and CAMS AODs at 550 nm in order to identify the observed (MODIS) and simulated/forecasted (CAMS) dust plume distribution, extent and AOD value intensity. The CAMS simulation follows the MODIS's observed dust plume extent, approaching its distribution but underestimating the peak AOD values (max MODIS values ≈ 3.5 and CAMS ≈ 1.9 over the Greek region). This underestimation pattern of the peak AOD values, is a consequence of imperfect forecasted meteorology and fading impact of the initial assimilation of MODIS AOD info on CAMS performance [34, 35]. Yet, despite this difference, the impact on the energy and SSR simulations is of the order of 10% (see below description) in most cases (>90% of the spatial coverage), which highlights that CAMS 1-day ahead forecasts are really of great value and usefulness for solar energy potential planning and policies [36, 37, 38, 1, 39]. Since the main inputs to the SENSE are the AOD and the SZA, which both can be forecasted (CAMS AOD) and pre-calculated (SZA), the real time spatial and temporal estimation of the dust events impact on SSR is realistically feasible. At Fig. 9 middle plots we simulated GHI (upper) and DNI (lower) under aerosol-free and under MODIS and CAMS aerosol conditions, near local-noon. In all cases we applied smoothing techniques in terms of data fitting to contour lines for better visualization results. The SSR simulations were calculated with the impact of the dust as characterized in terms of high AOD values from MODIS level 3 values and CAMS 1-day ahead forecast. The retrieved AOD for the SENSE calculations is at 550 nm, with spatial resolution of 1x1 and 0.4x0.4 degrees (MODIS and CAMS, respectively). The temporal resolution of MODIS overpass imaging is about 1 per day while for CAMS simulation is 1 per hour, highlighting also the ability of CAMS to provide significant information on the temporal evolution of solar energy availability. The panels in Fig. 9 right, describe the impact on energy in terms of percentage attenuation of SSR indicating the radiative impact of the dust plume over Greece.

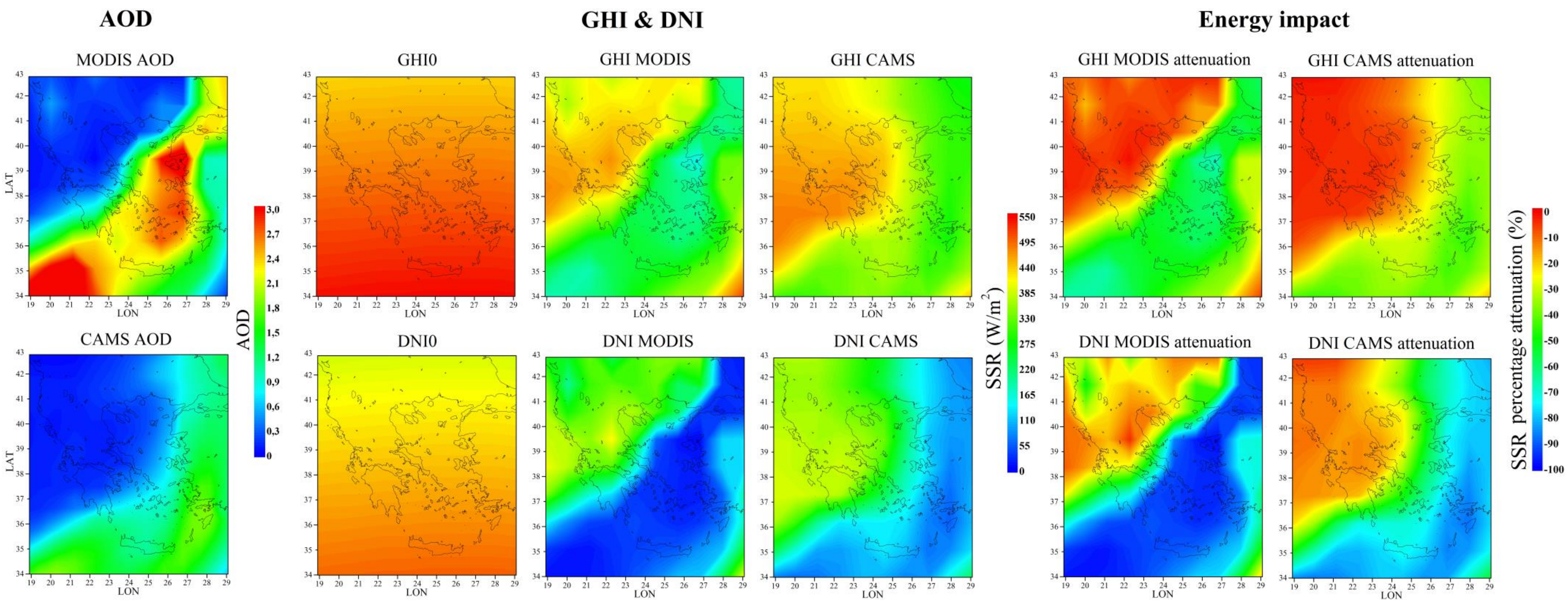


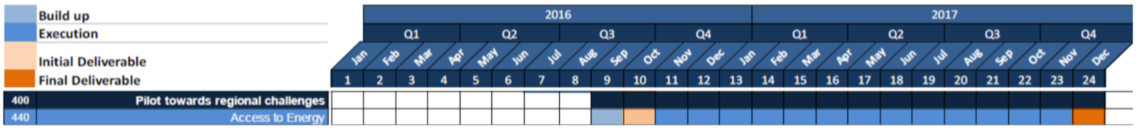
Fig. 9: (left plots) AOD from MODIS level 3 and the CAMS 1-day ahead forecast. (middle plots) RTM simulations at local noon on the day of the incursion on 1 Feb 2015 for GHI and DNI. GHI0 and DNI0 represent the simulations without dust (with only the effects of SZA). (right plots) The energy impact in terms of percentage attenuation relative to the dust-free simulations for GHI and DNI under MODIS- and CAMS-based AODs. For the GHI, the attenuation is about 30 – 70 % for MODIS and about 30 - 60 % for CAMS. For the DNI, the attenuation is about 70 – 100 % for MODIS and about 60 - 90 % for CAMS.

The simulated results showed mean GHI values of about 500 W/m^2 for aerosol-free conditions, while for full aerosol conditions this value is reduced to about 300 W/m^2. The corresponding radiation values of DNI are 450 W/m^2 for clean and clear sky and around 80 W/m^2 for dust event conditions. We need to highlight as well that the maximum AOD that was simulated with the RTM was of the order of 3.5, which classifies this dust event as one of the most intense cases in the eastern Mediterranean. In general, spring presents the higher frequency of dust events [40, 41, 30, 42, 1], while in winter occur the more intense dust events [43]. The percentage impact of the plume (Fig. 9 right plots) is in the range 30-70% (MODIS) and 30-60% (CAMS) for the GHI and 70-100% and 60-90% (MODIS and CAMS, respectively) for DNI, highlighting and illustrating convincingly the extreme attenuation of the direct component of the total SSR and at the same time quantifying the energy exploitation losses for PV and CSP applications. Overall, concerning the GHI and DNI percentage differences for the MODIS- and CAMS-based SENSE simulation, we found that the CAMS forecasts overestimate the SSR values under high aerosol loads, indicating the limited ability of MACC to predict high AODs [34], while it can efficiently capture the dust plume extent and distribution. As a result, higher percentage differences on DNI following the highest AOD values and the lowest SSR values with minimum induced energy impact (DNI < 50 W/m^2) is found. The percentage differences for GHI reach 80-100% for highest AOD values as well, with mean representative GHI attenuation below 50% (see Fig. 9 right plots), highlighting the usefulness for energy forecasting needs and applications. More information on the impact of dust on SSR can be found in [1].

2. Link of Sense with the output of the Inventory of capacities and user needs and the analysis, indicators and regional priorities

The SENSE pilot comes to unite the multifarious regional solar energy needs and sustainable development policies with the nowadays available capacities and state-of-the-art technologies. With the use of developed and improved EO real time and climatology services, products and data bases, SENSE pilot was intended to stimulate the interest of relevant stakeholders and decision makers like Ministries of Electricity and Renewable Energies, Electric Power Transmission Operators and Solar Energy investors from the private sector.

Table 2: The SENSE pilot Timetable.



This pilot activity spanned a period of 15 months (Table 2) and based on the in-depth analysis performed in WP200 and WP300 was totally refined and customized to the specialized regional needs.

North Africa, Middle East and Balkans are places with a serious amount of solar energy potential and its exploitation is critical for their national sustainable development through an efficient energy planning and a gradual independence from fossil fuels. The currents solar energy EO capacities in the RoI are degraded and as a result this field needs a complete and comprehensive revision and promotion in order to be established as a main contributor to national portfolios (Fig. 10).

	PV (MW)
1998	0.07
1999	0.1
2000	0.2
2001	0.3
2002	0.8
2003	1.4
2004	1.7
2005	2
2010	4
2015	7

Fig. 10 and Table 3: The solar energy production from photovoltaics and concentrated solar plants in Greece.

Equitable access to energy is a basic requisite for economic development and an important condition to galvanize economic activity. RoI: dependent on fossil fuels, coal and petroleum. Exploitation and distribution must be closely monitored to identify investment opportunities and drive greater efficiency, and avoid pollution and damage to water and land. Balkan candidate countries that must adopt European energy standards, requiring a drastic departure from the state of the art. Demographic trends in North Africa and the Middle East require informed long-term planning of energy sector investments on the national level to expand existing electricity production capacities and meet growing demand. North Africa and the Middle East have conditions for the largest production of renewable energy in the world. There has been demonstrated market traction for the region’s solar power in a growing export market for clean energy (Fig. 11).

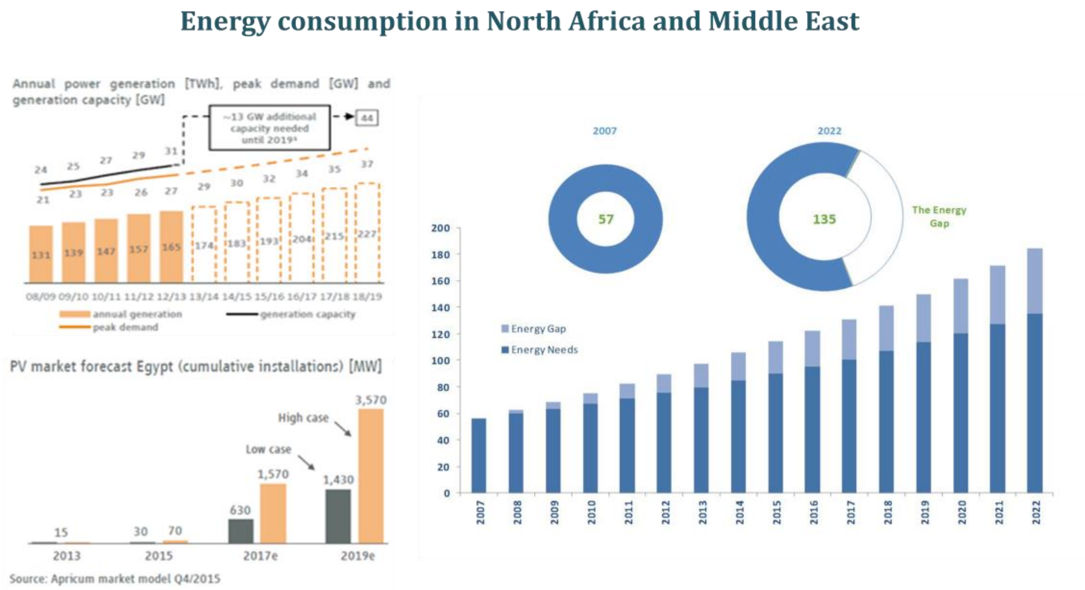


Fig. 11: The energy consumption in North Africa and Middle East (left figure) and the expected future energy status in Egypt (right figure).

The SENSE pilot comes to fulfill these regional needs for optimum solar energy exploitation and for active and effective integration of these technologies to the national sustainable development economies and strategies. The quantification of the clouds’ and aerosols’ impact on the solar energy potential guarantees the reliability of the SENSE pilot. Simultaneously, the synergistic inclusion from models, ground-based and satellite-based databases can be applied to the real time pilot services as well as to the solar Atlases requested from major regional end users (Egyptian Ministry of Electricity and Renewable Energy).

Fig. 12 presents the expected evolution of peak demands, something that is critical for the local and regional power transmission operator (IPTO for Greece).

Fig. 12: The expected evolution of peak demands (from 2009 to 2030).

Solar energy related interviews have revealed a variety of different aspects that are linked with the initial proposal of the SENSE pilot activities. As a result we re-introduce the Refined Solar Energy Nowcasting SystEm (SENSE) Pilot, the scope of which was established based on the specialized regional needs and existing maturity in relation to ''access to energy''. Indicatively we report the case study of Egypt (which eventually is one of the end-users). In light of efforts made by the Government of the Arab Republic of Egypt to achieve the desired economic growth while preserving the environment, the government tries to address the demand for energy efficiency through the use of renewable energy sources. The Egyptian Ministry of renewable energy needs from the SENSE pilot the full solar energy nowcasting system as well as the analytical solar Atlas of Egypt using EUMETSAT's radiation data [2]. The mean monthly solar energy maps are based on a 15-year complex and highly variable climatology taking into account the clouds and aerosols impact on Direct Normal Irradiance and Surface Incoming Solar radiation (DNI and SIS respectively), while the spatial resolution is almost 5 km, maximizing the exploitative value of the solar energy technologies. At the same time, the SENSE system is able to produce operational maps of Egypt at high resolution (1nm, 0.05 x 0.05 degrees, 15 min) and the whole approach is ideal for effective energy planning and services while it can support the local energy managing authorities.

With these additional needs we extended the total SENSE outputs in order to fulfill the regional requirements. At the same time we took into account the results of the WP2 and WP3 (Fig. 13) concerning the energy capacities, regional needs and maturity indicators, as well as the conclusions of the Morocco and Cyprus meetings with purpose to better refine the scope, objectives and upgraded methodologies of the SENSE pilot.

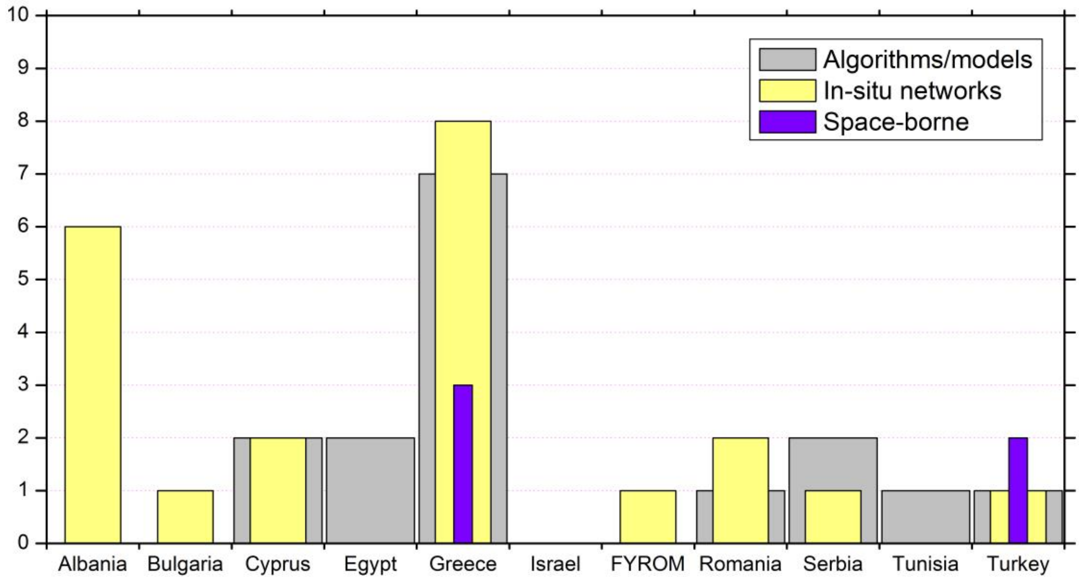


Fig. 13: Energy related partner capacities, regional needs and maturity indicators.

From the results of WP2 and WP3 we concluded that there are potential end-users for the application of the SENSE pilot. Starting from Greece and Egypt, we discussed with the local stakeholders and we finally agreed to provide (Table 4):

Table 4: The definition of the specific pilot sites.

Region	Product	Maturity	User
Greece	Energy Nowcasting + forecasting	high	Independent Energy Operator
Egypt	Nowcasting + solar atlas	Mod	Dep. Of Energy Egypt
Aegean and Adriatic sea	Solar UV Index	Mod	Superfast ferries

(i) the GHI nowcasting service to the Independent Power Transmission Operator (IPTO) of Greece (see at Fig. 16 the analytical map of the management control of the energy demands and at Fig. 17 a time-step map from the SENSE nowcasting service)

(ii) the same nowcasting service with additional,

(iii) the full solar Atlas of GHI and DNI to the Ministry of Electricity and Renewable Energy of Egypt. We will also provide the nowcasting UV-index service for the Bluestar and Superfast Ferries (private sector). At Fig. 33 we present the official presented product of this service that played at the 13 ships which have connections to the Adriatic and Aegean Sea.

