



GCREEDER 2018
April 3-5, 2018 Amman, Jordan

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Hybrid CSP – PV Plants for MENA Region

DLR (German Aerospace Center, Institute of Solar Research)

The University of Jordan (Jordan)

CDER (Renewable Energy Development Center, Algeria)

CRTEn (Research and Technology Centre of Energy, Tunisia)

University of Patras (Greece)





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Contents

- Project Objectives
- Work Packages
- Main Results
 - Collected Data
 - Hybrid CSP-PV Plant Simulation
 - Demonstration of Subsystems
 - Knowledge Transfer & Dissemination
- Conclusions and Next Steps



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Project Objectives

HYMENSO aims at increasing the **deployment of solar power plants in the MENA region**, considering the specific boundary conditions in Tunisia, Algeria and Jordan.

It may have an impact on the energetic and environmental sector and provide improvements to the social and labor situation in these countries.



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Work Packages

- **WP1 Market Research:** meteorological conditions, electricity demand, water and fuel costs, energy policy, potential sites, etc. for Jordan, Tunisia and Algeria.
- **WP2 Technology Development:** select CSP-PV technologies, determine technical and economic parameters, calculate yearly energy yield and search optimal configurations.
- **WP3 Demonstration:** Identify infrastructure at the partner's facilities to be used for data collection, refurbish those systems, operate and gather measured data.
- **WP4 & WP5 Knowledge Transfer & Dissemination** of project results



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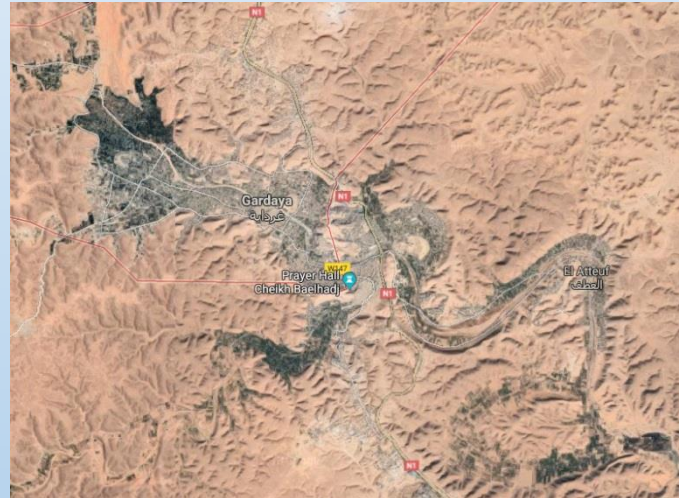
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Main Results: WP1 Market Research

Sites Selected for Simulation



Ma'an, Jordan
Source: Google 2018



Ghardaia, Algeria
Source: Google 2018



Tataouine, Tunisia
Source: Google 2018

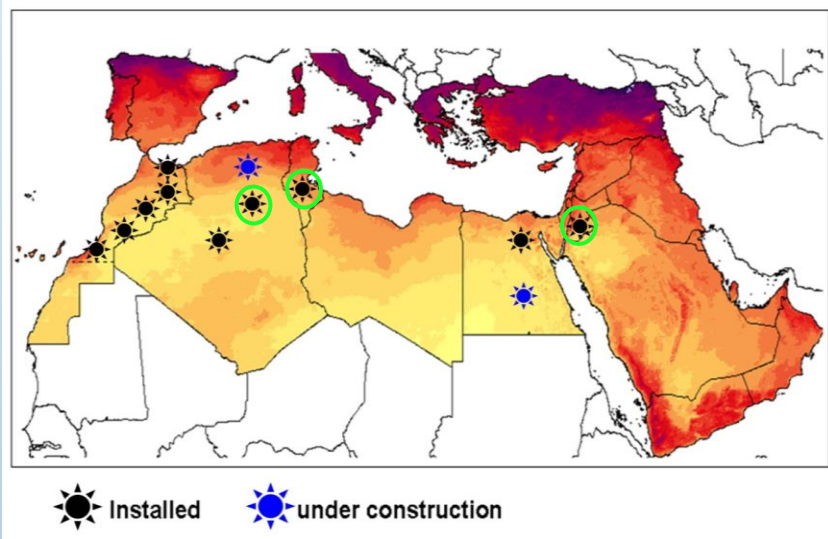


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Main Results: WP1 Market Research

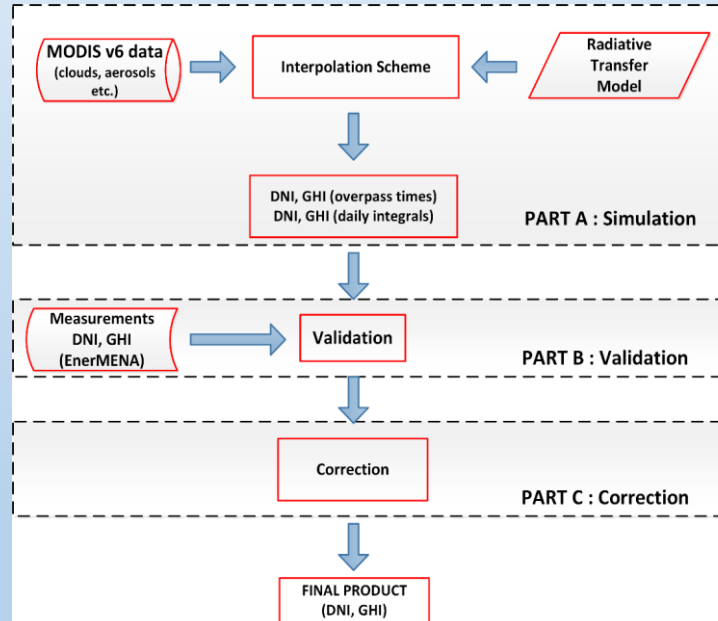
Location of enerMENA meteostations



Source: DLR

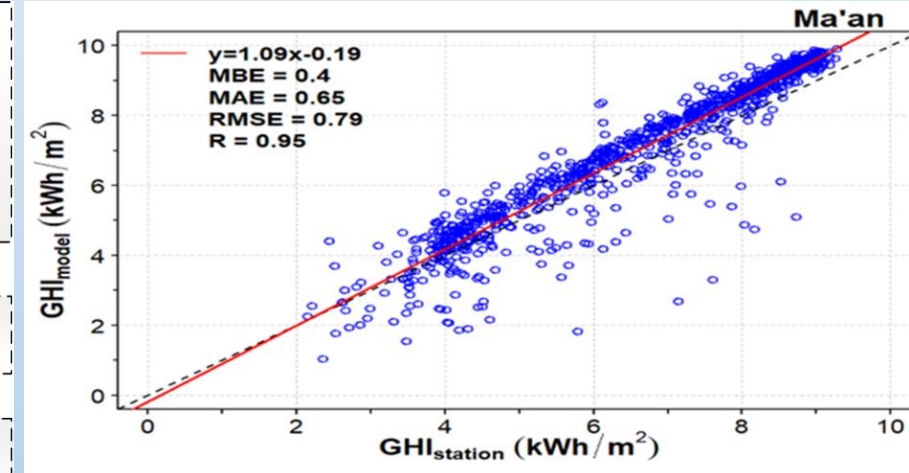
Solar irradiance model calculations and validation

Methodology:



Source: University of Patras

Sample Results:



