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Concentrating Solar Power Services

Pre-Feasibility Study for the Establishment of a
Pre-Commercial Concentrated Solar Power Plant in Namibia

Presentation of the First Draft for final version

June 2012

TECHNOLOGY AND DEVELOPMENT
POLYTECHNIC
OF NAMIBIA

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CSP TECHNOLOGY OVERVIEW

NAMIBIA SOLAR RESOURCE AND DNI ANALYSIS

ENVIRONMENTAL ANALYSIS AND SITE SELECTION

TOP 5 SITES SELECTION AND FINANCIAL ANALYSIS

GROUND MEASUREMENTS

CSP DEVELOPMENT AND IMPLICATIONS FOR NAMIBIA

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INTRODUCTION AND TECHNOLOGY OUTLINE (I/III)

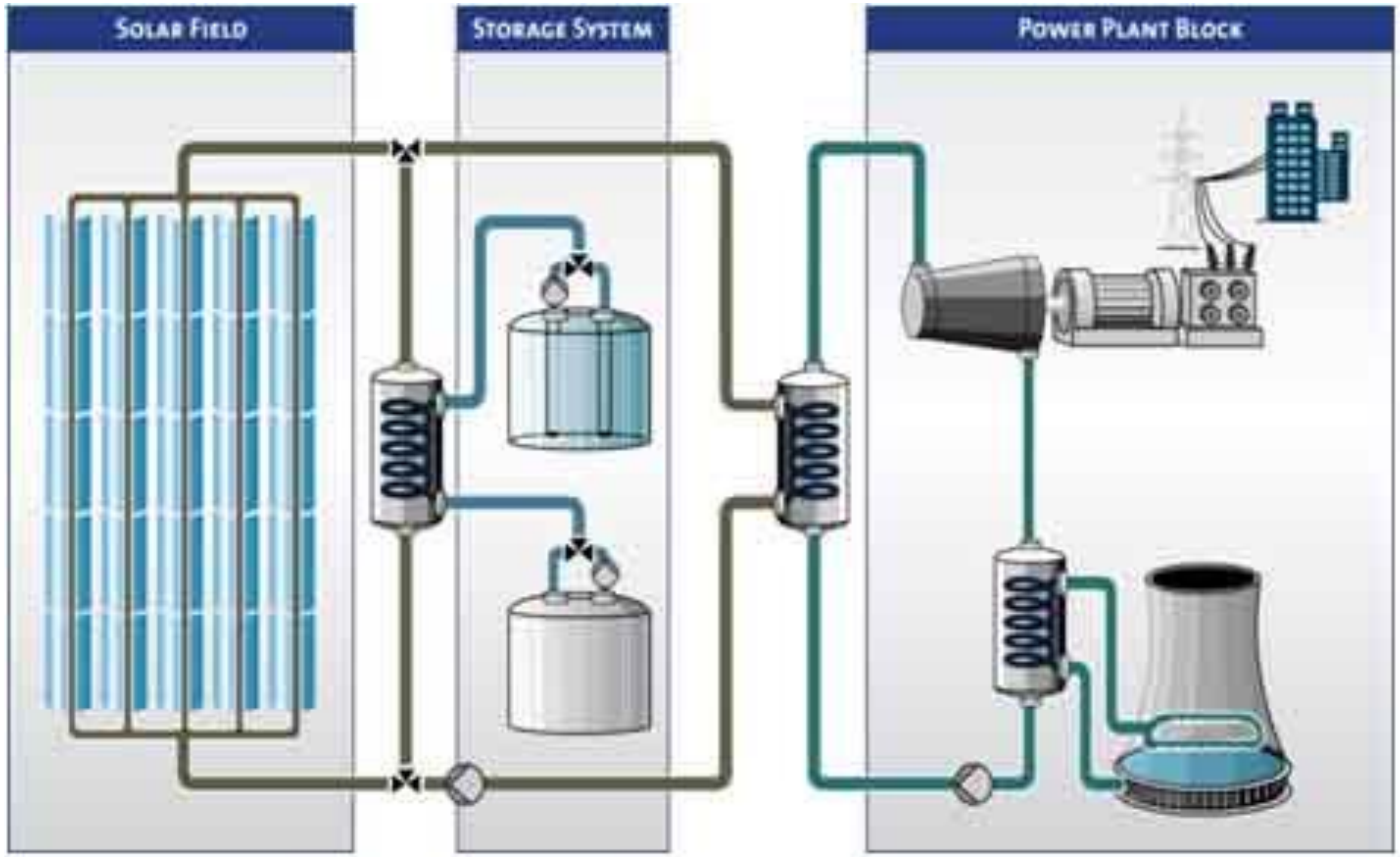
- Concentrating solar power (CSP) collects heat through the use of optical elements that collect the irradiance over a large area and focus it onto a smaller image area. This concentrated power can then be used by various systems to produce electricity via Solar Thermal systems, referred to generically as CSP.

- In general, CSP technologies aim to use optical systems to concentrate direct beam solar irradiance (or Direct Normal Irradiance), collect its energy as heat in appropriate fluids and use thermodynamic cycles to produce work and so be able to generate electricity.

- CSP technologies are eminently compatible with traditional steam turbine based power plants and their design. Most of the CSP plants are essentially a conventional thermal power plant with a solar field providing the heat input instead of a fossil fuel heat source.

- The first fully commercial CSP plants, the parabolic trough solar energy generating stations SEGS I-IX built after SEGS I, from 1981 through 1990. These latter constitute 354MW of natural gas backed solar plant that have been in continuous operation since their construction through the mid-eighties. The plants have incorporated successive improvements to the trough technology and have long been considered the benchmark for parabolic trough performance.

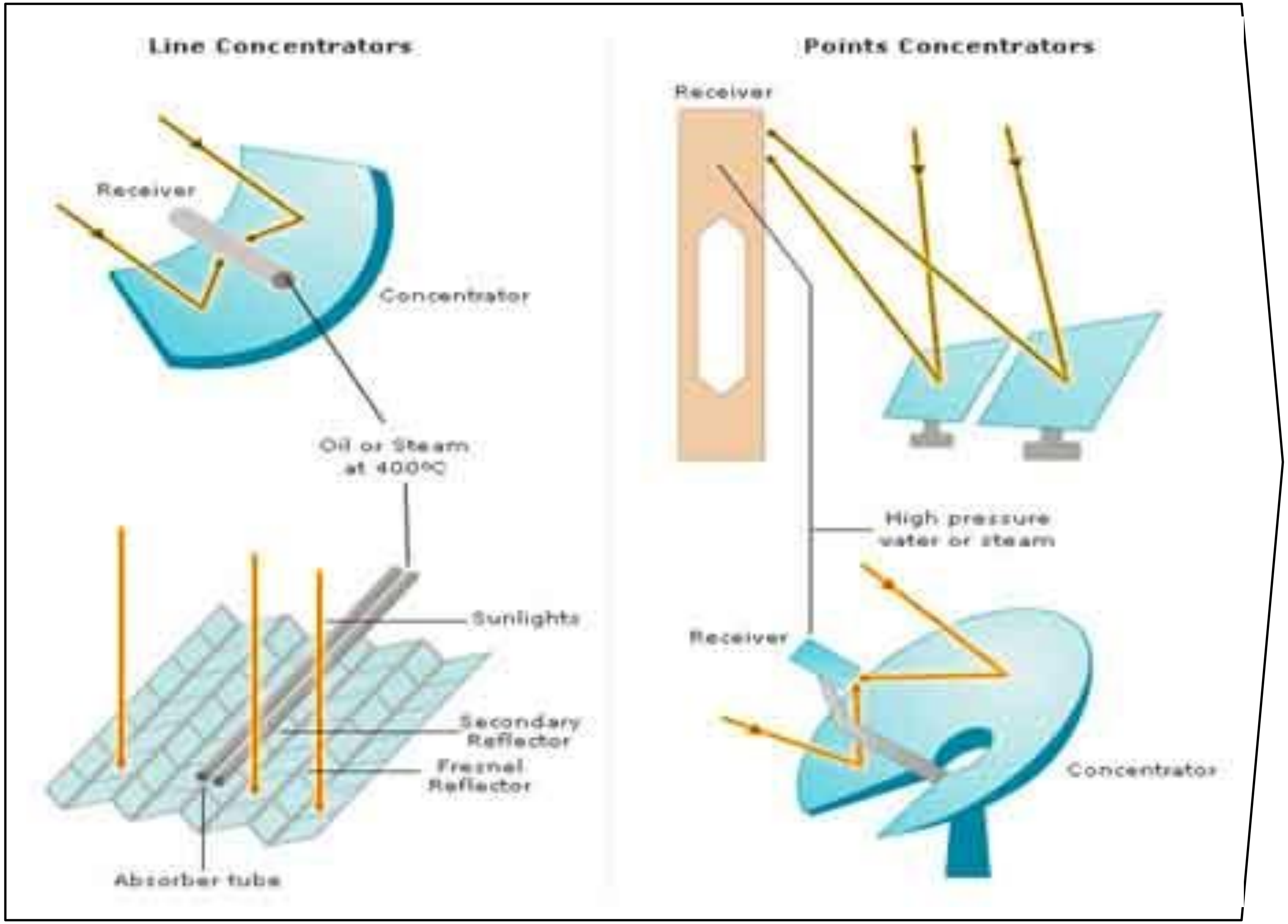
INTRODUCTION AND TECHNOLOGY OUTLINE (II/III)