From the other countries we could potentially achieve a collaboration with Romania (CEZ Trade and Tractabel Engineering SA GDF SUEZ) and Saudi Arabia (ARAMCO) concerning the solar energy nowcasting and Atlas services, something that was clarified in the Cyprus meeting and we contacted these stakeholders, which finally were not interested for collaboration in the framework of Geo-Cradle, since they have their own service and product providers. On the other hand, Tunisia with the Tunisian Electricity and Gas company and Morocco with the Morocco Water Basin agencies was mainly interested in electricity from water resources.

As a result, in addition to the nowcasting activity of GHI and DNI, we upgraded and refined the SENSE pilot with the followings:

- Short-term forecasts (0-2 hours)

- Impact of aerosols, mainly dust from Saharan Desert on energy forecasting using the Copernicus Atmosphere Monitoring Service (CAMS). We perform this aerosol upgrade because for the Northern Africa and the Mediterranean the aerosol is the most important factor for solar radiation (and hence solar energy) attenuation

- Development of regional Solar Atlases (climatology studies, yearly/monthly/daily), any spatial resolution

- Solar related effects on human health and agriculture (UV index, PAR, Vitamin D, DNA Damage, plant photosynthesis)

3. Pilot applications

3.1. IPTO

3.1.1. Objectives and expected results

The Independent Power Transmission Operator (IPTO or ADMIE) S.A. was established in compliance with Law 4001/2011 and European Union Directive 2009/72/EC regarding the adoption of common rules in the organization of EU electricity markets. According to Law 4001/2011 ADMIE undertakes the role of Transmission System Operator for the Hellenic Electricity Transmission System and as such performs the duties of System operation maintenance and development so as to ensure Greece's electricity supply in a safe, efficient and reliable manner. Although a wholly owned subsidiary of PPC S.A., ADMIE is entirely independent from its parent company in terms of its management and operation, retaining effective decision-making rights, in compliance with all relevant independence requirements of Law 4001/2011 and Directive 2009/72/EC.

The Operation Planning Section (OPS) of the Department of System Operation and Control is responsible for providing forecasting information to the market platform, which produces the optimal schedules. Among the forecast data provided by OPS is the system load forecast and the forecast of power produced by renewable sources. System load forecast and forecast of power produced by solar renewable sources (for brevity we shall refer to both as load forecast models) are produced by ADMIE utilizing proprietary software tools owned by ADMIE.

Once the market is cleared the system marginal prices are produced. Inaccurate forecasts may lead to sub-optimal schedules and it turns out that this has a significant impact in the economic cost of the operation schedules. More specifically, under-forecasts may lead to purchase of expensive services to deal with peaks and over-forecasts may lead to unnecessary capacity being committed.

In effect, load forecasting is fundamental in utility operation (Fig. 14) and increasing penetration of renewable sources has caused a significant change in the resource mix making the use of accurate forecasts necessary. These changes have constituted load forecasting to be a dynamic process that should continuously be improved.

Weather conditions are among the predominant factors that affect electrical power consumption, and are therefore used as predictors in short-term load forecasting (the weather variables are used differently in long term load forecasting – many important weather variables are hard to be predicted beyond two weeks). Large penetration of solar generation at the distribution network has created new challenges for load forecasting, as the negative load from distributed energy sources has to be taken into account. This has created the need to incorporate weather factors such as light intensity or cloud coverage to accommodate for these effects and divert away from the traditional load forecasting models that used only temperatures or humidity.

The accuracy of the weather forecasts affects the load forecasts and it is therefore important for the load forecast to be provided with reliable weather forecasts, which are updated at regular intervals throughout the day.

Fig. 14: The Independent Power Transmission Operator (IPTO or ADMIE) for Greece. It controls the energy demands and the effects of implementing demand-side management strategies on the daily demand curve.Here is the IPTO's area of operations.

The general constraints that the IPTO faces are mainly physical constraints. There are three factors that drive the upgrade and reengineering of the requirement according to a new weather forecast engine:

1. The large penetration of solar energy sources both at the system and the distribution. The light intensity measures that are currently available for four areas in Greece, used by the solar energy prediction model are not sufficient to capture the dispersed nature of solar production.
2. The need for a realistic, accurate and integrated consideration in the forecast of all renewable sources, so that, together with the production by the conventional units the actual load demand can be forecasted.
3. Upcoming amendments in the Greek Grid and Exchange Code will require renewable sources to participate in the electricity market. This has significant effects in the load forecast as the power produced by these sources will no longer be treated as negative load.

As a result, the services and products required from the SENSE feasibility pilot were the followings:

- Forecasting meteorological data concerning the mass penetration of Wind and PV energy into the Electrical System.
- Nowcasting solar energy potential for efficient energy planning.
- Realistic climatological estimations of surface solar irradiance.

3.1.2. Methodology, methods of implementation

For the IPTO feasibility study, the techniques used are the Multi-Regression Functions (MRF), the Neural Network that produces spectral irradiances (NNS) and which is presented in detail in [44], and a variant version of the NN that produces integrated irradiances. All three techniques have been optimized based on LUTs that are described in [44] and produce instantaneous (with less than one minute delay from the time that the MSG image is produced) SSR. The number of outputs depends on the region under study and can be of the order of 10^6 simulations, simultaneously. In this pilot case, for the real-time SSR we used as operational inputs the CAMS AOD and the MSG COT, in conjunction with the solar elevation angle, as they are the major attenuators of the GHI. Figure 15 illustrates the procedural flows of the three developed real-time modelling techniques for the IPTO's operational use. Starting with the MSG cloud flags (0=clear sky and 1, 2, 3=cloudy sky in terms of water, ice and mixed clouds, respectively), we identify the clear-sky and cloudy-sky pixels. For the cloudy pixels we incorporate the optical properties (COT) and types of clouds (CT), while for clear sky pixels we take into account the aerosols effect (AOD) and the total ozone column (TOC), which was derived using Ozone Monitoring Instrument (OMI) retrievals.

Then, for all sky conditions we generate the input files to the real-time techniques and, depending on their special characteristics, we produce spectral or spectrally weighted products at high spectral, spatial and temporal resolution (1 nm, 0.05°, 15 min). The actual outputs were SSR real-time time series and Greece maps in the same high resolution. Figure 16 presents an example of the effect of implementing Demand-side Management Strategies on the daily demand curve based on the SENSE operational outputs.

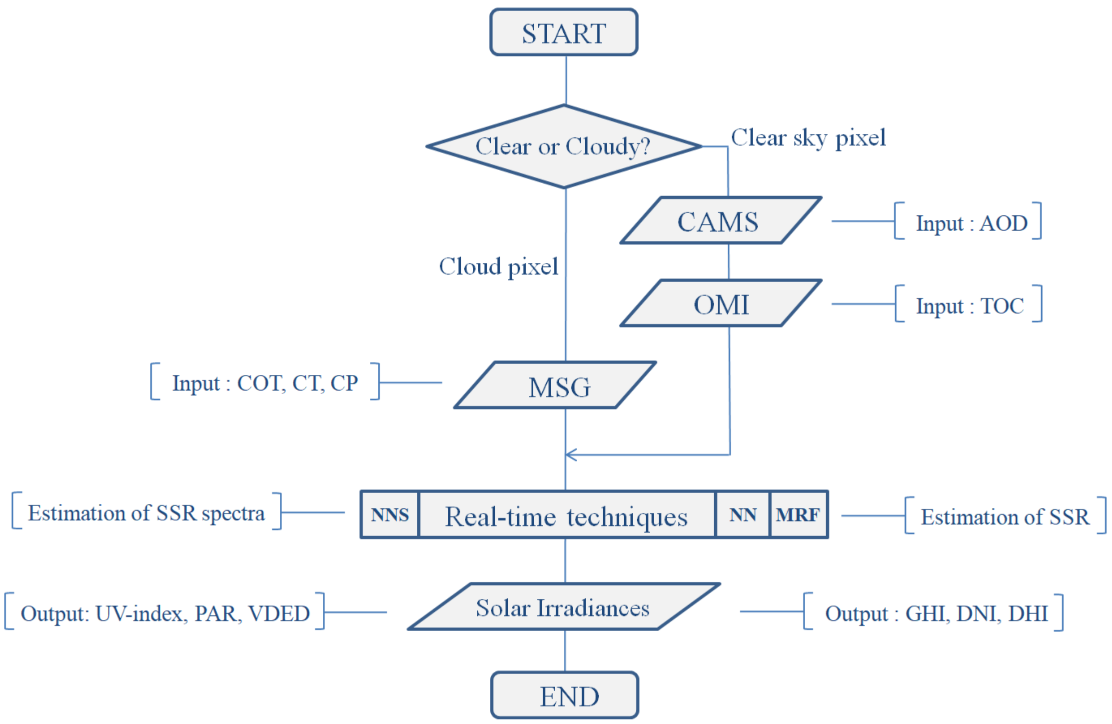


Figure 15: Flowchart illustration of the modelling techniques scheme. The initial pixel classification followed by the clear or cloudy sky inputs to the real-time solver resulting the spectral (NNS) and integrated (MRF and NN) SSR-related outputs.

The real-time SENSE outputs of the solar energy potential provided support to the efficient control of: (i) the energy demands and (ii) the electricity distribution by incorpotating the produced energy of the solar farms (PVs and CSPs) into the electricity grid. As a result, the IPTO's control system was tranformed into smart grid and the realization of a more efficient and without losses transmission operation become feasible. We hope next years to evolve further this synergistic system (IPTO's system and SENSE system) in order to make IPTO one of the most efficient and profitable electric power transmission operators in Europe.

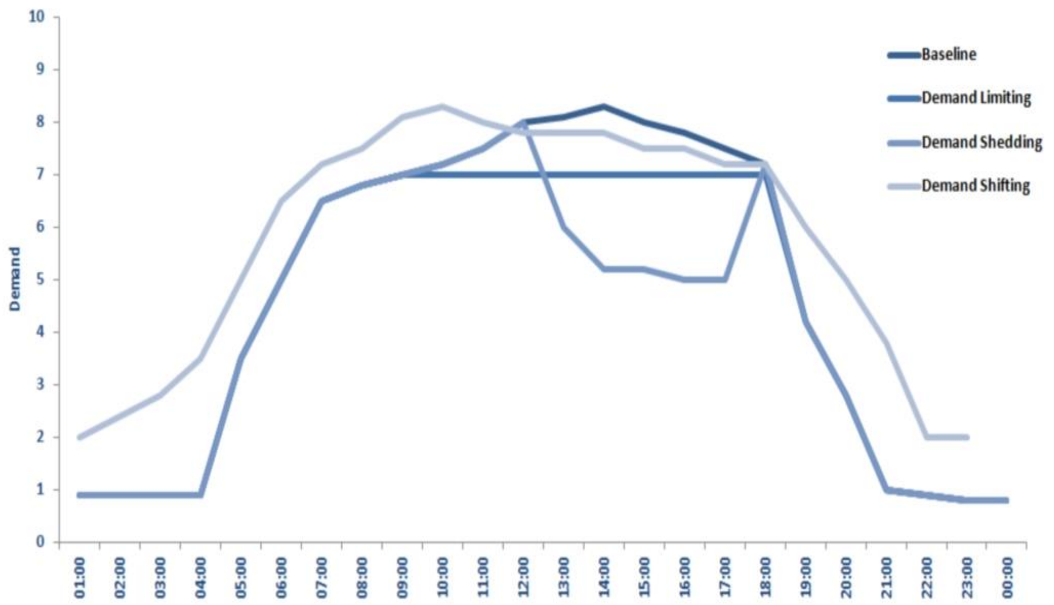


Fig. 16: Example of the effect of implementing Demand-Side Management Strategies on the daily demand curve.

3.1.3. Main activities and results of the pilot analysis

The main activities included the operational and real-time provision of the solar energy potential in map and database forms. The active and online link for the nowcasting map product is the following:

ftp://ADMIE:ADMIESOLEA@194.177.195.105/ENERGY.png

The database is in the same high temporal resolution of 15 minutes and spatial resolution of 5 km, which for the region of Greece reaches almost 70,000 pixels. The integration of SENSE into the operational planning of IPTO was implemented by the SENSE's and IPTO's IT teams, while the evolution of this synergistic system is an ongoing work that continues after the end of the pilot period (12/2017). An example of visualization of the SENSE nowcasting servite to IPTO is illustrated in the following Fig. 17. The results of this pilot activity revealed the usefulness of such a solar energy nowcasting system, since solar energy related installations have been increasing their share on the total energy demand as defined by the local and regional Distribution and Transmission System Operators (DSOs and TSOs, respectively). As a result, accurate, real-time and short-term forecasting estimations of the solar energy potential and more specifically the GHI related with the operation principles of PV installations, are vital. The SENSE's outputs were successfully applied in the IPTO's holistic control system with tangible results and impacts on the efficient near real-time decisions, linked with the PV related contribution to the Greek electricity grid.

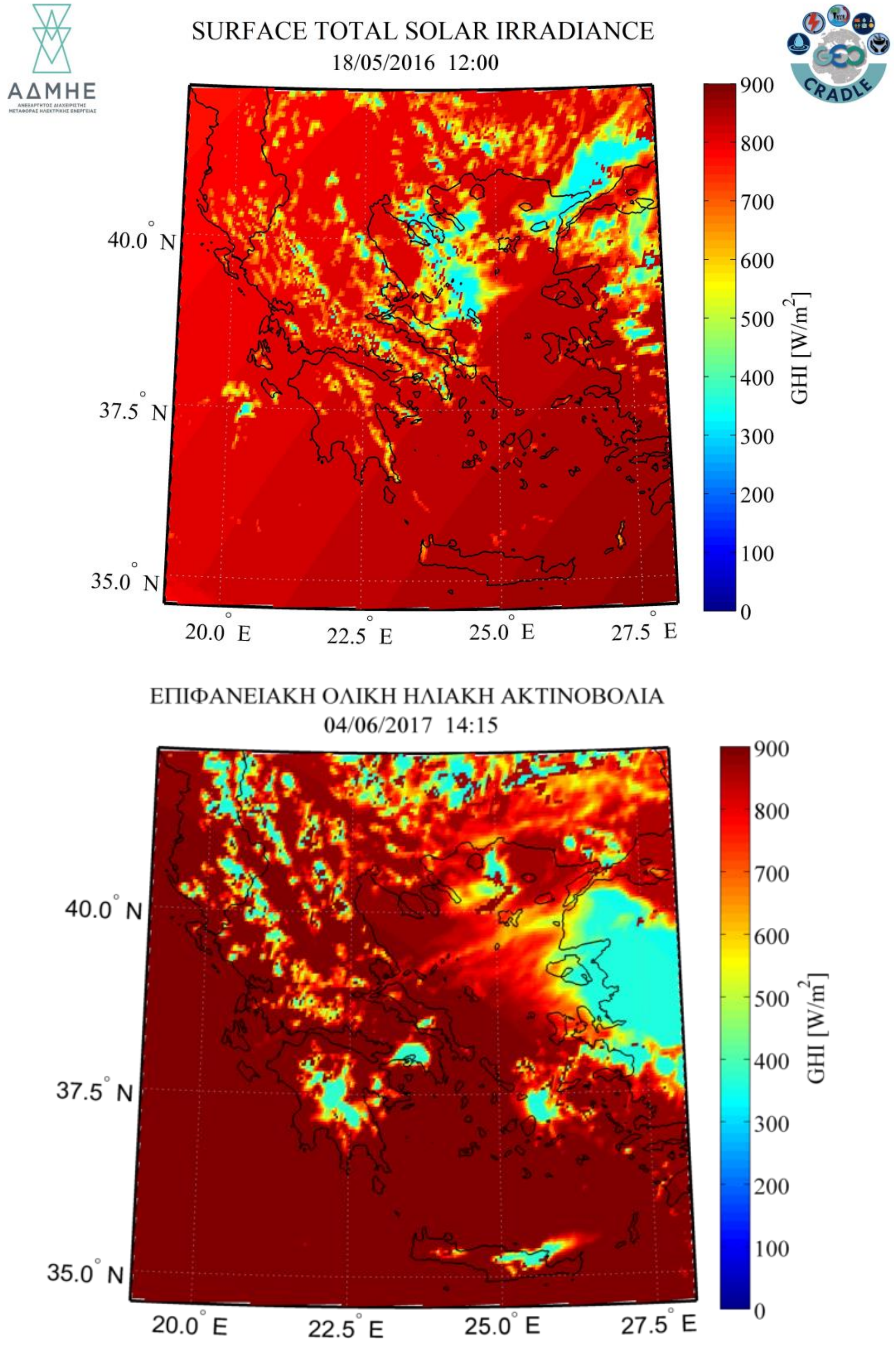


Fig. 17: Time-step example maps from the SENSE nowcasting service for the Greek IPTO.