Source: University of Patras

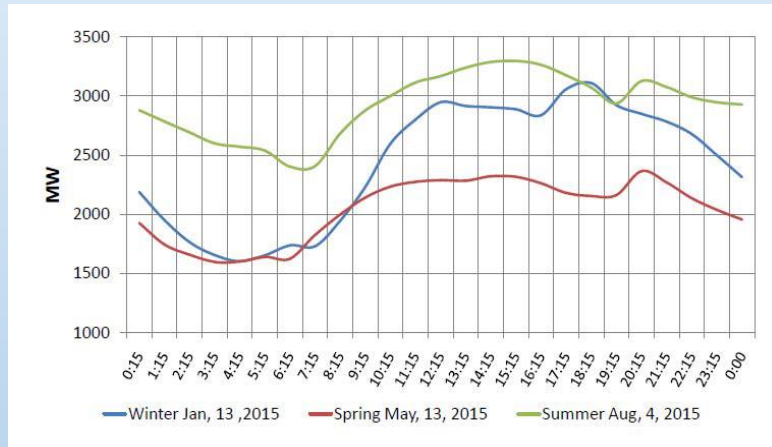


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April 3-5, 2018 Amman, Jordan

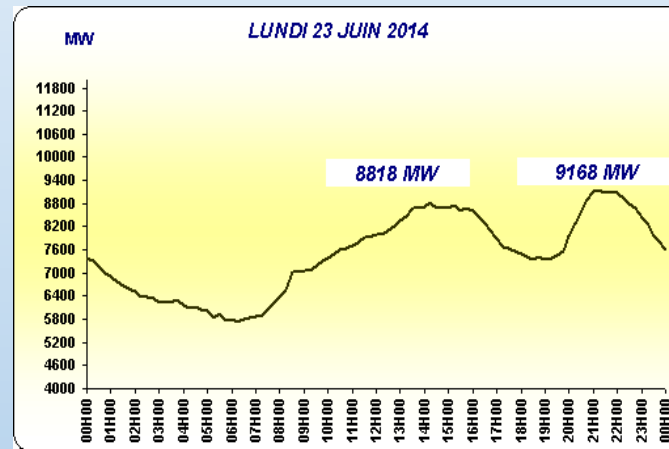
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Main Results: WP1 Market Research

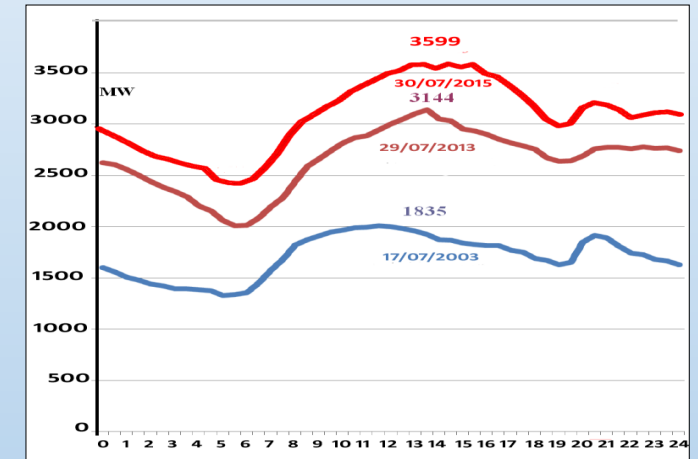
Load Curves



Jordan
Source: NEPCO



Algeria
Source: SONEGAS



Tunisia
Source: STEG



Main Results: WP1 Market Research

Example of Local Boundary Conditions

Country	Jordan	Algeria	Tunisia
Land Cost (\$/m ²) or Rent cost (\$/m ² /year)	5.46 \$/m ²	0.01 \$/m ² /year	Power plant 0\$/m ² (source:STEG) Regular Land Cost 20 \$/m ²
Water Cost (\$/m ³)	Treated wastewater tariff is 0,07 \$/m ³ for industrial reuses including power generating and cooling	0.05 \$/m ³	0.24 \$/m ³ Water pumped from well
Fuel Type & Cost	Natural Gas for industries: 34.3 \$/MWh (4/2017)	Natural Gas 1.48 to 2.86 \$/MWh (average value 2.5 \$/MWh)	- Natural Gas for industry: 30,7 US\$/MWh

Country	Jordan	Algeria	Tunisia
Electrical Energy demand			
Total Installed Capacity in The Country	4282 MW, 18911 GWh (2015)	15385 MW	In 2016 the installed capacity reached 5400 MW
Max Demand in the Country	3485 MW (2016)	13000 MW	3599 MW (2015)
Expected Demand in the Following years	3678 MW (2017), 3884 MW (2018), 4106 MW(2019)	25415 MW by 2025	CDER projection: 7800 MW by 2030



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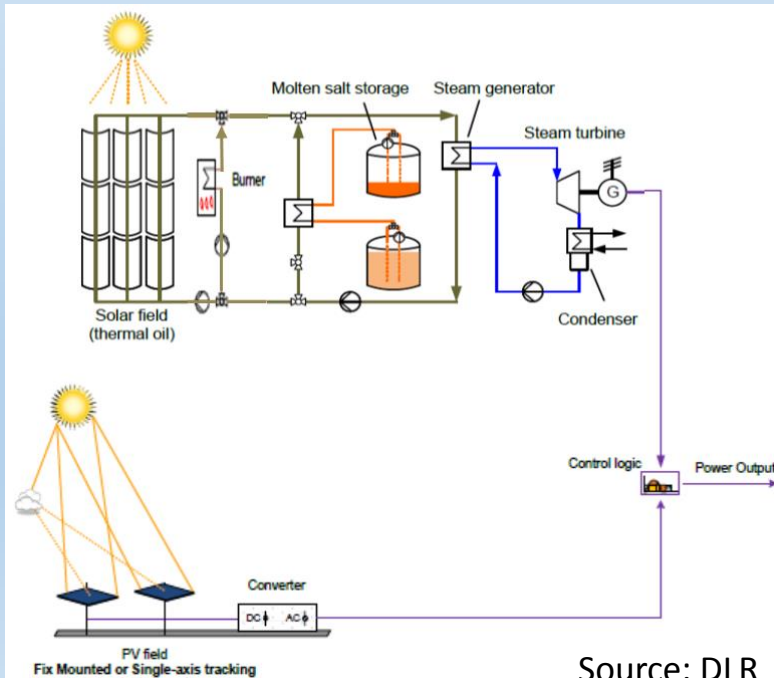
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Main Results: WP2 Technology Development

Selected Cases

Case CP1:

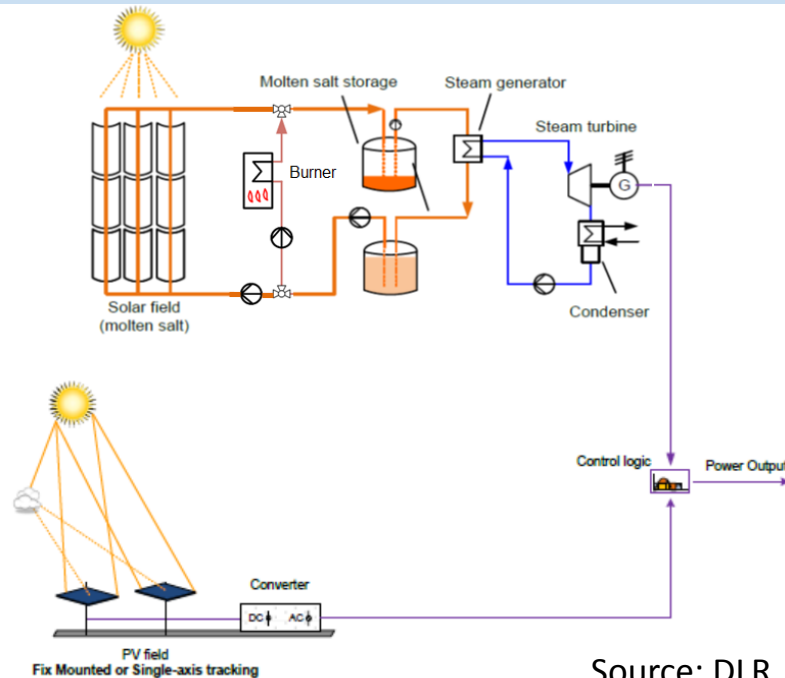
Parabolic Trough with **Thermal Oil** HTF and
Thermal Energy Storage
+ **Natural Gas** Back-Up
+ **PV Polycrystalline** single axis tracked



