EUROSUNMED

Final Publishable Summary Report (M1 – M48 Period)

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1. Executive summary

EUROSUNMED stands for "**Euro-Mediterranean Cooperation on Research & Training in Sun based Renewable Energies" (project N° 608593) and it was selected within the call ENERGY.2013.2.9.1.** The project started on 1st September 2013 and ended on 31st August 2017. The Consortium of 18 partners is composed as follows: six Research centres, four Universities, three Agencies, two Small/Medium Entreprises (SMEs), a Large Entreprise (LE). The European partners (EU) involved in the project are CNRS (Coordinator: CNRS-ICUBE), CENER, EMRS, EUREC, IK4-TEKNIKER, SINTEF-E, SINTEF Mat. and TURBODEN. From the Mediterranean Partner Countries' side (MPCs), there are Akhawain University, CNESTEN, MAScIR and University Mohammed V from Morocco, and Alexandria University, Helwan University and NVE company from Egypt.

In line with the DOW, EUROSUNMED has developed advanced research and technologies in three energy field areas, namely photovoltaics (WP1), concentrated solar power including storage (WP2) and grid integration (WP3). For WP1, the activities resulted in the fabrication and characterization of silicon foils as well as CZTS and silicon thin film to make solar cells and mini-modules. In WP2, the work has allowed the development of innovative and cost-effective heliostat concepts, the design and analysis of efficient solar receivers, and the analysis of Decoupled Solar Combined Cycles (DSCC). Finally, the main developments within WP3 are deep studies addressing the stability and reliability of Moroccan grid and the Egyptian grid in the conditions of implementing massive renewable energies.
Demonstration and testing were also part of the project. For this purpose, different photovoltaic prototypes fabricated by the partners were tested under real functioning conditions. Thus, several silicon based mini-modules were installed on the roof of three Moroccan universities, namely Rabat, Marrakech and Ifrane. The three sites differ by latitude, altitude, temperature and solar radiation. The photovoltaic performances of the prototypes were monitored versus sun irradiation, temperature and humidity. It is demonstrated that the degradation of the module quality is low which is favorable for the deployment of photovoltaics in these parts of Morocco. In the field of solar thermal, the remarkable outreach is that the first Heliostats experimental field was successfully established in Egypt, with the support of some Egyptian SMEs and public authorities. The Egyptian partners gained tangible know-how and technology transfer for Heliostats designs, manufacturing, control and operation thanks to a strong cooperation within the consortium.
Networking between EU and MPCs and transfer of knowledge was of high importance for the project. These activities were developed through visits of students, senior researchers/engineers in order to vehicle the transfer of knowledge and technologies. Thus, *70 individual secondments* were conducted during the entire project, which is remarkable. In addition to the visits, more than *10 training courses* for groups (lectures, seminars, …) were organized reaching a much larger audience. It is worth mentioning that about 35 master and PhD program students from MPCs' partners have defended their diploma thanks to EUROSUNMED support.
The dissemination of EUROSUNMED results was conducted during the whole period of the project using several tools. The outreach activity towards the general public was done through a dedicated EUROSUNMED web page (www.eurosunmed.eu), newsletters distributed every six months, as well as brochures and social media outlets distributed during several occasions (conferences, workshops, exhibitions…). In addition, several EUROSUNMED events were organized: three technical workshops covering WP1, WP2 and WP3, two roadmap meetings and two industrial workshops. In addition, *six international schools* were organized (three in Morocco, two in Egypt, and one in Italy) that attracted more than 500 students in total, with a majority from MPCs and paying attention to the gender balance. The scientific project results were disseminated to the scientific community through 32 publications in journals and 34 in conference proceedings. Several oral or poster presentations were given at key conferences and workshops (EMRS-2017, IRSEC-6, SolarSPACES, JNPV, JNES …).
Finally, the project offered the opportunity to set a roadmap for the development and deployment of solar energy in the Mediterranean with a focus on Morocco and Egypt. Thus, the bottlenecks were identified and action plans for human capacity building, research, industry and policy were proposed. It is worth mentioning that two new projects issued from EUROSUNMED were launched before the end of the project, namely MEDSOL (ERASMUS+) and INFINITE-Cell (MCSA-H2020), and others are under preparation.

2. A summary description of project context and objectives:

2.1 Project context

The Mediterranean Solar Plan complements the work being done under a number of interconnecting Mediterranean energy projects, funded under the European Neighborhood and Partnership Instrument (ENPI) or under specific FP7 calls. Among the last, EUROSUNMED project is aiming at the development of low-priced and appropriate technologies for the south Mediterranean countries as well as training highly skilled researchers/engineers and technicians who can understand, run and improve such infrastructures. An economy founded on knowledge is the economy of tomorrow. The focus for EUROSUNMED will be on Morocco and Egypt as these two countries have set a clear plan for development of renewable energies, and in particular for solar energy based technologies (Figure 1) thanks to the high level of solar irradiation in these countries (Figure 2).

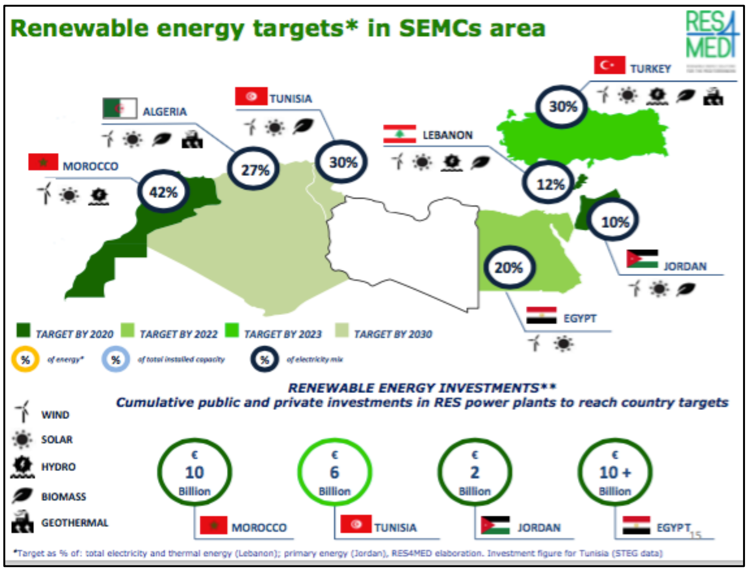

Figure 1: Renewable Energy targets in SEMC's area (from RES4MED).

In this context, Morocco has launched one of the world's largest solar energy projects costing an estimated $9 billion which aims at creating **2,000 megawatts of solar generation capacity by the year 2020**.

As for Egypt, plans are coming together for a slew of solar power generating plants worth around $3.5 billion, and will reportedly add two gigawatts (GW) of electricity for the nation

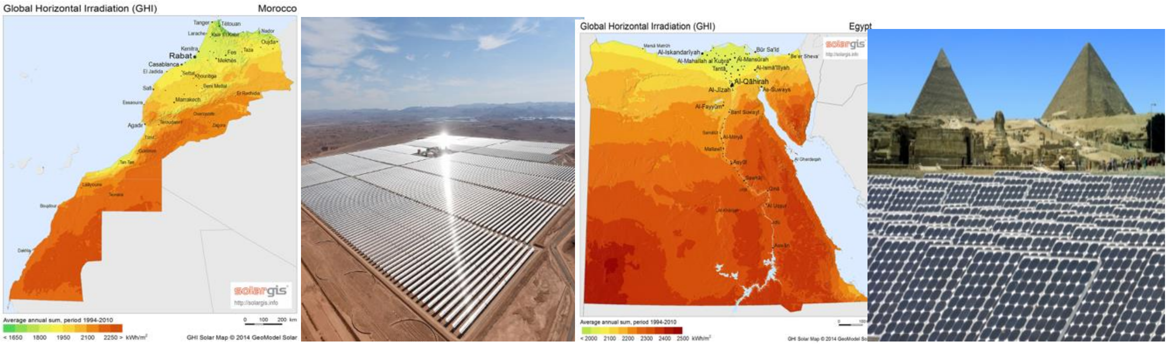

Figure 2: Solar radiation and photos of some installations in Morocco and Egypt

Given these intensive developments now and in the future, there is a need for further investment in education and training at lab and industry levels. A EUROSUNMED consortium was built to support these initiatives. The Consortium brings together leading groups from academia (HU, AU, UM5, AUI, CNESTEN), government research organizations (CNRS, CENER, SINTEF, MAScIR), agencies, knowledge societies (EUREC, E-MRS), and private technology oriented research centres (IK4-TEKNIKER) as well as industry (MASEN, TURBODEN, NVE). The varied experience of the partners and knowledge in the fields of PV, CSP and Grid are seen as an asset and contributes to the professional development of the researchers involved.

The work plan of the EUROSUNMED project lies on eight well identified workpackages (WPs) as illustrated in Figure 3.

The general objectives of the project in regards to the workpackages can be summarized as follows:

- ⇒ Developing advanced technologies in three energy field areas, namely photovoltaics (WP1), concentrated solar power including storage (WP2) and grid integration (WP3).
- ⇒ Testing and demonstrating PV and CSP components under specific conditions (WP5) of MPC is also planned.
- ⇒ Establishing strong networks (WP4) between EU and MPCs through exchange of students, senior researchers/engineers who will be the vehicles for transferring knowledge and technologies.
- ⇒ Disseminating (WP6) the results of the project through the organization of summer schools, workshops and conferences towards large public from universities, engineering schools and other stakeholders involved in the three selected energy areas and beyond.
- ⇒ Setting a roadmap (WP7) that paths the future collaborations based on the knowledge triangle: education-research-industry.

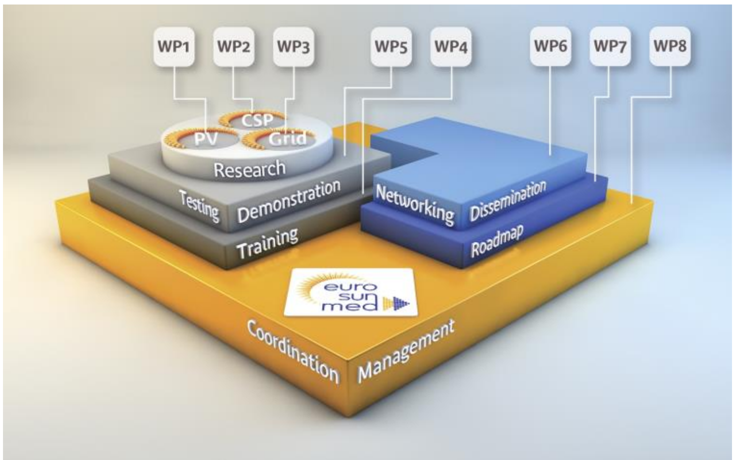

Figure 3: Breakdown of EURSOUNMED work packages

2.2 The technical objectives of the project:

Workpackage 1 (Photovoltaics)

Objective 01.1	To develop innovative methods for the processing of low-cost solar cell materials, which includes: (i) development of cost-effective thin film Si based solar cell structures; (ii) development of CZTS (Kesterites) based solar cell materials and relevant structures; (iii) development of cost effective TCO based materials for solar cells
Objective 01.2	To develop cost effective technologies for the processing of solar cell structures, which includes: (i) development of vacuum based technologies: magnetron sputtering, e-beam evaporation and PECVD based methods for deposition of thin film or nano-whiskers/nano-rods based materials and related structures; (ii) development of cost-effective non-vacuum based methods (spray, sol-gel) for deposition of solar cell materials and related structures, (iii) development of advanced crystallization as well as exfoliation and bonding methods for thin Si film based layers and relevant solar cell structures.
Objective 01.3	To develop advanced methods for optical confinement for TF based solar cell structures, which includes: (i) Development of an internal reflector in thin solar cells on low-cost substrates; (ii) development of advanced wet chemical texturing and reactive ion etching methods for thin film based solar cell structures, (iii) application of plasmon nano-particles enhanced light absorption in thin film based solar cells.
Objective 01.4	To analyse the electronic properties of individual solar cell materials and their interfaces as well as the relationship between the deposition parameters and the device properties, which includes: (i) analysis of optical and electrical properties of individual solar cell structure layers; (ii) analysis of the relationship between the properties of individual layers and interfaces, and the final properties of solar cells; (iii) simulation of technological processes of growth, crystallization of thin layers as well as properties of final solar cell structures using advanced softwares; (iv)

	development of the quality inspection specific equipment and methodology for the express analysis of solar cell structures on nano-scale
Objective 01.5	To develop advanced processes equipment for cost-effective fabrication of thin film based solar cells, and assembly into modules, which includes: (i) selection and development of cost effective prototypes of high throughput advanced equipment and process flows for the cost effective processing of thin film based solar cells; (ii) optimization of cost effective processes, for fabrication of thin film based solar cells, formation of the solar cell base, the emitter and the TCO based antireflection coatings (ARC), as well as methods for their stabilization; (iii) development of metallization schemes for large scale thin film based solar cells; (iv) assembly of the advanced solar cells into complete modules at a processing cost targeting ~1 Euro/Wp.