A typical CSP solar plant

- Solar field
- Heat transfer fluid system and heat exchangers
- Optional back-up parallel boiler or storage system
- Steam cycle feeding into the turbine
- Power block and ancillary wet/dry condenser, deaerator, feedwater and pumps
- Grid connection

INTRODUCTION AND TECHNOLOGY OUTLINE (III/III)



Main types

- Linear focus systems (Parabolic troughs and linear Fresnel reflector systems)
- Point focus systems (towers

CSP Advantages

- Easy and cost effective implementation of thermal storage
- Easy combination with combustion fuels (hybridization)
- Slow response to short-term fluctuations of solar irradiation due to thermal inertia of the system
- Usability for other purposes than electricity generation (e.g. solar cooling, process heat, seawater desalination)

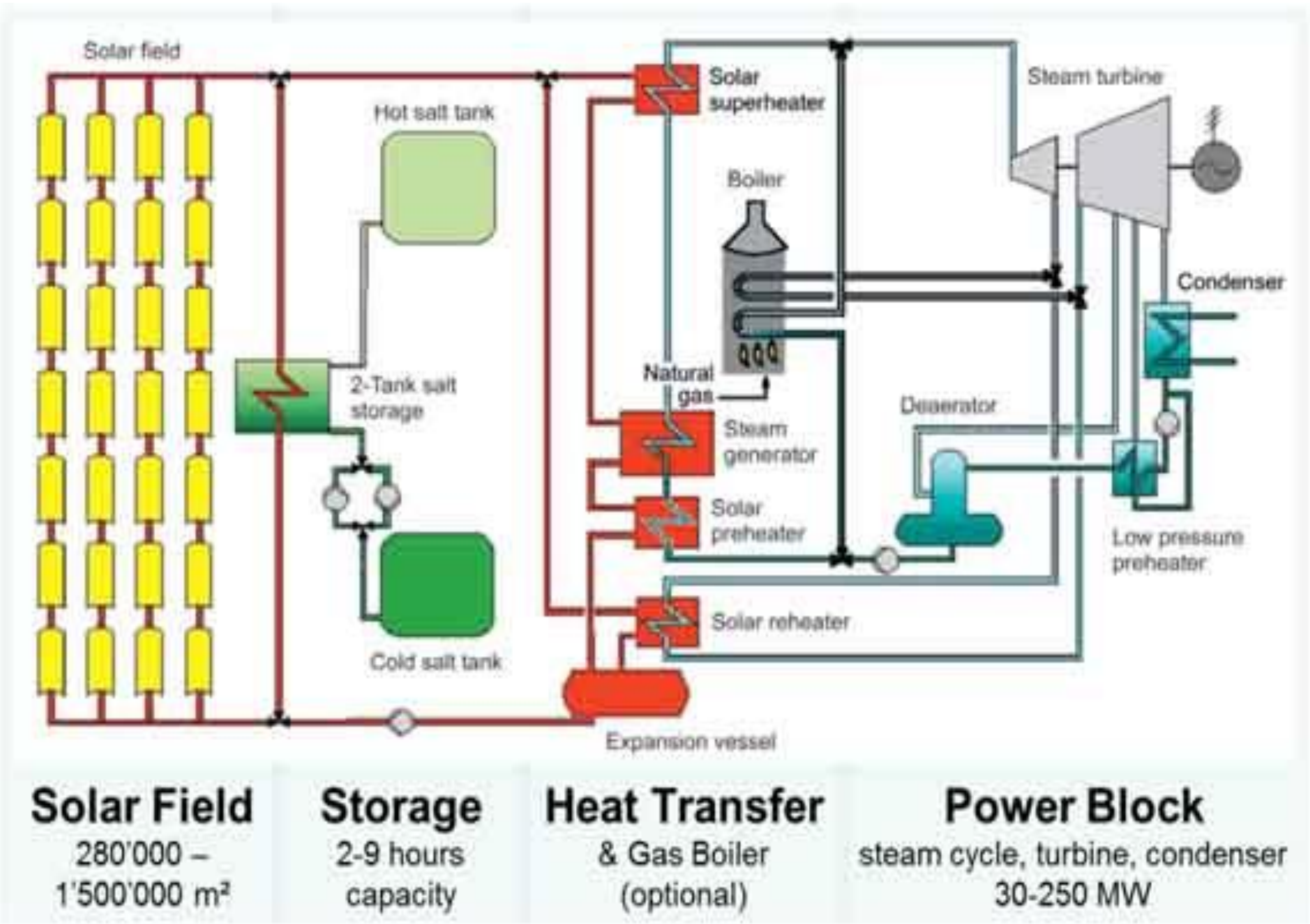
PARABOLIC TROUGHS (I/III)

- The operating principle of a parabolic trough power plant :
- Parabolic mirrors track the sun about one axis, usually north-south, and focus its rays, with typical concentration factors of 70-80, onto linear, specially coated, heat collecting elements (**HCE**).
- HCE are coated steel pipes with a surrounding evacuated glass tube that minimizes heat losses
- Heat transfer fluid (**HTF**) is circulated through the HCEs to carry the heat from the solar field to the power block.
- Superheated steam is used to run the turbine.
- The plant includes conventional sub-systems – the power block steam turbine and generator, wet

cooling towers or dry air cooled condensers, feedwater pumps and deaerator for the steam cycle and a steam drum.

- Optional storage and/or auxiliary gas burners can be used to cover transient weather conditions and for production during night time or to protect the HTF against freezing.

PARABOLIC TROUGHS (II/III)



- Schematic diagram of a typical parabolic trough solar power plant
- Possible sizes for the different components

PARABOLIC TROUGHS (III/III)

Some projects that can be considered as milestones in the development and commercial adoption of this technology are:

SEGS I-IX, California, USA (completed 1981-1990), 354 MW

- The SEGS (Solar Electricity Generating System) plants in California were the first commercial CSP plants in the world. The largest plants have a capacity of 80 MW. They are still operative today, demonstrating the reliability and durability of this technology.

Nevada Solar One, Nevada, USA (completed 2007), 64 MW

- This plant was the first parabolic trough plant to be built almost two decades after the SEGS systems. It comprises a 0.5 hour storage.

Andasol 1, Andalusia, Spain (completed 2008), 50 MW

- Andasol 1 was the first commercial CSP plant in Europe and the first one with a large storage for 8 hours of full load operation without sun.