Source: DLR

Case CP2:

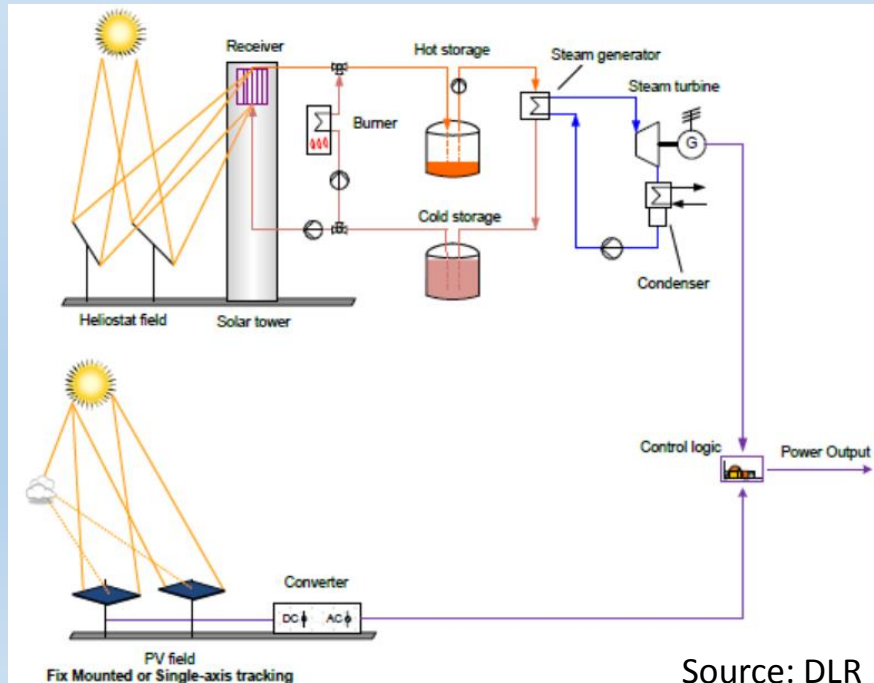
Parabolic Trough with **Molten Salt** HTF and
Thermal Energy Storage
+ **Natural Gas** Back-Up
+ **PV Polycrystalline** single axis tracked



Source: DLR

Case CP3:

Solar Tower with **Molten Salt** HTF and Thermal Energy Storage
+ **Natural Gas** Back-Up
+ **PV Polycrystalline** single axis tracked



Source: DLR



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Main Results: WP2 Technology Development

Methodology

Set-Ups Defined:

3 Sites: Jordan, Algeria, Tunisia
3 Technology Cases: CP1, CP2, CP3
2 Options: with Natural Gas and Solar-Only

= 18 Set-Ups

Parametric variation ranges:

CSP Solar Multiple: 1.8 to 3.4 in 0.2 steps, plus 1.4 case
Thermal Energy Storage: 3 to 21 h capacity in steps of 3h
PV Capacity (DC output): 0 – 227 MWp (10 Steps, 28.4 MWp)

= 700 Configurations x 18 Set-Ups = **12.600 Configurations to Simulate**

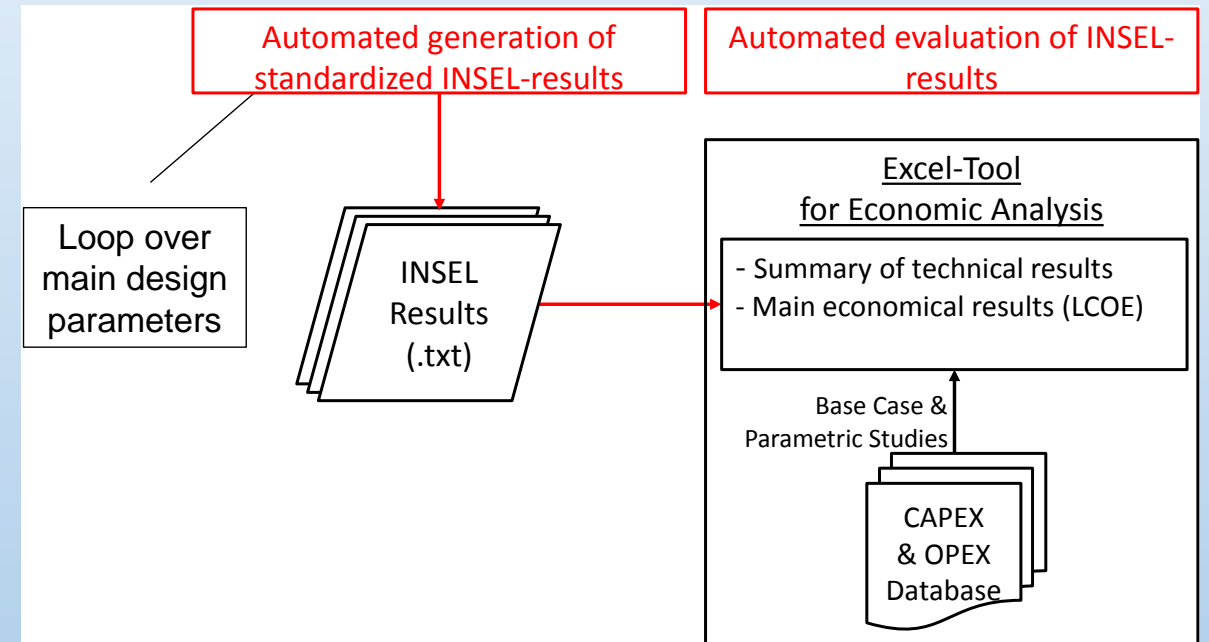


Main Results: WP2 Technology Development

Methodology

- 1) Techno-Economic modelling
- 2) Parametric variation ranges
- 3) Automatic performance calculation with **INSEL software**
- 4) Economic evaluation