Workpackage 2 (Concentrated Solar Power)

Objective 02.1	Development of an innovative and cost-effective heliostat concept
Objective 02.2	Design and analysis of an efficient solar receiver
Objective 02.3	Development and analysis of decoupled combined cycles and optimized storage systems
Objective 02.4	Integrated plant modelling

Workpackage 3 (Grid Integration)

Objective 03.1	Identifying the potential and barriers for large-scale grid integration of renewable energy and suggest strategies that will enable this potential to be realised in Mediterranean Partner Countries (MPC).
	3.3.2. Strategies for large-scale integration of renewables

Workpackage 4 (Training)

Objective 04.1	**Defining important skills and knowledge that should be transferred**
Objective 04.2	**Handling the exchange and training activities within the project**
Objective 04.3	**Identifying and communicating important training events**

Workpackage 5 (Testing and Demonstration)

Objective 05.1	To conduct a series of tests to check the correct operation, optical properties and durability of the low cost heliostat.

Objective 05.2	To define and conduct a series of tests to check the correct operation of the control system.
Objective 05.3	To define and conduct a series of tests to check the correct operation of the automatic calibration system.

Workpackage 6 (Networking and Dissemination)

Objective 06.1	To organize and manage dissemination and training events such as conferences, workshops and summer schools
Objective 06.2	To coordinate and propose means of dissemination to different communities (scientific, industrial, general public, public bodies, etc…)
Objective 06.3	To manage and monitor IPR related issues and exploitation opportunities based on project results

Workpackage 7 (Roadmap)

Objective 07.1	To define a Roadmap for long-standing cooperation between the involved partners at all levels: research, training, industry development, policy.

3. *Description of main S&T results/foregrounds:*

EUROSUNMED project aims at developing low-priced and appropriate technologies for the MPCs as well as training highly skilled researchers/engineers and technicians who can understand, run and improve such infrastructures. EUROSUNMED consortium involves leading groups from academia (HU, AU, UM5a, AUI, CNESTEN), government research organizations (CNRS, CENER, SINTEF, MAScIR), agencies, knowledge societies (EUREC, E-MRS), and private technology oriented research centres (IK4-TEKNIKER) as well as industry (MASEN, TURBODEN, NVE).
Figure 4 gives more details about the countries of the involved partners.

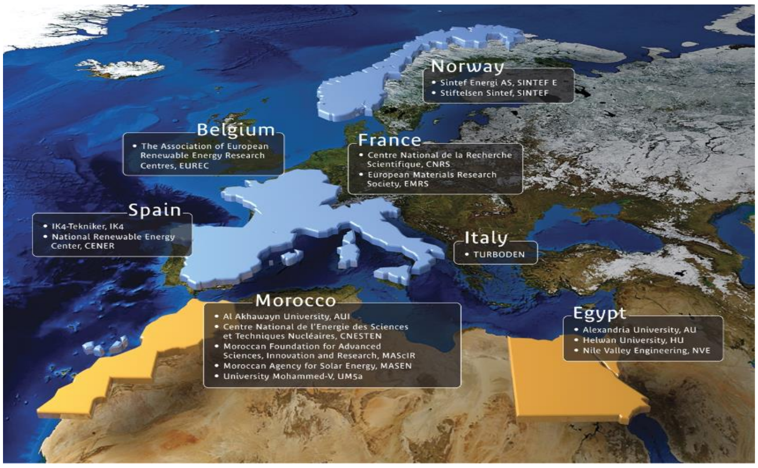

Figure 4: Map of partners' names and countries

The varied experience of the partners and knowledge in the fields of PV, CSP and Grid are seen as an asset and contribute to the professional development of the researchers pursued.
The work plan of the EURSOUNMED project lies on eight well identified workpackages (WPs). The graph in Figure 5 gives the concerns of each WPs.

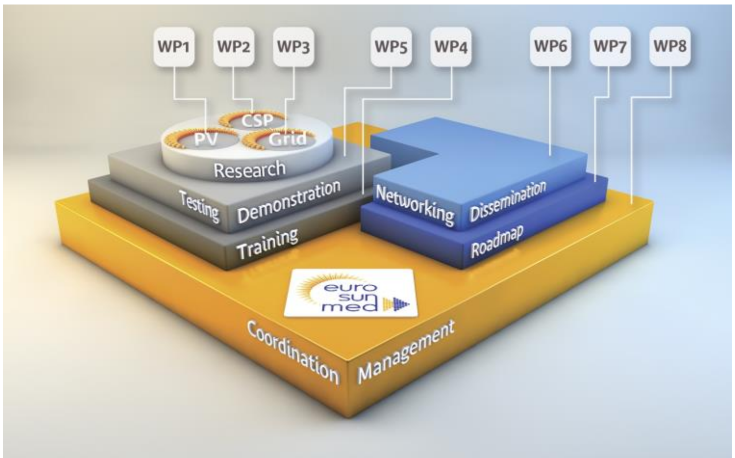

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Figure 5: schema of EUROSUNMED workpackages.

The objectives of the project can be summarized as follows:

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- ⇒ Testing and demonstrating PV and CSP components under specific conditions (WP5) of MPCs is also planned.
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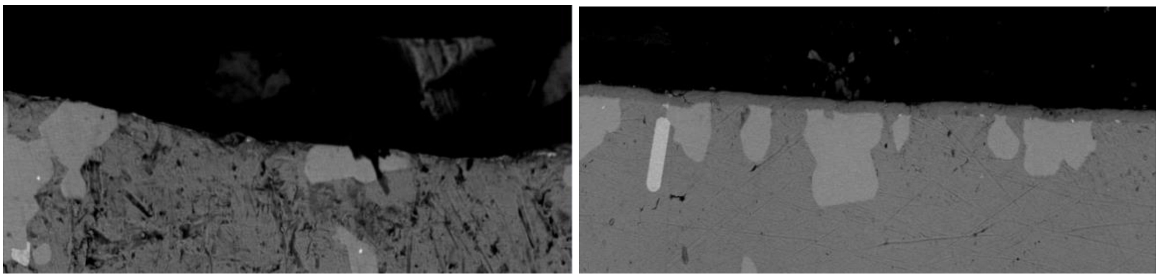
- ⇒ Setting a roadmap (WP7) that paths the future collaborations based on the knowledge triangle: education-research-industry.

In the following, the main scientific and technological achievements obtained over the whole period of the project will be described in regards to the corresponding workpackage:

workpackage 1 (photovoltaics or PV) intended to develop advanced scientific and technological platforms for the cost effective processing of solar cell materials, solar cell structures and modules, which were selected, optimized and adjusted taking into account specific conditions and needs of MPCs.
In this context, we have developed innovative methods for the processing of low-cost thin film (Silicon, CZTS) solar cell (SC) materials.
For silicon, we have extensively investigated the *formation of crystalline silicon thin films (<2 μm)* based on several substrates such as powder pressed silicon, pure Al or Al-Si alloy (SRAS) substrates. The crystallization of the amorphous silicon deposited by PECVD or e-beam was carried out either thermally or by laser. Figure 6 shows cross-section SEM images after thermal treatment at 550°C during 12h, of an Al-Si alloy substrate and of PECVD amorphous silicon layers of different thicknesses on RSAS.



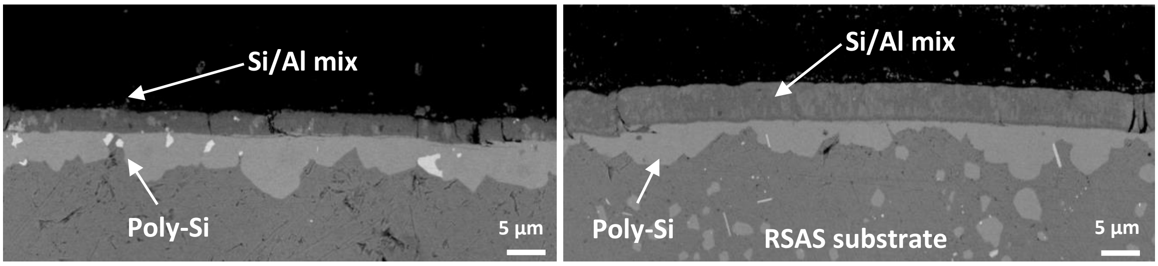


Figure 6: SEM observations on the cross-section samples (RSAS), after annealing at 550°C during 12h, without amorphous silicon layer (a) and amorphous silicon layer with different thicknesses: (b) 1 µm, (c) 3 µm and (d) 5 µm.

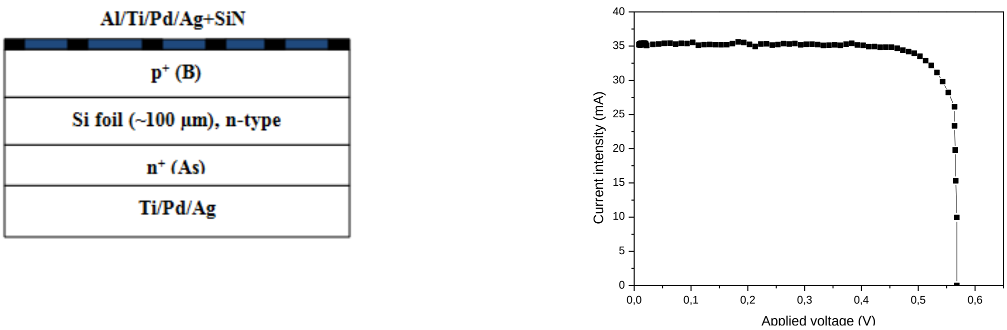
One can also mention that crystallization above 600 °C of e-beam deposited Si layers on Al substrates was demonstrated (MAScIR, SINTEF). It has been shown that fast crystallization (in about ~20 min) of e-beam deposited Si layers occurs if anneals are done at above 600 °C. In particular, Raman, XRD, SEM and EDS analyses confirm that the crystallized film is composed of large grains poly-Si and a full crystallization can be reached after short duration of annealing 10 minutes at 640°C.

Such research has conducted to publications in several Journal papers and a patent was accepted.

For silicon solar cells, we have also fabricated *thin Si films* (*< 100 □m)* using two different exfoliation methods (CNRS-ICUBE, CNRS-CEMTHI, SINTEF): smart-cut (proton implantation) and Slim-cut (Epoxy stress layer) was studied. Raman measurements on exfoliated films have been performed at SINTEF. These silicon foil films served as base absorbing materials for solar cells (**Erreur ! Source du renvoi introuvable.**a). Conversion efficiencies as high as 14.5% were obtained on about 100 micrometers thick foils using conventional technologies (**Erreur ! Source du renvoi introuvable.**b), which is remarkable as the feasibility of solar cells on SLIMcut foil films was demonstrated for the first time.

Ultra-thin silicon foils have also been produced using high energy proton implantation (1.5 to 2.5 MeV for thicknesses between 30 and 70µm) on both (111) and (100) oriented silicon wafers using doses in the range of $5x10^{16}$ to $2x10^{17}$ at/cm^2. These layers have also been used for the production of solar cells using the process above, and **efficiencies up to 9.7%** have been achieved. Modelling of layer transfer by combining of the stress induced layer transfer and ion implantation was also investigated (CEMTHI, CNESTEN). Analytical modelling and by Finite-Element-Method have been performed.

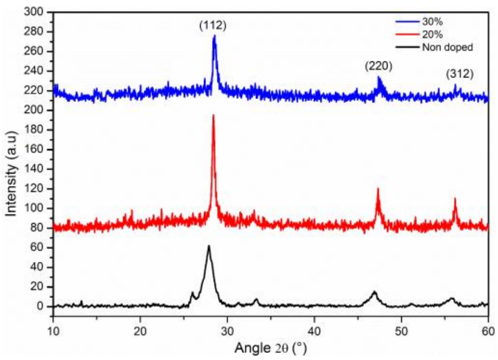
A patent on the combination of silicon foil solar cells fabrication and attachment to an Al supporting substrate is under evaluation.



a) b)

Figure 7: (a) schema of a silicon foil based solar cell; (b) Illuminated Current-voltage characteristic measured on a 90□m thick SLIM-cut silicon foil.