ISCC Morocco, Ain Beni Mathar, Morocco (completed 2011), 470 MW (20 MW solar)

- This project can be considered the first large scale hybrid power plant, where waste heat from a gas fired turbine is combined with heat from a solar field to drive a steam turbine.

LINEAR FRESNEL REFLECTORS (I/II)

- Can reach solar concentrations of 30 – 100 suns
- Open the possibility of using simple, non-industry specific, commodity materials as optical and construction elements in CSP plants.
- Use flat rather than curved mirrors, low profile construction, leading to rapid on-site assembly.
- Rotating reflectors
- Non-evacuated standard steel tubes and are protected by plain glass sheets.
- Solutions exist with evacuated tubes as well

- Collector frame structures are fixed in place, dispensing with high temperature moving joints and implemented direct steam generation (DSG i.e. water as HTF) in the receivers
- Cost of Fresnel solar fields is cheaper than that of parabolic troughs.

LINEAR FRESNEL REFLECTORS (II/II)

Commercial LFR have a number of recognised advantages

- Compact footprint, lowest at ~1.3ha / MW at 35° lat., less closer to the equator.
- Slope requirements, they can accommodate up to ~5° slope.
- Medium to high operating parameters achievable, temp range 270°C to 500°C and pressures 50 bar to 165 bar suitable for large steam turbines.
- Demonstrated hybridisation with gas
- Low cost, widely available construction materials, potential for high local content
- Simple field assembly
- Modularity, from ~10MW to 250MW
- Applications span industrial steam, fuel saver/Booster and standalone power plant
- Financially Strong companies are backing the technology e.g. Areva, ABB, *JFE*

Main disadvantages of this technology

- Lower efficiency, latitude dependence can decrease instantaneous output by 2% to 8% for latitudes 10° to 40°.
- No demonstrated long term storage
- Few implemented projects
- Lack of industry acceptance of the technology and project bankability

POWER TOWERS (I/II)

- Power tower (or central receiver) technology, the collecting optics are called heliostats
- Individual 2-axis sun tracking heliostats concentrate direct beam sunlight onto an absorber, called receiver, which is fixed atop a tower.
- Possible to have thermal energy storage system and/or a fossil fuel firing system to enable round-the-clock operation of the plant if required.
- Possibility of very high solar concentration ratios of up to 1000 suns

- Allowing for very high HTF operating temperatures (565 to 1000°C), depending on which technology is used
- Enormous potential for achieving the highest Carnot efficiencies among the CSP thermal power plants

Requirements

- Atmospheric conditions (e.g. amount of particles in air) must be suitable as the intensity of scattering of radiation by particles has to be reasonably low. This aspect is especially meaningful in comparison to other CSP technologies, because the irradiation collected by the heliostats is transferred over distances of up to above 1km through the air layer close to the ground which can be containing a lot of dust and other particles, thus severely reducing the amount of energy arriving at the receiver.
- The site should ideally be flat but this is not a prerequisite i.e. a slight slope could be tolerated. Until now, all but one power tower plant, the research tower THEMIS in France, were erected on relatively flat ground.
- If a form of wet or hybrid cooling technology is to be used then the plant would have to be located near a water source such as a river or a lake which carries or holds sufficient amounts of water throughout the year. A high efficiency turbine requires less water.
- Social and environmental concerns/impacts should be properly assessed

DISH STIRLING (I/II)

- Dish Stirling technology has been developed as relatively small power generation systems when compared with other CSP technologies
- Power ratings are between 3 to 25 KW though recently larger systems are being attempted
- The system is a stand-alone, which tracks the sun in two axes and concentrates the direct solar irradiation onto a receiver - at the focal point of the paraboloid reflector or dish - where an engine using a Stirling cycle converts heat into mechanical energy through a piston engine, which in turn is transformed into electricity by an electrical generator directly connected to the engine's crankshaft.
- Highest peak conversion efficiencies of above 30% solar to electricity and a daily average of up to 25 %, however, this record is due to their high concentration ratios up to 3000x and high working temperatures of above 750ºC plus the environmental conditions

- Requires a relatively "cold side" which is the case in some deserts with clear skies (DNI can be quite high and still due to the bright skies the temperature is not high)

DISH STIRLING (II/II)

Key issues for project location and design:

Ratios of land usage

- 3.5 to 4.1 ha of land per MW.

Slope and other requirements for suitable land

- Slopes of up to 4%, if they are mounted on a single pole that stands up several meters above the ground, then there is no need for such a flat ground as in the case of systems that use a circular tracking ring to enable azimuth tracking.

Water usage

- No water requirement for cooling the Stirling engine, the only water use for dish engine facilities is for washing of mirrors

Effluents

- No effluents
- Leakage of working fluids is possible, such as spilling small amounts of engine oil or coolant or gearbox grease.

Design constraints

- Layout of solar field of i.e. distances between dishes is critical as it influences the power output of the system and land area requirement; while close packing of dishes, can reduce land requirement, electrical cabling losses and cost, the dishes can cast shadow on each other and solar system performance is reduced.

STORAGE (I/III)

- Solar DNI is intermittent and has daily and seasonal cycles, so solar heat collection from a CSP field is necessarily variable and sometimes reaches higher levels than the design maximum of the associated power block.

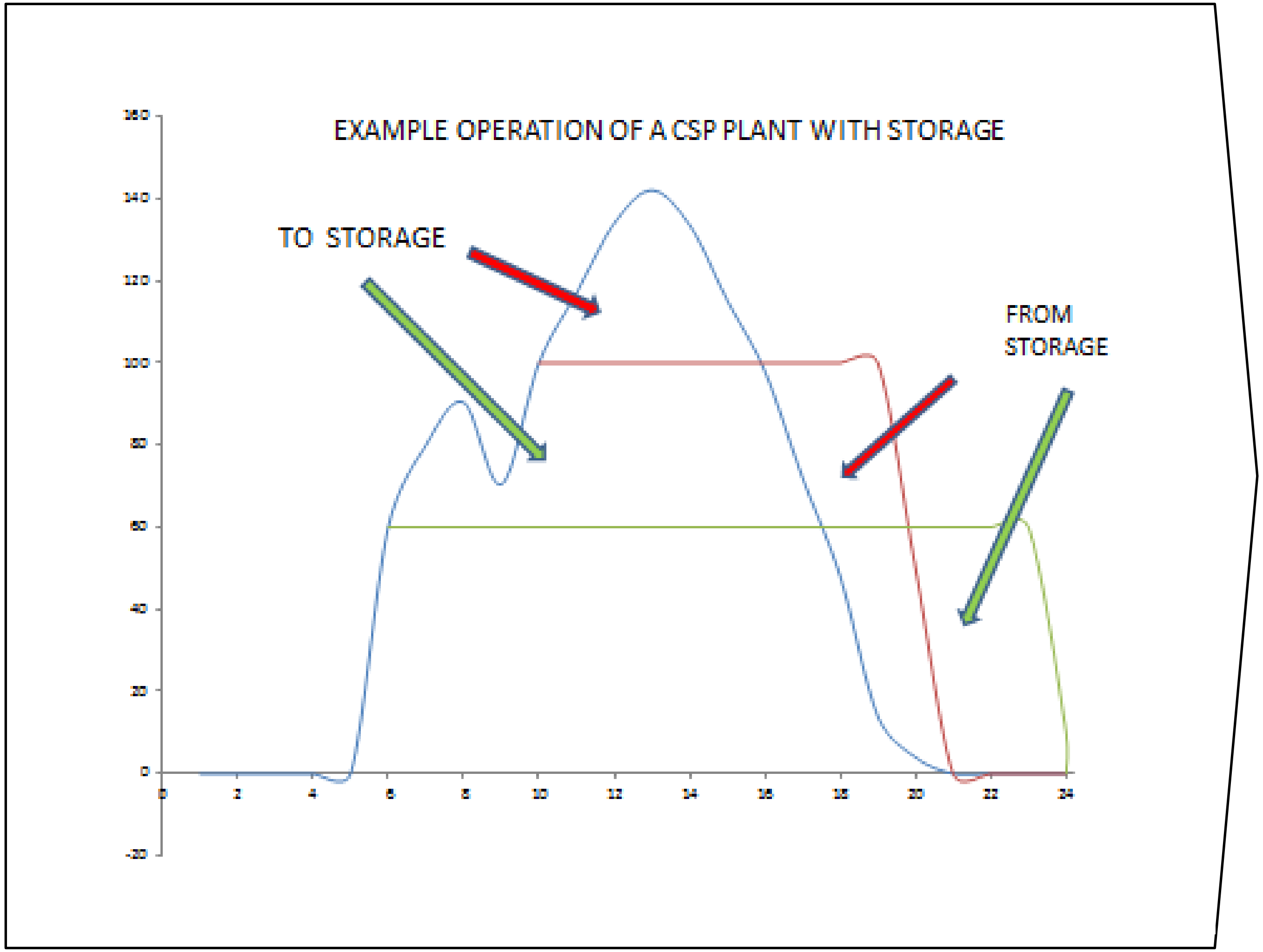
- In a plant without storage, this excess heat, often present around midday and in summer periods, cannot be used and is either rejected or clipped before collection (e.g. via mirror defocusing).

