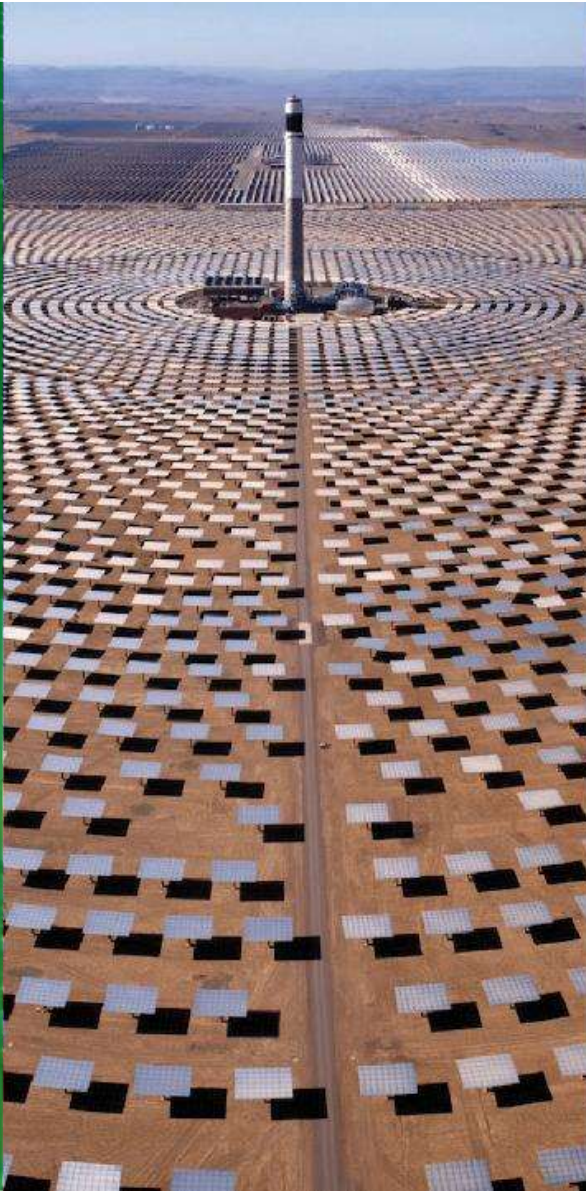




Solar Field for CSP Tower Technology: Best Practices and Lessons Learned in Operational Commercial Projects.

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Agenda



Introduction: From the Power Point to the Power Plant
01

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Introduction: From the Power Point to the Power Plant
01

Accommodation of Tower CSP into:

Multivariable and Political Context.

- Viable but Incipient Technology.
- Tough Market.
- Hard Competitors.
- Growing Demand.
- Geographical Location.
- Reliability and Availability Required.
- Technologies Diversified.
- Future Niches.

- Zero Carbon Emissions.
- Storage and Efficiency.
- Economy of Scale.
- Flexibility in Demand.
- Sponsorship.
- Dispatchable and Grid Harmonization.
- Market Regulation.
- Integration with Other Technologies.
- Market Competitiveness.