For CZTS based materials, several deposition techniques were developed for the first time at the Moroccan partners premises. CZTS is a very complicated material because of the difficulties to get a layer with free defective phases, which has limited the solar cell efficiencies to 12% worldwide. Thus, MASCIR has used the sputtering and sol-gel methods while UM5 has investigated the ultrasonic technique. The Moroccan partners have produced very good layers with appropriate composition, thickness and bandgap but the parasitic phases were still present. An extensive work concerned also the effect of annealing conditions and passivation using alkali metals (Potassium and Sodium) on the crystallinity of *CZTS based thin films*. As a matter of fact, the XRD pattern depicted in Figure 8 a good CZTS kesterite structure (produced by solgel at MASciR) with a preferential orientation along plane (112). Doping CZTS with KCl (as source of K) improves the crystallinity, an amount of 20% is providing the best CZTS crystal quality. The SEM image cross section shows large grains with non-homogeneous distribution. The transmittance of CZTS doping with K (20%) shows a high absorption with a band gap of 1.5 eV. On the other hand, the crystallinity substantially improved by doping with Na (10%). However, the crystal quality decreased slightly with high concentration and some secondary phases appear such as SnS_2**.** Same as doping with K, SEM images of CZTS doping with Na shows large grain but inhomogeneous distribution**.** The transmittance shows a high absorption in the visible region with a band gap of 1.47 eV.



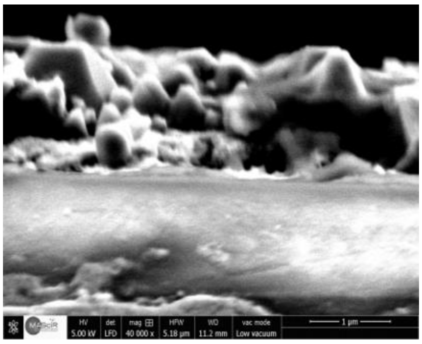
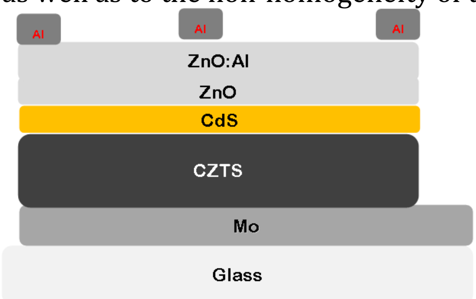


Figure 8(a): XRD of CZTS doped K.; (b) SEM image of CZTS doped 20

Attempts to fabricate CZTS based solar cells was done at CNRS-IPCMS and CNRS-ICube using the materials produced by MASCIR and UMV. The whole cell (Al/SnO_2/ZnO/CZTS/Mo/ITO/glass) was completed (Figure 9) during the PhD student's training and the best efficiency reached was 0.3%. This low efficiency can be attributed to the high series resistance, to the small grain size (50 nm) as well as to the non-homogeneity of the composition in volume and to the pinholes.



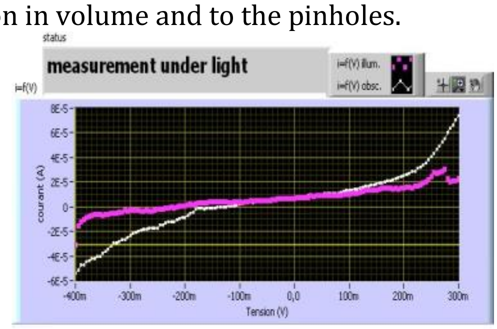


Figure 9(a): structure used for CZTS solar cells; (b) I-V curve of the prepared cell using S4a.

The work on CZTS/Si tandem structure consisted in two parts. We first have modelled a monolithic CZTS/Si tandem cell as shown in Figure 10. The result shows that the best efficiency is obtained for a semi-transparent CZTS film with a thickness of about 0.3-0.35mm. A conversion efficiency of about 19% is expected while the silicon bifacial cell alone has an efficiency of 13.5% (no texturing no antireflection coating).

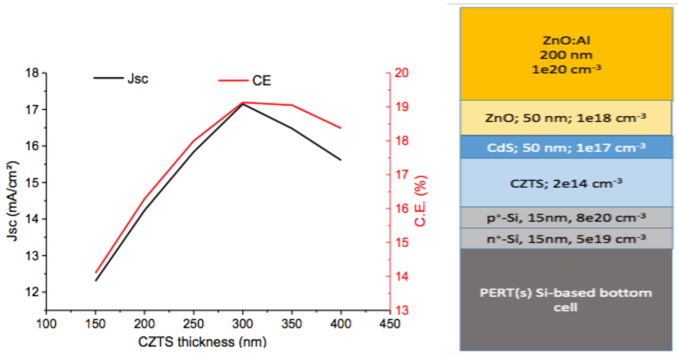


Figure 10(a): Short circuit current and efficiency of a CZTS/Si solar cell; (b) schema of a CZTS/Si solar cell.

We have then proceed to the fabrication of *CZTS/ Si tandems cells* and mini-modules. The CZTS films used in this task were provided either by the EUROSUNMED partners namely MASCIR and UMV or by IREC (Bercelona, Spain) with whom a collaborative work was established and served later on to launch a common European project. The research of IREC on CZTS is part of another European project entitled NASCENT (ENE2014-56237-C4-1-R). The CZTS, Si and CZTS/Si tandem cells were analyzed by current-voltage measurements under illumination. The bottom silicon solar cell prepared at SINTEF and ICube with an efficiency of 13.4 % is connected to the CZTS cell to form the CZTS/Si tandem cells. The best efficiency reached 4.8 %.
Several Tandem CZTS/ Si mini-modules composed of 4 CZTS/Si were connected in series to make a mini-module (Figure 11a). CZTS films with an energy band gap of around 1.45 eV were prepared for this purpose. The best mini-module device gave a conversion efficiency around 7%. The milestone of 10% was not reached as planned but our results can be considered as very good result given the difficult preparation of semi-transparent CZTS films with high quality (no parasitic phases).

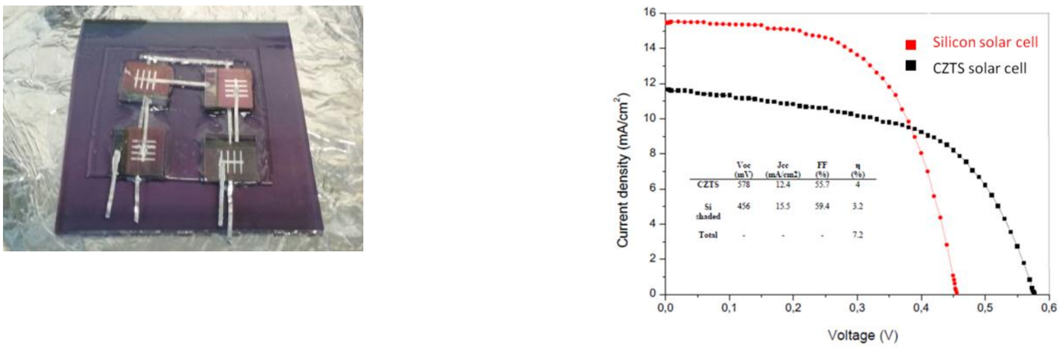


Figure 11(a): picture of the first mini-module based on CZTS/Si tandem cells; J-V characteristics of the CZTS/Si solar cells

Despite the moderate solar cells quality, such collaborative work between EU and Moroccan partners has allowed to acquire competences in the growth of complex materials, to deep knowledge on several characterization techniques and to learn about the fabrication of thin film based solar cells. It has also to be pointed out that, to our knowledge, such CZTS/Si tandem cells were fabricated for the first time which is an achievement by itself.

Another important task of the workpackage 1 was to estimate the *cost of Si/CZTS tandem cells*. A value as low as 0.4€/Wp was found for a conversion efficiency of 22.5%. A decrease in the cost could be obtained by an optimization of the preparation steps of the polycrystalline silicon layer which represents about 60% of the total cost. It is stated that cost of CZTS/Si tandem structure could be competitive compared to that for conventional Si based cells if the conversion efficiency of the tandem reaches a value of around 19%. This means an efficiency of 10% for silicon and 9% for CZTS (2 terminal approach), or 12% for silicon and 7% for CZTS (2 terminal approach), which is reachable with an effort in producing high quality semi-transparent CZTS solar cells. It should be mentioned that the CZTS/Si tandem activity will continue thanks to the recently accepted project named INIFINITE-Cell and dealing with CZTS/Si tandem cells and modules. In this project, several of the WP1 partners will be involved.

Workpackage 2 dealt with the development of novel elements (heliostat, receiver, storage components…) as parts of a **concentrated solar power** plant.

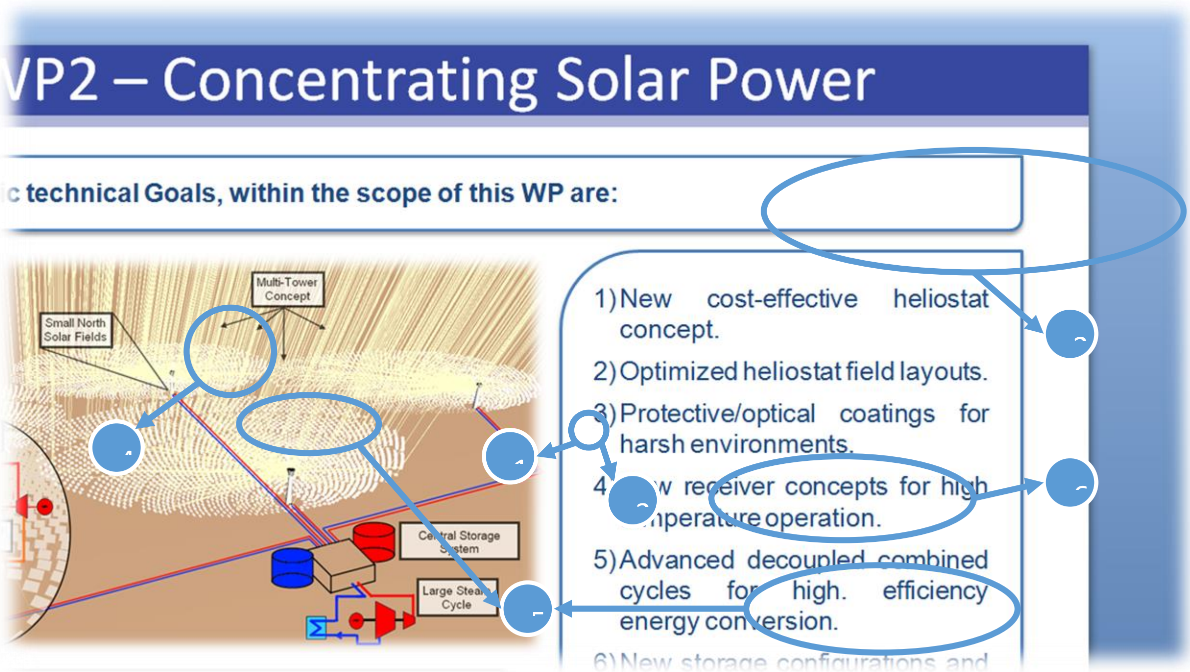


Figure 12: Schema of solar tower plants

The specific technical goals, within the scope of this WP are:

- New cost-effective heliostat concept
- Optimized heliostat field layouts and control
- Protective coatings for harsh environments

- New receiver concepts for high temperature
- Advanced combined cycles (high efficiency)
- New storage configurations and materials for high temperature
- A simulation model to optimize the whole plant

Among the relevant achievements, it is worth highlighting the development of an innovative and cost-effective heliostat concept that led to the local manufacture of several complete heliostat prototypes in Egypt based on local technology and available components Figure 12). Moreover, a heliostat test facility with the required equipment and capacities is now running at Helwan university, thanks to the strong involvement of the company NVE (both partners from Egypt). In addition, promising protective coatings for heliostat mirrors as well as an associated deposition technique have been developed and further work is envisaged to valorise these results in the near future.