- If storage is present, this excess heat can be stored and then used effectively to supplement the DNI when the latter is either not sufficient to drive the power block alone or is non-existent.

- Most CSP plants can store heat for short periods due to the bulk of materials used in the construction of their receivers and field piping. This allows them to “ride through” small temporal variations in irradiance, e.g. those due to small cloud passage. This is not considered storage, but system inertia.

STORAGE (II/III)

- If the solar field size can provide more than the heat needed to drive the power block at maximum rating (solar multiple greater than 1), by selecting an operating point for the power block at 100% of its rating, or say 60% of its rating, electricity production can be maintained for a number of hours beyond sunset or through into the evening.
- Solar multiples for CSP plants with storage are typically greater than 2.



- This allows extended operation and eventually, 24/7 operation of the power plant. CSP plant may be operated as peaking plant or as base load power plant.

STORAGE (III/III)

Storage

Molten salts

60% sodium nitrate, 40% potassium nitrate
Indirect two tank molten salt storage system, direct two tank storage system. In the latter, the molten salt acts as both heat transfer fluid and storage medium, while in the former molten salts are only used as storage medium. Single-tank molten salt system is being developed, using thermocline or sharp vertical temperature transition from cold to hot.

Ceramic with air as heat transfer fluid

It combines the use of a gas as the heat transfer fluid and a ceramic material for heat storage at these temperatures. The hot gas, specifically air, is blown through an insulated bed of ceramic materials (silicate sand or aluminosilicate ceramic bricks have been used)

Pipes in solid media + PCM

Comprise three sub-systems operating at low, medium and high temperatures respectively. Both low and high temperature ranges are provided by, for example, pipes-in-concrete subsystems relying on sensible heat of the cast concrete. The medium temperature subsystem uses latent heat storage in a PCM which has a phase change temperature close to that of the steam input to the turbine.

Sand

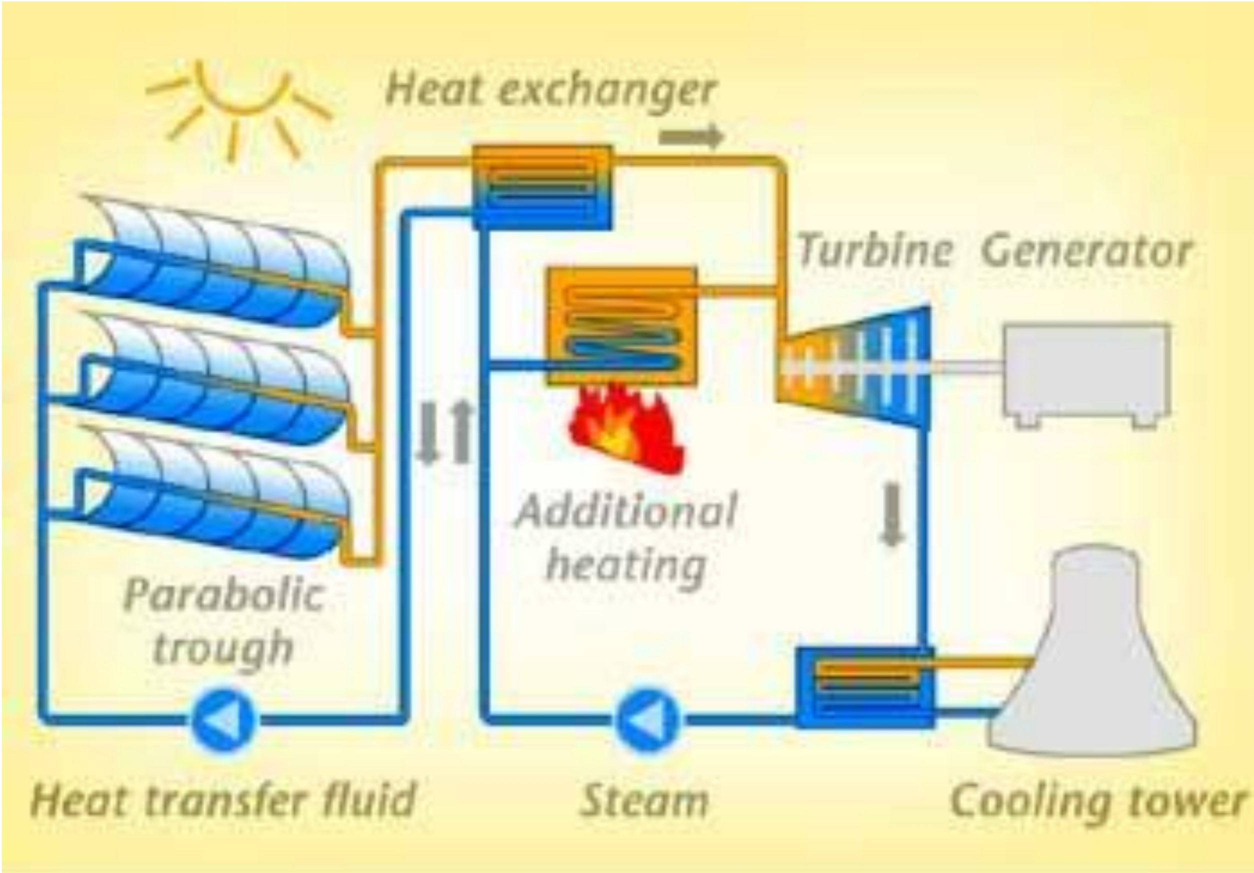
Sand is used as heat transfer and storage fluid. In this case, the sand is directly irradiated by the solar beam as a falling particle curtain inside the receiver, and stored for later use. This is under research.

HYBRIDIZATION AND AUGMENTATION

- One of the biggest challenges of concentrating solar power (CSP) is the intermittency associated with clouds during the day which can lead to transients.
- It can be mitigated by storage, hybrid system or also called back-up.
- All CSP technologies have the option of hybridization, because heat is what generates electricity in: parabolic trough plants, power towers, Linear Fresnel Reflector and dish Stirling systems.
- The ease of hybridization for troughs, tower plants and Linear Fresnel Reflector stems from the fact that the boiler is an entirely separate component, while for dish Stirling systems the hybridization needs to be an integral part of the design, and that has proven to be more difficult to design and implement.
- Hybridization can come with natural gas, biomass and coal, while in the latter case it is usually called augmentation.