3.1.4. Sustainability

In terms of investment for the future, this pilot ran without further funds. The sustainability of the project relies on the end-user engagement, which include the National energy transmission systems (the Greek Independent Power Transmission Operator), and local authorities for services related to energy and solar radiation related health aspects using CAMS products. Long term funding in this domain of science towards applications could be found from the private sector (direct, indirect), the public sector (energy operators, EPAs, public information sectors e.g. weather and meteorology related bodies), government-based initiatives, EU projects (GEOSS related, user oriented products, case studies), bilateral calls, as well as Copernicus-related calls. Government related authorities have been already showed their interest on long-term collaboration for energy now-casting services. SENSE operated without additional funding required for the Geo-Cradle defined pilot period (1.1.2017 – 31.12.2017).

There are specific opportunities to fund EO related market uptake projects like SENSE. These opportunities come from private stakeholders and also from the EU related energy efficiency funding opportunities such as €100M that are available in the Horizon 2020 Energy Efficiency Call 2017, where coordinations and support actions will be funded. The SENSE pilot project has the potential to be linked with existing Geo and GEOSS investments related with Geo Energy and Geo Agriculture.

SENSE structure have been defined aiming on engaging and working with governments, national and international energy agencies, the energy industry, research communities and other stakeholders aiming in:

- understand and map the user needs and requirements for specific energy data sets (e.g. solar energy and atmospheric related data);

- develop the best practices for the integration of information as well as support capacity building.

The use of EO related data together with the real time energy product that is derived from SENSE provides the opportunity of collaborating with Copernicus related satellite ground segments using the advantage of the rapid/online information flow that can be provided.

3.2. Egypt

3.2.1. Objectives and expected results

Egypt is a country with high solar energy potential and its exploitation is critical for a national sustainable development through an efficient energy planning and a gradual independence from fossil fuels. Equitable access to energy is a basic requisite for economic development and an important condition to galvanize economic activity. Demographic trends in Egypt require informed long-term planning of energy sector investments on the national level to expand existing electricity production capacities and meet growing demand. Egypt has conditions for the largest production of renewable energy in the world and as a result there has been demonstrated market traction for the region's solar power in a growing export market for clean energy. This solar atlas comes to fulfill these regional needs for optimum solar energy exploitation and for active and effective integration of these technologies to the national sustainable development economies and strategies. The quantification of the clouds' and aerosols' impact on the solar energy potential guarantees the reliability of the atlas.

Several actions point to the fact that a more climate-resilient economy and society must be built in Egypt, such as measures aimed at reducing fuel consumption for energy production, emphasis on energy efficiency and conservation as well as on power generation from renewable sources such as the Sun. Egypt is one of the few worldwide countries endowed with potential for electricity production from renewable sources because of its climate and with short-term objectives to increase the production from renewable energy sources to at least 50% of the total national energy production. To manage the electricity grid with high amount of solar energy will require high-quality information on everyaspect of solar power generation, and in particular, solarradiation and energy atlas. Solar yield climatology is still on an early state in terms of accuracy and coverage and with this Atlas based on EUMETSAT data we deal with the climatology of the solar resources and itsapplication for management of solar-based electricitypower plants and grid integration strategies.

Solar energy is the most abundant renewable resource and therefore much of the focus on sustainable energy is targeting on the optimum solar energy. By 2050, the MENA Energy Policy Plan aims to limit climate change by capping the global temperature rise to no more than 2°C. For this reason provided the possibility for a reduction of Green House Gases (GHG) emissions in Egypt by 80 - 95% and hence established a goal of 50% of primary energy from renewable origin by 2020. In order to achieve this goal, the MENA countries have laid out specific technology-roadmaps that will lead to the integration of low carbon energy technologies, and in particular the deployment of Concentrated Solar Power (CSP) plants and Concentrated Photovoltaic (CPV) installations in the energy economy.

The administration of energy issues is mandated to the Ministry of Electricity and Renewable Energy (MOEE) for the most part, with a smaller role for the Ministry of Petroleum. MOERE currently owns all public companies in the energy sector organised into an umbrella entity called the Egyptian Electricity Holding Company (EEHC). Within EEHC, there are 16 subsidiaries including six generation companies, nine distribution companies and the Egyptian Electricity Transmission Company (EETC).

By mid-2018, in accordance with the Electricity Law No. 87/2016, EETC is obliged to become an independent transmission system operator, separated formally from the EEHC and other state power generators and distributors. The state company will remain a monopolist in electricity transfer, but must become impartial, showing with no preferential treatment to producers or consumers. Simply put, EETC is not allowed to refuse transfer of electricity between an independent generator and their customers. It will also assume new responsibilities including:

- Establishing transmission regulations;
- Guaranteeing stability of the grid by purchasing ancillary services and providing stabilisation power;
- Generating annual reports on power supply, specifically to estimate growth in demand, and thus inform strategic energy decisions by the Cabinet of Ministers;
- Becoming responsible for power purchases from licensed producers.

There are currently six authorities with a specialised focus in the electricity sector that report directly to the MOERE. This includes the New and Renewable Energy Authority (NREA), created in 1986 to promote renewable sources of energy including solar power. NREA has two main roles. The first is to lead renewable energy projects for the government, and successively operate the power plants. Its second role is to support independent renewable energy producers. 7,600 km^2 of desert were allocated in 2014 for future renewable energy projects, with all permits for land allocation already obtained by NREA. This land is available to private actors on the basis of preference and availability. Environmental impact assessments for these plots have already been completed by NREA in cooperation with international consultants. Land concessions are granted in return for 2% of total power generated by the power plant.
In the framework of this pilot case we developed with MOEE a common website (the following link) in which we disseminate the real-time and climatological solar energy products of SENSE.

http://cedarekmp.net/solaratlas/web2/index.html/

This website is running on the official ministry website. At the same time we prepared an official Solar Atlas Book presenting the analytical solar energy climatology of Egypt and it was presented to the audience in October 2017. Finally MOEE proposed almost 30 places of Egypt in order to be used as potential solar farms. For these locations we provided them with analytical solar energy potential calculations. The methodology and results of this pilot activity in Egypt is presenting in the followng sections.

3.2.2. Methodology, methods of implementation

The mean monthly solar energy maps are based on a 15-year climatology of the Direct Normal and Global Horizontal Irradiances (DNI and GHI respectively) in W/m2. The climatological radiation data have been downloaded from the EUMETSAT's (http://www.eumetsat.int/website/home/index.html) Satellite Application Facility on Climate Monitoring (http://www.cmsaf.eu/EN/Home/home_node.html) Surface Solar Radiation Data Set - Heliosat (SARAH) which is a satellite-based climatology of the solar surface irradiance and the surface direct normalized irradiance, derived from satellite observations of the MVIRI and SEVIRI instruments onboard the geostationary Meteosat satellites. The data cover the region ±65° longitude and ±65° latitude. The products are available with a spatial resolution of 0.05° x 0.05°. The solar atlas maps shown here were produced for Egypt and they cover the mean monthly DNI and GHI from January of 1999 to December of 2013, as well as the climatological monthly means and the solar radiation atlas total means.

Electricity producing systems use different quantities of solar radiation: The Direct Normal Irradiance (DNI) is applicable in Solar Thermal Power Plants while the Global Horizontal Irradiance (GHI) in Photovoltaic systems. The energy source for any stand-alone photovoltaic (PV) system or Concentrated Solar Power (CSP) plant is the solar insolation available at the location of the installation. The performance of such systems is directly affected by the amount of insolation available to the system. PV systems enable direct conversion of global horizontal irradiance (GHI) into electricity through semi-conductor devices, while CSP systems generate solar power by using mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area. Electricity is generated when the concentrated light is converted to heat, which drives a heat engine connected to an electrical power generator or powers a thermo-chemical reaction. Heat storage in molten salts allows some solar thermal plants to continue to generate after sunset and adds value to such systems when compared to photovoltaic panels. For the design, implementation and efficient operation of these systems, the weather-dependent production plays a key role and determines the balance between production and demand.

To enhance their efficient control and improving the accuracy of information on the availability of solar radiation, quality solar radiation data and validated forecasts are essential for planning and deployment purposes. Photovoltaic technology (PV) hasprevailed as the preferred solution across the board, while the uptake ofconcentrating solar systems (CSP) has been limited in geographicalscope due to their higher insolation requirements. Nevertheless, CSP adoption is expected to continue to rise in areas which benefit fromhigh levels of long-term yearly direct normal irradiance (DNI), such as the Middle East and North Africa (MENA) region.

As mentioned above, the energy potential was calculated based on a 15-years (01/1999 - 12/2013) radiation climatology of the EUMETSAT's Satellite Application Facility on Climate Monitoring (CM SAF), in order to have a real perspective on annual variability, and to get a sense of the actual average potential and the possible natural deviations from year to year. The data used have been benchmarked by ground measurements and the validation results can be found here. The calculations have also taken into account the local aerosol and cloud effect in terms of Aerosol Optical Depth (AOD) and Cloud Optical Thickness (COT) from the Monitoring Atmospheric Composition and Climate (MACC) project, and the related aerosol model and the Meteosat Second Generation (MSG) cloud products respectively.

Concerning the aerosols, the main source is Saharan dust and more specifically the Khamaseen potential dust storms that are more frequent from mid-March through April; thus, the calculations have incorporated these fifty days (Khamaseen in Arabic means ''fifty'') phenomenon. Figure 18 presents the mean annual solar energy potential in Egypt in kWh/m2.

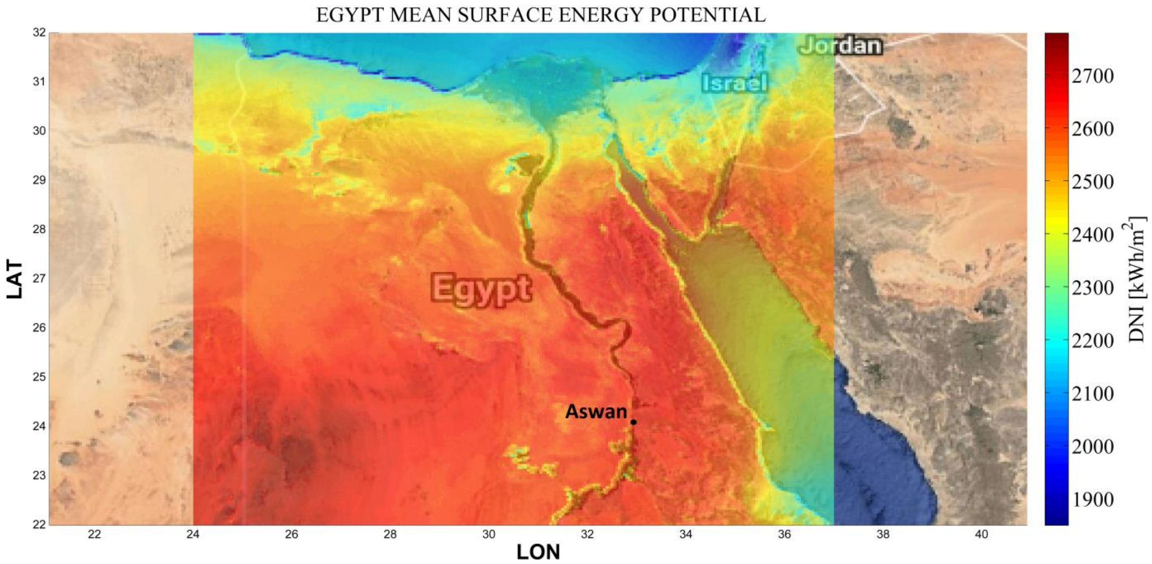


Fig. 18: The solar energy potential in Egypt in kWh/m^2 together with the MSG pixel-based specific location of Aswan (longitude: 32.90^o and latitude: 24.09^o).

For the real-time service, we provided the SENSE system as discussed in previous sections and the active link that is running operationally in MOEE's website from January 2017 until now is the following:

ftp://EGY:GEO@194.177.195.105/ENERGY.png

3.2.3. Main activities and results of the pilot analysis

This Section initially presents an analysis of the solar power potential in Egypt with specific reference to solar power plants for electricity production. In the analysis provided, the mapping of solar radiation components is calculated from long-term monthly EUMETSAT data of DNI and GHI over a period of 15 years (Jan 1999 - Dec 2013). The climatological solar power results of this Section are in W/m^2. These data enable the modeling of PV and CSP production for several sunshine-privileged locations where solar power plants exist, are under construction, or being planned by NREA. This analysis helps establish the solar potential for electricity generation in Egypt, and can support the design and decision-making process for solar energy systems in the country.

The 15-years mean monthly DNI and GHI reveals a clear seasonal variability with the maximum solar inputs in summer months and the minimum in winter months. In all months we highlight the distinct anthropogenic impact in large cities mainly in the northern Egypt, along the Nile and in the Delta of Nile. In April, May and September the impact of dust is intense in the southern part of Egypt, while the cloud presence can be extended in October in addition to the spring season as a result of the synoptic climatological conditions. The impact of dust aerosols and clouds on DNI is much stronger than on GHI, and this effect is clearly reflected in the following solar atlas maps and in mean monthly curves.

The Direct Normal Irradiance (DNI) is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. Typically, you can maximize the amount of irradiance annually received by a surface by keeping it normal to incoming radiation. This quantity is of particular interest to concentrating solar thermal installations and installations that track the position of the sun. The Global Horizontal Irradiance (GHI) is the total amount of shortwave radiation received from above by a surface horizontal to the ground. This value is of particular interest to photovoltaic installations and includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DIF).

Figures 19 and 20 presents the mean monthly climatological GHI (upper plot) and DNI (lower plot) as calculated by the mean monthly EUMETSAT data from Jan 1999 to Dec 2013. Figure 21 shows the atlas maps of GHI and DNI (the mean of means), which correspond to the absolute mean solar energy potential in Egypt for efficient PV and CSP exploitation planning and design. The mean surface DNI was calculated by using the mean monthly DNI values from January 1999 to December 2013. This 15-years climatology of DNI allow us to quantify the solar power and energy potential in Egypt for efficient exploitation in CSP installation. For the mean surface GHI we used the mean monthly GHI values for the same 15-years period and can potentially support the local authorities to identify the optimum locations for PV installations. Note that the scale range of color bars was adjusted for optimum visualization.

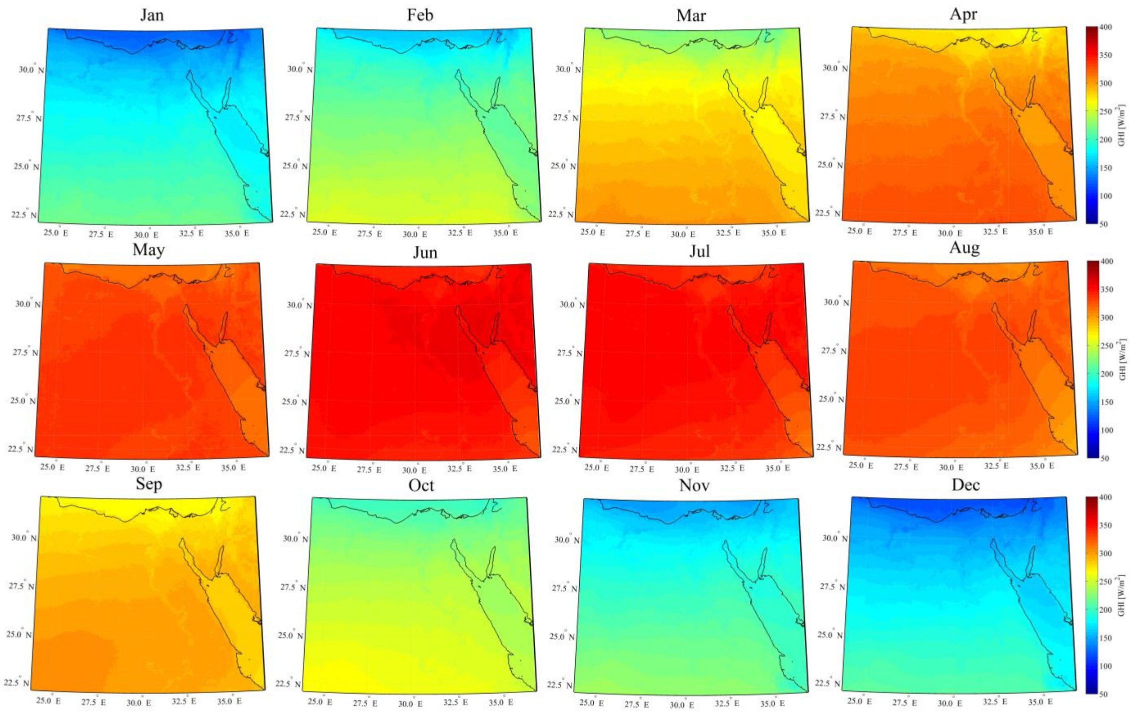


Fig. 19: Monthly mean GHI (in W/m²) in Egypt derived from the EUMETSAT's Satellite Application Facility on Climate Monitoring (CM SAF) for the period 1999 - 2013.