... Part of the answer

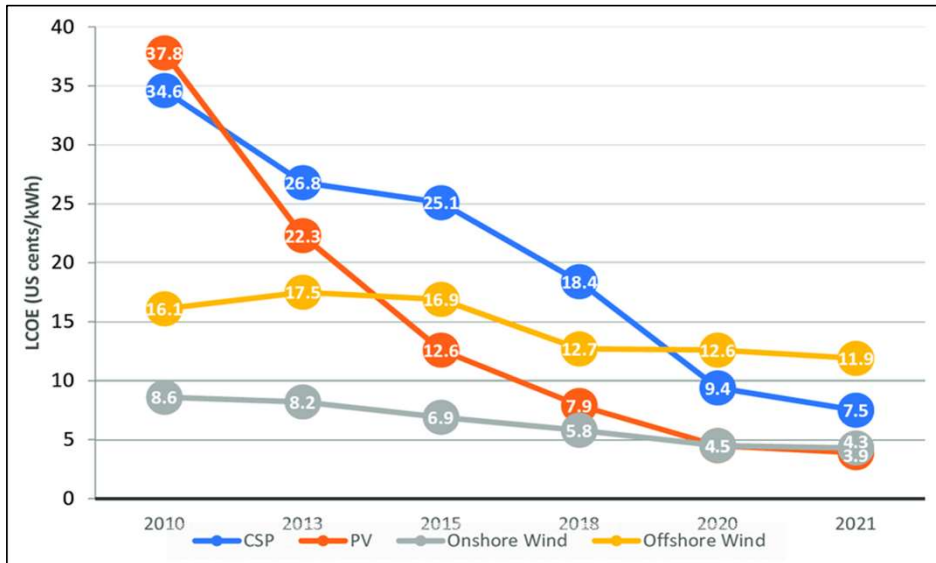
General Context



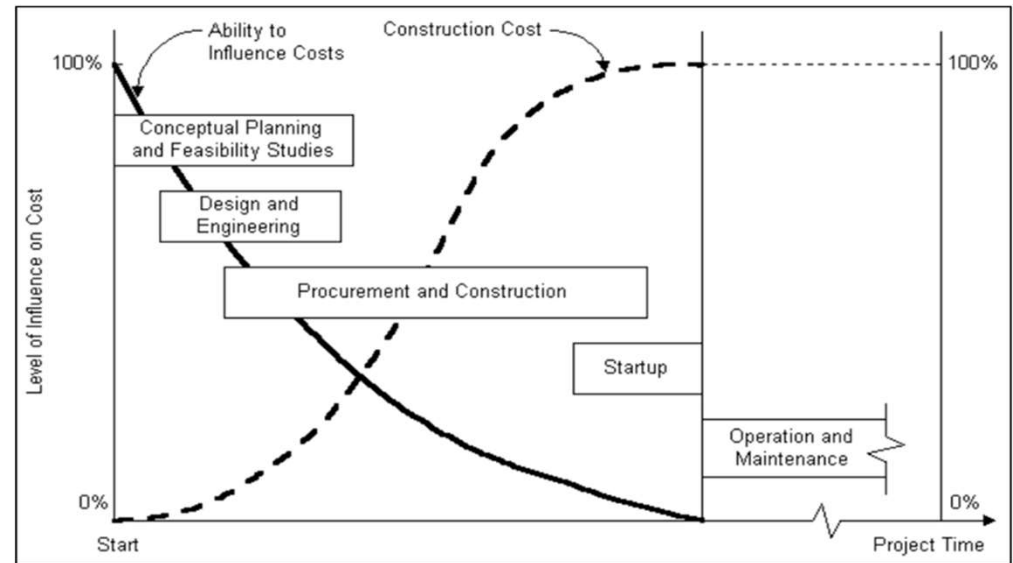
Costs

Objective:
LCOE optimization

Performance



Falling Costs of Renewables in terms of Levelized Cost of Electricity (LCOE). CSP = concentrated solar power, kWh = kilowatt-hour, LCOE = levelized cost of electricity, PV = photovoltaic. Source: IRENA.



Power Plant Influence lifecycle cost: made in the earliest phases of a project.

Central Receiver Technology Highlights



Central Receiver Technology Typical Stages and Impact	
Topic	Focal Stage / Impact
Normalized Standards	Design
Industrial Specifications	Design
Testing Standars	Design
Heliostat Design	Design
Technology Scale-up	Design
Pedestal Installation	Construction
Heliostat Cleanliness	O&M
Wether Forecast Deviation	O&M
Solar Field Tagging	O&M
Hydraulic units failure	O&M
SF Roads for Maintenance and Cleaning	O&M
Lack of Procedures and as-built	O&M
SF PLC Hardware Obsolescence	O&M
Electrical: UPS issues	O&M
I&C: encoders and limit switches	O&M
Heliostat Availability	Construction, O&M
SF pedestals issues	Construction, O&M
SF lack of QC/QA: lack of availability	Construction, O&M

Central Receiver Technology Typical Stages and Impact	
Topic	Focal Stage / Impact
SF Calibration	Commissioning, O&M
Instrument Reliability	Commissioning, O&M
Heliostat Tracking Errors	Commissioning, O&M
SF bad electrica termination	Commissioning, O&M
Heliostat Local Control	Commissioning, O&M
Electrical: Ground and EM noise	Commissioning, O&M
I&C: Comunication PLC-DCS	Commissioning, O&M
Heilistat Calibration errors	Commissioning, O&M
Heliostat foundation issues	Commissioning, O&M
Facet Blocking	Design, O&M
DNI deviations vs expected	Financial, O&M
Enviromental conditions more adverse than expected	Financial, O&M
QA/QC Supervision and doc	Construction, Commissioning, O&M

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Solar Field - Project Phases
02

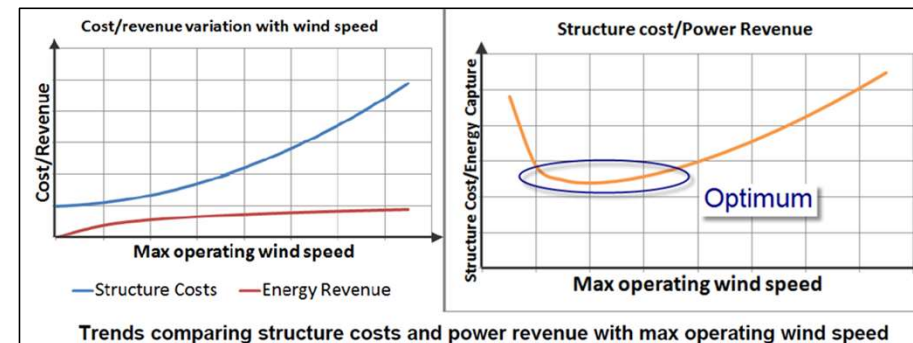
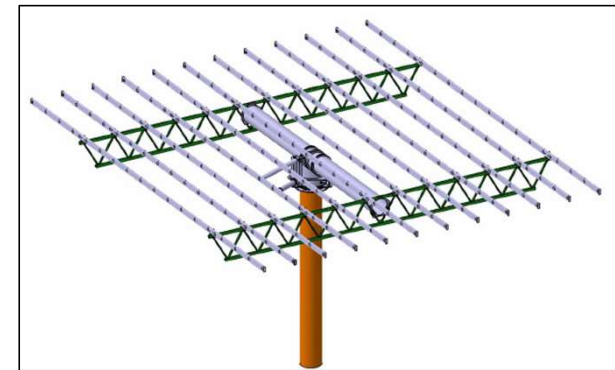
Phase 1: Engineering