HYBRIDIZATION WITH NATURAL GAS (I/II)

- The current CSP power plants in Spain have an auxiliary backup natural gas boiler to mitigate the number of shutdowns of the turbine as well as the intermittency associated with the solar radiation and consequently the steam generation.
- The use of small amounts of gas Backup may be justified by the investment in the Balance of Plant infrastructure namely the turbine
- The backup via natural gas boiler has a relatively low investment cost and is mature, low risk technology.



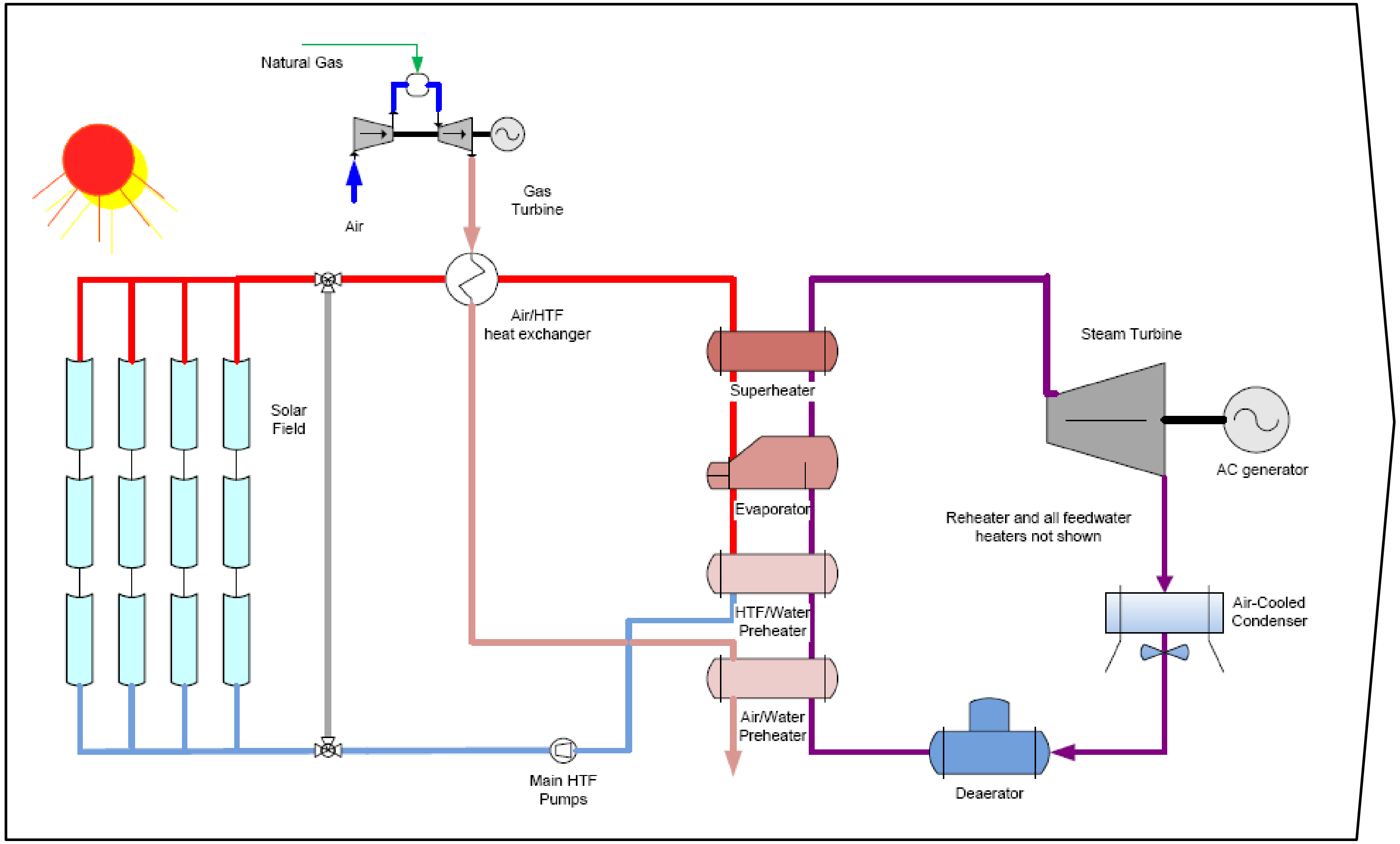
The concept of backup is simply explained in the following diagram

HYBRIDIZATION WITH NATURAL GAS (II/II)

- The integration of CSP technology with a combined cycle power plant is referred to as integrated solar combined cycle systems (ISCCS)

- Examples of its application exist in the world, namely in Morocco, Algeria and Egypt

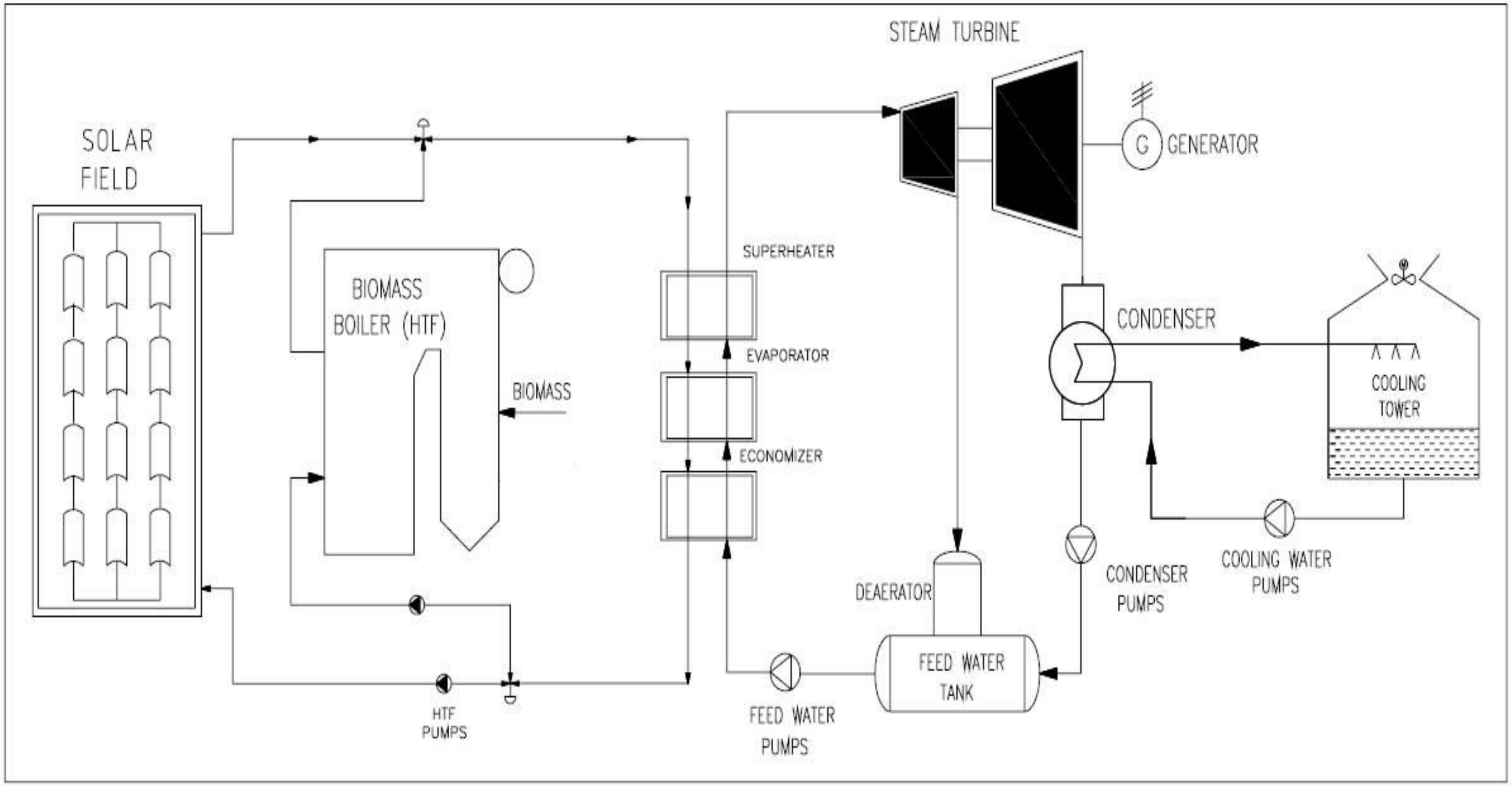
- The gas turbine generates electricity and at the same time heat which is coupled with the heat from the CSP solar field to generate power through a steam based turbine.