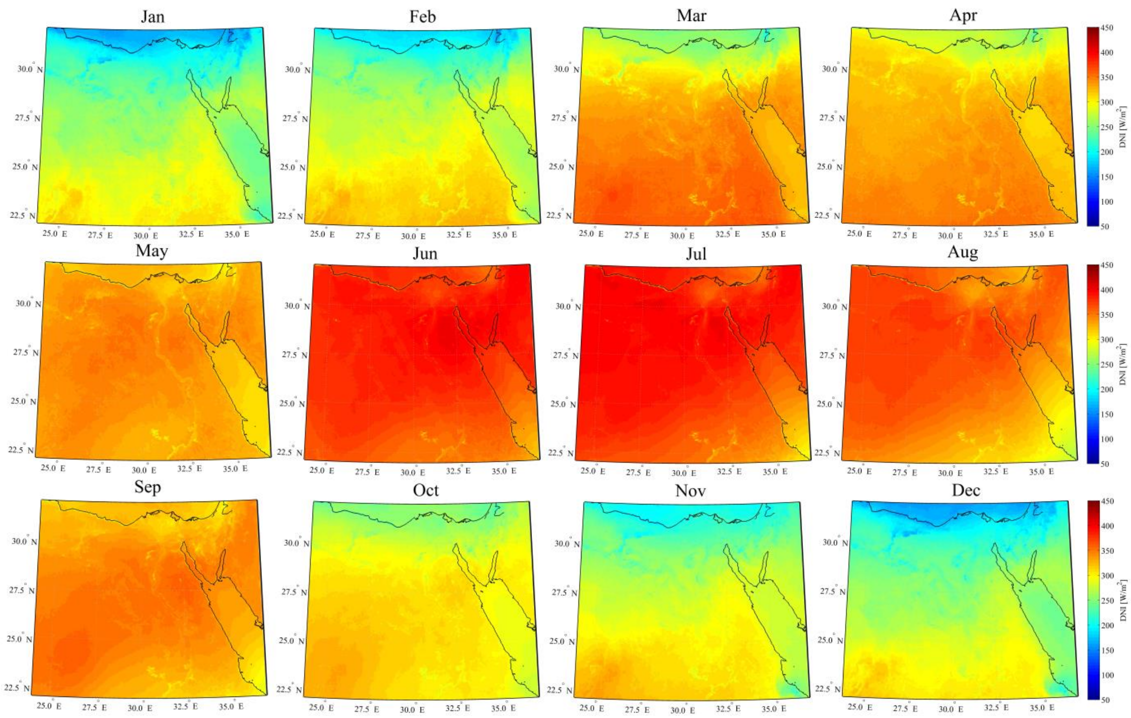


Fig. 20: Monthly mean DNI (in W/m²) in Egypt derived from the EUMETSAT's Satellite Application Facility on Climate Monitoring (CM SAF) for the period 1999 - 2013.

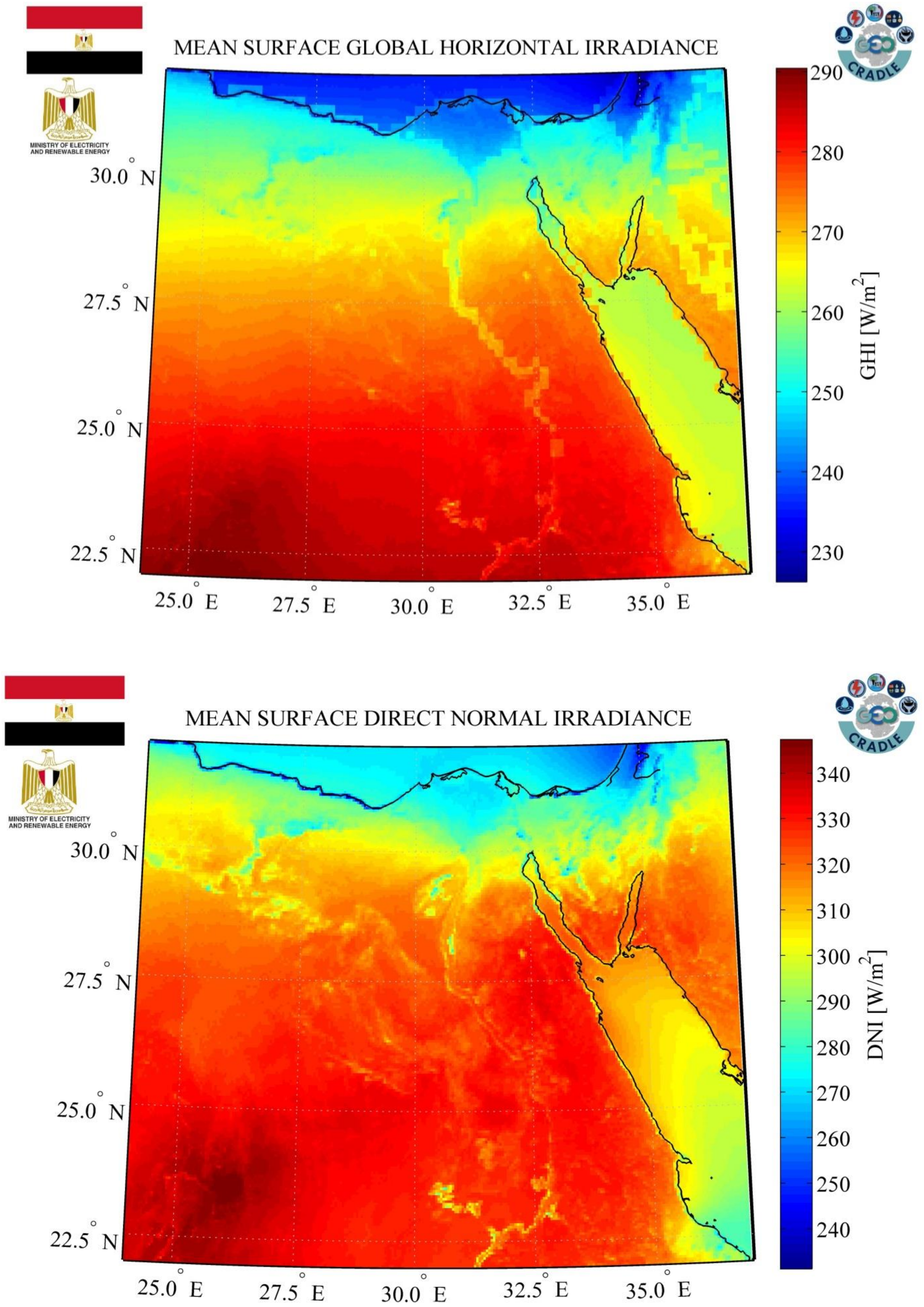


Fig. 21: Upper plot: The GHI Solar Atlas 1999-2013. Lower plot: The DNI Solar Atlas 1999-2013.

All data and maps are available via the MOEE's specific website developed by SENSE pilot, and via the GEO-CRADLE's DATAHUB and the SENSE new official webpage (under development).

In addition to the massive solar energy maps and data for the whole Egypt region, we present the mean monthly GHI and DNI for three specific locations covering various geographical and climatological conditions. From the northern part of Egypt we covered the greater area of Alexandria, in the center of Egypt, the greater area of Cairo covering the southern part of the Delta of Nile, and finally, in the southern part of Egypt we selected the greater region of Luxor and Aswan. This analysis is based on the same EUMETSAT radiation database of the DNI and GHI for the period Jan 1999 - Dec 2013. Figure 22 presents the momentum of the SENSE pilot study in Egypt.

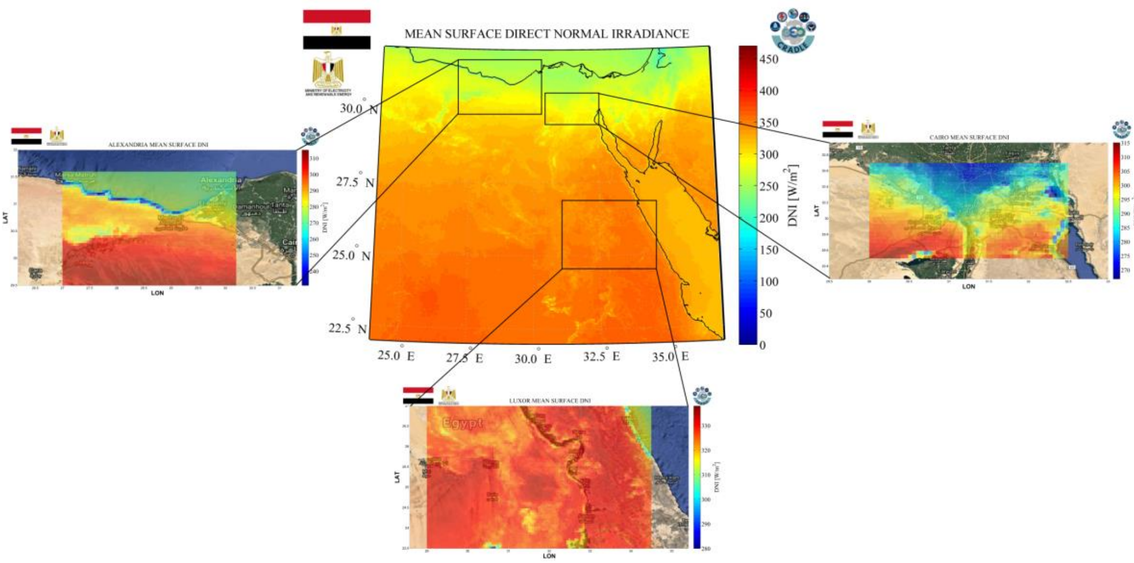


Fig. 22: The mean DNI in Egypt together with the three specific locations studied (greater Alexandria region, greater Cairo region covering the lower Nile's delta, and the southern region covering the greater regions of Aswan and Luxor).

The same EUMETSAT dataset was implemented for the specific greater regions of Alexandria (Northern Egypt), Cairo (Center Egypt, greater Delta Nile region) and Southern Egypt (greater area of Luxor and Aswan). In both DNI and GHI maps we provide a comprehensive view of the climatological surface irradiance conditions as to compare in general the potential solar power and energy conditions at places with different geographical and climatological background (Fig. 23).

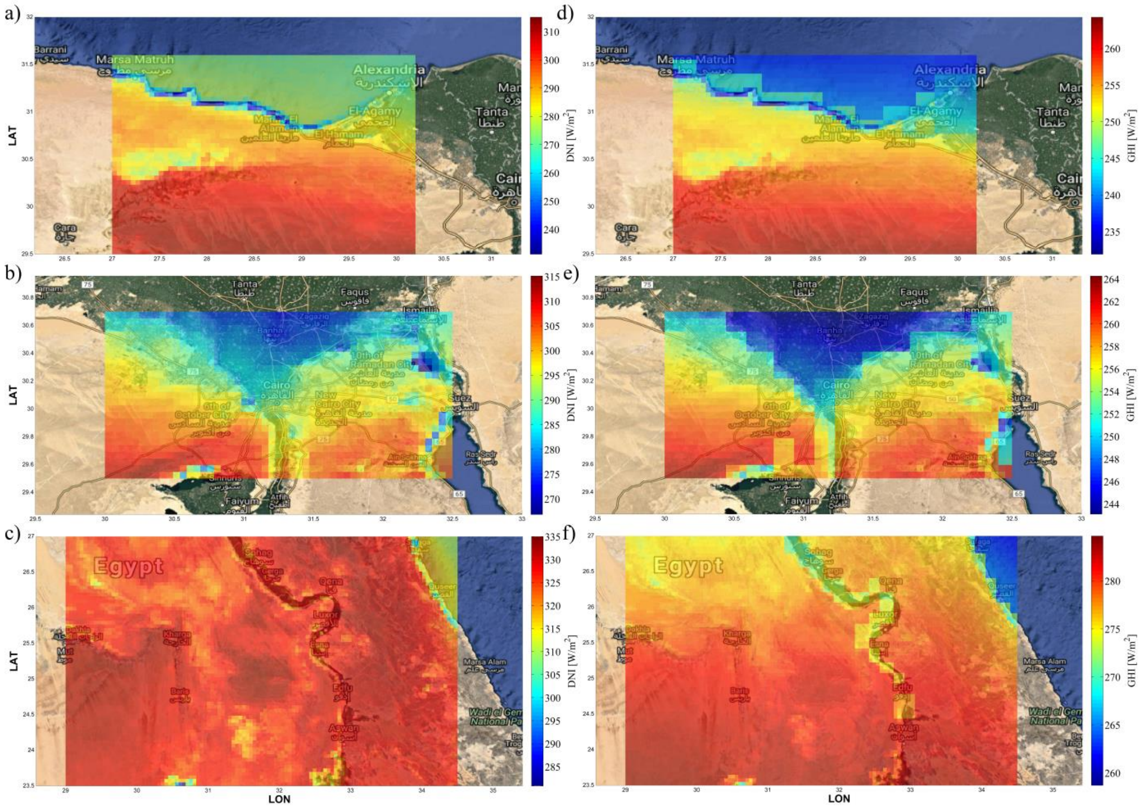
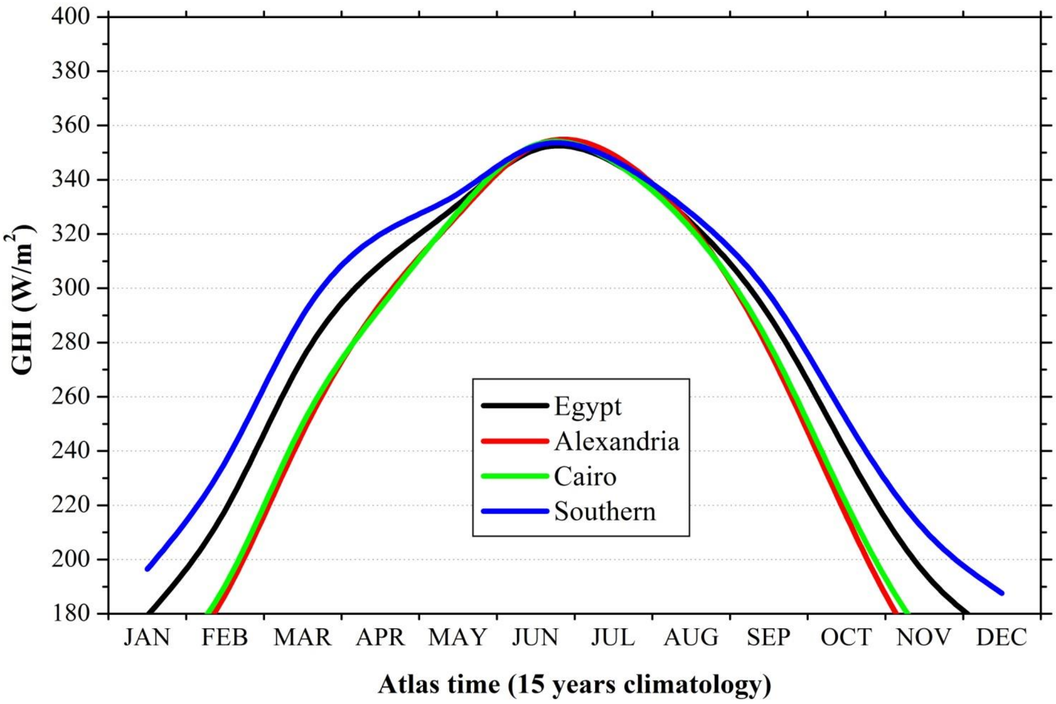


Fig. 23: Mean DNI (a, b and c panels) and GHI (d, e and f panels) for the three sub-locations (a and d the greater Alexandria region, b and e the greater Cairo region, and c and f the southern region).

The Figure 24 and Table 5 below represent the mean inter annual GHI and DNI curves by calculating the mean of means for the 15-years period (Jan 1999 - Dec 2013) for the whole Egypt region as compared with the three sub-locations. The GHI shows a typical summer maximum in all cases reaching means values around 350 W/m^2, while in winter months the lowest GHI is about 180 to 190 W/m^2. Southern Egypt has the largest values in all months and the lowest are in northern Egypt (greater region of Alexandria).

The DNI presents the maximum mean values in summer months as well starting from March with DNI of about 330 W/m^2 (Egypt) to 380 W/m^2 in July. A local reduction in April and May for the southern Egypt region and the mean values of Egypt was found and has to do with the relatively increased cloud coverage and frequent dust storms in the late spring (mean DNI in the period April-May is 325-350 W/m^2). Southern Egypt has the highest mean DNI values in winter and autumn, while in summer the highest power values are in Delta of Nile and northern Egypt regions reaching 390 W/m^2.