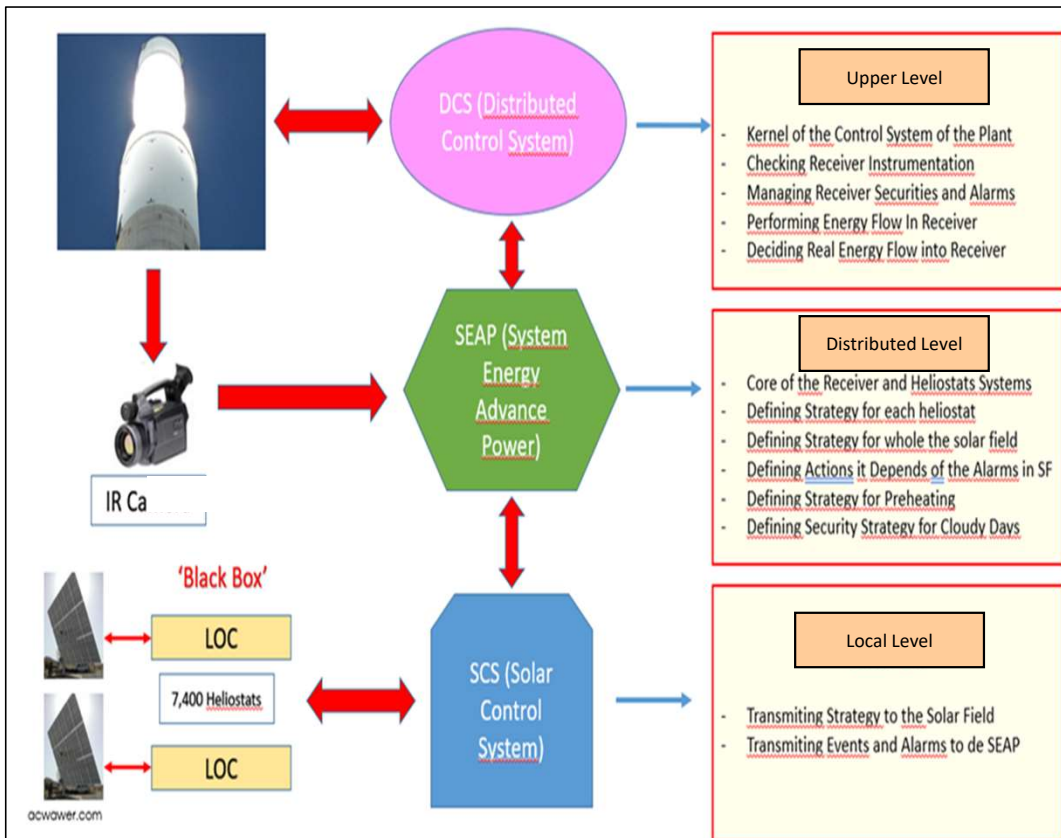
Objective: Definition and Design of the CSP Project in order to meet the business case of the owner considering an approach to balance the plant capital costs and guarantee future reliable operation with the required revenue generation.

Key Decisions/Considerations:

- **Largely complete shortly after construction begins.**
- **Disciplined top-down engineering review:** support by experts in different areas and especially in CSP technology.
- **Apply normalized well-known industry standards:** future standardization for CSP tower technology.
- **Heliostat Design as a nuclear element of the SF:** large/small area, mechanical parameterization, choice of active elements (hydraulic control units/motors) and I&C (encoders, inclinometers). Study autonomous approach (PV+Battery+Wireless).
- **Final shape of the SF Optimization:** customized to the plot, location weather, performance based on heliostats site, blocks and shadows, roads and drainages.
- **Accurate Software Models as basic tool:** feedback with real plant parameters. Annual cost-performance simulation.
- **Accurate Site Weather Information:** Extensive database and impacts taken from the facility in advance - DNI and ANI, cloud transients, impact of wind and dirt, effect of aerosols and dust in suspension, effect of dust storms. Accurate and short sampling measures.



Phase 1: Engineering



- **Communications Topology:** Avoid overlapping of too many elements in series (robustness of communications, signal degradation), topology based on differentiated meshes or redundant rings, guarantee enough speed between the DCS and SF.
- **Control System:** division of functionalities in different autonomous layers but distributed and integrated in the final control solution of the plant.
- **HMI:** Definition of screens and synoptics.
- **Integration Solar Field – Receiver Packages:** same supplier.
- **Cleaning Truck Design:** customized according the final heliostat design.
- **Electrical:** minimization of wiring and connections. Avoid overlapping of too many elements in series (robustness of communications, signal degradation), different maya-based topology and groundings, isolation from lightning strikes.
- **Documentation:** Functional Descriptions carefully developed (recommended CSP and O&M specialists involved). Special attention: unifilar and communication diagrams, heliostat control logic and P&IDs.