- The idea is to increase or augment the output of the power plant
- The concept has run into some problems and is being questioned as a viable option. In any case the idea is now associated to augmentation and not to hybridization.

HYBRIDIZATION WITH BIOMASS

- Mature technology
- Cost of hybridization is low – boiler and burner
- CSP generally require a considerable power rating to be economically viable, so boiler is in the MW range



The combination of these two technologies benefits from increased overall efficiency of the power plant, reduced number of shutdowns of the turbine and reduced investment per unit of power generated compared to CSP with molten salts heat storage, for example

COAL AUGMENTATION (I/II)

- CSP systems are highly flexible for integration with conventional power plant design and operation and for blending the thermal output with fossil fuel, biomass and evn geothermal resources. Basically all technologies that use heat can be coupled or augmented by solar thermal.

- One of the ways is to reduce fossil fuel usage and/or boost the power output of the steam turbine. To reduce the fuel usage the steam generated by the CSP power plant is injected in a low pressure (LP) point or even high pressure (HP) of the steam cycle or in the economizer.

- Successful cases have been more successful at the latter and also using LP feed heaters.

- The heat supplied by the CSP power plant will theoretically avoid the usage of the conventional fuel for the same operation.

COAL AUGMENTATION (II/II)

- CSP solar field is much cheaper than a CSP power plant and in a conventional power plant the whole power plant is available

- CSP solar field generates steam for a conventional power plant will yield interesting paybacks as it has been shown by Hu, David Mills, Graham Morrison and Peter Le Lievre in the paper *Solar power boosting of fossil fuelled power plants* (published in ISES back in 24th May 2003).

- Liddel CSP solar field to augment a coal power plant as one of the first projects of this nature in the world.

DESALINATION (I/III)

Renewable Energies can be used for desalination based on two ways: heat or power. Usually the electricity route is used with membranes and the heat is used for evaporation.

Three technologies stand out as being the most mature:

- Reverse osmosis (RO)
- Multi-effect distillation (MED)
- Multi-stage Flashing (MSF)

The heat used for the mentioned processes above have come from fossil fuels and usually such projects are incorporated with thermal power plants to use the waste heat, but some CSP systems have also been developed to provide a way to use solar energy for desalination as well as with biomass as the heat source. On the RO route the electricity may come from PV modules, wind turbines or any other clean source of electricity, including the CSP for power generation.

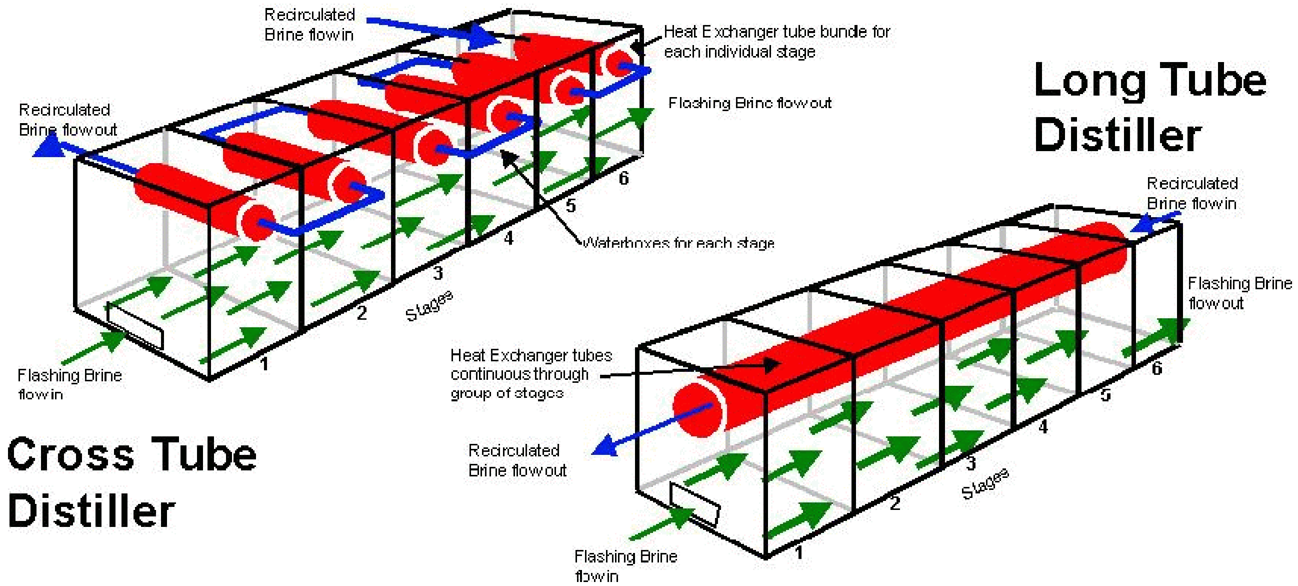
Reverse osmosis (RO) uses electricity to pump water against a membrane while the other technologies use heat to evaporate and condense water. New processes of RO with nanotubes and biomimetics are in development and on the heat side improved concepts are also being researched.

Multi-stage Flashing (MSF)

Series of stages in which “flash” evaporation takes place from the flow of salt water or brine that occurs in the lower part of the evaporator

The vapour released in flashing is filtered to remove brine droplets and condenses to yield water on heat transfer tubes at the top of the evaporator

The seawater or brine flowing through the tubes is heated by the transfer of latent heat from the condensing vapour, giving a temperature rise equal to the temperature drop in “flashing”