Global Horizontal Irradiance



Direct Normal Irradiance

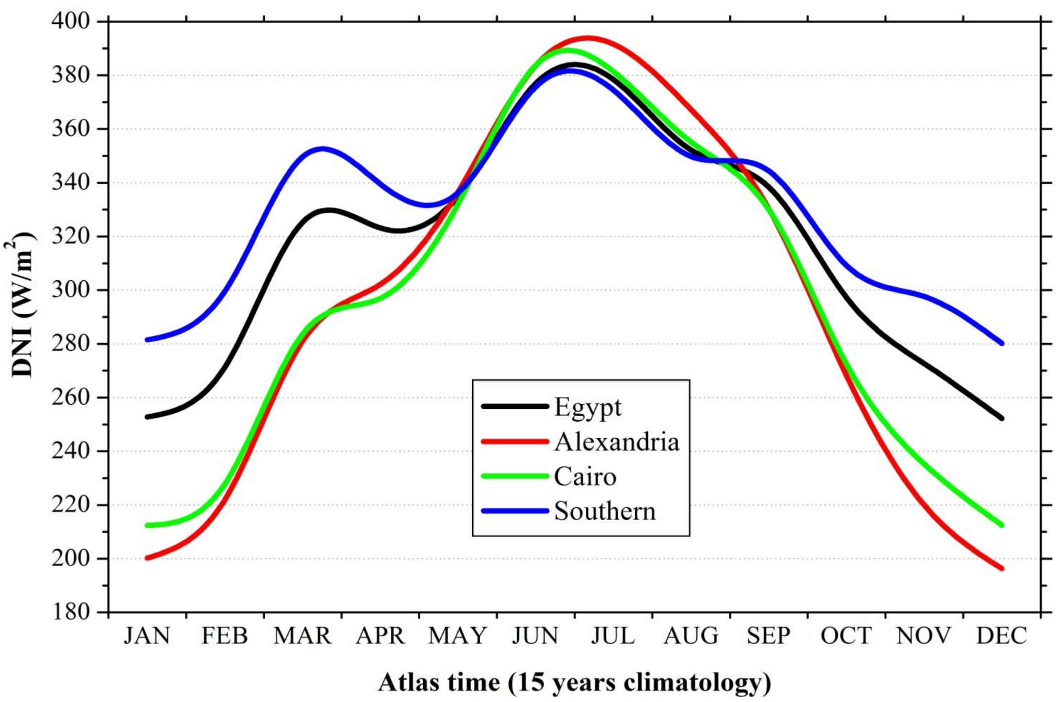


Fig. 24: Mean inter annual curves of GHI and DNI for Egypt and the three sub locations.

Table 5: Mean solar power and energy for Egypt and the three sub-regions.

Atlas 15 years climatology	Solar power (W/m²)		Solar energy (kWh/m²)	
	DNI	GHI	CSP	PV
Egypt	292	252	2554	2208
Alexandria	294	255	2572	2230
Cairo	328	279	2875	2447
Southern	315	269	2756	2357

Once an exporter of oil and gas, Egypt is now struggling to meet its own energy needs. Whilst Egypt has proven oil reserves of 4.4 billion barrels and proven natural gas reserves of 78 trillion cubic feet, an ever-increasing percentage of its daily production is being used to meet the country's growing energy needs (Fig. 25).

Egypt's demand for electricity is growing rapidly and the need to develop alternative power resources is becoming ever more urgent. It is estimated that demand is increasing at a rate of 1,500 to 2,000MW a year, because of rapid urbanization and economic growth. Development of the renewable energy industry has become a priority over recent years for the Egyptian government. Egypt's present energy strategy aims at increasing the share of renewable energy, this target is expected to be met largely by scaling-up of renewable energy projects.

Fig. 25: The expected future energy status in Egypt

Due to its location, topography and climate, Egypt has an average level of solar radiation of between 2,000 to 3,200 kWh per square meter a year, giving it significant potential for utilizing this form of renewable energy. Egypt is recognized as having vast potential for solar and wind energy application.

The Egyptian government is making good progress towards becoming a significant player in the renewable energy industry; it has long since recognized the need for reform of the electricity sector in order to attract private sector investment in power generation as it is accepted that the private sector will be instrumental to Egypt's ability to deliver its renewable energy targets. One of the key models that the decision makers in Egypt are pursuing is the presidential decree of devoting a number of lands for those renewable energy projects, in addition to encourage scientists to work on all tools and facilities that improve those proposed projects.

One of the major steps is the presidential decrees (ex. No. 116 year 2016) of devoting a number of Egyptian zones (including sub-zones) to the Development and Using New and Renewable Energy Authority and Ministry of Electricity and Renewable Energy, to use it in electricity generation stations from wind, solar energy, and photovoltaic cells.

In the following Figure 26 and in Table 6 we conclude on the 29 lands devoted by NREA for PV and CSP potential installations and we present the indicative solar energy results for comparison reasons. We extended the analysis for specific exploitation areas as to quantify the potential energy outputs for PV and CSP installations. All the analytical results can be found in the official Solar Atlas book that was drafted in the framework of GEO-CRADLE. The main findings are:

- The proposed by NREA lands showed that the majority of the locations in Egypt are favorable for PV exploitation since the mean winter GHI values range from 140 to 200 W/m2 and during summer are 340-360 W/m2.
- CSPs are ideal for the Egyptian climatological conditions in terms of high mean DNI values which are from 160 to 300 in winter and reach 400 W/m2 in summer.
- The sums of the monthly mean solar energy potential values suggest that the proposed locations have energy potential for PV exploitation starting from 2100 kWh/m2 at the Northern Coast locations to more than 2450 at Aswan location. East Nile zone reaches annual energy potential of 2400 kWh/m2, while the Red Sea Coast Zone, the Suez Governorate, the Kuraymat and the West and East Nike locations have mean energy potential of more than 2300 kWh/m2.
- CSPs benefit from the cloudless conditions but at the same time have to deal with the dust storms which are favorable during spring and in particular in April. However, the range of the solar energy potential is from 2250 kWh/m2 at the Northern Coast locations to almost 2900 kWh/m2 at the Southern locations including the greater region of Aswan and the southeast Nile zone.

Solar energy from all locations in kWh/m^2

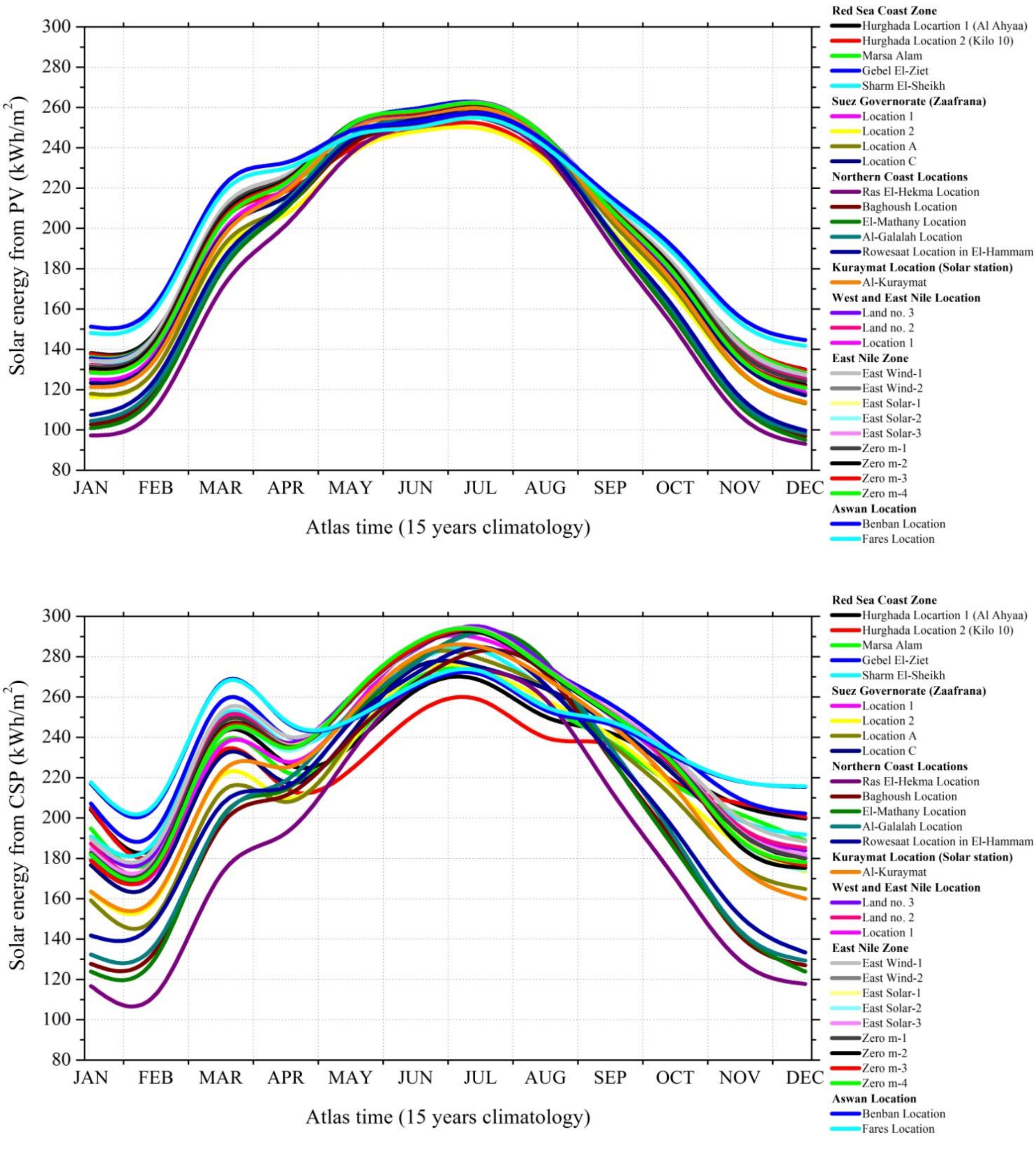


Fig. 26: The mean inter annual solar energy potential in the 29 specific locations for PV (upper plot) and CSP (lower plot) exploitation.

Table 6: The analytical annual solar energy results for the 29 specific locations together with the expected energy output to the electricity grid based on the specific exploitation area of each NREA devoted location. More information on the specific locaction can be found in the Solar Atlas of Egypt book.

Solar energy potential in Egypt	CSP		PV	
	kWh/m^2	TWh/year	kWh/m^2	TWh/year
Red Sea Coast Zone				
Hurghada Location 1 (Al Ahyaa)	2747	0.09	2365	0.08
Hurghada Location 2 (Kilo 10)	2670	6.68	2338	5.84
Marsa Alam	2712	6.91	2363	6.02
Gebel El-Ziet	2909	1909.37	2395	1572.13
Sharm El-Sheikh	2802	0.07	2372	0.06
Suez Governorate (Zaafrana)				
Location 1	2767	221.34	2326	186.08
Location 2	2607	198.10	2216	168.39
Location A	2577	21.11	2262	18.53
Location C	2685	23.27	2298	19.91
Northern Coast Locations				
Ras El-Hekma Location	2250	0.10	2100	0.09
Baghoush Location	2413	0.14	2162	0.13
El-Mathany Location	2443	0.10	2164	0.09
Al-Galalah Location	2479	0.15	2190	0.13
Rowesaat Location in El-Hammam City	2491	0.05	2197	0.04
Kuraymat Location (Solar Station)				
Al-Kuraymat	2653	7.35	2296	6.37
West and East Nile Location				
Land no. 3	2824	1303.64	2360	1089.37
Land no. 2	2819	4005.96	2379	3379.97
Location 1	2791	1498.33	2352	1262.74
East Nile Zone				
East Wind-1	2847	2130.77	2396	1792.83
East Wind-2	2788	220.06	2355	185.82
East Solar-1	2799	1164.67	2373	987.44
East Solar-2	2778	329.65	2361	280.18
East Solar-3	2811	1020.65	2358	856.25
Zero m-1	2800	169.28	2374	143.52
Zero m-2	2782	162.33	2363	137.89
Zero m-3	2782	49.71	2356	42.10
Zero m-4	2791	269.76	2352	227.35
Aswan Location				
Benban Location	2885	107.16	2472	91.81
Fares Location	2895	44.03	2439	37.10

3.2.4. Sustainability

One of the proposed locations by the MOEE was the Aswan area which covers almost 1.26 km^2 (Fig. 27 upper plot). For this location we developed a number of possible exploitation scenarios using PV and CSP technologies and a synergy of them. In Figure 27 (lower plot) we present an example of the realistic solar energy output to the Egyptian electricity grid. We show the temporal energy distribution of a 12 MW system using CSP (left) and PV (right) technologies. In both cases the actual annual mean energy output is almost 30,822 MWh. For combined solutions, one must highlight the bridging of the gap between the different energy distribution of the CSP and PV exploitation technologies.

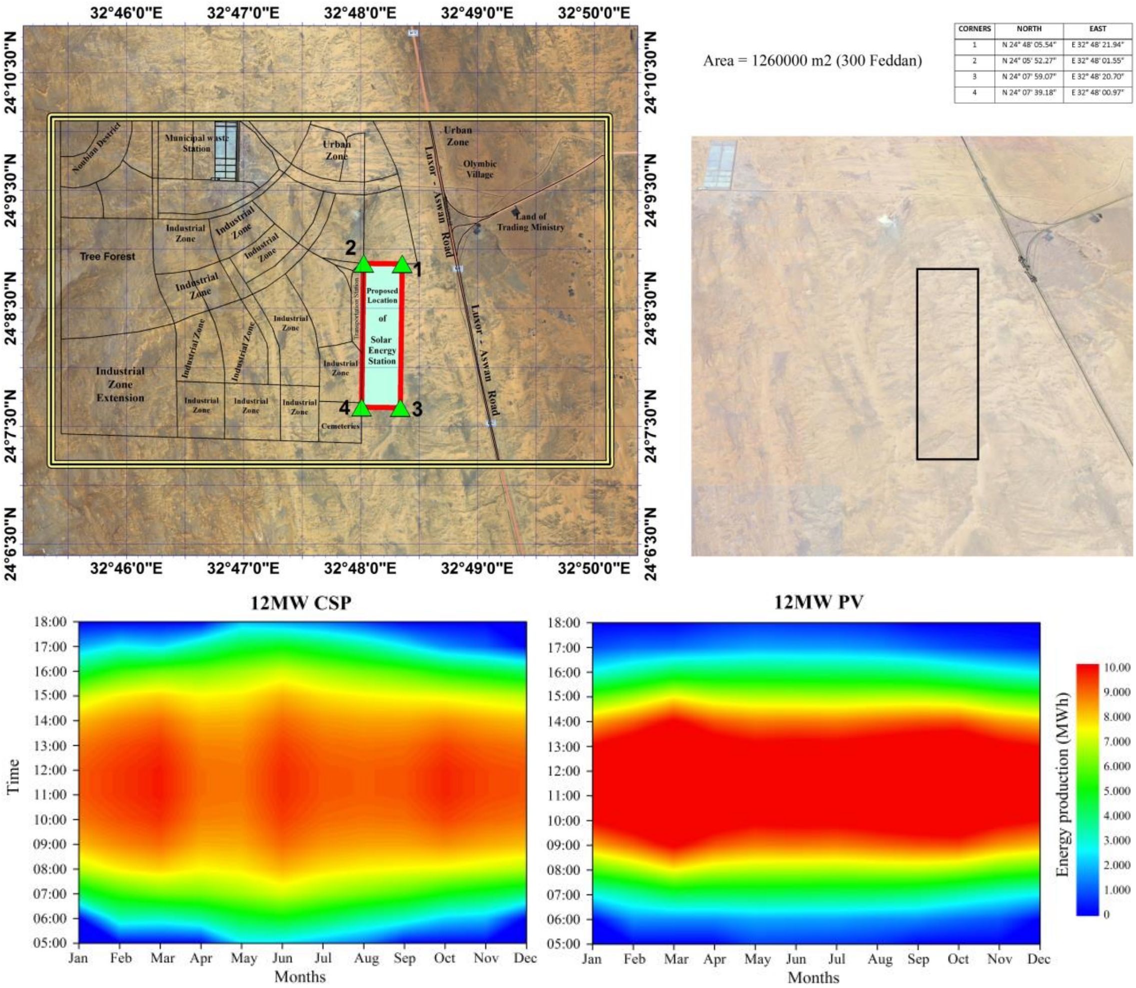


Fig. 27: Upper plot: One of the proposed locations for the development and exploitation of a solar farm. Here is the case study location of solar station for Dr. Magdy Yacoub Medical Center in Aswan. Lower plot: Contour plots of the analytical monthly mean energy production distribution in Aswan from a 12MW PV (left plot) and a CSP (right plot) system.