Figure 13: Detailed design of the heliostat prototype

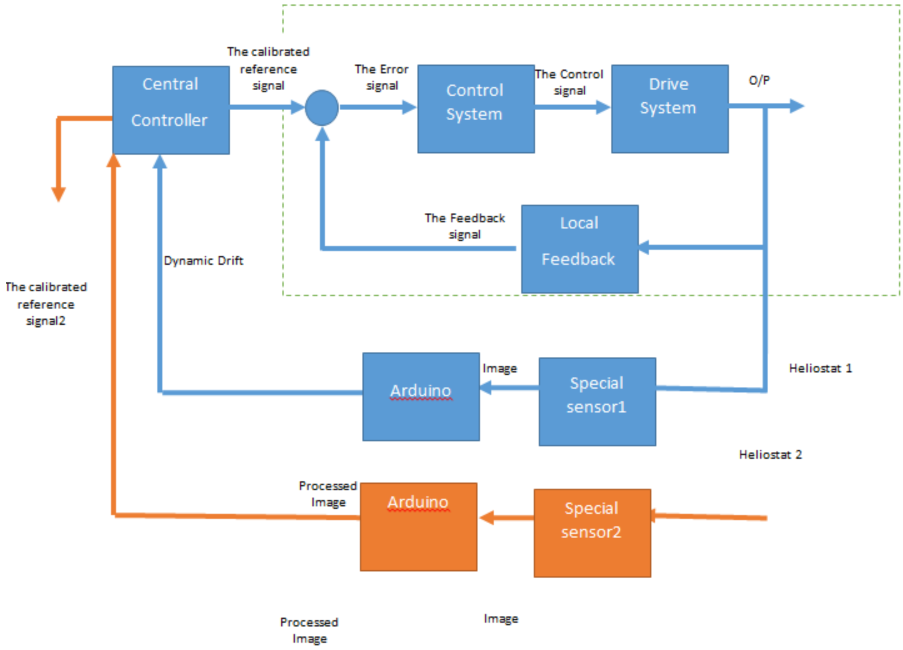


Figure 14: Block diagram for the proposed calibration system

Thin films of several materials including organic and inorganic compounds and their composites have been fabricated (AU, TEKNIKER) and characterized (AU, TEKNIKER, CNRS-CEMHTI) to explore their potential for application as a homogeneous, stable, reliable, and durable protective coating of both front first reflective surface as well as back surfaces (Figure 15). Among the composites, several additives were used as catalyst and hardeners to improve the film mechanical and optical properties. In addition, wide ranges of composition ratios have been tested to maximize adhesion and transparency of the deposited films to the coated surface.

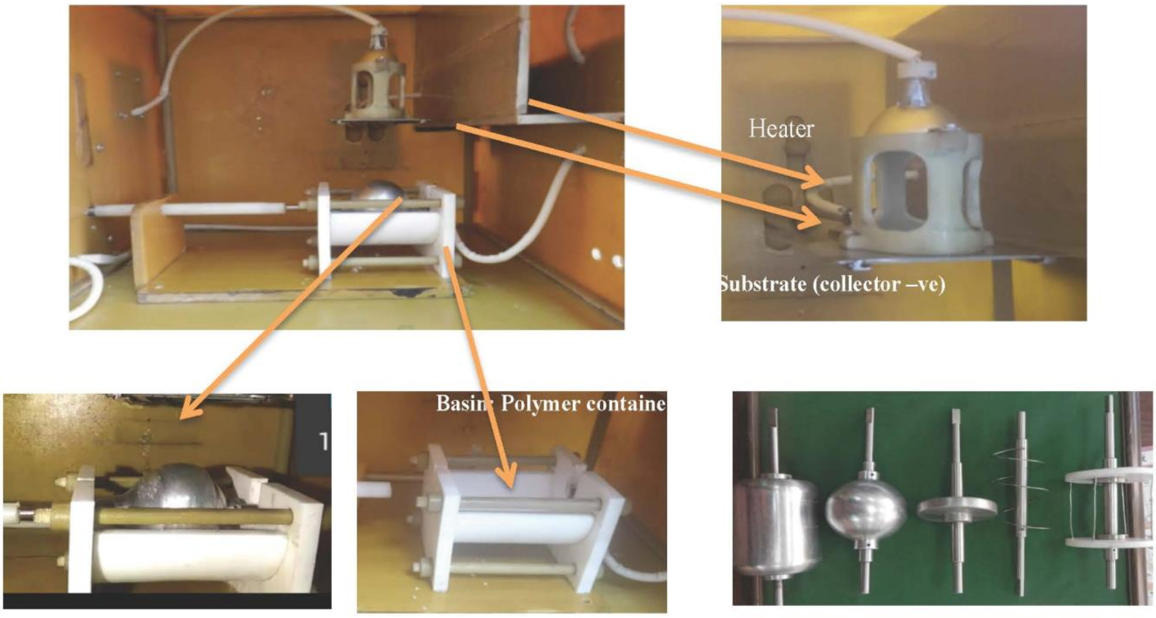


Figure 15: Pictures of various components of the developed NEP equipment

The fabricated organic composites include PDMS/SiO2 (Poly Di Methyl Siloxane / Silicon dioxide) and PDMS/TEOS (Poly Di Methyl Siloxane /Tetra Ethyl Ortho Silicate) which were subjected to several heat treatments under different conditions and were also exposed to UV radiation to examine the effect of aging condition on their quality and behaviour. Specifically, at least six different categories of materials were prepared and at least four different types were prepared under each category (AU). The coatings were subjected to several post deposition heat treatments and other curing processes. Also the effect of using different solving agents was studied.

Necessarily, a complete characterization of the coatings has been done in order to verify the complete transparency of the coatings and the highly specular reflectance of the surfaces. Therefore, all fabricated thin films were subjected to aging tests and characterized. For this, TEKNIKER has manufactured several samples of first surface mirrors which have been used by all the partners (AU, TEKNIKER) to test protective coatings on them. The measurements utilized to determine the characteristics of the deposited coatings included optical transparency, adhesion, thickness, hydrophobicity by contact angle, and durability. Accelerated environmental effect on the film characteristics and composition was also studied.

Another task of the project in WP2 was dedicated to the design and analysis of efficient solar receivers, in addition to a large work and knowledge build on the *detailed analysis (simulation) of open air volumetric receivers*. As a result, an innovative design approach based on *a stacked-plate* *construction allowing for more complex light-trapping geometries and increased light penetration has been proposed*. What's more, and extending the original scope of works of the project, *small-scale stacked-plate receiver prototypes have been manufactured and tested* (Figure 16) on a high flux solar simulator for assessing and improving the design, and work in this line will continue in another EU project named CapTURE.

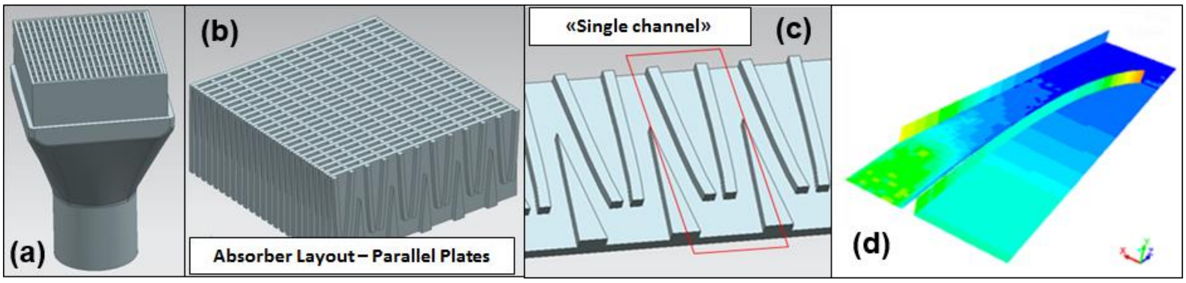


Figure 16: New innovative CPC stacked-plate receiver model

As for the technical goal regarding the development and analysis of Decoupled Solar Combined Cycles (DSCC), several promising *plant schemes have been identified and techno-economically optimized* to assess the benefits of such plant concept (Figure 17).

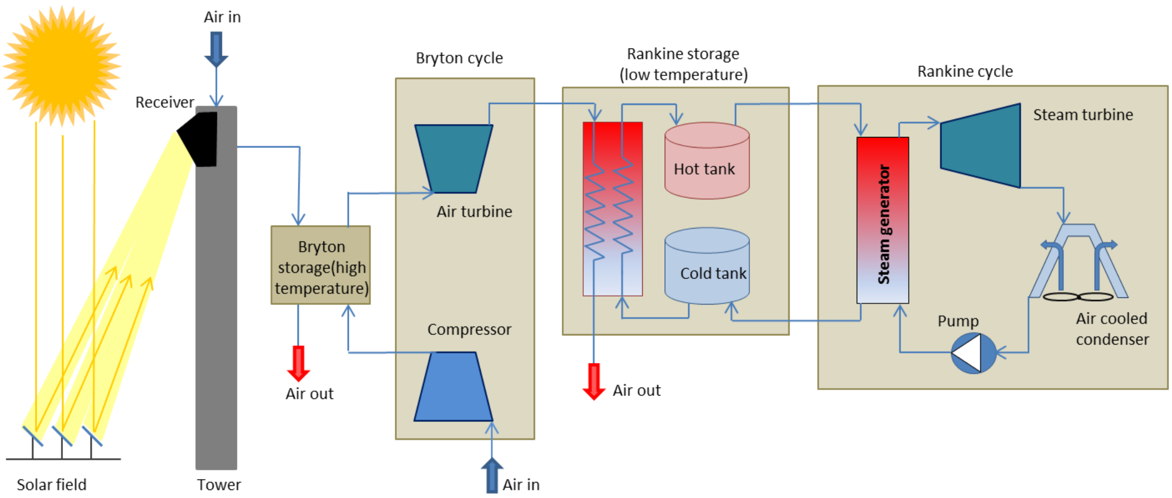


Figure 17: Decoupled Solar Combined Cycle (DSCC) plant scheme and model representation

The main conclusion from the technical analysis was that the proposed plant schemes showed to be a promising power cycle for DSCC solar towers (Figure 17). It showed also that, to ensure an appropriate assessment of coupled dependencies and relations in such a complex system, the simulations need to be performed not only in a design point basis, but also in long term transient simulations. Simulation results showed that an increase in solar to electric efficiency over 30% (from 12.63 to 16.78) can be achieved by using two bottoming Rankine cycles at two different temperatures, enabling low temperature heat recovery from the receiver and Gas Turbine exhaust gasses. The complete study was communicated to the 22nd SolarPACES Conference, 11-14 October 2016, Abu Dhabi (UAE) and is also part of the deliverable *D2.8 Identification of an optimized* *decoupled combined cycle.* In these two documents, more detail in the procedure and results can be found.

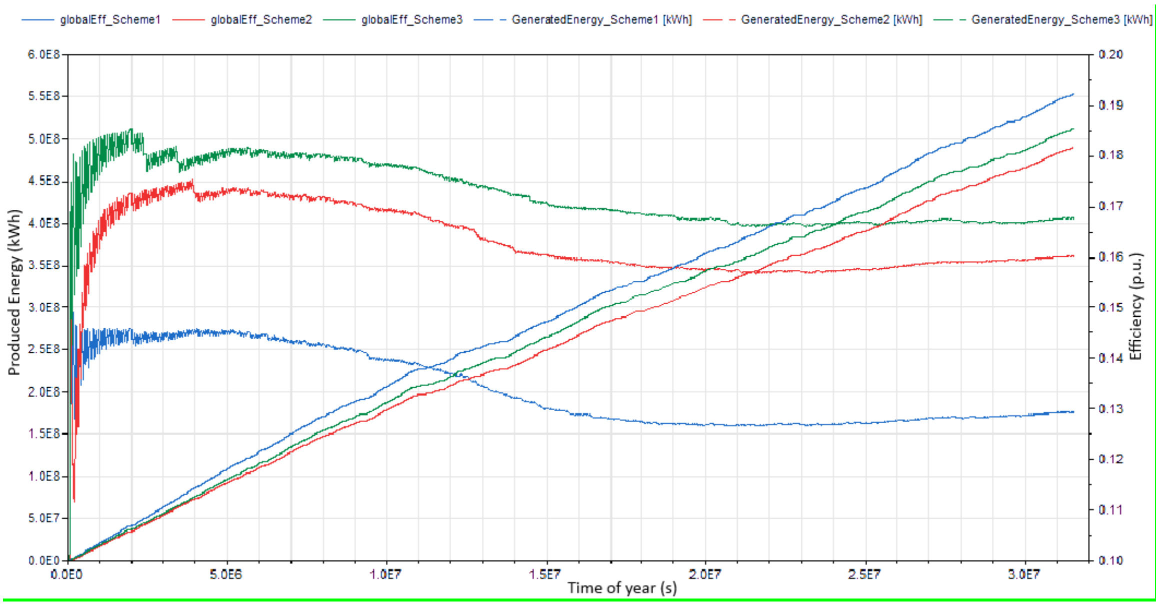


Figure 18: Annual electricity production and global solar to electric efficiency for each of the proposed schemes

In the storage side, innovative *storage media for both medium and high temperature applications have been identified* and thoroughly characterized and evaluated. In this sense, a large number of natural stones from different locations (Morocco, Egypt and France) have been tested for their use in medium temperature packed bed storage configurations, while also a large number of material from industrial wastes (furnace slags, coal ashes and clinker, and more) have been studied for high temperature storage systems. Worth mentioning is the development of an innovative and low-cost Silicon Carbide/Mullite material with promising characteristics not only as storage media but also as a receiver construction material. Also, in this topic further work is envisaged to valorise these results in the near future (Figure 19). Concerning the objective related to the complete plant modelling, this has been satisfactorily accomplished since it was required for the rest of the WP objectives.