Phase 1: Engineering

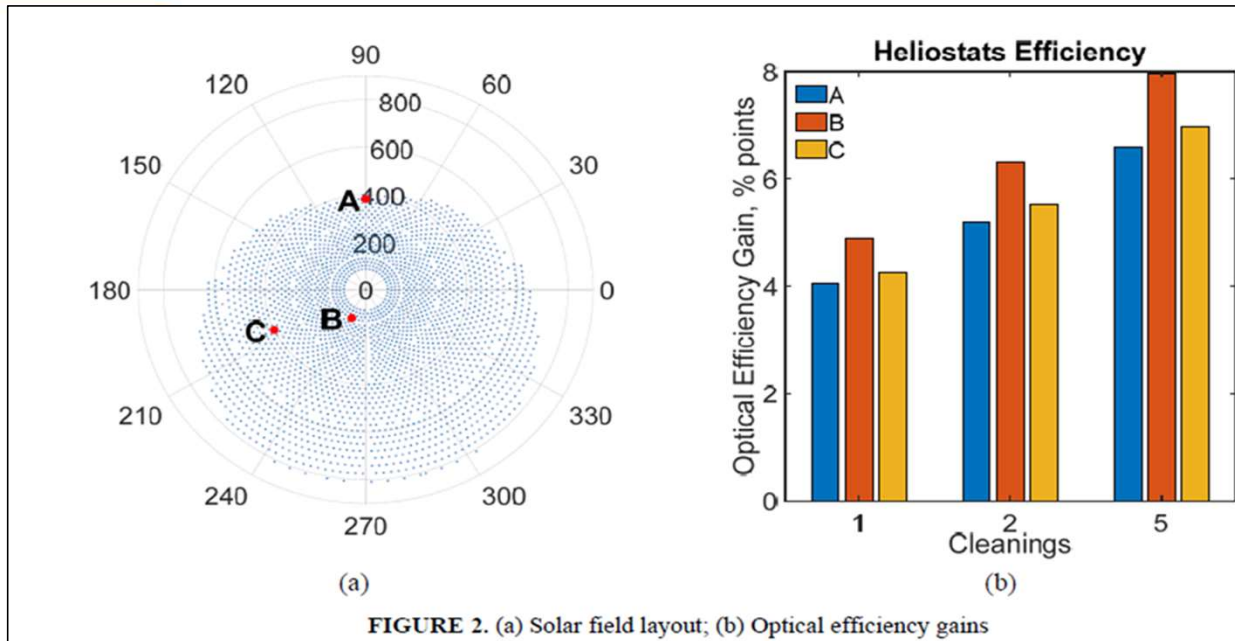
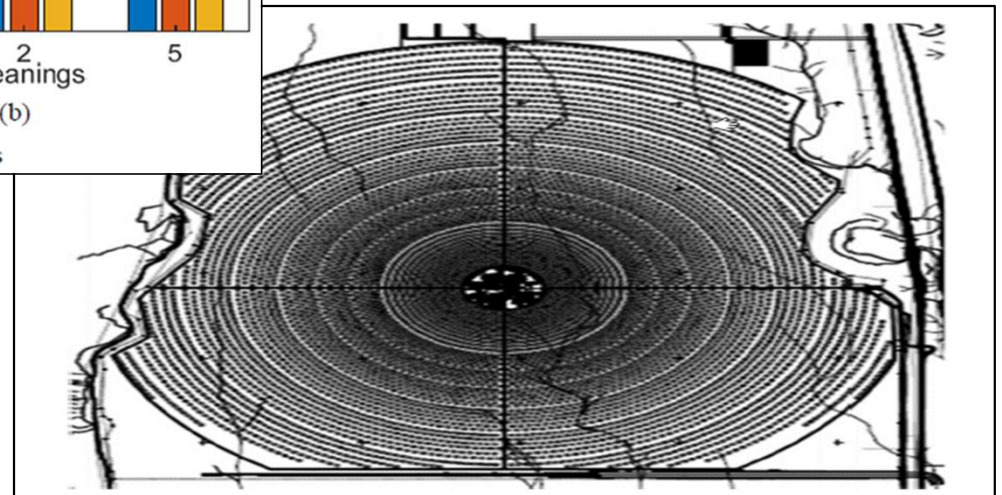


FIGURE 2. (a) Solar field layout; (b) Optical efficiency gains



Phase 2: Construction



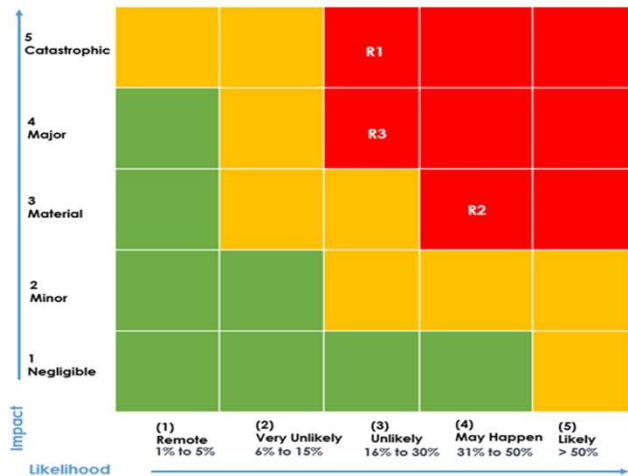
Objective: Execution of the CSP Project focused on costs and schedule and assure enough quality for the different systems and process to guaranty after completion the operability of the plant for the rest of the life-cycle.