Based on the 29 devoted locations by the MOEE, we believe that a massive analysis and exploitation of these areas is feasible, in order to attract investments from the local and regional related investors. To this direction, the existing website that we developed and is currently online and in the main official webpage of MOEE (Fig. 28), could support the efficient dissemination of SENSE pilot. Simultaneously, the real-time service is able to control the the share of solar energy related installations on the total energy demand as defined by the local distribution and transmission system operators. As a result, accurate, real-time and short-term forecasting estimations by SENSE of the solar energy potential is vital. Finally, with the practical support from the Egyptian decision makers, like the Minister of Electricity and Renewable Energy, the Consul General of Egypt in Los Angeles and the Minister of Immigration and Egyptian Expatriate Affairs (Fig. 29), we hope that SENSE pilot for Egypt is setting a promising framework within which the Egyptian solar energy investment community can be led to a market uptake.

Fig. 28: The SENSE pilot on the official website of the Egyptian Ministry of Electricity and Renewable Energy.

In light of efforts made by the Government of the Arab Republic of Egypt to achieve the desired economic growth while preserving the environment, the government tries to address the demand for Energy efficiency through the use of renewable energy sources. We find that the idea of the Solar Energy Nowcasting SystEm (SENSE) pilot in order to produce (i) the analytical solar energy Atlas of Egypt mainly for the efficient solar energy exploitation and (ii) the nowcasting of the solar energy potential in real time in order to support the Egyptian energy authorities to better plan solar energy demands, are of great and absolute importance. The Ministry of Electricity and Renewable Energy (MOEE) together with the Renewable Energy Authority of Egypt (NREA) considers this developed Solar Atlas as an excellent addition and complementing the government's efforts in finding other venues of electricity production. Moreover, the nowcasting product running on the official ministry website as well as on NREA website adds an expediting element to realize efficient operational solar based projects. This project straddles the intersection of the Earth System Science and Computational Science disciplines, demanding high-resolution numerical model data, sensitive remote sensing observational data, data mining and machine learning techniques. It is also a clear example of successfully building a value chain through a partnership between innovation and capacity building provider, Geo-CRADLE team, working with the ministry and associated renewable authority, to deliver the Solar Atlas and the dynamical output, hopefully to meet the mandate of the investors and fund providers resulting in better schemes of energy production and hence in customer satisfaction.

Dr. Mohamed Shaker El Markabi

Minister of Electricity & Renewable Energy

A proud nation is a nation inspired by the strive for excellence of its people. Egypt has always been proud of its sons and daughters who, despite living far away from their homeland, have always been strongly tied to their origins, cherishing their culture and longing to serve their country. It is the role of the Egyptian consulates abroad not only to keep this bond alive, but more so to encourage their Egyptians living within their jurisdictions to interact with their mother land and to participate in bringing about the wellbeing of their brothers and sisters back home. Accordingly, we constantly communicate with our community in the Western states. We share with them ways and means through which they can be a valuable asset helping in the advancement of our country. In fulfilling this endeavor, we develop strategies to utilize their amazing diverse skill base. We facilitate meetings with government officials, organize conferences and fundraisers to increase their presence and connection with Egypt. A perfect example of an Egyptian who wanted to give back to his country is Prof. Hesham El-Askary of Chapman University. Through his work as the regional coordinator for North Africa and Gulf region on the Geo-CRADLE project funded under the H2020's Framework, he with his colleagues from the National Observatory of Athens and World Radiation Center, Davos, Switzerland were able to provide Egypt with its First Solar Atlas; A much needed deliverable to address the increasing demand for energy through the use of renewable sources. Thus, achieving Egypt's goals in economic growth, while preserving the environment. Dr. El-Askary's work with the Geo-CRADLE team is a witness on the effectiveness of partnership between the Consulate in LA, the Egyptian Scholars and the government in catering to the prosperity of our beloved Egypt.

Lamia Mekhemar

Consul General of Egypt in Los Angeles

In our goal to contribute to Egypt's development, the Ministry of Immigration and Egyptian Expatriates Affairs acts as a bridge and link between Egyptians abroad and their country. We are committed to reinforce communication with Egyptian emigrants to strengthen their ties to their homeland as well as utilize their experiences and competencies in various fields and specialties. For that reason the Ministry organized and hosted first National conference of scholars and Egyptian experts abroad "EgyptCan 2016" that was held in December 2016 in Hurghada, Egypt., where Dr. Hesham El-Askary of Chapman University (USA), presented the dynamical Solar Atlas of Egypt. The Solar Atlas is a result of Dr. El-Askary's effort with his colleagues from the National Observatory of Athens and World Radiation Center, Davos, Switzerland through the GEO CRADLE project funded under the H2020's Framework. The Solar Atlas is one of the most important and early results of "EgyptCan2016" and has been commended and currently being utilized by the Ministery of Electricity and Renewable Energy (MOEE). This deliverable is a continuation of efforts that started by a meeting arranged by H.E. Ambassador Lamia Mekhemar, Consul General of Egypt in Los Angeles with Dr. El-Askary and being in direct and constant communication with him since then. I would also like to encourage all Egyptians Aboard to follow this model of giving back to their motherland Egypt. As they always say, it is the three Ts, Treasure, Talent or Time. Give back what you can, when you can.

Nabila Makram Ebeid Abdel Shahid

Minister of Immigration and Egyptian Expatriate Affairs

Fig. 29: User testimonies from the SENSE pilot in Egypt.

3.3. *Shipping companies*

3.3.1. Objectives and expected results

Attica Holdings S.A. (Attica Group or Attica) is a leader in the provision of ferry services for passengers and cargo in the Eastern Mediterranean Sea. Serving more than 40 destinations in the Greek domestic market (including the more remote Greek islands destinations) and on the international routes between Greece and Italy, Attica Group's brand names, Superfast Ferries and Blue Star Ferries, are established in the European maritime transport industry as synonyms of high end quality ferry services.

In April 2015, the Intelligent Media company designed and deployed an exclusive digital signage network on behalf of Attica Group, owner of the Blue Star and Superfast Ferries fleet. The digital signage monitors have been installed across the seating areas and high foot traffic points of the 13 passenger ferries (lounges, receptions, restaurants etc.). Intelligent Media is responsible both for the operation of the network and the management of content.

Fig. 30: The Superfast and Bluestar lines to the Aegean and Adriatic sea.

The four (4) Superfast vessels serve the lines to Angona and Bari ports in Italy, with their departure port being Patra in Greece (Fig. 30). The remaining nine (9) ferries, under the brand Blue Star, serve destinations in the Aegean sea. These destinations include Cyclades, Crete, Dodecanese and East Aegean Islands. The departure port of these vessels is the port of Piraeus. Both brands serve annually 4,2 million passengers with 50% of this number being tourists.

The network itself consists of vertically installed digital signage monitors (Fig. 31) with a diameter of 42”. The content displayed is a narrow-casted program managed by Intelligent Media through specialized digital signage software.

The content is a mix of general information regarding the services provided by the ferries, real-time information including weather forecasts and news, plus selected advertising content. The particular digital signage network is an ideal medium for the communication of products and services due to long travel times that ensure the delivery of the advertisement to the potential customer.

To this direction and after the related interviews with the decision makers of Attica Group and Intelligent Media we agreed to provide them via SENSE pilot, the UV-index in real time. This service intended to be displayed on all the onboard digital signage monitors for both Aegean and Adriatic lines. The pilot duration was for the whole 2017, with a potential continuation depending on the acceptance of the public and the passengers.

Fig. 31: The onboard digital signage monitors of Superfast and Bluestar ferries.

3.3.2. Methodology, methods of implementation

Attica Group places particular importance on environmental issues; therefore, it is committed to environmental protection in acknowledging the impact that its business operation may have on certain environmental aspects. The Group companies evaluate annually such environmental issues and seek to minimize their impact on the environment. The most important of these issues pertain to air emissions, discharges into the sea, waste disposal, land pollution, use of raw materials and resources, and environmental demands of local communities.

The Group's environmental awareness cannot be viewed separately from our commitment to offer high quality services to the satisfaction of our passengers. Further to strict compliance with all international, regional and local regulations on environmental protection the Group aspires to the following policy objectives:

- Continuous investment in new technologies and to implement environment-friendly methods;
- Minimization of any adverse effects of machinery operation also by ensuring the unimpeded equipment operation through its proper and timely maintenance;
- Encouragement of staff (office and maritime personnel) to adopt environment-friendly practices and develop environmental awareness through proper information and training;
- Active participation in organizations that promote the principles of environmental safety and protection;
- Participation in international research and development programs that promote efficiency, accountability and pollutants reduction within the shipping sector;
- To be constantly updated on environmental issues and to adopt new cutting edge practices regarding the environment.

The Attica Group fleet consists mainly of modern, newly built vessels that meet the full range of international regulations on environmental protection, the major thereof being MARPOL 73/78 Regulation of the International Maritime Organization (IMO).

Examples of application of strict environmental criteria of operation include:

- Selection of non-toxic antifouling paints in order to prevent the poisoning of marine organisms; another one of the Group's practices that was implemented before the international regulations rendered it mandatory.
- All chemicals used in ships have been selected based on their friendliness to the environment.
- Prohibition of use of substances that cause ozone depletion; all chemical additives in use have been chosen for their environmental compatibility.

As far as human resources are concerned , Attica Group trains its employees on best practices and minimum disturbance of the environment. Onboard, designated officers are responsible for the implementation of the adopted environmental measures.

Ashore, qualified engineers and executives monitor the performance and establish the guidelines for general and specialized, needs-based, environmental training. Ships, together with office-based staff, are periodically participating in environmental emergency scenarios, in cooperation with local authorities.

As a result the inclusion of the real-time UV-index on their operational planning and policies was intended to be a sustainable development tool through which Attica group meets and stengthens its environmental friendly practices and policy. For the implementation of this SENSE's feasibility study, we used the spectral information of SENSE's capacity and based on the UV part of the spectrum we produced the UV-index in the same high spatial (5 km) and temporal (15- min) resolution. The IT team of Attica Group took over the dissemination of SENSE's outputs to the 13 ships which serve the lines to the Aegean and the Adriatic sea.

3.3.3. Main activities and results of the pilot analysis

The active link for the SENSE's real-time UV-index maps can be found in the following FTP URL links:

For the BlueStar Ferries – Aegean sea maps:

ftp://UVAK:12@194.177.195.105/UVAEG.png

For the SuperFast Ferries – Adriatic sea maps:

ftp://UVAK:12@194.177.195.105/UVADR.png

An example of the final format and visualization of the provided service is illustrated in the following Figure 32, while in Figure 33 we show a recent example map for the Adriatic sea region.

The main result of this SENSE pilot activity was that this service finally attracted the passengers interest. They were taking photos of the service running on the monitors, they asked for additional information on the destination's UV-index conditions and they demanded even more layman information. Overall, the service was successful in terms of public impact and visibility, while the most constructive period was summer, as expected, since the majority of passengers (more than 3 million passengers) observed the UV-index real-time service. We note that this service was accessible to the audience for 30 seconds every 6 minutes, according to the loop of the rest of displayed advertisements. Unfortunately, Attica Group did not manage to attract relevant ads (sunglasses, sunscreen protection products, etc) in order to efficient advertise the service and create a targeted market uptake.

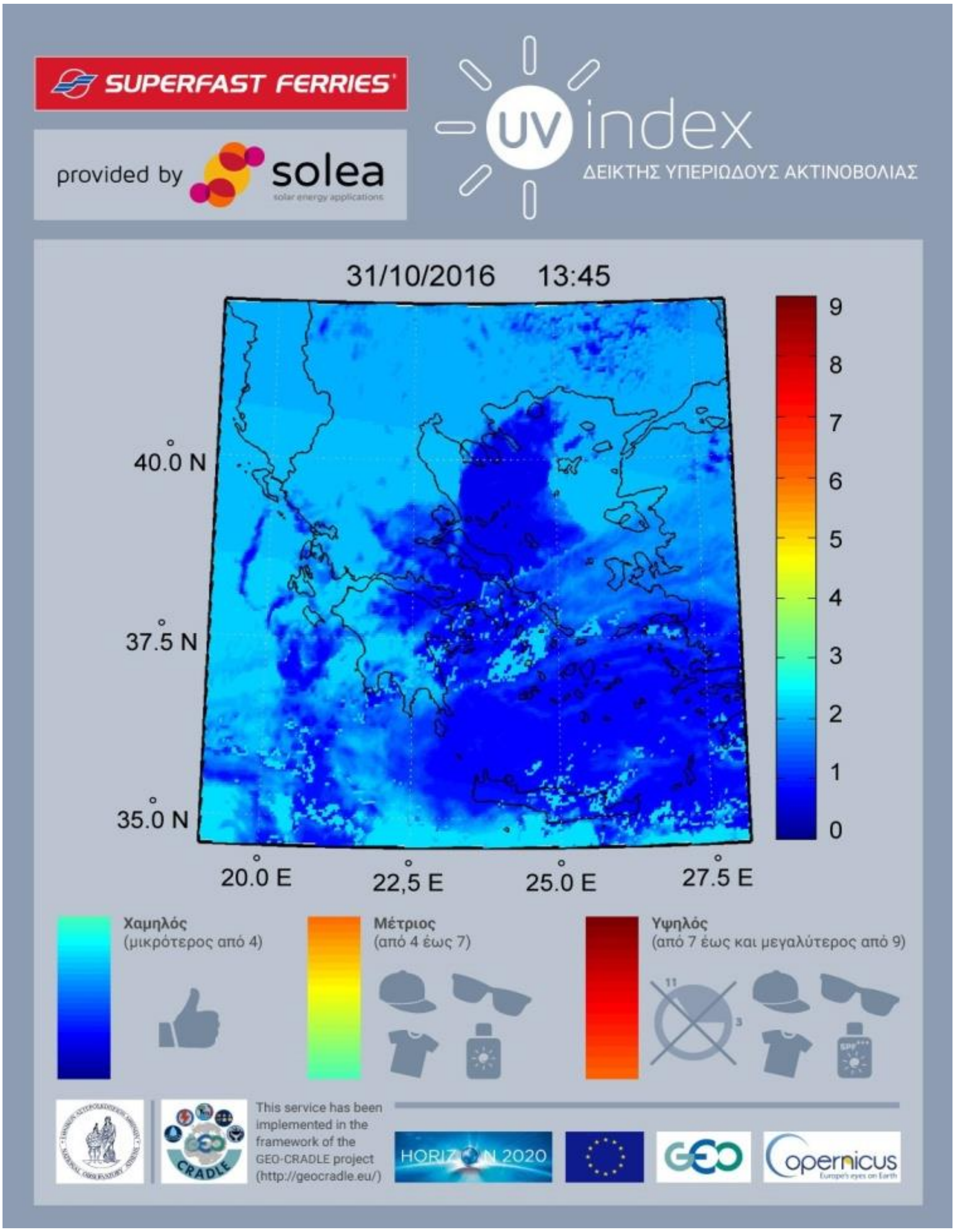


Fig. 32: A time-step visualization from the SENSE UV-index nowcasting service for the Superfast and Bluestar Ferries. Here is an example for the Aegean sea lines.

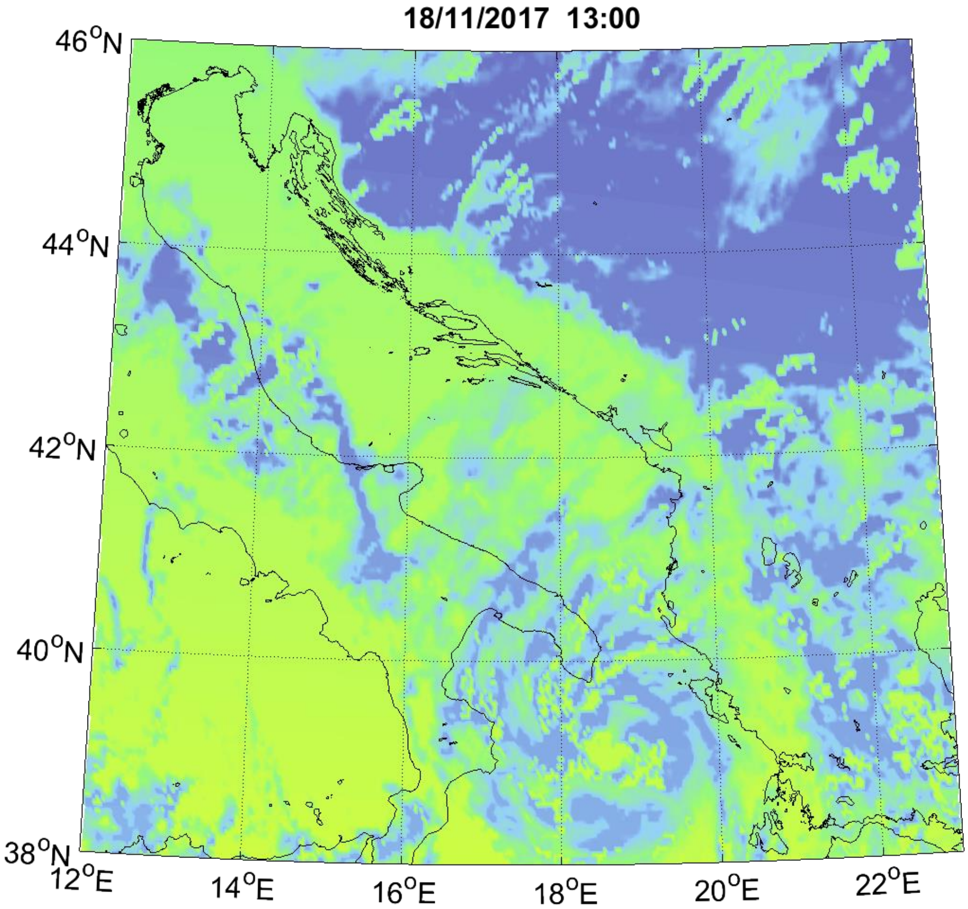


Fig. 33: An example of the corresponding UV-index map for the Adriatic sea lines.