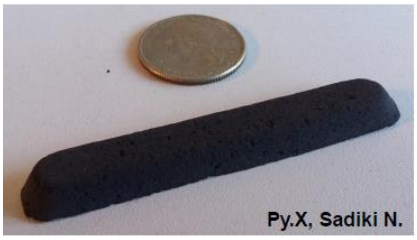


Figure 19: SiC/Mullite recycled ceramic from CFA and Pitch

The results of the optimization process are shown in Table 1 where the optimum values for each of the optimization parameters is shown along with the main results of the annual simulations corresponding to the optimum configurations and the resulting LCOE.

Table 1: Results of the optimization

Optimization Parameters	Optimal values			
	Scheme 1A	Scheme 1B	Scheme 2	Scheme 3
Solar Field aperture (m^2)	121625	122438	144125	82188
Number of towers	15	11	14	19
High temp. TES volume (m^3)	9450	7356	11144	8394
Low temp. TES volume (m^3)	-	-	14139	11541
Rankine cycle gross power (MWe)	50	50	63	48
TES level to turn on power block	0.1	0.1	0.1	0.1
Low temp. TES hot tank temperature (ºC)	-	-	182.5	168.8
ORC gross power (MWe)	-	-	-	15.6
Simulation Results	Scheme 1A	Scheme 1B	Scheme 2	Scheme 3
Solar Field Efficiency	59.36%	59.42%	57.93%	63.24%
Thermal to Electric Efficiency	24.20%	24.13%	27.62%	27.61%
Solar to Electric Efficiency	11.41%	11.35%	12.64%	13.86%
Annual Production (TWh)	577.01	424.36	707.07	597.67
CAPEX (millions €)	901.2	667.9	1099.8	955.7
LCOE (€/kWh)	0.1285	0.1293	0.1280	0.1312

As derived from the table below, the performed optimization process for the whole tower plant proved that reasonably low LCOE values could be reached using air receiver technology with several DSCC schemes. The three plant schemes techno-economically optimized in this work show increasing levels of complexity and performance by implementing additional cut-offs of heat rejection and heat losses from the original scheme. However, despite their technical potential, the results showed that the increased complexity of the more efficient cycles can hardly overweigh the increased costs of the system. Only the second scheme, posing a two-temperature levels heat recovery based on two storage fluids, presents a lower LCOE than the original DSCC plant scheme (-0.4%), at the cost of a more complex configuration and critical control constrains. Considering the accuracy of the models, this had to be regarded as a negligible difference and thus the original DSCC plant scheme with optimized parameters can be considered the best approach for this type of power plants.

As a summary of the work and results achieved in WP2, we have demonstrated that utilizing air technologies and specifically the Decoupled Solar Combined Cycle concept in CSP plants with tower technology is a promising alternative to the state-of-the-art molten salts solar tower power plants. The proposed solutions based on small and low cost heliostats, small and more efficient solar fields in combination with a multi-tower approach and the decoupled Brayton-Rankine cycle approach based on low cost storage systems can effectively lead to increased flexibility in the plant design and opens new possibilities for reducing the energy cost. Nevertheless, the results show that the thermal-to-electric conversion efficiency achieved with this approach is still lower than the efficiency of the large steam cycles currently used in the molten salts technology. In this sense, future works should be focused either on further reducing the system costs, on further increasing the system efficiency or, preferably, on both. Accordingly, new projects focused on improving the receiver-Brayton unit, like the ongoing European project CapTURE, promoted by several EUROSUNMED partners, are of great importance.

The **workpackage 3 (Grid integration)** on grid integration has covered a wide range of issues, from grid code development, grid development and interconnectors, energy storage integration and power system stability. The last point has been in focus during the last twelve months, with studies addressing the Moroccan grid and the Egyptian grid.

A reduced grid model of Morocco was created, with internal grid constraints that limit the power output from renewable power plants. The 2030 scenario includes a very large demand increase in Morocco, and a large increase in solar and wind power generation capacity. To facilitate this expected renewable production and demand growth, large investments in electric infrastructure are needed. The study computed operational cost information from PowerGAMA simulations and combined this with a separate investment analysis in order to perform cost-benefit assessments.
The results from the Morocco study indicate that 16 branch investments can be the preferable investment strategy for Morocco towards 2030, giving an annual reduction of 279 M€, and spillage reduction of 92 % compared to a case without any grid investments. This work was presented at the European Energy Management Conference in Porto in June 2016.
For the Moroccan case, numerical grid models have been developed with the country's expected production in 2018 and 2020, including large solar power plants in the South. Steady-state and dynamic analyses have been performed to identify potential grid stability problems and strategies for how to enable large-scale grid integration of renewables. To reduce the modelling and computational burden, dynamic analyses considered only the southern parts of Morocco, where most of the new wind and solar power is expected to come. The aim of this investigation was to determine the critical fault clearing times for 225 kV and 400 kV power lines. The results from these dynamic analyses show that the loss of a 400kV network line causes serious instability issues and could lead to a total loss of the entire southern sub network. To overcome these issues, multiple solutions were proposed; such as the reinforcement of the electric network, or the reduction of maximum power generation of some renewable energy stations in the southern region. Using the latter solution, a simulation was performed with a 280 MW reduction of the total renewable southern power capacity.

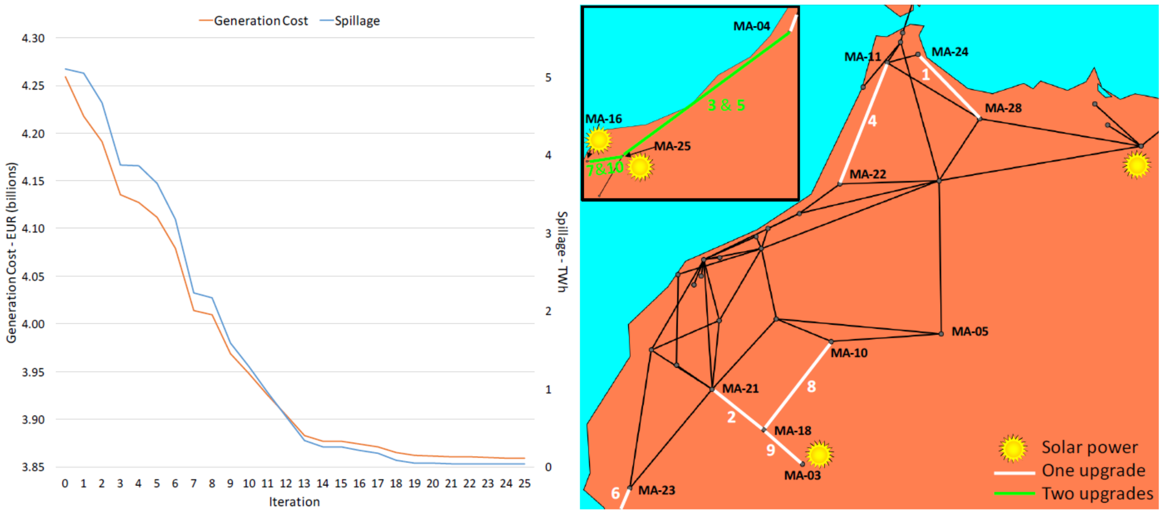
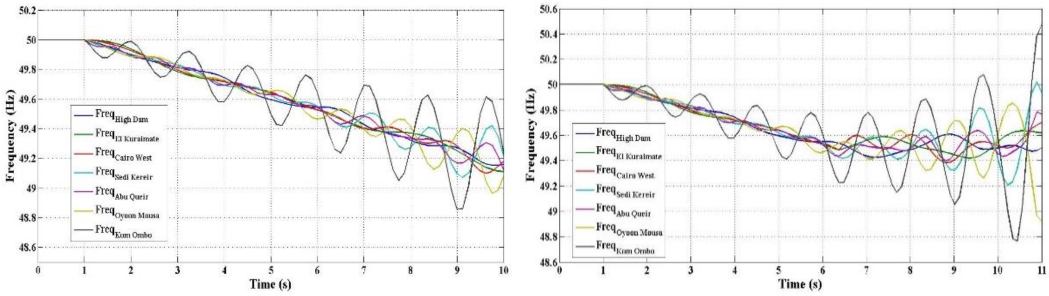


Figure 20: Results from analysis of beneficial grid upgrades in 2030 Morocco scenario

For the Egyptian case, numerical models including the highest voltage levels have been developed and analysed. Several issues related to the integration of renewable energy have been considered. One is the siting of solar power plants, considering both the resources, the reliable operation of the grid and power transmission losses. Another important topic is the transient stability in the future system with more wind and solar and less traditional power generators connected to the grid. The reduced inertia in the power system makes it more volatile and maintaining system stability requires additional measures.

In particular, intensive work concerned the case for a new generation reliability index for PV plants, and the application of this to different potential PV sites in Egypt. Results have highlighted that Cairo is considered as the best site for fixed plane PV plants, while KomUmbu is the best for sun tracing PV ones. Both fixed and sun-tracking plants have the same degree of reliability in KomUmbu. Suez does not have any benefits, from reliability point of view, for PV plants compared by the other studied sites, as shown in the following Table 2.
Furthermore, another study concerned the effect of large scale CSP plant with conventional thermal storage, and proposed hybrid battery/thermal storage system to maintain long-term frequency stability. The proposed scheme was applied on an Egyptian case study with results as shown in the figures below (Figure 21):



(a) *(b)*

Figure 21: long term stability for CSP plant. a) with conventional thermal storage, b) with hybrid proposed scheme

An important work dealt with the simulation study of stability with large-scale integration of renewables in the Egyptian power system. The simulation model of the Egyptian transmission system, developed in DigSILENT PowerFactory, has been improved and updated according to new knowledge about the real system. The model has been expanded by adding more nodes at 500 kV level, and by including parts of the 220 kV system in line with recommendations from Helwan University.

Two base cases (high load and low load) representing the present situation, and cases representing possible future situations with large share of power from renewables in the system, have been defined. For the purpose of the study it is assumed that most of the new renewable power plants will feed power into the system via power electronics converters (PV, full-converter wind turbines). Steady-state results indicating the generation mix for these cases are shown Table 2 **below:**

Table 2: Steady-state results indicating the generation mix for these cases

Case	Type of renewable	Power generated from renewable power plant	
		Generated power [MW]	Share of total [%]
High load, base case	Hydro	2 239	8.3
	Solar	123	0.5
	Wind	437	1.6
	Total renewables	2 798	10.4
High load, high renewable scenario	Hydro	2 161	8.1
	Solar	1 693	6.3
	Wind	4 086	15.3
	Total renewables	7 490	29.8

Case	Type of renewable	Power generated from renewable power plant	
		Generated power [MW]	Share of total [%]
Low load, base case	Hydro	885	11.5
	Solar	95	1.2
	Wind	388	5.0
	Total renewables	1 367	17.8
Low load, high renewable	Hydro	852	11.0
	Solar	1 289	16.7
	Wind	2 253	29.1
	Total renewables	4 394	56.8

In addition to the scientific results themselves, the work has enabled a significant step up in research capacity for partners, providing training and experience with state-of-the art software (PSSE, PowerFactory, PSAT, Matlab) and methods for analysis of grid stability. This experience, and the grid models that have been developed, have a high value beyond the project duration and is a key outcome of the work package.