→ **Goal:** search for **LCOE minima** per CO₂ emission range or demand coverage





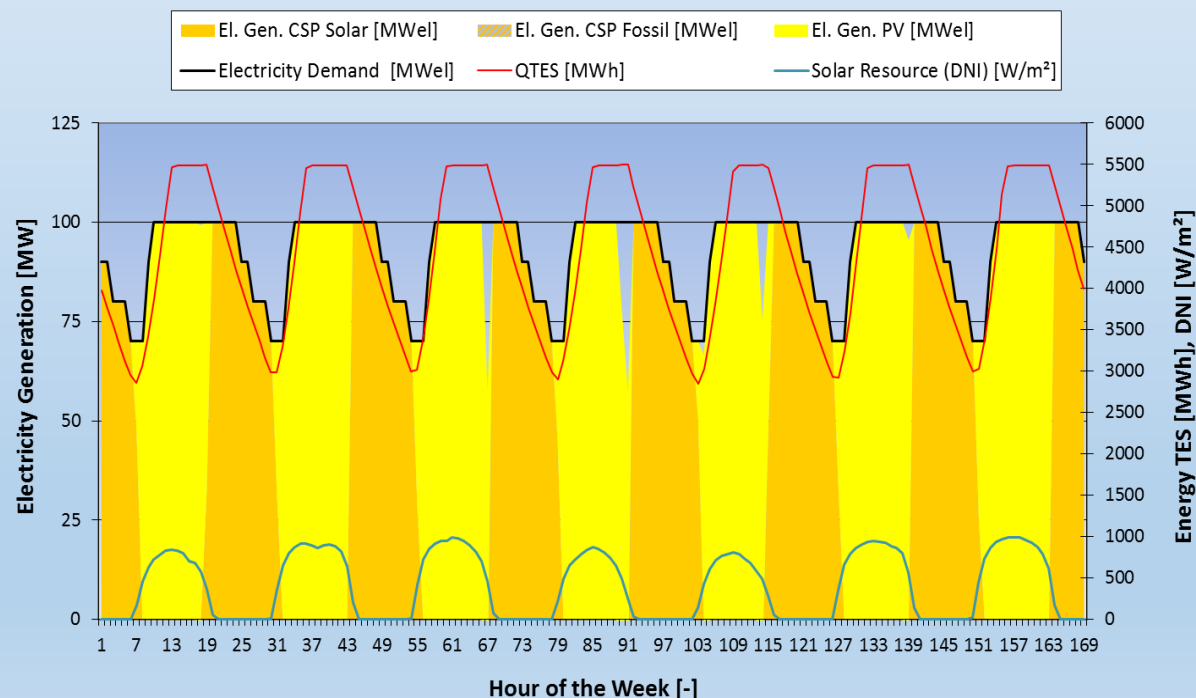
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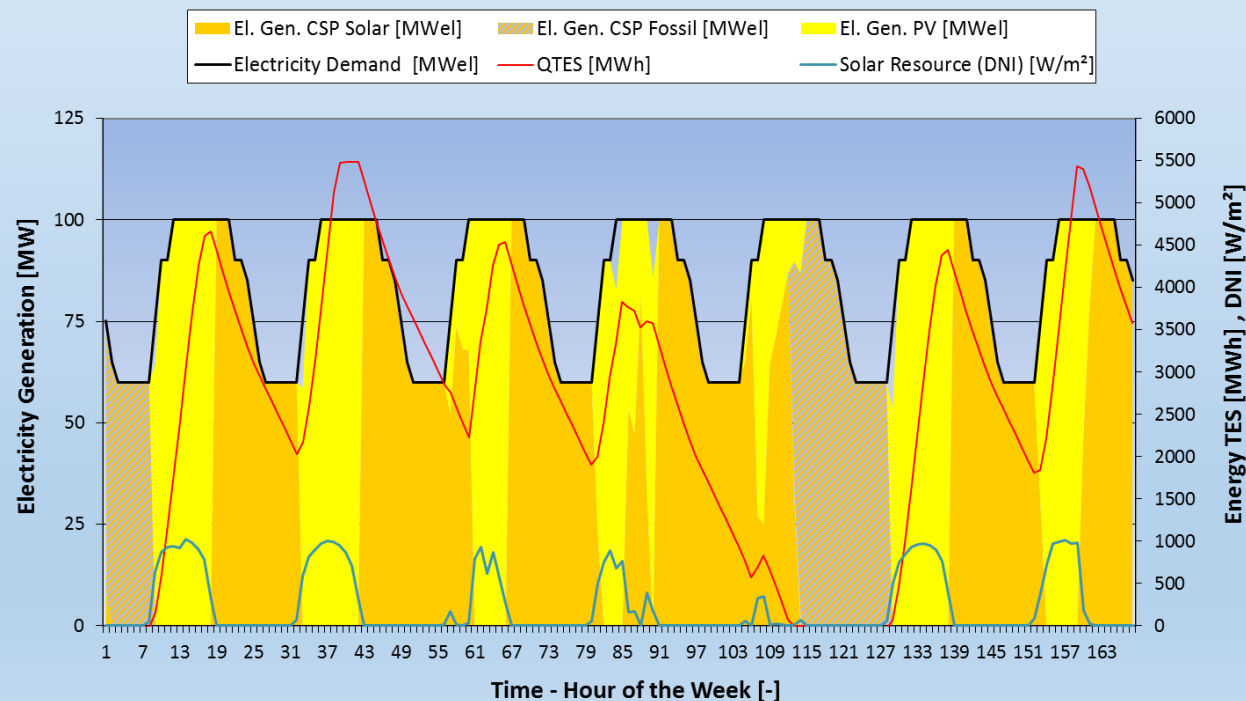
Main Results: WP2 Technology Development

Low Fuel Use example. 30 g CO₂/kWh, solar share 94%, LCOE 10.9 €cent/kWh
CSP solar multiple 2,4; TES capacity 21 h; PV cap. 170 MW

Electricity Generation Profiles - Summer Sample Week (CP3, Jordan)



Electricity Generation Profiles - Winter Sample Week (CP3, Jordan)