3.3.4. Sustainability

The continuation of the SENSE's UV-index service on Superfast and Bluestar ferries after the end of the pilot period depends on the Attica Group's intention to invest on such products. The evolution and further popularization of the UV-index visualization techniques could include the end users beneficial exposure time in terms of minutes to hours for each skin type, or the suggestion of specific sunscreen products considering eac time (every 15 minutes, since this is currently the temporal resolution of SENSE services) the UV radiation levels. Finally, Intelligent Media is running similar digital signage monitors to maternity hospitals, pharmacies and agricultural cooperative societies, so a potential extension of collaboration in the framework of provision of other spectrally-weighted products like the Vitamin D effective dose, the DNA damage or the Photosynthetically Active Radiation, is feasible.

3.4. PRE-TECT

3.4.1. Objectives and expected results

PRE-TECT is an atmospheric experiment organized by the National Observatory of Athens in the framework of the ACTRIS. The experiment took place from 1st to 30th April 2017 at the Greek atmospheric observatory of Finokalia of the University of Crete, and advanced desert dust microphysical characterization from remote sensing measurements. It employed advanced inversion techniques developed in the framework of ACTRIS, focusing on aerosol absorption, and fulfilled the objectives of the ACTRIS JRA1 activity ("Improving the accuracy of aerosol light absorption determinations"). The specific aim of the campaign was to validate the remote sensing retrievals against surface and airborne in-situ measurements.

PRE-TECT was clustered with a number of atmospheric experiments that were implemented during the same period in Eastern Mediterranean. Specifically, PRE-TECT was framed by the following projects and initiatives:

1. The D-TECT ERC project, aiming to assess the impact of particle electrification on desert dust dynamics and long-range transport. During PRE-TECT, new sensors for atmospheric electricity were tested in order to combine these measurements with the advanced ACTRIS aerosol products.

2. The A-LIFE ERC project, aiming to provide fundamental new understanding on aerosol absorption and its impact on dynamics. The campaign is also supported by the operation of the LACROS facility of TROPOS in Cyprus. The ACTRIS ground-based stations at Finokalia and Limassol provided high-quality aerosol products for A-LIFE.

3. The GEO-CRADLE project aiming to coordinate and integrate state-of-the-art Earth Observation Activities in the regions of North Africa, Middle East, and Balkans in order to develop links with GEO related initiatives towards GEOSS. Two thematic pilots of GEO-CRADLE were addressed in PRE-TECT, the dust forecast service and the SENSE energy system for the determination of solar energy. Both services were validated against dust and radiation measurements that were performed from ground and air over Greece and Cyprus.

4. The CAMS Copernicus Atmospheric Service , aiming to provide continuous data and information on atmospheric composition, supporting applications in a variety of domains including health, meteorology and climatology. PRE-TECT provided an unprecedented aerosol and cloud dataset to evaluate respective CAMS components over Eastern Mediterranean.

5. The ECARS TWINNING EU project, aiming to boost INOE's research capacity in the domain of atmospheric remote sensing and create a pole of excellence in East Europe. The scientists of PRE-TECT organized a summer school for ECARS, aiming to introduce young researchers in a large-scale atmospheric cal/val exercise, focusing on the evaluation of aerosol and cloud satellite products employing ground-based and airborne sensors. During the summer school the students were exposed on dedicated hands-on training activities.

3.4.2. Methodology, methods of implementation

This pilot service was developed in the framework of the GEO-CRADLE project under the grant agreement No 690133 (HORIZON 2020). The objective of this feasibility study was the operational application of the Solar Energy Nowcasting SystEm for the PRE-TECT campaign. Figure 34 presents an example of the SENSE pilot real-time product.

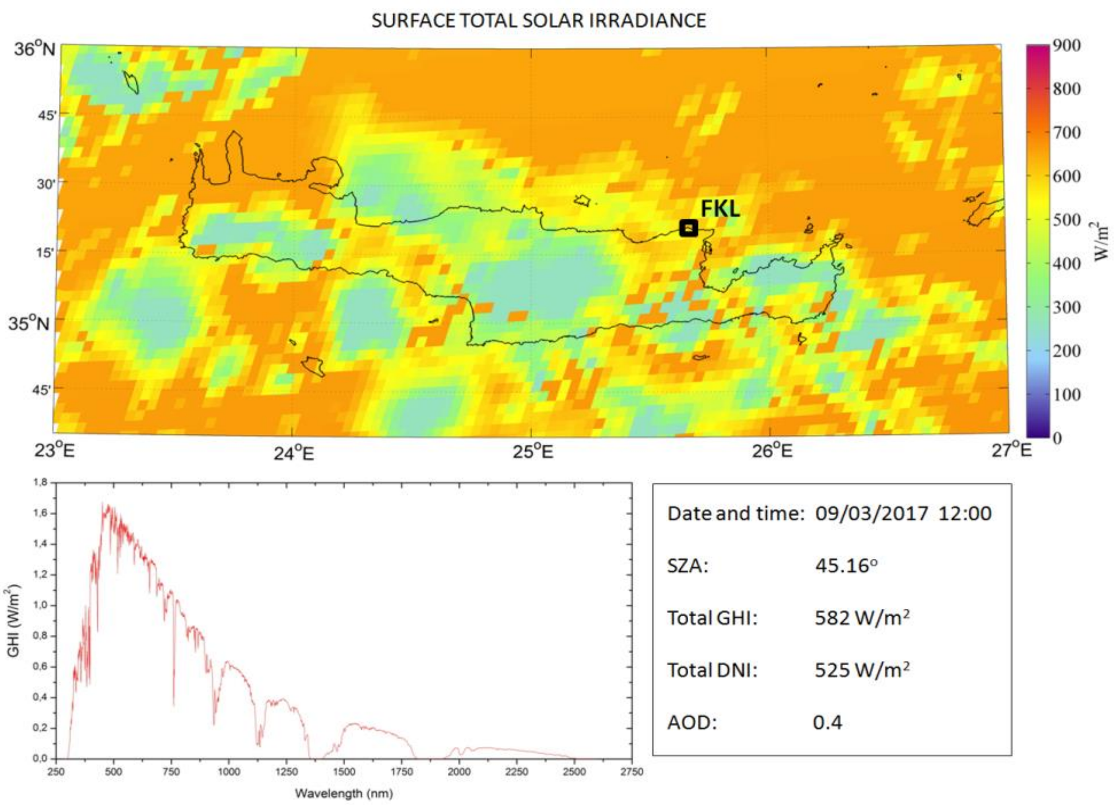


Fig. 34: An example of the SENSE spectral product for the PRE-TECT campaign.

SENSE is capable of producing maps of spectrally-integrated irradiances of the order of 1,000,000 pixels within 1 minute and hence provide the capability needed to serve high precision solar power applications for energy planning. Surface spectra for Direct Normal Irradiance (DNI), which applies to Concentrated Solar Plants (CSP), as well as Global Horizontal Irradiance (GHI), which applies to PhotoVoltaic (PV) installations are produced at high resolution using input data from Copernicus Atmosphere Monitoring Service (CAMS) for aerosols impact and from Spinning Enhanced Visible and InfRared Imager (SEVIRI) onboard the Meteosat Second Generation (MSG) for clouds impact. The technical background of this system is described here.

The Solar Energy Nowcasting SystEm (SENSE) produced operational maps of Crete, for the duration of the PRE-TECT campaign/project (April 2017), at high resolution (1nm, 0.05 x 0.05 degrees, 15 min) and is based on the synergy of Neural Networks, Radiative Transfer simulations and real-time satellite retrievals.

3.4.3. Main activities and results of the pilot analysis

Figure 35 presents the online application that was developed for the purposes of the PRE-TECT campagn. The active link for this SENSE pilot service is the following:

http://pre-tect.space.noa.gr/instruments/25/

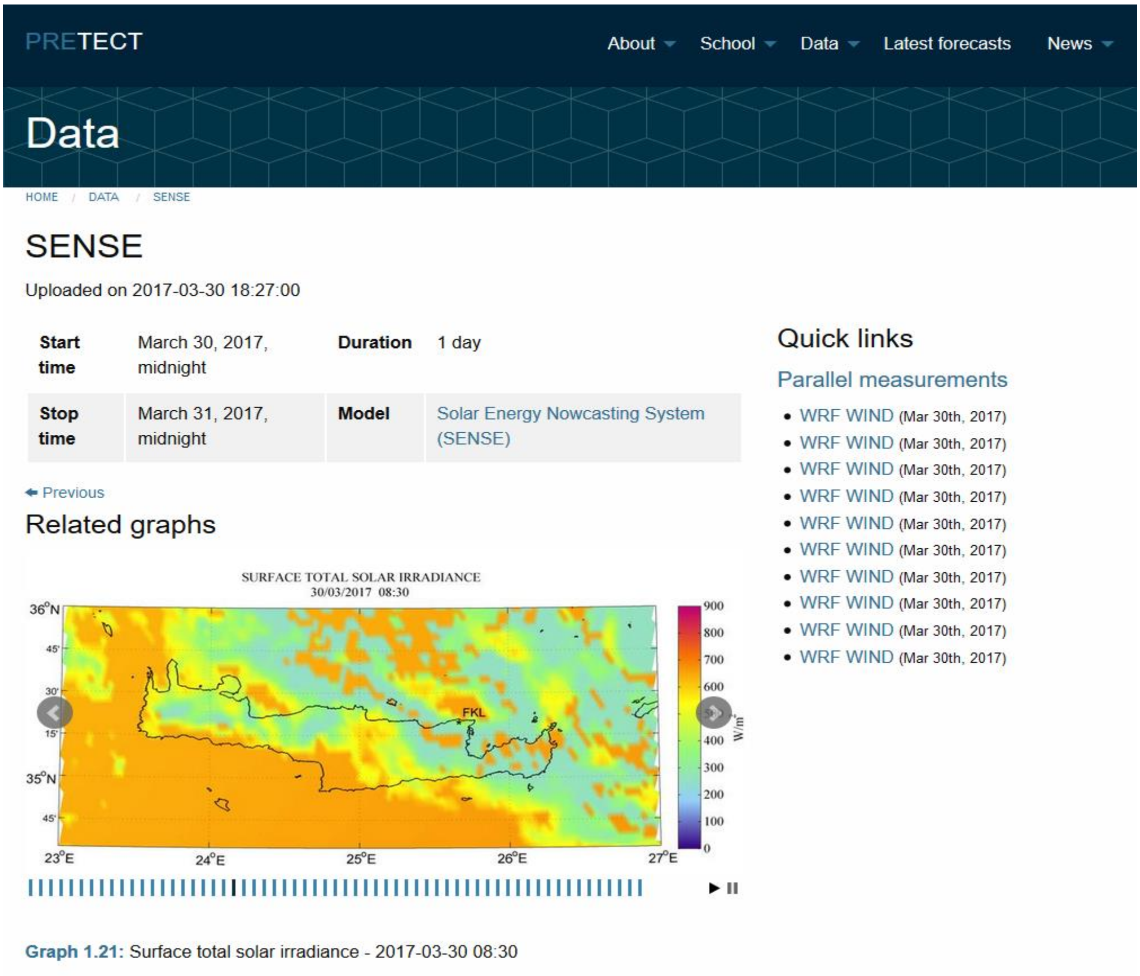


Fig. 35: The online SENSE pilot service for the PRE-TECT campagn (April 2017).

Since the main target of PRE-TECT campaign was the investigation of the aerosol and dust impact on climate, in the framework of SENSE pilot activity, we additionally performed an assessment of dust impact on surface solar irradiance and hence on solar energy. For this purpose, we studied the attenuation of SSR using as inputs the AERONET mean monthly climatology over Athens (ATHENS-NOA AERONET site). For this reason we calculated the mean monthly Level 1.5 AOD values and ranges based on an 8-years AERONET climatology (07/04/2008-31/03/2016) and the results are shown in Fig. 36. At the same time we investigated the corresponding impact under an extreme dust case (1 Feb 2015). All the technical details and the overall analysis can be found in [1].

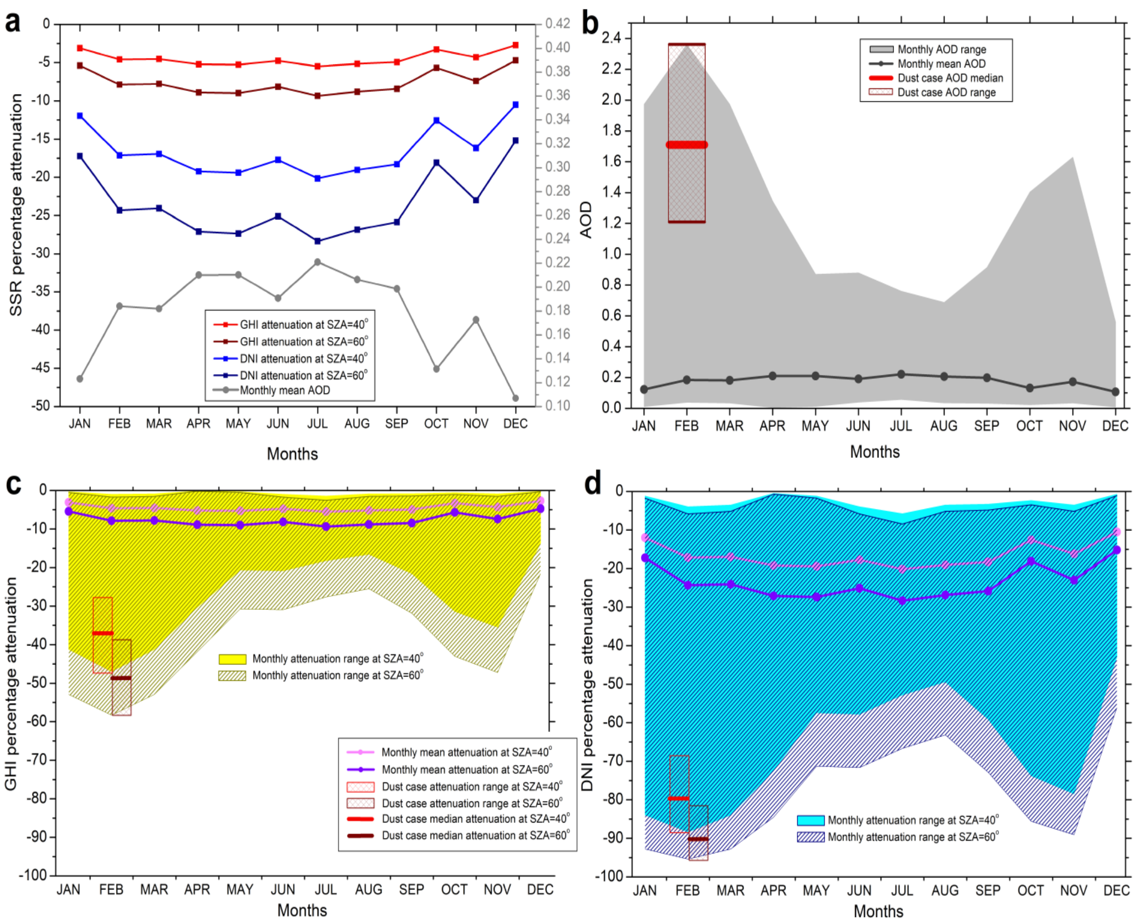


Figure 36: Mean monthly GHI and DNI percentage attenuation in Athens as a function of solar zenith angle and AOD (a) together with the mean monthly range of AOD (b), the percentage attenuation range for GHI (c) and DNI (d). The red-shaded insets shows the corresponding median values and ranges at the peak of the strong dust incursion over the region on 1 Feb 2015.