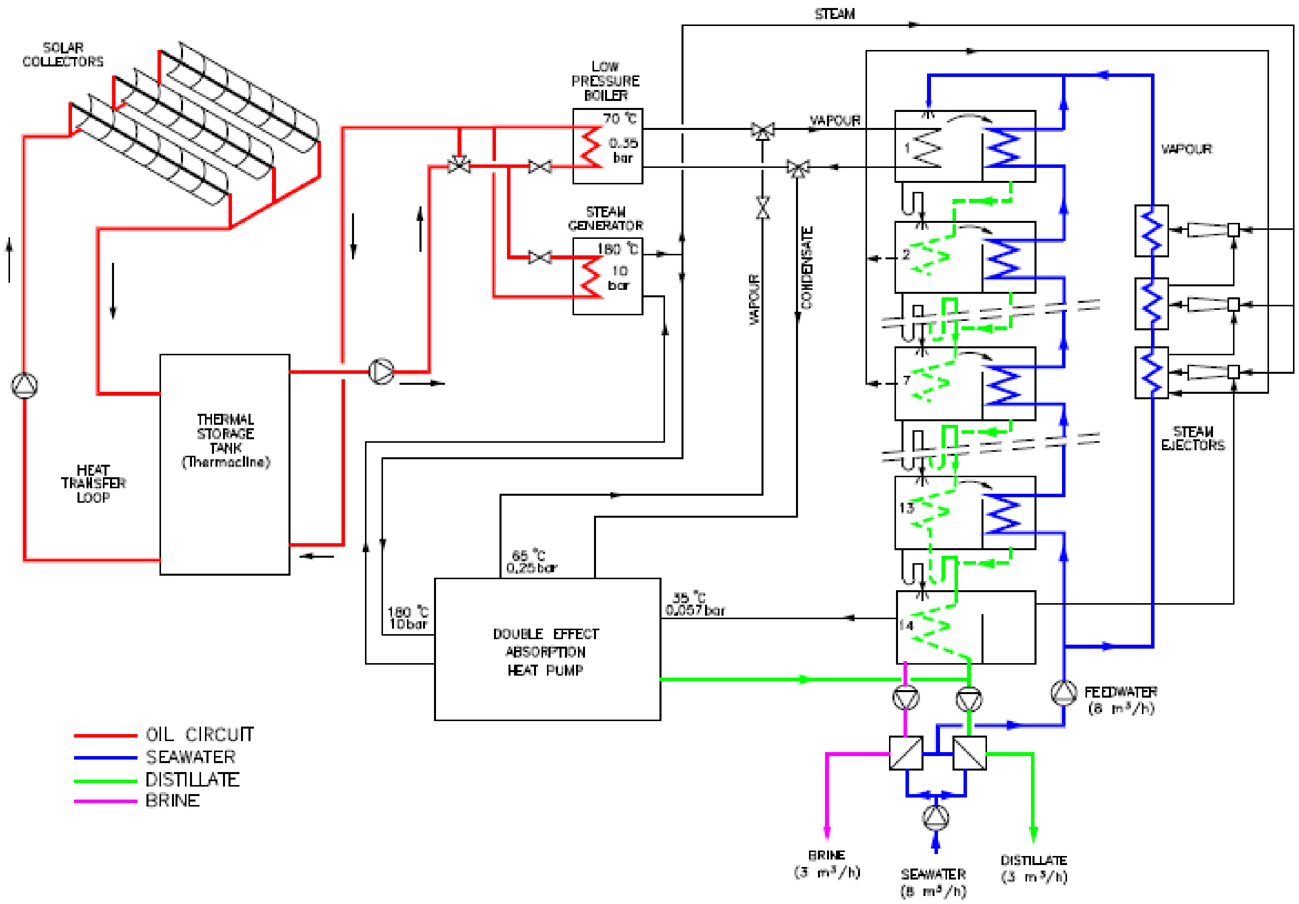
Example of a MSF process

Multi-effect distillation (MED)

Vapour formed in each effect flows to the condensing side of the heat transfer surface in the next (lower temperature) effect

The latent heat of condensation is transferred through the tube wall to evaporate part of the saltwater or brine flowing across the surface.

Evaporation is from a seawater film in contact with the heat transfer surface



Schematic diagram of the solar MED system installed at PSA

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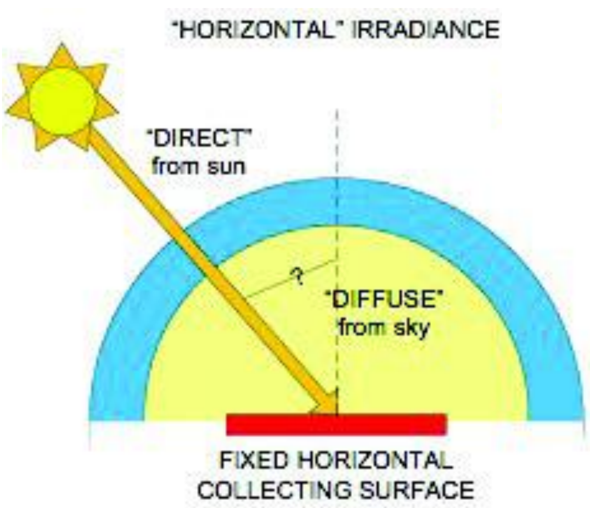
SOLAR IRRADIATION AND AEROSOLS (I/II)

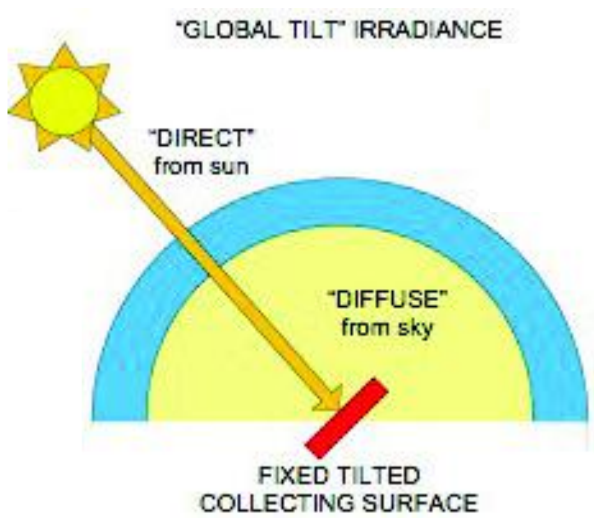
- **Concentrating solar power (CSP) plants must focus sunbeams on a collector to generate high temperatures**. **Only direct radiation from the sun can be concentrated this way**. This makes CSP plants more sensitive to atmospheric conditions than if they could also use diffuse radiation, as with flat-plate collectors (PV or thermal).

- Diffuse radiation normally varies in the opposite direction of direct radiation. Therefore, **direct normal irradiance (DNI) is much more sensitive to clouds or aerosols in the atmosphere than global irradiance**, which is the “fuel” for fixed mounting collectors.

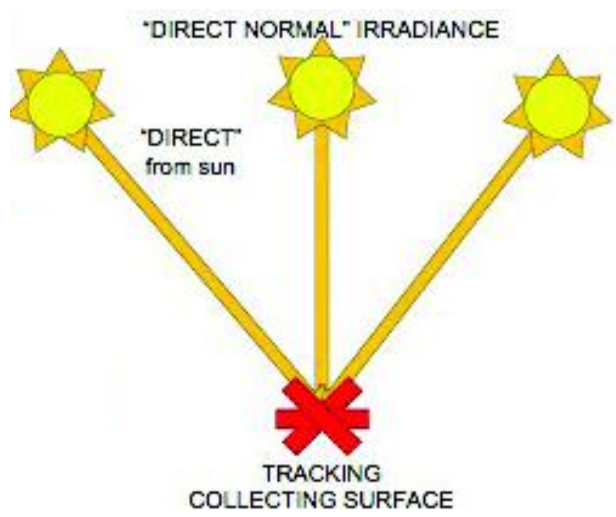
- **An area with a good solar resource in global horizontal irradiance (GHI) is not necessarily suitable for CSP projects**.



Direct normal irradiance (DNI) is the fraction of the downward flux directly emanating from the sun disk that is incident on a plane normal (i.e., perpendicular) to the sunbeams, and that has not undergone any extinction in the atmosphere



Global horizontal irradiance (GHI) is the sum of the projected DNI on a horizontal surface and of diffuse horizontal irradiance



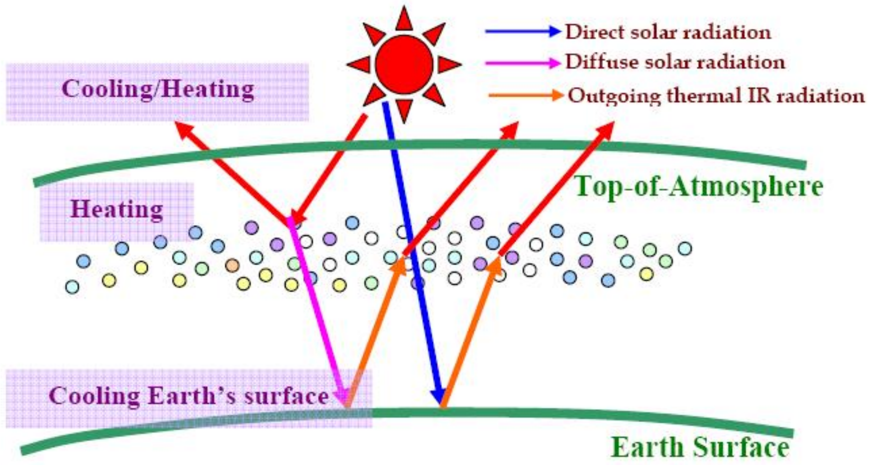
Diffuse horizontal irradiance (DHI) is the downward flux emanating from the sky vault, excluding the sun.