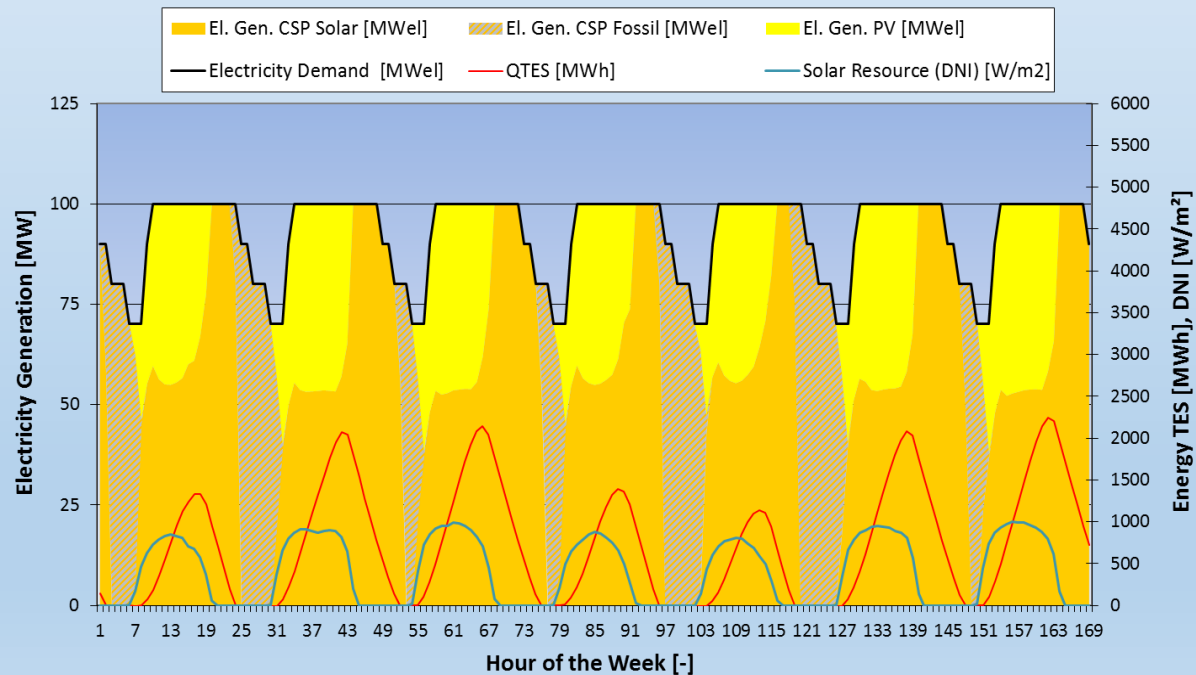
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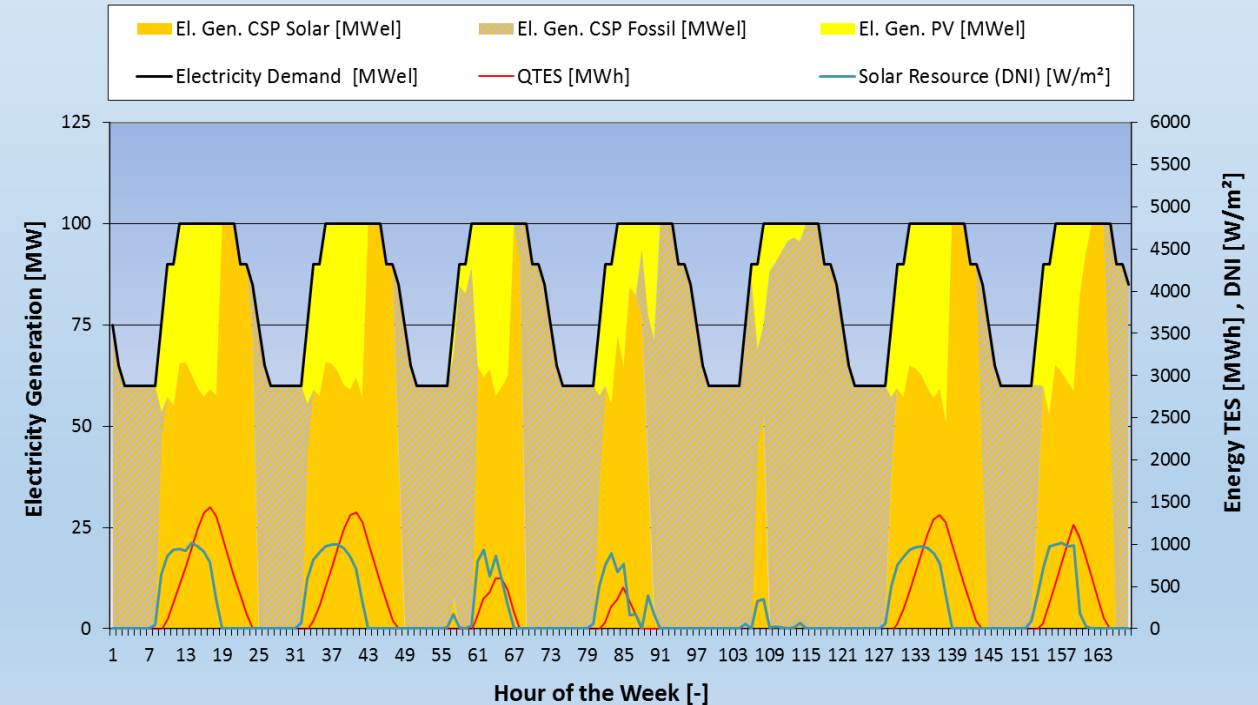
Main Results: WP2 Technology Development

High Fuel Use example: 188 g CO₂/kWh, solar share 66%, LCOE 8,6 €cent/kWh
CSP solar multiple 1,4; TES capacity 9 h; PV cap. 57 MW

Electricity Generation Profiles - Summer Sample Week (CP3, Jordan)



Electricity Generation Profiles - Winter Sample Week (CP3, Jordan)





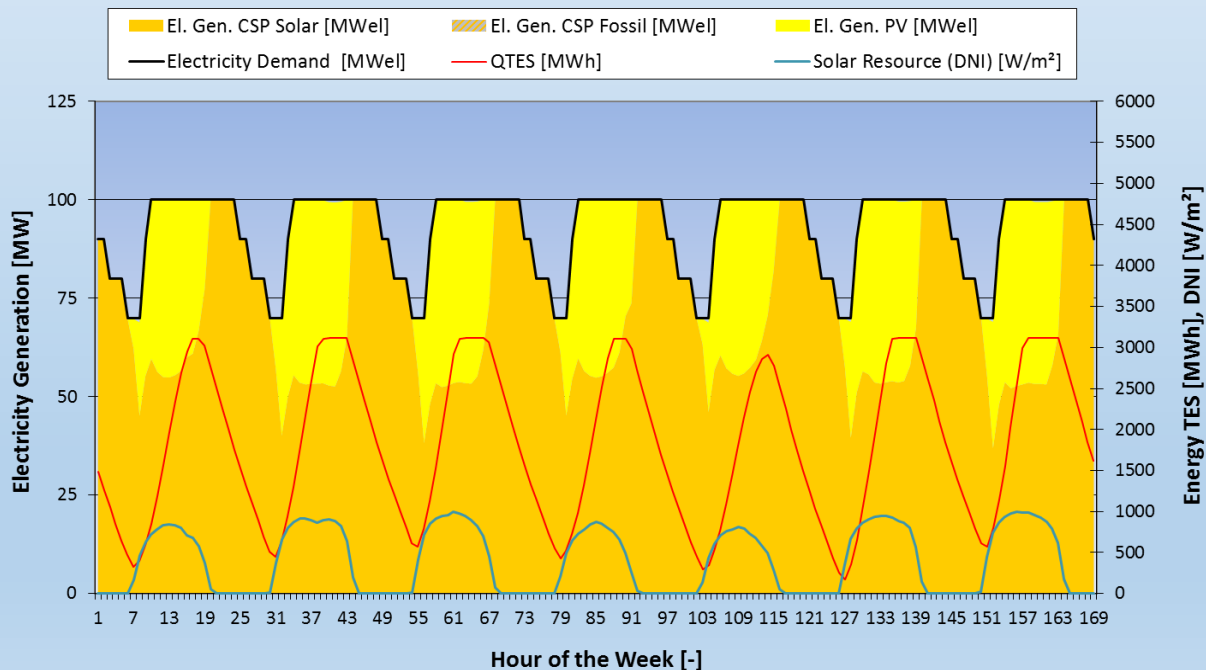
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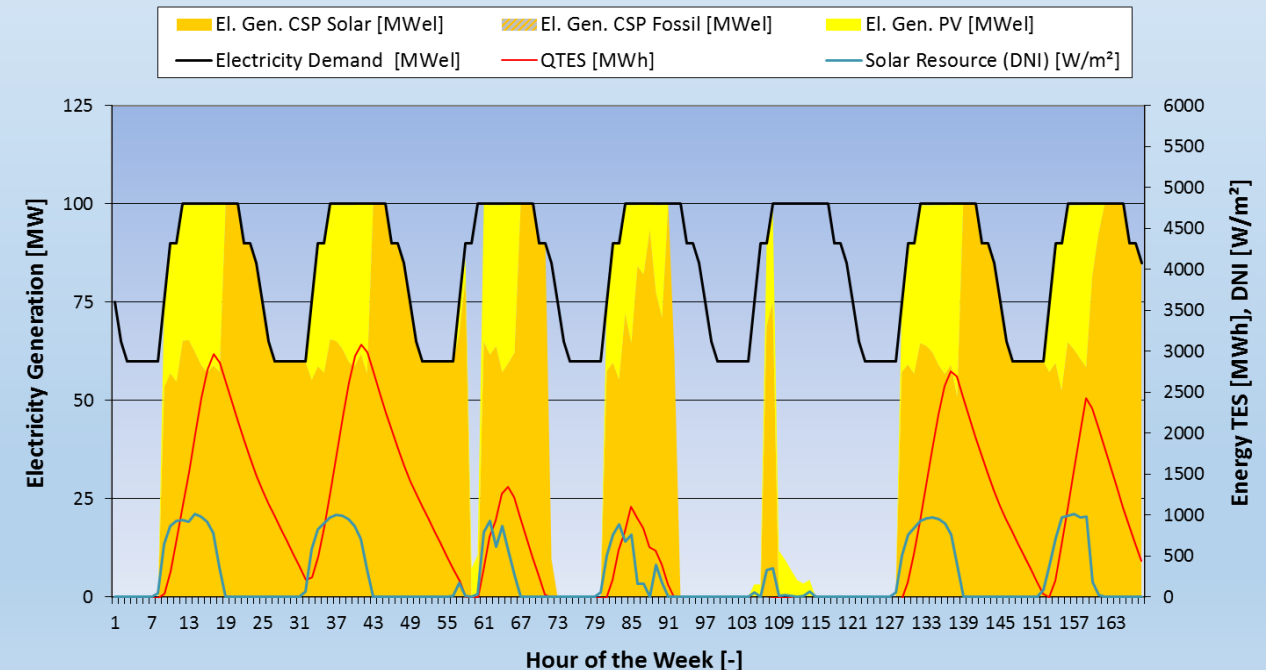
Main Results: WP2 Technology Development