Another essential activity in EUROSUNMED is that developed within **workpackage 4** dealing with training activities and exchange of staff.
We have distinguished different training activities:

- *Individual visits or Secondments:*

During the entire project, a total of 70 visits were counted. Most of training activities were carried out during the 3 first years of the project

Table 3: distribution of exchanges during the project

WP1/WP5 WP2/WP5 WP3 WP7

	2013				2014											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CNRS									1	1					2	
SINTEF													1			
SINTEF E							2									
CENER						2										
TEKNIKER																
EUREC																
EMRS																
CNESTEN					1								1		1	
MASCIR										1						
UM5A									1							
AUI																
MASSEN																
HU									1				2			
AU									1							
TURBODEN																
NVE									1					1		
	0	0	0	0	1	2	2	0	5	2	0	0	4	1	3	0

	2015											
	17	18	19	20	21	22	23	24	25	26	27	28
CNRS								1		1	1	1
SINTEF												
SINTEF E						1					1	
CENER						2						
TEKNIKER												
EUREC												
EMRS												
CNESTEN												
MASCIR										1	1	1
UM5A					1							
AUI								1	1	2		
MASSEN												
HU		2								1		1
AU		7										
TURBODEN												
NVE		2			1							1
	0	11	0	0	2	3	0	2	1	5	3	4

	2016											
	29	30	31	32	33	34	35	36	37	38	39	40
CNRS		1		1		2						
SINTEF												
SINTEF E												
CENER					1						2	
TEKNIKER											2	
EUREC												
EMRS												
CNESTEN												
MASCIR												
UM5A					1							
AUI												
MASSEN												
HU								1			2	
AU											2	
TURBODEN												
NVE											1	
	0	1	0	1	2	2	0	1	0	0	9	0

	2017								
	41	42	43	44	45	46	47	48	Total
CNRS					1				13
SINTEF									1
SINTEF E				1					5
CENER									7
TEKNIKER									2
EUREC									0
EMRS									0
CNESTEN									3
MASCIR									4
UM5A					1				4
AUI									4
MASSEN									0
HU									10
AU									10
TURBODEN									0
NVE									7
	0	0	0	1	2	0	0	0	70

These last visits were linked to WP1, WP2 and WP3 (Figure 22) with a majority from MPCs to EU (Figure 23). These exchanges allowed students and researchers to create a solid and creative network and to increase the synergy through joint research in order to obtain high quality results, products, and publications. Moreover, these activities allowed the MPC partners in the consortium to gain new and important knowledge with regards to advanced technologies needed for the development of renewable energies in their region. All WPs were concerned by training

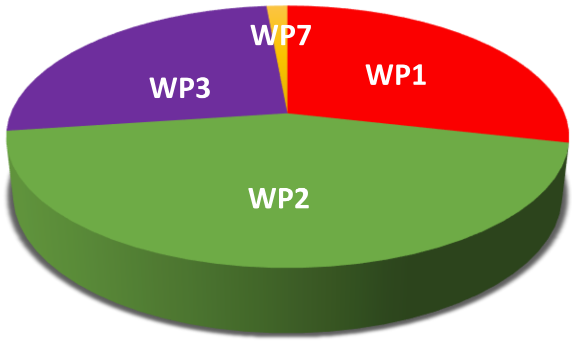


Figure 22: Breakdown of secondments versus Workpackages

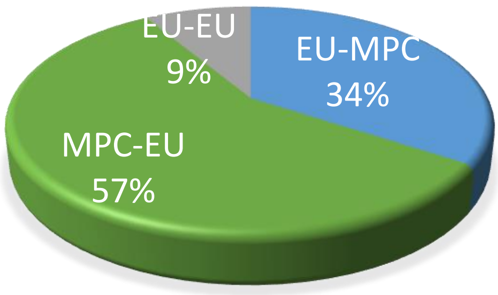


Figure 23: Breakdown of directions of secondments

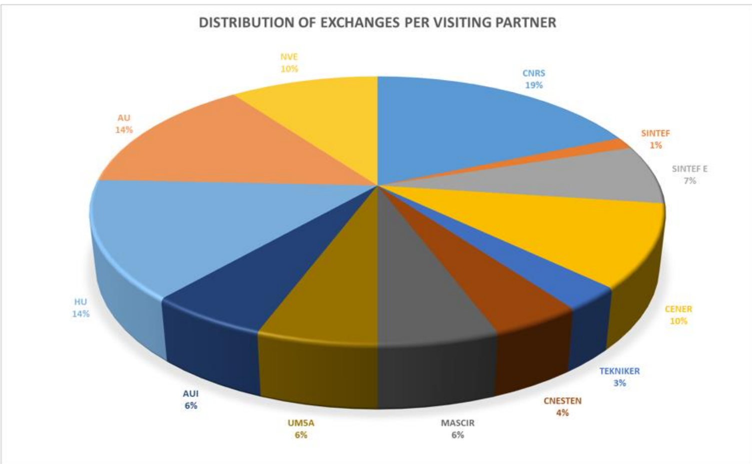
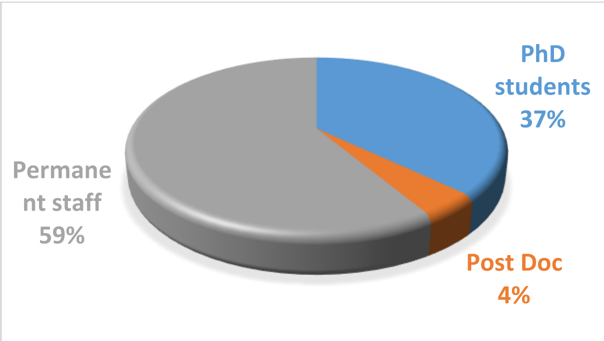


Figure 24: Breakdown of secondments per partner

Figure 24 shows that all partners (Academia, research centres, private sector) have benefited from the training.

The following diagrams show that most of the training (59%) concerned permanent staff from MPCs with the objective to train the trainers. About 37% of the training concerned PhD students (26 in total).



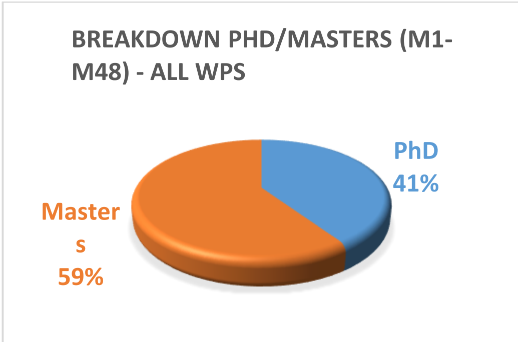


Figure 25: Breakdown by staff category participating in the exchanges and by type of diplomas prepared

- *Training through schools:*

Four EUROSUNMED international schools were organized as shown below. More than 400 students received teaching on renewable energies. This training benefited in majority the MPCs students to enhance the capacity building in these countries.

Table 4: Details regarding the international schools organized during the project

EUROSUNMED International Schools M1-M48									
Event title	Place	Date	Number of Professors	Number of Female Students	Number of male Students	Total number of Students	Nb of Students per Region		
							EU	MPC	Others
Eurosunmed "State of the Art" on Renewable Electricity Generation"	Rabat (Morocco)	7-11 April 2014	15	70	102	172	8	163	0
Eurosunmed International School on PV, Grid Integration and the Economics of Renewable Energy	Sharm el Sheik (Egypt)	28-31 March 2015	16	43	67	110	7	102	1
International School of solid state physics 5th course on "Materials for Energy and Systainability V" and 3rd Course of the "EPS-SIF International School on Energy	Erice (Italy)	13-19 July 2016	31	48	31	79	40	24	15
EUROSUNMED - REUNET CSP training	Ouarzazate (Morocco)	24-27 April 2017	4	26	32	58	0	58	0
			66	187	232	419	55	347	16

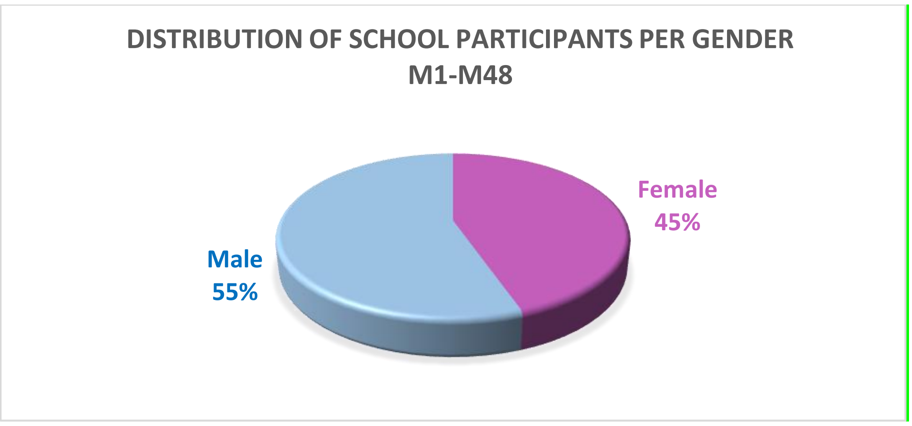


Figure 26: distribution of school participants per gender

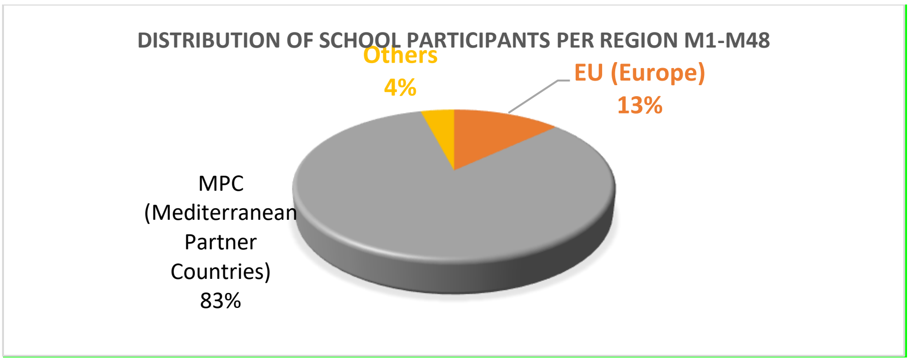


Figure 27: distribution of school participants per region

The **workpackage 5** entitled **demonstration** is intended to the test, under real functioning conditions, of different prototypes developed during the R&D period. Demonstration linked to WP1 consisted in testing about ten silicon based mini-modules produced under real condition of sun irradiation and humidity in three Moroccan cities, namely Rabat, Marrakech and Ifrane. The photovoltaic performances of the modules were recorded versus time (16 months' operation), solar irradiation and temperature. The major result is that the performances of the mini-modules were not reduced over time (deviation less than 0.5%) whatever are the type of silicon module technologies. This is good news for the deployment of photovoltaics in these parts of Morocco.

On the other hand, it should be pointed out that the first Heliostats experimental field was successfully established in Egypt. The Egyptian partners gained tangible know-how and technology transfer for Heliostats designs, manufacturing, control and operation in cooperation with EUROSUNMED partners. This important achievement was reached thanks to the involvement of some Egyptian SMEs and public authorities in EUROSUNMED. Yet, additional experimental work should be conducted to enhance the auto tracking of the Heliostats system against the source of error.

Workpackage 6 is dedicated to the **dissemination** activities of the work carried out in EUROSUNMED and beyond. Many tools were used to this end. The outreach activity towards the general public was continued during this third period through several mechanisms such as the EUROSUNMED web page (www.eurosunmed.eu) continuously updated, newsletters sent every six months, brochures and social media outlets distributed during different events. Thus, as figures we can cite 48367 hits of the project website, 13 newsletters disseminated to 886 addresses and 773 likes on Facebook page.

The project aims and outlooks were also presented at different conferences. The list of the EUROSUNMED events are presented in the table below. Such events have allowed to generate a very strong international network as well as disseminating EUROSUNMED results to a very large public as well as acquiring new knowledges.

Table 5: List of Eurosunmed events

Project Month	Date(s)	event	Local host , City (Country)
M8	7-11 April	1st International School and workshop	MAScIR Rabat (Morocco)
M20	28 - 31 March	International school	HU, AU, NVE Sharm el-Sheikh (Egypt)
M21	14 - 15 May 2015	EUROSUNMED AMREN-1 Symposium at EMRS Conference	EMRS Lille (France)
M32	14 April 2016	EUROSUNMED 1st Roadmap workshop	EUREC Brussels (Belgium)
M33	5 May 2016	EUROSUNMED AMREN-2 Symposium at EMRS Conference	EMRS Lille (France)
M35	13 - 19 July 2016	3rd International School	Erice (Italy)
M38	14 - 17 Nov. 2016	2nd Roadmap workshop	Marrakech (Morroco)
M43	20 March 2017	1st Industrial Workshop	Helwan University, Cairo(Egypt)
	21 March 2017	Solar Festival	Helwan University, Cairo (Egypt)
M44	20 April 2017	2nd Industrial workshop	MASEN, Casablanca (Morocco)
	24 - 27 April 2017	International School	MASEN, Ouarzazate (Morocco)

In particular, the dissemination of the project results towards the scientific community was carried out via about 32 publications in journals and 34 in proceedings. About 148 communications as oral or poster presentations were given at several key conferences and workshops (EMRS-2017, IRSEC-6, SolarSPACES, JNPV, JNES ...).

The main objective of **Workpackage 7**, EUROSUNMED Roadmap, is to create a long-standing cooperation between the involved partners both from EU and MENA region, with a focus on Mediterranean Partner countries (MPCs).

The general targets for long-standing cooperation can be defined as follows:
For MENA countries:

- Possibility to satisfy an electricity demand, which grows by 5-9% per year
- Reduction of energy costs (in most MENA countries, fossil fuels are subsidized)
- Development of a green economy with opportunities to create a local industry and job opportunities
- Control and reduction of pollution

For the EU:

- Reduction of oil and gas imports
- Boosting the EU energy industry along the whole value chain
- Reduction of electricity costs, by optimizing exchanges
- Reduction of CO2 emissions

Based on these assessments, we have built a comprehensive roadmap upon different inputs developed within the EUROSUNMED project as illustrated in Figure 28:

- Results of activities developed by WP1, WP2 and WP3 related to the development of new technologies for, respectively, photovoltaics, solar thermal electricity, and grid integration
- Deliverable 7.1, which makes a review of the existing resources in the MPCs (with a focus on Morocco and Egypt)
- Roadmap workshops, organized in April 2016 and November 2016, where EUROSUNMED partners, as well as identified external experts, brainstormed and discussed potential actions to be developed between partners from EU and MPCs on solar energy and grid integration technologies.