The range of climatological AODs is ≈ 0.11-0.22 with two peaks in Spring and Summer. Spring is the most favourable season for dust transport from North Africa to Greece [43, 42, 40, 41], while the summer peak is related to transport of pollution from continental Europe (e.g. [41]) and increased agricultural burning and forest fires (e.g. [45]). The range of monthly minimum and maximum AOD values revealed two different peaks in Winter (2.36) and Autumn (1.63) something that indicates that the most extreme aerosol events occur in these two seasons. This finding has to do mainly with intense dust transport in February (our dust case with AOD=1.21-2.36 and median value 1.71) and urban/industrial aerosols [46, 43, 42], as well as wood burning cases with direct relations to the Greek economic crisis the last 7 years [47]. These values were incorporated into the RTM and we simulated the GHI and DNI percentage attenuation at 40 and 60 degrees of solar zenith angle which are typical solar elevation angles for the region of Greece in the winter season. The results show significantly higher attenuation values for larger SZAs and for DNI in general. In particular, at SZA of 40 degrees, the percentage decrease for GHI is around -5% and for DNI -17%, while at 60 degrees of SZA, the corresponding values are -7% and -25% respectively. All the above results are comparable with similar studies [48, 49, 50], in terms of AOD range (0.11-0.25 in EM) and mean aerosol radiative forcing under cloudless conditions (≈ -5% for GHI and -15% for DNI). Under the impact of the studied dust event as measured by AERONET, with median AOD in the specific site around 1.71, the GHI decrease is -37% at 40^o and -49% at 60^o, and the DNI is -80% and -90% at 40 and 60^o respectively.

3.4.4. Sustainability

This feasibility study was implemented only for the purposes of the PRE-TECT campaign which took place in Crete for the period 1/4/2017 - 30/4/2017. As a result, there is no obvious reason for an extension of collaboration. However, SENSE could potentially support the D-TECT ERC project in order to further study the impact of dust on solar radiation and energy at surface, at top of the atmosphere and in various heights. It could also quantify (mainly using 1D and 3D RTM modelling techniques) the exact direct component of solar irradiance that worldwide models estimates and that the particle electrification impacts.

3.5. *Air quality*

3.5.1. Objectives and expected results

Volatile organic compounds (VOC) are emitted into the atmosphere from natural sources in marine and terrestrial environment. As a matter of fact, globally, biogenic sources of volatile organic compounds are estimated to exceed those from anthropogenic sources by a factor of ten to one. More specifically in Europe, anthropogenic and biogenic NMVOCs emissions have comparable magnitudes: annual biogenic NMVOCs emissions are estimated at 14 Tg compared to man-made emissions of around 24 Tg.

A great number of VOCs are emitted from vegetation with isoprene (C5H8) and monoterpenes (C10Hx) being the most abundant species. The remaining biogenic emitted species consist of a number of oxygenated compounds, such as alcohols and aldehydes and they are referred to as other VOCs (OVOCs).

The calculation of their fluxes is an important input in air quality models, since they are highly reactive in the troposphere by affecting regional photochemical processes. They react with the hydroxyl radical, ozone and the nitrate radical, resulting in the formation of carbon monoxide and organic species (including secondary organic aerosols) that can enhance concentrations of ozone and other oxidants in environments rich in nitrogen oxides. On a global cycle, Biogenic Volatile Organic Compounds (BVOCs) contribute to the global carbon cycle and have a key role in the global climate. Furthermore, most of them are oxidized to carbon dioxide (CO2) into the atmosphere and determine the growth rate of atmospheric methane concentrations.

The BVOCs emissions depend on the different types of vegetation and meteorological conditions. Concerning the isoprene, it has been shown that it is emitted mainly from deciduous trees under high temperature and Photosynthetically Active Radiation (PAR) conditions. On the other hand, monoterpenes are emitted mostly by coniferous trees. They are mainly temperature dependent except for some evergreen oaks and Norway spruce that are temperature and light dependent.

Presently in Greece there does not exist a detailed gridded database with recent data concerning the biogenic emissions even though it is well known that BVOCs emissions play a significant role in the creation of photochemical pollution, especially during the warm months. In addition, this region, similarly to the Mediterranean, should be studied in detail with regard to biogenic emissions due to the specificities it presents. More precisely, it has a complex vegetal biodiversity quite different from the usual northern latitude or US vegetation, it receives high fluxes of solar radiation in the summertime and is dominated by high temperatures.

Finally, high ozone concentrations are often very pronounced due to primary pollutant emissions in a regional scale dominated by high radiation fluxes and temperature values. The most recent studies concerning the estimation of biogenic emissions in Europe and the Balkan Peninsula, including Greece were performed by [51, 52] with the aid of emission models or a Geographic Information System (GIS). Both studies referred to 2003, with outdated land use data and adopted modeled meteorological input information.

The present SENSE's pilot work supports the National and Kapodistrian University of Athens (NKUA) in order to present results of the computational system developed for estimating BVOCs emissions based on GIS technology over Greece. It covers the year 2016 and has the possibility to be regularly updated to include more years.

3.5.2. Methodology, methods of implementation

Solar radiation data, have been calculated with the use of an existing methodology (Taylor et al., 2015) that has been used in the pilot study SENSE of the Geo – Cradle project (http://geocradle.eu/en/). It is based on solar irradiance spectra produced via a synergy of satellite data, radiative transfer simulations and neural network techniques. The method has been validated in Kosmopoulos et al. (2017b), by comparison with ground based solar radiation measurements. The Photosynthetically Active Radiation (PAR) was calculated using the spectral global horizontal radiation SENSE output for every month of 2016 having 0.05° latitude by 0.05 ° longitude spatial resolution and 1hr temporal resolution. Then, with the aid of GIS, these radiation values were adjusted to the area of interest with a spatial resolution of 6x6 km^2.

3.5.3. Main activities and results of the pilot analysis

Figure 37 presents an example of the monthly mean PAR climatological maps that produced for the purposes of this feasibility study. Here is the PAR map for April. In Figure 38 we show the analytical hourly mean PAR per month as climatological mean daily curves for the year 2016. The calculated with SENSE PAR data covered the whole 2016 with spatial resolution of 5 km and temporal resolution of 1 hour (1 hour means). All the climatological data can be requested by SENSE team, while this study is an under review scientific paper of Dimitropoulou et al. (2018). This methodology can be implemented for longest period, since it is based on the SENSE's spectrally weighted products.

3.5.4. Sustainability

In conclusion, given the importance of biogenic emissions in atmospheric photochemistry in Greece, it is essential to continuously monitor, record and improve the methods estimating the emissions from natural sources as well as the study of their interaction with the anthropogenic emissions and finally, their overall contribution to ozone and to aerosols matter formation. To this direction, this method can be extended to more years (here we provided the PAR for the year 2016) in order to develop an analytical emission inventory in support to local and regional health-related authorities and decision makers.

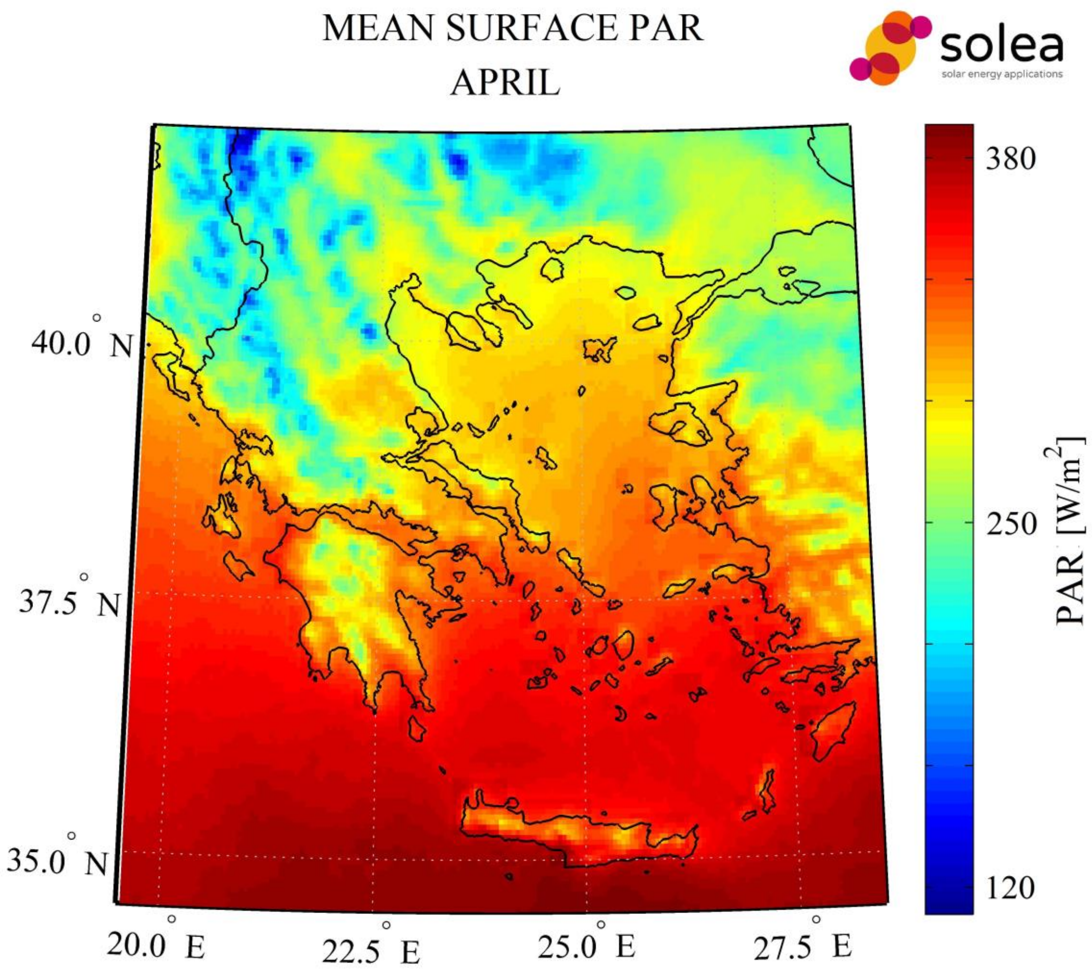


Fig. 37: The mean monthly climatological PAR of April over Greece as calculated by SENSE pilot.

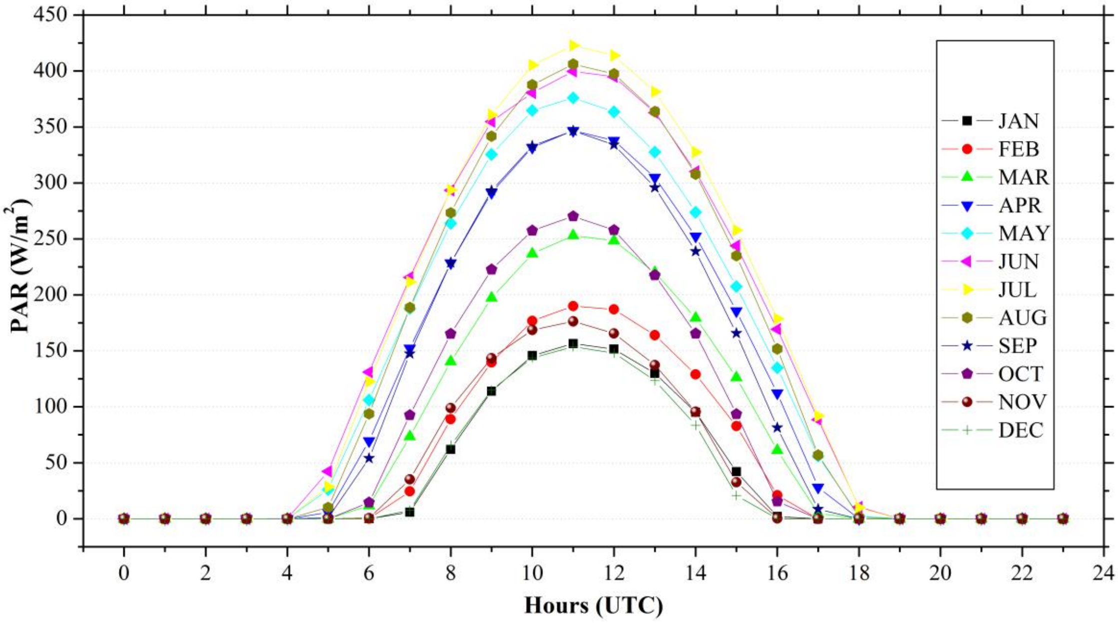


Fig. 38: SENSE's analytical inter-annual hourly mean PAR per month for the region of Greece.

4. Key recommendations and next steps

According to the SolarPower Europe Association, by 2017, the European solar heating sector, which consists of SMEs, will generate more than 100 terawatt-hours, while it is expected to grow 80% by 2019. Extreme volatility of wholesale electricity prices, can be up to two orders of magnitude higher than that of any other commodity or financial asset. SENSE has the potential to disrupt the energy trading business, by providing nowcasts and short-term solar energy forecasts. This information is crucial in the energy exchange marketplace, where on-the-spot energy prices are defined by supply and demand equilibriums, and “energy liquidity” is vital. If the energy traders can have an accurate estimate for the solar energy supply, three hours from now, this provides them with a competitive advantage with clear economic benefits for their day-to-day market operations. In parallel, SENSE team believe in the potential for market uptake of the products/services that will be generated in the forthcoming EuroGeoss initiative. Large scale, high temporal and spatial resolution EO-based nowcasting and short-term solar spectral irradiances forecasting, seems to be an emerging market prospect. SENSE is capable to tap on this opportunity due to the in-house physical modelling and machine learning processing expertise, and the Copernicus Virtual Earth Observatory cloud optical thickness forecasting ability, plus the cloud processing and storage resources provided by NOA.

Energy security is critical for the growth and prosperity of European and MENA economies. As solar power production increase throughout Europe it becomes more and more important to be able to predict production and hence the “impact” on the electricity system. The lack of forecasts or inaccurate forecasts results in an inefficient operation of the electricity system and can even endanger security of supply. Without accurate forecasts, it is not possible to efficiently plan which power plants to run and which ones to turn off and this results that you either are running too many or too few. Running too many power plants adds additional costs to the system and running too few force the start-up of expensive peak plants. At the same time, in most parts of Europe, the supply and consumer demand for energy defines its prices, in what is considered to be an energy commodity marketplace. In this context, energy traders are buying, selling and moving of bulk energy from where it is produced to where it is needed. There are even initiatives for community solar energy sharing: indicatively in Australia there have been trials of a block chain-based software program for peer-to-peer energy trading, in which consumers buy, sell or swap excess solar electricity directly with each other.

For the above challenges, SENSE will enable the solar industry to better plan clean energies, its transmission and distribution, which in turn will boost the ralative contribution to national portfolios. So, the next step of SENSE after the end of GEO-CRADLE is the creation of a commercial exploitation scenario for the solar spectral irradiances nowcasting and forecasting services. To this direction, the SENSE team will issue one preliminary business plan for the commercialization of SENSE products and services and the launch of a spin-out company under the description name SOLar Energy Applications (SOLEA).

For the future, there are three major obstacles in SENSE that have to be surpassed:

- The improvement of the SENSE scientific accuracy. This improvement requires additional atmospheric data that has to be used as real time inputs in order to improve important RT inputs. Such parameters are related with cloud properties, aerosol properties, surface albedo and concentrations of water vapor and trace gases. In order to calculate accurate solar energy products, each of the properties related with such atmospheric parameters require different spatial and temporal frequency that has to be matched by the current availability of satellite based products of known missions (active and scheduled Sentinel missions, EUMETSAT related satellites and NASA related ones). As an example, water vapor concentration (a measure of solar irradiance attenuation due to water in the atmosphere) is needed with low spatial and high temporal resolution. Cloud optical depth (a measure of solar irradiance attenuation due to clouds) is needed in both high temporal and spatial resolution. Finally, surface albedo is needed with high spatial and lower temporal resolution. The integration of all these parameters in an on-line system in order to provide the optimum solar related RT input data, requires the availability of both multi-modal satellite data in RT and the ICT resources to timely process them. In addition, an online validation tool of model input (e.g. aerosols) and output information (Solar energy), using surface based in-situ monitoring data is essential in order to assess the quality of the energy product.
- Improvement of the spatial resolution, coverage and the temporal resolution. Concerning the spatial coverage, it is clear that the step from national to regional and multi-national scale can be achieved only with a new technological approach on handing such an amount of data in real time. This is true for both the pre-processing part, where all the satellite based available data are retrieved and transformed to RT inputs and to the post-processing part where millions of spectra are produced. Concerning the enhancement of spatial and temporal resolution, this will be achieved through the exploitation of diverse, frequently updated, Copernicus sources.
- Inclusion of the short-term forecasting. For the case of short-term forecasting, prediction of information about cloud and aerosol properties will be integrated in the SENSE scheme in the near future. For the case of clouds one of the most important parameters is the Cloud optical thickness (COT) that will be derived/projected in the near (0-3 hours) future, in real time. Such techniques are based in the calculation of cloud motion vectors based on past cloud spatial distributions. This information will be provided with a 15-minute time step, thus providing an output eight times bigger in volume with respect to the nowcasting product. For the case of aerosols, the CAMS AOD forecast product will be used. Further adjustments will be applied in real time using online satellite based AOD products, especially for the cases of aerosol events (e.g. dust transport from Saharan desert). Failure to capture such events has a significant impact especially on Direct Normal Irradiance (DNI) now-casting and forecasting as aerosol attenuation in such cases can reach 80%.

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