Solar-Only example: 0 g CO₂/kWh, Demand covered 80%, LCOE 9,1 €cent/kWh
CSP solar multiple 2,2; TES capacity 12 h; PV cap. 57 MW

Electricity Generation Profiles - Summer Week (CP3 Solar Only, Jordan)



Electricity Generation Profiles - Winter Week (CP3 Solar Only, Jordan)



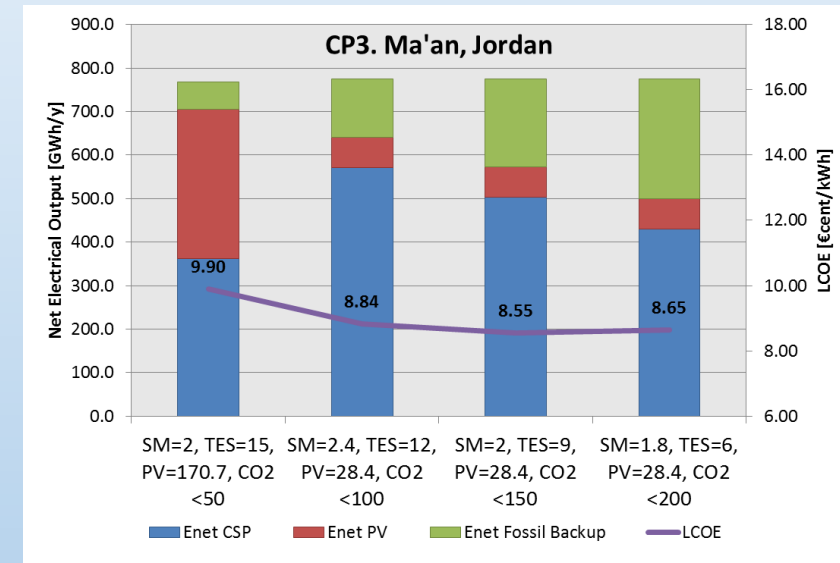
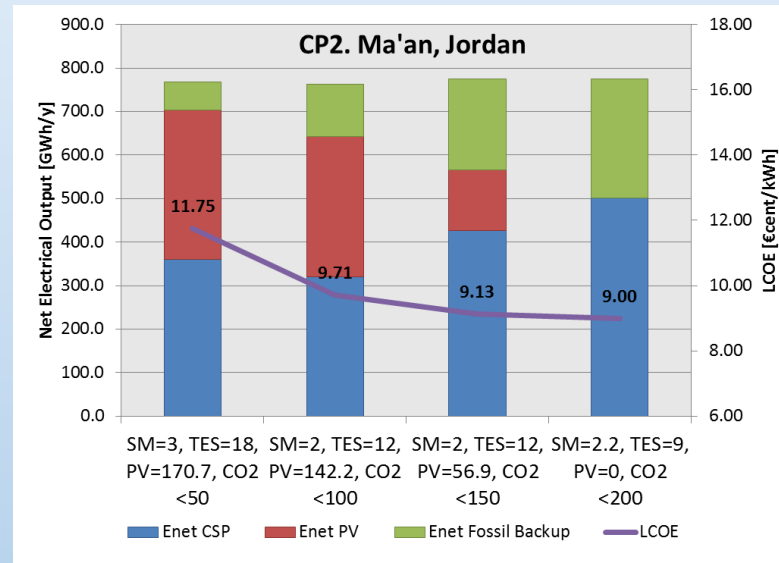
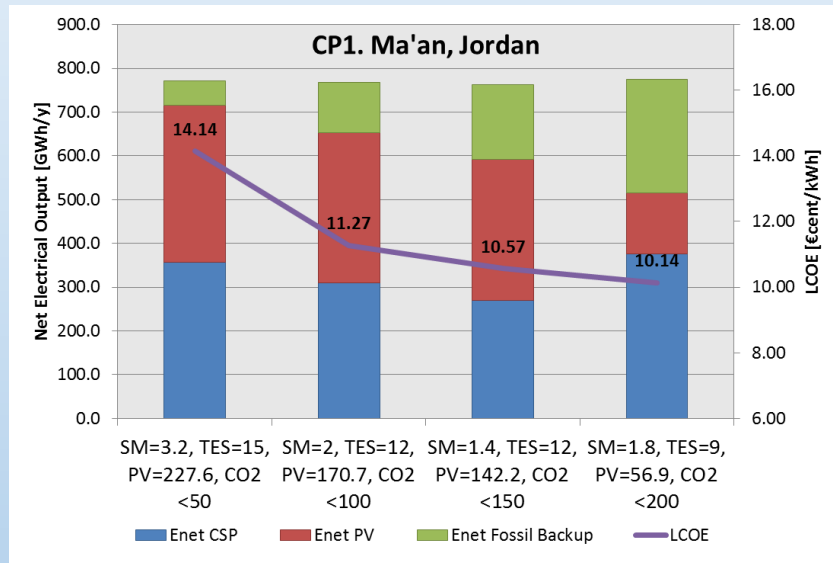


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Main Results: WP2 Technology Development

Configuration Selection, with Natural Gas



CO2 emissions (g/kWhe) →

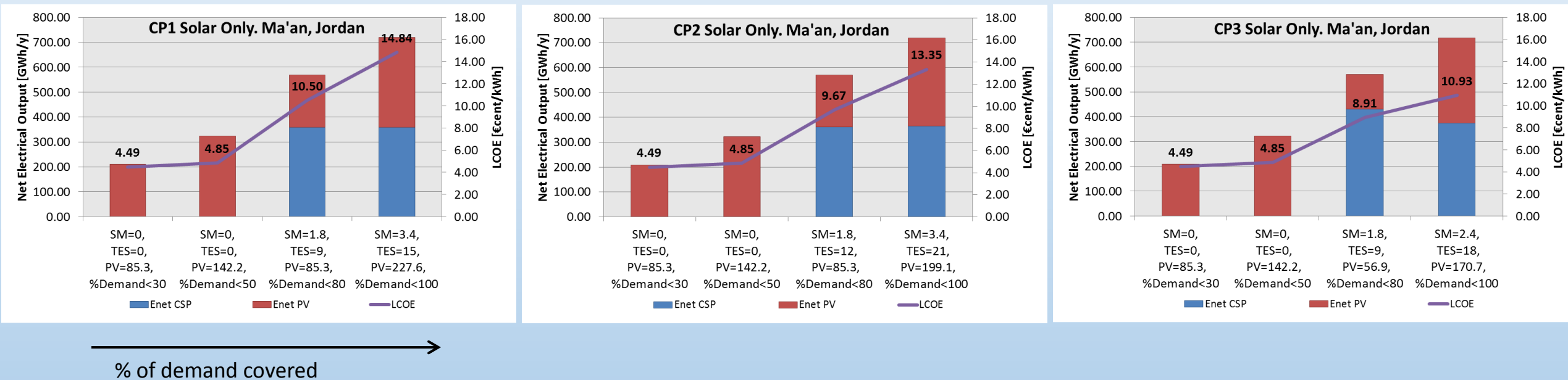


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Main Results: WP2 Technology Development