Key Considerations:

- **Agenda:** ensure execution times so as not to introduce deviations in planning that have an impact on project extensions and increased expenses.
- **HSSE standards:** applied to all processes, areas and subcontracts as a standardized and consolidated element of technology.
- **QA/QC process:** included visits to factories and FAT tests especially for optical elements and PLC/Control system.
- **Procurement:** guarantee delivery - different elements from different manufacturers.
- **Warehouse:** guarantee labeling and tracking in a centralized database. Storage in appropriate places (especially for electrical and electronic components of the heliostat). Avoid poor housekeeping.
- **Delivery:** divide shipments by different routes and carriers. Analyze in advance the limitations of access to the country and time in customs, means of transport and access to the site.
- **Start O&M Mobilization process.**



Phase 2: Construction



- **Optical:** careful canting of facets and transport to the final location (guarantee curvature and focus). Quality assessment at the end of the process by a third party. Beam-characterization targets on top of the tower.
- **Civil:** topography assessment for each heliostat. Study if the existing soil condition allowed a secure attachment without the use of concrete. Guarantee SF accessibility, identification of each heliostat (tag). road quality for cleaning and rainfall drainage system.
- **Mechanic:** review of installation of pedestals and concrete. Installation of hydraulic system or motors.
- **Electrical:** guarantee good contact with the soil, protections and ohmic resistance of each grounding. consideration of electric harmonics. SF UPSs installation, protection and configuration.
- **I&C:** Position sensors, local PLC, isolators and protection to avoid EM noise/harmonics
- **Software:** delivery and back-up of logics.
- **Documentation:** DB updated by manufacturer and equipment, delivery of procedures, Start of development of as-built documentation (especially topography, foundations, single lines, communications, control logic). Equipment checklist prior to commissioning.
- **Start of Training for the O&M Team.**
- **Punch-list:** generation for all the subsystems that make up the solar field.

Phase 2: Construction



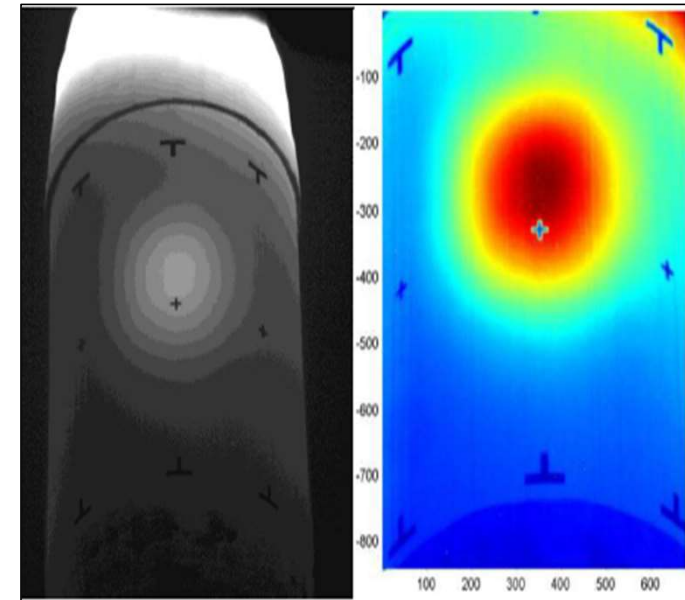
Phase 3: Commissioning



Objective: check, inspect and test every operational component of the SF and integration with the rest of the plant systems (especially: Receiver, I&C, DCS and electrical). Functional tests to demonstrate safety, operability and efficiency prior to handover to O&M.

Key Considerations:

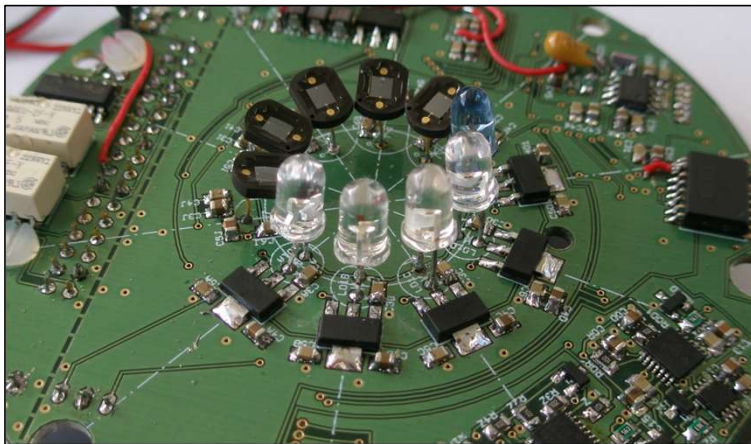
- **Extensive and thorough QA and QC for the different elements:** movements in Az and El, encoders, communications, hydraulic systems, mirrors curvature, PLC's availability, SF UPS availability and protections,
- **Calibration of the SF in an early stage:** deviation identification and action plan.
- **Review supplier/factory tests carried out by the EPC during the procurement activity:** especially for hydraulic system, torque box, optical elements and PLC/Control system.
- **Instrumentation:** accuracy and functioning
- **Checks on the functioning of the control system:** from the local PLC to the different DCS layers. Specially care with Control Receiver integration and auxiliary systems (UPS, thermographic cameras, etc.)
- **Involve future O&M Team:** gain familiarity from the ground (specially maintenance team) to the Control Room (specially operation team).
- **End of the O&M mobilization process**