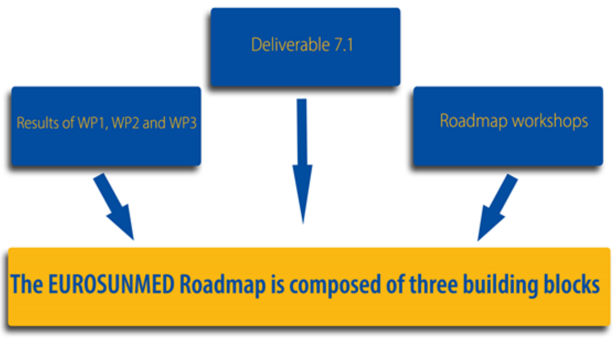


Figure 28: The pillars for setting the EUROSUNMED Roadmap

Network of experts and expertise:

To support the roadmap, a network of experts from research, industry, academia and civil society was set up with the following objectives:

- Identifying areas where research cooperation on renewable energy is further needed (wind, solar, biomass, hydro)
- Identifying barriers and best practices for the introduction of renewable energies in MPCs (case studies on MPCs)
- Developing professional courses on renewable energy
- Defining general principles for public awareness campaigns
- Organizing an annual conference and several experts' meetings

Thus, the built database of external stakeholders is composed of 411 experts. It includes 170 companies, 102 public institutions and NGOs, 139 research centres and universities. A breakdown of the experts' data in terms of type of organizations, geographical distribution and number of companies per sector is given in Figure 29.

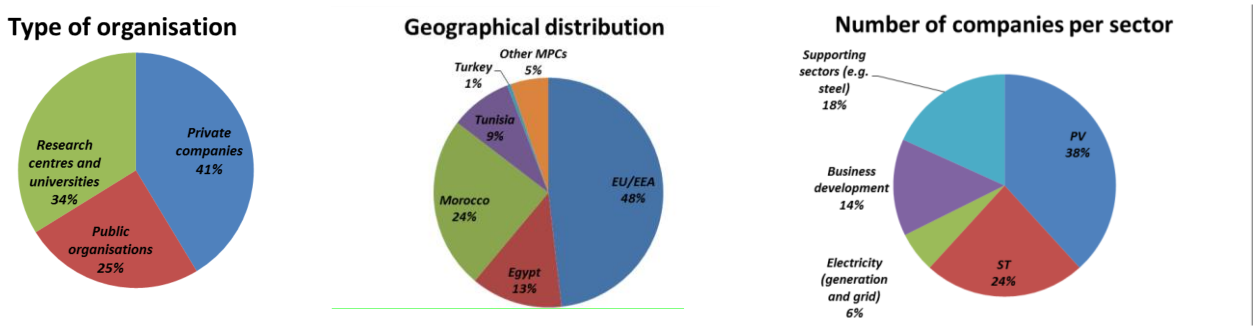


Figure 29: Composition of the pool of experts per organization, geographical distribution and companies'sector

From the technical side, we have found that local manufacturing of components is important in order to ensure the development of a local industry (Thin Film PV cells, CSP heliostats, transformers, PV modules, Biomass technologies). The fields are the following:

- Energy storage technologies
- Power electronics for grid integration
- Smart grids and demand side management
- Energy efficiency and integration in buildings
- Material science research on RE (polymers)
- Water desalination
- Advanced hybridisation between PV and CSP
- Component durability
- Innovation management
- Process heat

<u>EUROSUNMED Roadmap workshops:</u>

The second pillar of setting a roadmap is organizing a workshop to discuss potential actions to develop solar energy and grid integration technologies at MPCs with the support of EU partners. Thus, the 1st roadmap workshop was organized on 14th of April 2016 in Brussels in cooperation with REELCOOP. The agenda was the following:

- Plenary session in the morning
- Parallel sessions in the afternoon
    - Targets for long-standing cooperation
    - Identification of needs to identify the above-defined targets

Pictures taken during the 1st Roadmap workshop in Brussels.

A 2nd roadmap workshop was organized on 15th November 2016 in Marrakech during IRSEC '16 conference and COP22. More than 40 participants attended. Several outstanding international speakers gave general talks: David Ginley (NREL, USA); Arthouros Zervos (REN21, IT); Obaid Amrane (BoD of MASEN, MO); Marcel Bial (ESTELA, B); Philippe Malbranche (INES, FR); Said Azhi (QEERI, Quatar). The presentations were followed by intensive discussions about the tools to reach long standing cooperation between the partners.

Picture taken during the 2nd Roadmap workshop in Marrakech.

<u>EUROSUNMED Roadmap:</u>

We have identified several tools that will facilitate long standing cooperation between EU and MPCS in the solar energy sector. The table below is presenting a large overview. More details can be found in Deliverable 7.3 dedicated to the roadmap.

Table 6: Roadmap tools to facilitate long standing cooperation between EU and MPCs

Technology development	Access to capital	Policy framework	Workforce
Local cost-effective manufacturing of solar cells and other components	Development of public-private partnerships	Creating government bodies, agencies and institutions	Development of local industry
Cost reduction of CSP technology translating into a supply price of <10c€	Different financial needs according to the project scale	Legislation related to the electrical grid	Scientific/ engineering profiles
Development of next generation STE technologies	Involvement of local banks	Increasing public awareness	Project managers
Harmonised grid codes between North Africa and EU	New financial schemes and guarantees	Regulatory body for the monitoring of the energy market	Training and education along the whole value chain (from construction to operation)
Smart grids and demand-side management		Economic incentives and financial infrastructures for RE and EE	
Energy storage technologies (controllers, inverters, fuel cells…)		Advantages to facilitate investments from the private sector	
Power electronics for grid integration		Government guarantees for local banks	
Energy efficiency and integration in buildings (e.g. BIPV)		Incentives to attract foreign investments	
Software and monitoring systems		Developing standards	
Material science research on renewable energies			
Water desalination			
Advanced hybridization between between PV and CSP			
Components' durability			
Solar fuels			
Process heat			

Finally, two industrial workshops were organized to disseminate the EUROSUNMED Roadmap:

- in Cairo on 20th March 2017
- in Marrakech on 20th April 2017

The total number of participants for both events was about 100.

It is worth mentioning that several new projects, initiated by EUROSUNMED partners or in which they were invited to participate, are now running which insure already continuation of cooperation between EUROSUNMED partners and beyond. Namely:

- MEDSOL *(Erasmus+ call on Solar Energy in Med countries)*
- INFINITE-Cell *(MCSA-Rise call on CZTS/Si solar cells)*
- CAPture *(Competitive Solar Power Towers)*
- 5TOI (Open Innovation in Energy, Water, Agriculture in The South Mediterranean Neighborhood
- International Associated Lab (CNRS-UMV) on PV

4. *Potential impact and main dissemination activities and exploitation results*

EUROSUNMED intended to have a major impact on the existing European know-how of PV (CZTS/Si tandem cells on low cost substrates), CSP (novel materials for heliostat coating, controllers, receivers and storage) and Grid technologies (modelling, limitations for the integration…) since it gathers sharp and complementary experiences from the consortium. EUROSUNMED also aimed at contributing significantly towards facilitating the transfer of knowledge on both sides of the Mediterranean Sea and the spread out of technical and management skills and encouraging field training for high caliber graduates intending to pursue a career in academia or industry. Finally, EUROSUNMED has offered opportunities for industrials involved in the project and beyond, to gain new knowledge and increase their competitiveness.

In the following, we will give some insights on the potential impact and the main dissemination activities and the exploitation of results that EUROSUNMED has generated after four years of the project.

- ***Knowledge related impacts:***

Several events such as symposia, workshops and schools were organized during the whole period of the project either to get knowledge or to disseminate the EUROSUNMED results. The list of events is displayed in Table 7.

More concretely, EURSOUNMED has generated the following outreaches over the whole period:

- More than 400 students were trained on renewable energies, and solar energy and related in particular
- More than 65 publications in high ranked journals and in proceedings, with a majority as joint publications. More than 15 papers are under review. This enhances the international visibility of the field and that of the partners. This is good for the employment of the next generation of students.
- More than 70 communications to conferences and workshops, which contributed to increase the ability of students and researchers to communicate to the outside world. This also will ease the employment during the interviews.
- Initiation of two European projects dealing with solar energy (MEDSOL, INFINITE-CELL) which will allow the continuation of enhancing the capacity building of MPC and EU countries in the field of solar energy.
- Initiation of an International master degree on renewable energies, with a focus on solar energy and storage. It is important for a large deployment of the RenEn in general.
- Initiation of an international Research lab (CNRS (FR) and UM5 (MO)). It is a good opportunity to enhance the international cooperation between the two countries, and beyond.

Table 7: list of events

Project Month	Date(s)	event	Local host , City (Country)
M8	7-11 April	1st International School and workshop	MAScIR Rabat (Morocco)
M20	28 - 31 March	International school	HU, AU, NVE Sharm el-Sheikh (Egypt)
M21	14 - 15 May 2015	EUROSUNMED AMREN-1 Symposium at EMRS Conference	EMRS Lille (France)
M32	14 April 2016	EUROSUNMED 1st Roadmap workshop	EUREC Brussels (Belgium)
M33	5 May 2016	EUROSUNMED AMREN-2 Symposium at EMRS Conference	EMRS Lille (France)
M35	13 - 19 July 2016	3rd International School	Erice (Italy)
M38	14 - 17 Nov. 2016	2nd Roadmap workshop	Marrakech (Morroco)
M43	20 March 2017	1st Industrial Workshop	Helwan University, Cairo(Egypt)
	21 March 2017	Solar Festival	Helwan University, Cairo (Egypt)
M44	20 April 2017	2nd Industrial workshop	MASEN, Casablanca (Morocco)
	24 - 27 April 2017	International School	MASEN, Ouarzazate (Morocco)

The possibilities for the exploitation of results are summarized below for photovoltaic (PV), Concentrated Solar Power (CSP) and Grid Integration (GI):

Table 8: Exploitation results

WP	Exploitable result and type	Expected use	Benefiting partner/sector/business
PV	Silicon foil (80-100 µm thick) based solar cells were produced; quantum efficiencies of about 14%were reached. they also serve as bottom cell for the CZTS/Si tandem structures Ultrathin Polycrystalline silicon films (2-10 µm thick) were prepared by solid phase crystallisation of amorphous silicon and subsequent epitxay par ECR-PECVD process on Al substrate Semi-transparents CZTS cells were prepared by ultrasonic spray or by sputtering, to serve as a top cell for CZTS/Si tandem structure with silicon More than 15 papers were published in referenced journals concerning Si and CZTS. A patent is accepted for the growth of poly-Si films on Al substrates, and another one is under review.	Development of low-cost solar cells to compete with conventional thick silicon wafer based solar cells and modules	Photovoltaic companies such as PHOTOWATT in France, STILE in France, SolarWord in Germany
CSP	Development of new conceptual designs of economically viable heliostat and controllers due to the use of small size mirrors and commercially mass produced components. Development various optical coatings that can be deposited on the first reflecting surfaces of mirrors to protect against harsh environmental condition. The process and the system used of to deposit theses coatings were also developed within this task efforts	Development of less expensive solar field for central tower receiver concentrated solar thermal plants. Both the coatings and the process are valuable for industries involved in	Industrial intensities and research institutions and partners involved in construction and R&DT activities targeting cost reduction of CSP plants. Industries and project partners involved in developing protective coatings of reflecting surfaces.