Configuration Selection, Solar-Only



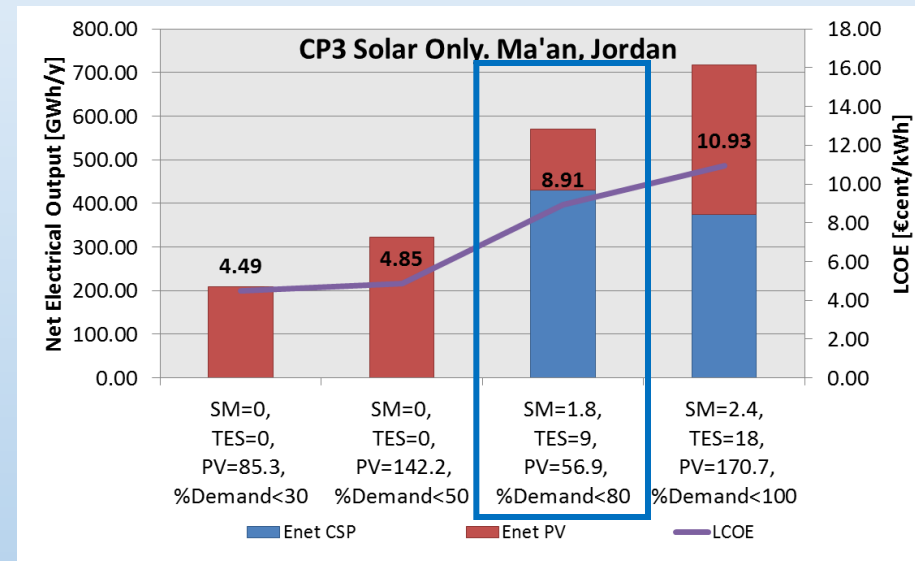
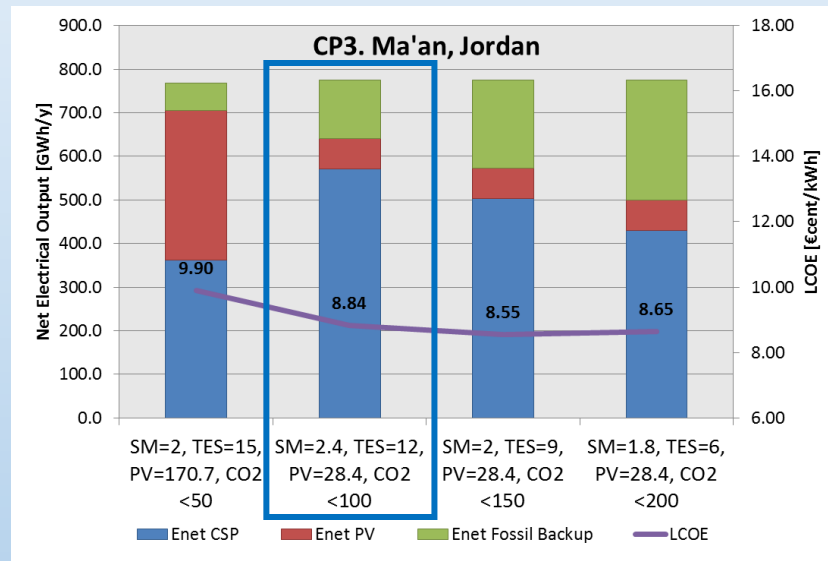


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Main Results: WP2 Technology Development

Back-Up Fuel vs. Solar Only



Similar LCOE for configuration with **100 gCO₂/kWh** (84% Solar Share) and **100% demand covered** as solar-only (100% solar share) and **80% demand covered**



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Main Results: WP3 Demonstration



57.6 KW (AC) Roof-mounted grid-connected PV system used for refrigeration rooms.

Suntech 320 W, (STP320-24-Vd polycrystalline)
Central Market for Vegetables and Fruits Zarqa
city, Jordan



9.54 KW (DC) Grid – Connected Photovoltaic system at CDER, Algeria.
The PV system consists of 90
IsofotonI106 monocrystalline PV
modules.



16 KWth Parabolic trough used to
power an absorption chiller for air
conditioning.
Borj Cedria Tunisia
CRTE n



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Main Results: WP4 & WP5 Knowledge Transfer & Dissemination

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MENA Hybrid Solar System

HYMENSO aims to support the implementation of solar energy systems in the MENA region by following a holistic approach covering aspects of cost, reliability and dispatchability.

HYMENSO aims to serve as a reference to guide local researchers and industry about the optimization of the power plants configurations to cover their necessities.

HYMENSO partners



ERANETMED is funded by the European Commission's 7th Framework Programme



Relationship to ERANET objectives

- Cooperation:** joint efforts of scientists and researchers from Germany, Greece, Tunisia, Algeria and Jordan
- Coordination and synergy:** differences and similarities will be identified and through the information exchange between project partners, the impact of the investigation will be much higher for each country and the international energy community than separate independent studies.
- Networking:** direct communication between experts of all the involved research areas from the participating countries
- Societal impact:** increase the deployment of solar power plants in the region, considering the specific boundary conditions of each country

Main scientific objectives

- Create a data base of relevant local conditions for CSP and PV plants, such as meteorological data, industry capacity, energy demand, current energy production, and grid capacity of the participating MENA countries.
- Develop country specific solar energy roadmaps and concepts for combination of PV and CSP.
- Enhance local participation through capacity building and dissemination of results.
- Produce specifications of hybrid systems, to be applied on future prototypes and demonstrators to be developed in the continuity of this project.
- Demonstrate available subsystems in pilot applications.

HYMENSO Partners



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www.hymenso.eu



HYMENSO
MENA Hybrid Solar System



Energy demand in all Middle East - North Africa (MENA) countries is satisfied by fossil resources despite the fact that there is an excellent availability and quality of solar radiation. Yet the penetration of renewable energies in the MENA region is developing slowly. HYMENSO aims to support the implementation of solar energy systems in the MENA region by following a holistic approach covering aspects of cost, reliability and dispatchability. A combination of PV (Photovoltaics) and CSP (Concentrating Solar Power) systems is investigated, in order to harvest the advantages of both systems.

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The approach proposed is to cover the selected electrical demand with hybrid solar plants and determine for each technology case and site the best configuration by minimizing the LCOE. Due to the low cost of natural gas, it is important to determine the CO₂ emissions and analyze which limitations should be set for solar power plants, in order to avoid operation towards high fossil fuel consumption. Additionally, solar-only cases are also analyzed.

The assessment of the key design parameters as well as the annual yields is performed with the simulation tool DISEL. DISEL is a graphical programming language to design, monitor and visualize renewable and conventional energy systems. The DLR moved using DISEL several years ago and contributed to extend the tool capabilities by including new modules (e.g. CSP library, Desalination library) in the commercial library. In addition, the tool has been used within several research projects and pre-feasibility studies [1], [2], [3]. Sensitivity analyses and parametric studies can be carried out within the simulation of the DISEL graphical user-interface by means of batch scripts.