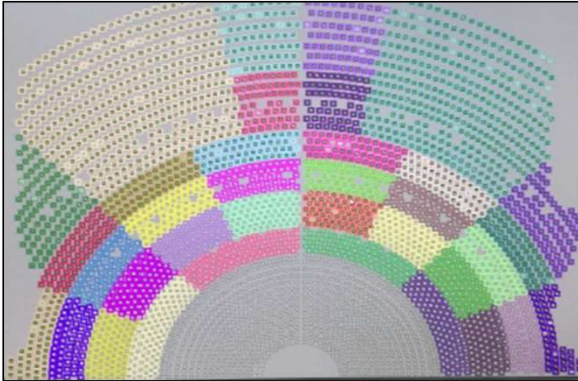
Phase 3: Commissioning



- **Identify damage equipment. Guarantee no basic design or assembly errors have been made:** torque box, hydraulic system, broken mirrors, instrumentation and local PLC's, communication speed between SF and CR.
- **Prior Solar Field Performance Test:** Pre Start-up Safety Review (PSSR), Safety Record Clearance Certificate (SRCC), Turnover Package (TOP).
- **Check HMI interfaces:** local connection with the heliostat PLC and intermediate communication nodes. Screen and synoptics in the control room.
- **Operation Modes Testing:** start-up, shut down, transitories, emergency defocus, cleaning and stow positions, group selection
- **Documentation (quantity and quality):** SF as-built documentation, detailed O&M procedures (involve future O&M team). Equipment check list, punch-list consolidation along with warranties, completion of legal and environmental documentation.
- **Solar Field PM plan Generation.**
- **O&M Team Training Completion**
- **Database Assessment:** maintenance and storage at warehouse.
- **Solar Field Spare Parts:** to be delivery by the end of construction stage.



Phase 3: Commissioning



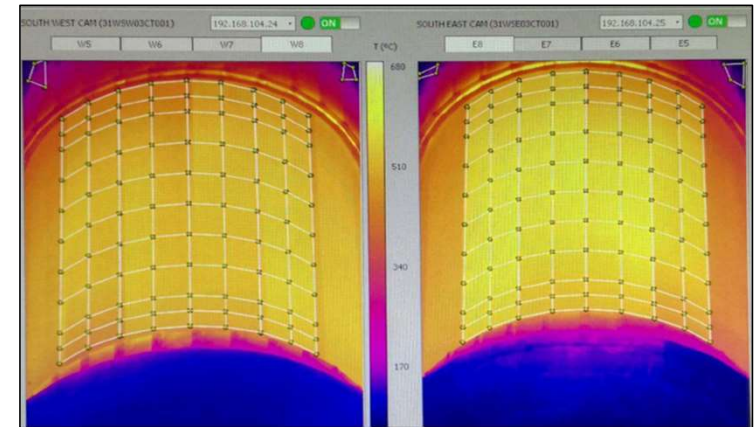
Phase 4: Operation and Maintenance



Objective: provide diligent and safe services during the rest of the life cycle to achieve PPA expectations. Aspiring to optimize performance ratio above the one considered in design stage.

Key Considerations:

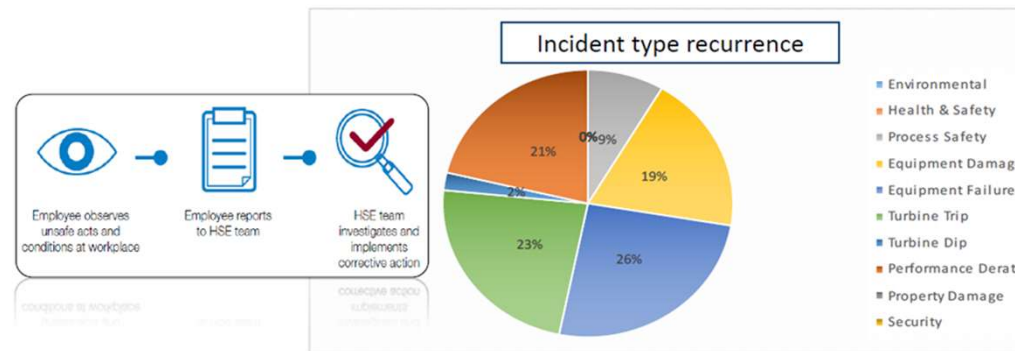
- **O&M staff:** to be completely trained and fully mobilized
- **O&M plan fully developed:** SF strategies, organizational plan (org. chart: functional groups/roles) safety compliance, plant performance, annual budget, operational, maintenance and staff training programs. Spare part and inventory control. Contractual, environmental, and regulatory compliance.
- **Long-term service agreements (LTSA) and general service agreements in place:** remote access to the Solar Control System, Hardware (PLC, encoders, hydraulic system), Cleaning Trucks.
- **Adequate performance measurement for the different Solar Field processes - HSSE, Operation, Maintenance and Logistics:** Standardization into the Daily Production Report.
- **Dashboard and Key Performance Indicators (SF-KPI):** Heliostat-field availability (target: 99%), Cleanliness Factor (target: > 95 %), Water Consumption, Weather (DNI, wind, transmissivity), Cleaning Trucks Available, Number of Heliostat Cleaned, Cleaning Strategy (Spray, Brush).



Phase 4: Operation and Maintenance



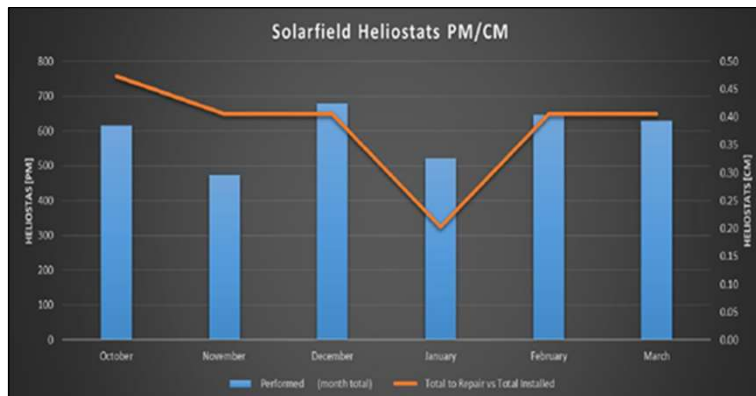
- **Specific Spare Parts and Special Tools:** guarantee the delivery before finalizing commissioning, prevent component obsolescence in advance, avoid stock-out situations, local (mechanical, electrical) or external (electronic, instrumentation, mirrors) suppliers to evaluate levels and costs.
- **Warehouse Management and Housekeeping:** ERP solution implementation- updated & integrated information on maintenance plan, spares, tagging, consumables and supply chain.
- **Optimization of operating modes integrated with relevant information from the weather forecast:** pre-start-up, nominal conditions, transient clouds, defocus and trips, storage & generation, storage without generation. Storage management strategy to flexibly cover demand during off-peak and peak hours. Cleaning, windy, defrost and stow modes.