	Development of low cost and very efficient absorber for central receivers. This material is produced from industrial waste. Development of several thermal energy storage (TES) materials that have a potential for utilization as a low cost TES for the CSP storage tanks. The results included materials obtained from industrial waste as well as molten salts with Nano-materials additives Development of new schemes and configuration of the power block of CSP power plant in addition to improved utilization efficiency of the solar field More than 15 papers in journals were dedicated to these topics. The first CSP demonstration unit is installed in Cairo and will be a strong tool for training.	production of protective coating of commercial mirrors used in desserts and remote areas. The materials developed in this effort can be used for production of low cost and efficient receivers and storage systems for CSP plants. Applying new schemes would improve the efficiency and dispatchability of CSP power plant.	Industries and technology developer of CSP plants. CSP system designers and operators Universities and research centres. System installers can also make use of these knowledge for human recourse development

The efforts made by each project partner in the domain of exploitation of results is summarized as follows:

Table 9: efforts made by each project partner in the domain of the exploitation of results

Participant		Expertise	Exploitation foreseen	Exploitation
1	CNRS	• Materials and photovoltaic devices • Materials for storage • Conc. solar power	• Increase knowledge • Publications/patent s	• 10 communications at international conferences • 8 papers in journals • 2 patents (1 accepted, 1 under review)
2	SINTEF	Materials and photovoltaic devices	• Increase knowledge • Publications/patent s	• 7 communications at international conferences • 5 papers in journals • 2 patents shared with CNRS-ICUBE
3	SINTEF E	• Power system analysis	• Increase knowledge	• 2 communications at international conferences

		• Component modelling of generator units with regard to analysis of power system integration issues with special focus on dynamic interactions. • Optimization of power systems with regard to both design topology and operation. • Expertise in measurement for verification and testing of model development. Both laboratory test benches and field measurement campaigns.	• Publications/patents	• 3 papers in journals • SINTEF Energy Research aims to exploit the PowerGAMA software as a means to develop new projects and collaborations, and possibly by applying it on a service basis for commercial clients. As an open source tool, the software itself cannot be sold, however the expertise in using it is highly valuable.
4	CENER	Applied research and development, and promotion of renewable energies.	• Increase knowledge • Publications/patents	• 8 communications at international conferences • 5 papers in journals
5	IK4	Centre of mechatronics, manufacturing technologies and micro-technologies, in areas such as industrial products designing and consumer goods.	• Increase knowledge • Publications/patents	• 4 communications at international conferences • 2 papers in journals
6	EUREC	European association representing research centres and university departments active in the area of renewable energy	• lobbying for the deployment of renewable energies • organization of industrial workshops	• NA yet
7	EMRS	the largest conference organizer in Europe in the field of advanced functional materials,	• Dissemination of knowledge and networking	• Organization of 4 school and 4 workshop
8	CNESTEN	Research and services in energy, health,	• Increase knowledge • Publications/patents	• 2 communication at an international conference

		industry, water and environment, mines and geology		• 1 paper in journals
10	MASCIR	Materials and nanotechnology, including optics & photonics, to microelectronics and biotechnology,	• Increase knowledge • Publications/patents	• 8 communications at international conferences • 6 papers in journals
11	UM5a	Research lab on semiconductors and oxides	• Increase knowledge • Publications/patents	• 8 communications at international conferences • 6 accepted publications
12	AUI	Research activities in: solar thermal energy, photovoltaic installation, wind generators installation, biomass to bioethanol fuel, smart grid and smart metering.	• Increase knowledge • Publications/patents	• 9 communications at international conferences • 3 accepted publications
13	MASEN	Promotion of solar resources in every aspect	• Deployment of RenEn in Morocco and other MPCs • organization of industrial workshops	Contact with the industrials dealing with the development of solar plants worldwide. Important for the roadmap.
14	HU	Research on CSP and Grid	• Increase knowledge • Publications/patents	• 7 communications at international conferences
15	AU	Research on PV and CSP	• Increase knowledge • Publications/patents	• 5 accepted publications
16	TURBO	Turboden designs and develops turbo-generators, based on the Organic Rankine Cycle (ORC	• Increasing the experience in Concentrated Solar Power. • Studying plant configurations with higher solar to electric energy efficiency • Disseminating the ORC technology in the Mediterranean area thanks to the road map plans and the training activities	• 2 communications at international conferences

17	NVE	SME mainly working in the field of Electro-Mechanical jobs	• NVEC busICube development and scope of work expansion • Increase shareholders Return on Investment • Create a new market for the company and increase busICube volume • Expand the company market & being introduced to the regional markets • Increase NVEC working force • Improve technical staff and introduce new training courses	• Participation in one H2020 event in Cairo, Egypt

- ***Economical impact and opportunities for industrials:***

  - A confirmed patent and two pending ones.
  - First Heliostat experimental field in Africa, which can serve for developing new heliostats, receivers, electronics that are compatible with harsh environmental conditions.
  - Test plate-forms for photovoltaic modules that can serve for education but also for new installed companies in Morocco.
  - Nile Valley Engineering in Egypt has extended its activities from cooling/heating systems and ICT components to the solar energy sector; Thanks to the network and meeting organized within EUROSUNMED, the company NVE is now in contact with several stakeholders in Europe and in North Africa and Turkey.
  - TURBODEN company was introduced to the Moroccan and Egyptian market through the different EUROSUNMED events
  - Availability (and knowledge) of grid codes (Powergamma…) at universities (AUI (MO), HU (EG)) that can be of use by the electricity providers in Morocco (ONEE) and in Egypt (NREA).

A detailed list of Exploitable results and type versus expected use and in which business sector is given below to complete the information.

Table 10: detailed list of exploitable results and type versus expected use

Exploitable results and type	Expected use	Benefiting sector or business
Identification of improved solar field layout algorithms+	Creating concentrating solar power plant designed with larger optical efficiency in the heliostat field. These algorithms can be used in two ways: 1) to assess the actual technology potential and study innovative and more efficient plant schemes and, 2) to propose and use these algorithms towards their customers while developing new plant designs.	Concentrating Solar Power
Lab-scale volumetric air receiver test bench	Validating new or existing volumetric air receiver designs by testing lab-scale samples under real-like solar fluxes and operating conditions. Also, in the development of future high temperature volumetric air receivers that could lead to improved efficiencies in concentrating solar power plants based in the air technology.	Concentrating Solar Power
Volumetric air receiver validated simulation model	For its own projects or for industrial customers to aid in the design of improved volumetric air receivers. Also, to design or help in the development of future high temperature volumetric air receivers that could lead to improved efficiencies in concentrating solar power plants based in the air technology.	Concentrating Solar Power
Decoupled Solar Combined Cycle power plants simulation model	For its own projects or for industrial customers to aid in the design of improved concentrating solar power plants based in open air technology (not only in the Decoupled Solar Combined Cycle scheme but in almost any other scheme based in open volumetric air receivers). Also, to design or help in the development of future high temperature volumetric air based concentrating solar power plants that could lead to improved efficiencies and reduced generation costs.	Concentrating Solar Power
Identification of optimized Decoupled Solar	Creating concentrating solar power plant designs with larger solar to electrical efficiency and/or cost effectiveness.	Concentrating Solar Power

Combined Cycle plant scheme	Assessing the actual technology potential and study innovative and more efficient plant schemes.	
Optimization of CZTS properties	Controlling the stoichiometry of the CZTS thin films for PV application. The process can control the concentrations and the annealing treatment conditions to develop CZTS films with the required properties.	Photovoltaic Cell
Optimization of ITO process at low temperature	Preparation and characterization of ITO prepared at low temperature by sputtering (PVD). the prepared ITOs present high conductivity and transparency required for thin films solar cell.	Photovoltaic Cell
Optimization of FTO process	Preparation and characterization of FTO prepare by spray pyrolysis with high conductivity and transparency. An optimization process is done to control the electrical properties in order to get the optimum properties for PV application.	Photovoltaic Cell
Characterisation of natural rocks as alternative materials for thermal energy storage for CSP	Analysis of thermophysical behaviour up to 1000°C by DSC, HT-XRD, heat capacities, thermal emissivity, thermal diffusivity… showed that a very careful selection of the basalts materials can provide the optimal thermal energy capacity of the system.	Concentrating Solar Power
Transfer of silicon guiding by hydrogen implantation	Controlling the thickness of the transfer layer by vaying the thermal budget. It was demonstrated that the nature of defects formed after thermal treatment is fundamental in determining the transferred thickness. Seed with thickness equivalent to implanted depth is produced with high thermal budget and layer thickness decreases with the thermal budget.	PV solar cells
Building of solar cells with the transferred layers	Solar cells built with the transfer layers provided very promising efficiencies even if there is still a window for improvements. The open circuit voltage improvement remains one of the issue to be addressed.	PV solar cells
Optimization of CZTS properties	Polycristalline thin films of CZTS thin films, with a good stoichiometry and an adequate electrical and optical properties, for photovoltaic solar cells.	PV solar cells

prepared by ultrasonic spray		
Study of mini-modules PV parameters under outdoor conditions	Study of the evolution of PV mini-modules in 3 regions of Morocco under real conditions of temperature, radiation and humidity.	PV modules
Design, control, and calibration for single facet heliostats	Analysis and design of control systems for single facet small heliostats using microcontroller and wi-fi communication system. This is a solid background for local manufacturing of small single facet heliostats.	Concentrating Solar Power
Local manufacturing of single facet small heliostat with control system	Local supply chain, involvement of local SMEs, expertise gained by technicians, engineers, and researchers are valuable outcomes of this manufacturing experience.	Concentrating Solar Power
Micro scale investigation of ceramic foams for high temperature energy storage applications	Analysis of micro structure characteristics of ceramic foam on the performance of thermal energy storage systems. Moreover, the model can be applied for the analysis of other storage materials.	Solar thermal energy storage
Thermo-mechanical analysis and micro-design of ceramic based volumetric solar receivers	Complex design, analysis, and optimization of ceramic based solar receivers, porous and honeycomb geometries. The model is capable of investigation the effect of micro-structure parameters, materials properties, and macro geometry on the volumetric effect and overall efficiency of volumetric solar receivers.	Concentrating Solar
Heliostat field demo test plant for tasting and control	Research facility for future development of new concepts of heliostat systems and units. It can also be used for the assessment of the effects of harsh environment on the durability of materials of mirrors and structures.	Concentrating Solar Power

Grid integration barriers and possibilities	It summarizes the current status, barriers and possibilities related to the large-scale integration of renewable energy sources (RES) in MPC power systems; and a second part that will assess grid code standardization and further development. It helps investors in power field to define potential of power market in MPC power systems.	Grid integration
Balancing of demand and generation with large-scale renewable energy	Measuring the effects of large scale integration of renewable energy in an MPC power system via case studies in line with targets for 2020 or 2030. Helping power system planner and operator in their analysis.	Grid integration
System stability with large-scale renewable energy	Investigating MPC power system stability and how it is affected by large-scale integration of renewable energy. Helping power system planner and operator in their analysis.	Grid integration
Design, control, and calibration for single facet heliostats	The analysis and design of control system needed for single facet small Heliostat using a Wi-Fi communication system. Two systems were developed. A field integrated control for several Heliostats was also developed and being under test now.	Concentrating Solar Power
Local manufacturing of single facet small heliostat with control system	Manufacturing locally the different components and make assessment for the suitable foundations could be used for mounting in different types of soil.	Concentrating Solar Power
Demonstration test site with a 25-meters testing tower and an installed infrastructure and cabling system	Future works that could be needed for any future design.	Concentrating Solar Power

Characterization of Materials for PV	Initialization to equipment not available at UM5, such as photoluminescence and Raman.	Photovoltaic
Thin layer PV solar cells: synthesis, deposition and characterization	Skills are developed on synthesis and deposition of thin layers solar cells at laboratory scale using low cost and relatively simple process of sol-gel combined with spin-coating and dip coating techniques; these experimental tools will be used for R&D tasks and for students training.	Photovoltaic
PowerGAMA software for grid analysis	The software package has been further developed. The package itself is open-source, but commercial exploitation is possible by applying it on a service base, for doing analyses for e.g. grid owners or planning authorities	Grid integration
Power system analysis of large-scale solar integration	Skills and experience in analysing power system transient stability in systems with large amounts of solar power integration	Grid
Formation of silicon foils by SLIM-cut or proton implantation	Thin silicon foils (<100 microns) are of interest to produce low cost solar cells because of the reduction in materials cost; the method can be exploited by photovoltaic or microelectronic companies looking for thin silicon films; difficult to have an IPR on this as many variants exist already	Photovoltaic
formation of silicon layers on conductive substrates	purpose: Producing ultrathin crystalline silicon on foreign substrates such as Al sheets; possible exploitation: solar cell manufacturers; a patent was submitted and accepted	Photovoltaic
Tool for ORC performance analysis	The software has been developed to provide a simple and responsive tool to analyse the performance of Organic Rankine Cycle turbo-generators that can be easily utilized by non-expert users. The software provides preliminary estimations of electrical/thermal efficiencies and power outputs given specific boundary conditions. It can be used by Turboden's potential customers to evaluate the feasibility of heat recovery and renewable applications.	
Analysis of the thermal stability	The working fluids used in ORC plants can change their chemical composition and their characteristics if they are	

of the ORC working fluid	exposed to high temperature for a long time. The scope of the analysis of thermal stability consists in the development of skill and experience in the characterization of working fluids.	
Formation of silicon layers on conductive substrates	Ultrathin crystalline silicon on foreign substrates such as Al sheets; possible exploitation: solar cell manufacturers; a patent was submitted and accepted	Photovoltaic
Sintering of low-cost conductive substrates from Si powders	Purpose: Producing of low-cost conductive substrates by hot pressing of Si powder or growth of multi-Si from Si powders.	Photovoltaic

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