- The variation of the design parameters lead to a combination of 700 different configurations per case and country selected with the following parametric study:
- CSP thermal energy storage: 3 to 21 full-load hours (FLH) capacity in steps of 3h
 - CSP solar multiple: 1.8 to 2.4 in 0.2 steps plus 1.4 case
 - PV installed capacity (nominal DC): 0 to 221.2 MW in 25.4 MW steps
- An important factor for the optimization of the plant configuration is the energy output that the plant needs to fulfill. Especially the load profile is relevant due to the variable incoming power from the sun and affected by the weather conditions. For this reason, local demand curves for the countries were generated based on the local market research performed by the partners.

The demand profile selected for summer and winter for MENA, Jordan is shown below:

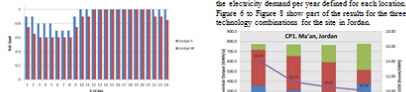


Figure 4: Exemplary demand profile. Source: DLR

The operation strategy of the hybrid solar power plants is shown explicitly in Figure 5 below. It represents the operation of 7 consecutive days in summer. The light yellow area is the energy generated by PV, the orange area is the energy from CSP and the assigned brown-yellow area is the energy from natural gas. The red line

DISEL software developed by DLR/Institute of Energy Conversion (IEC) [Dec. 2018] <http://www.iec.de/index.php?id=1000000000>

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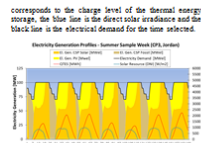


Figure 5: Daily energy production example. Source: DLR

3.3. Optimization Results

3.3.1. With fossil fuel

As mentioned above, due to the importance on the participant countries (especially in Algeria) hybridization with natural gas is considered. For this reason, the configurations with the lowest LCOE are presented according to the relative emission in gCO₂ per kWh. Increased electric energy. Results with emissions above 200 g/kWh are not presented because in that case it makes more sense to use the natural gas in a more efficient way, for example with a gas turbine, than burning it within a solar power plant.

The legend below each bar in the charts displays the main parameters of the configuration that obtained the lowest LCOE, which are solar multiple (SM), thermal storage capacity in full load hours (TES) and the nominal PV capacity in MW. The curve shown in purple is the LCOE per configuration in €/kWh. The sections of each bar represent the amount of net electrical energy per technology source. The total net electrical output is practically constant for each case, which corresponds to the electricity demand per year defined for each location.

Figure 6 to Figure 8 show part of the results for the three technology combinations for the site in Jordan.

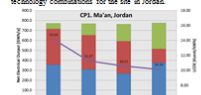


Figure 6: Simulation results. Case CSP, Jordan. Source: DLR

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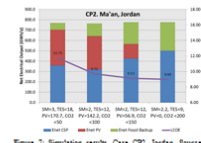


Figure 7: Simulation results. Case CSP, Jordan. Source: DLR

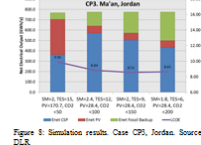


Figure 8: Simulation results. Case CSP, Jordan. Source: DLR

3.3.2. Solar Only

In order to analyze the impact on the costs and the energy supply of solar-only plants, the same cases have been simulated, without fossil fuel. For these diagrams, instead of displaying the CO₂ emissions the demand covered in percentage (%Demand) for the plants configurations with the lowest LCOE are displayed.

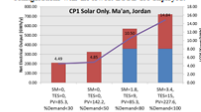


Figure 9: Simulation results. Case CSP, Jordan. Source: DLR

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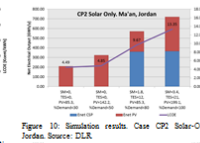


Figure 10: Simulation results. Case CSP, Jordan. Source: DLR

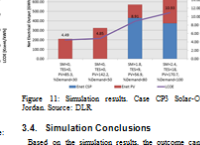


Figure 11: Simulation results. Case CSP, Jordan. Source: DLR

3.4. Simulation Conclusions

Based on the simulation results, the outcome can be summarized as follows:

- In general, due to the still low natural gas price compared to electric energy from solar power plants, the LCOE is lower if the generated CO₂ emissions are high.
- For the case of Jordan, with the highest natural gas price among the three countries analyzed, the LCOE curve becomes flat for lower emission levels than the other two countries. This means that permitting more CO₂ emissions do not reduce the LCOE considerably, which is positive for solar power plants.
- In the case of Algeria, with a natural gas price about 50% lower than the price of Tunisia and Jordan, the LCOE decreases practically linearly with the use of natural gas. Therefore if only the electricity price is considered, the preferred configuration will be that with less PV and CSP installed and the highest natural gas consumption, leading to higher greenhouse gas emissions.
- For the solar-only cases, because electrical batteries are not included, PV systems provide the lowest LCOE and about 50% of the energy demand is covered. After 50% the combination CSP+PV is required.
- By comparing the solar-only results with the results with natural gas used, it can be seen that the LCOE difference is not so high if fossil fuel is avoided as long as not all the demand is covered. For instance in the case of Jordan, the case CSP with CO₂ 100g/kWh has a LCOE = 1.84 €/kWh, while the case CSP solar-only with 72% demand covered has a LCOE = 1.91 €/kWh (4% difference).
- For the case of large thermal energy storage (selected for low CO₂ emissions), its capacity is not completely



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April 3-5, 2018 Amman, Jordan

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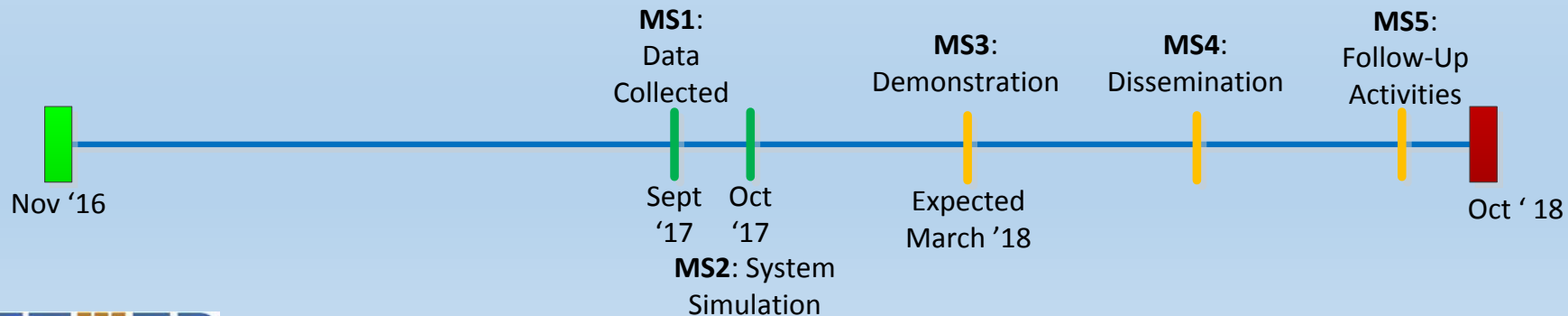
Conclusions and Next Steps

It has been confirmed, that the conditions in the analyzed MENA countries are excellent for the deployment of hybrid CSP-PV plants.

The load curves can be satisfied to a large extension with solar-only plants or to its totality if fossil back-up is allowed.

The combination of CSP + PV leads to electricity costs higher than PV but lower than CSP alone by increasing the capacity factor and the grid stability.

A complete system demonstration was not possible in HYMENSO due to lack of funding





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THANK YOU
for your attention!

THANKS to my colleagues
for their work and input

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