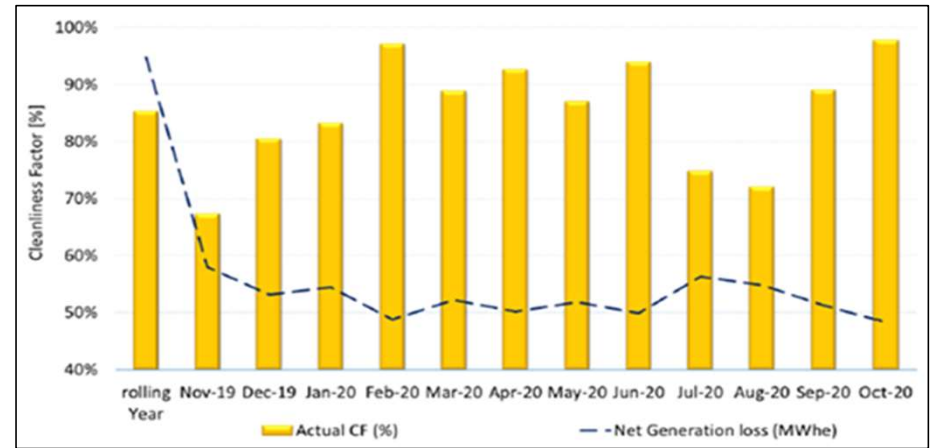
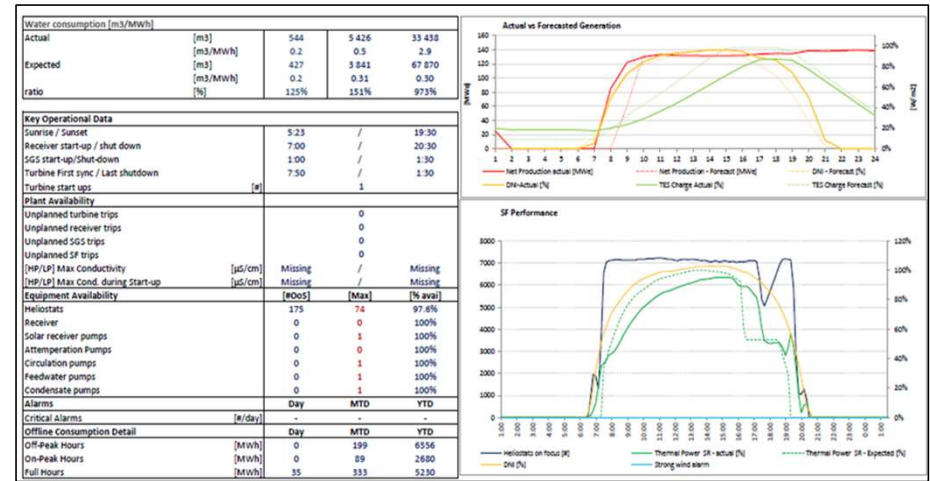
Phase 4: Operation and Maintenance



- **SF optimized cleaning strategy (different from parabolic trough):** SF topology and geometrical heliostat performance, weather forecast, availability of cleaning trucks, SF maintenance works, water and fuel savings. Implementation of soiling events rapid-response plan and daytime cleaning in times of excess of energy.
- **Specific SF Maintenance Program:** Corrective (mirrors, encoders, electronic), Preventive (hydraulic units, and active components) and Predictive (UPS)
- **Guarantee SF early availability:** avoid delays for turbine start-up and synchronization.
- **SF management:** aligned with the TES system storage strategy.
- **Alarms and Trips from HMI CR:** optimization and debugging



Phase 4: Operation and Maintenance



Agenda



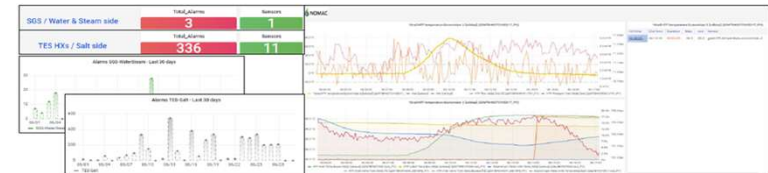
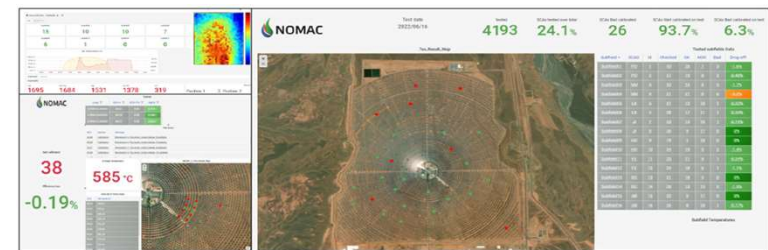
Improvements: A Glimpse to the Future
03

Improvements: A Glimpse to the Future



Objective: Automation - repetitive SF activities that consume large media resources (personnel, technical, financial). Cost optimization throughout different stages. Improve CM and PM process. Integration & visibility. **Outcome:** improvement in business decision-making, Lessons Learned and cost effectiveness.

- Increase level of plant automation: 'one single button approach', systems automatic protection.
- Weather Forecast Models Improvement: 'Deep Learning' approach
 - Integrate information from different sources: site, regional stations and satellite.
 - Provide information in different frame-windows: hard and soft real time
- Drone Technology for Maintenance Tasks (due to activities arising into the SF huge extension and many elements): Broken Mirrors, Tracking errors, Dirty-Soling Areas, Cleanliness Factor measurement, Heliostat stopped for corrective actions.
- Digitalization for Maintenance Tasks:
 - Integrate into the same ERP: Checklists, Technical Documentation, CM and PM Tasks, CM and PM status and resolution.
 - Visibility for both Operation and Maintenance Teams, Tablets and Smartphones as basic tool.
- Digitalization for Performance Tasks: Technical models integration and automation analysis

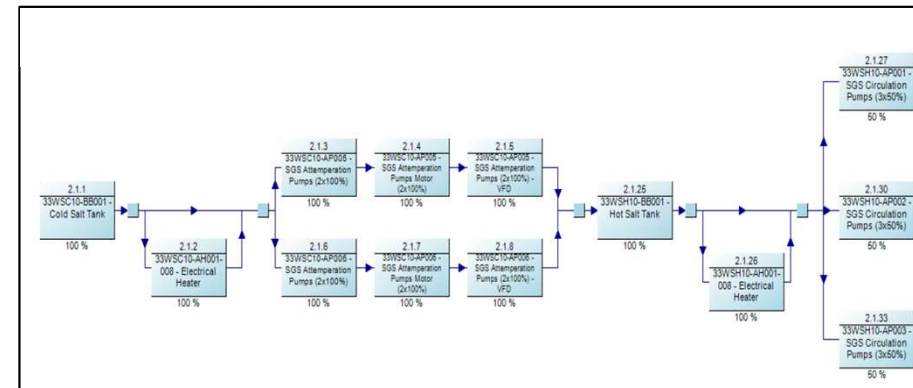
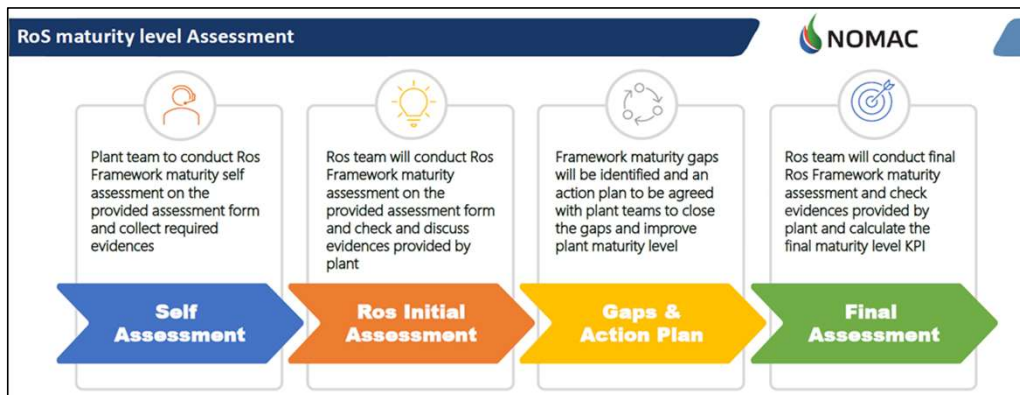


Improvements: A Glimpse to the Future



Heliostat Technical and Expenses Improvements:

- Standardization of models and tests customized to the project requirements.
- Improvement in the competitiveness between companies for manufacturing and assembly processes.
- Heliostat Power and Controls Cost Reduction.
- Betting on autonomous solutions: power (PV + Batteries) and communications (wireless).
- Flux radiation measurement: methodology improvement. Currently, no method capable of estimate incident power on the receiver with an accuracy of $\pm 1\%$
- Reliability and Single point of Failure analysis since engineering phase: *to be updated during the entire life-cycle of the project.*



Agenda



Conclusions
04

Conclusions



- **Technology:** Still needs final consolidation to ensure adequate financial returns.
- **Business and Profitability:**
 - CSP projects have the potential to meet demand and find a stable niche using storage and dispatch capacity in certain regions within a competitive market involving different players.
 - The measure of competitiveness could be established based on the LCOE: optimization of costs and proper functioning throughout the entire life cycle of the project.
- **Current Development:** Few tower projects in the commercial operation stage, compared to parabolic trough assets. Different result regarding performance and reliability.
- **Main expected objectives:**
 - Reduction of costs Reduction: design, construction and O&M. Standardization of processes, schedules and materials, diversification of suppliers and the economy of scale, can be key.
 - Availability (99%): both in nominal operation and in start-up, stop and transients.
 - Reliability (97%): Optic and tracking accurate enough together with reflectivity in order to achieve ratios comparable to the theoretical designs.
 - Future Success: will be determined by the improvement of processes: Performing and Scalability, Automation and Digitization. Full integration as a whole within the main plant systems.

Conclusions





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