SOLAR IRRADIATION AND AEROSOLS (II/II)

- Aerosols are composed of various particles in a large range of sizes. They include sea salt in suspension, sand dust, and many other particles generated by vegetation (e.g., pollen), volcanic activity, anthropogenic emissions (pollution), smoke, etc.

- Under low-aerosol conditions, horizontal visibility is excellent (more than 50 km) and the sky color is dark blue. On days with much higher aerosol loads, the sky becomes hazy (whitish) and visibility decreases significantly.

- Aerosols move much slower than clouds, so that both very clear and very hazy conditions may last hours, if not many days.



- Proper quantification of the solar resource in the absence of local irradiance measurements requires precise information on clouds, aerosols and humidity at any instant. Models do exist to turn this information into estimates of DNI, and such radiative models are widely used in solar resource assessments.

- The limitations in the accuracy of the DNI estimates offered by data providers is the inherent uncertainty in the underlying data—cloudiness and aerosols most importantly. Improved information on the quality, quantity and variability of aerosols is among the essential goals in current solar resource research

AEROSOL OPTICAL DEPTH (AOD) – GROUND OBSERVATIONS (I/II)

AOD measurement stations in Southern Africa – AERONET network

The AOD at multiple wavelengths can be derived from spectral irradiance measurements obtained with ground-based sun photometers.

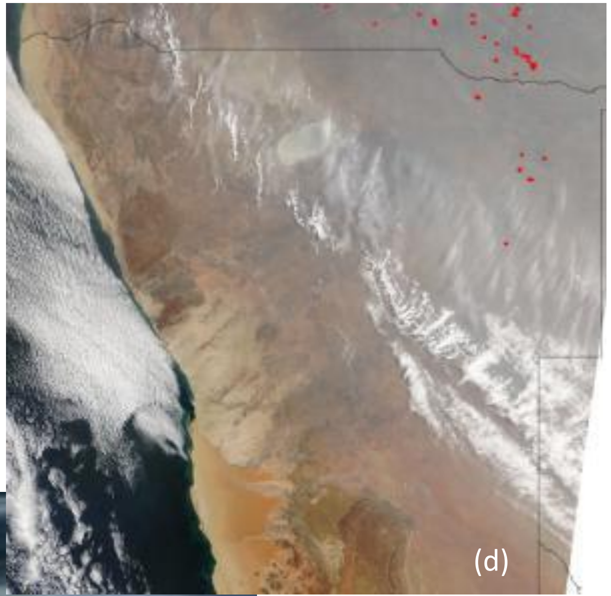
Networks: AERONET (NASA), GAW (WMO), SKYNET

AEROSOL OPTICAL DEPTH (AOD) – GROUND OBSERVATIONS (II/II)

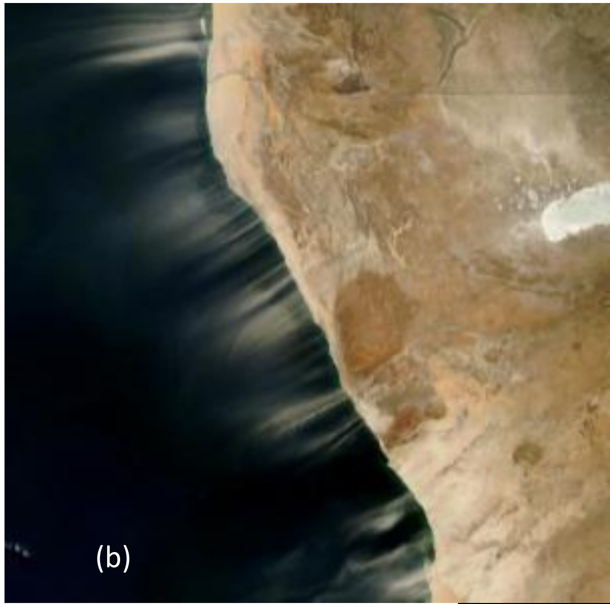
- Although hundreds of AERONET sites in the world have reported data so far, most of them have been short lived, typically recording data during a few weeks for a specific scientific field campaign. In southern Africa, one such field campaign was the Southern African Regional Science Initiative (SAFARI 2000).
- In Namibia, only three AERONET stations exist or have existed: Etosha Pan has provided data from 8/2000 to 6/2001; Henties Bay has only recently (11/2011) started operations; Swakopmund has provided data only during 9/2000. A fourth AERONET station, Sesheke, Zambia (located less than 1 km from Katima Mulilo) collected only 4 months of usable data in 1997.
- The only stations that have accumulated a significant amount of data are Mongu, Zambia (1995–2010); Skukuza, South Africa (1998–2011); and Wits University, South Africa (2002–2009)
- The SAFARI 2000 network was implemented during the fire season, so smoke conditions are heavily over-represented in the ground-truth data. Consequently, no particular station is representative of what could be considered a good site for CSP applications, which is a serious limitation.

AEROSOL OPTICAL DEPTH (AOD) - SPACEBORN OBSERVATIONS (I/IV)

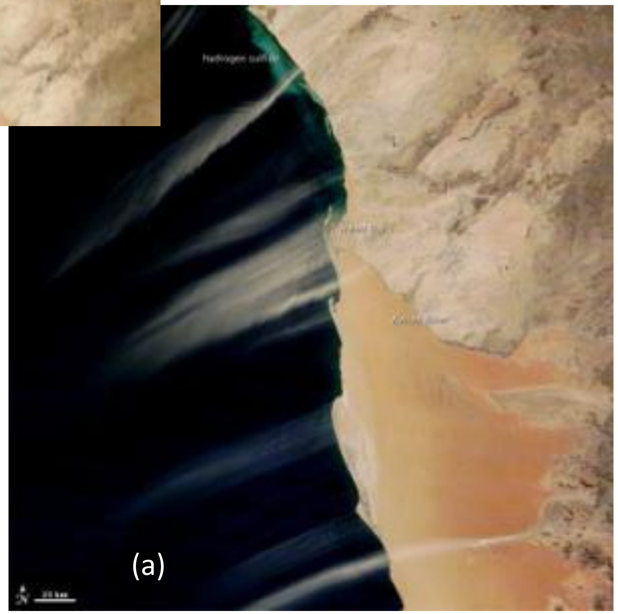
Few satellites currently carrying spectoradiometers specially developed to observe AOD in a few spectral bands. The best known of these instruments are MODIS and MISR, which fly on the same polar orbiter (Terra)



(d) Active wildfires (red dots) on Sep. 7, 2005. Source: MODIS/NASA.



(b) Dust clouds on June 9, 2004 (looking down); Source: MODIS/NASA.

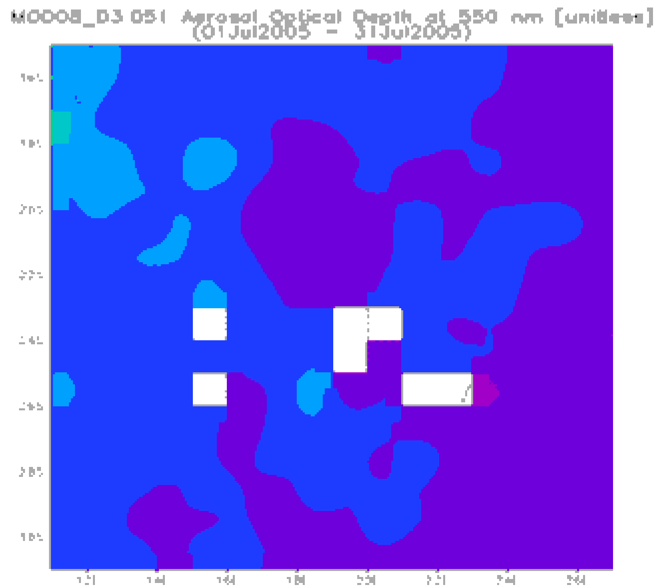


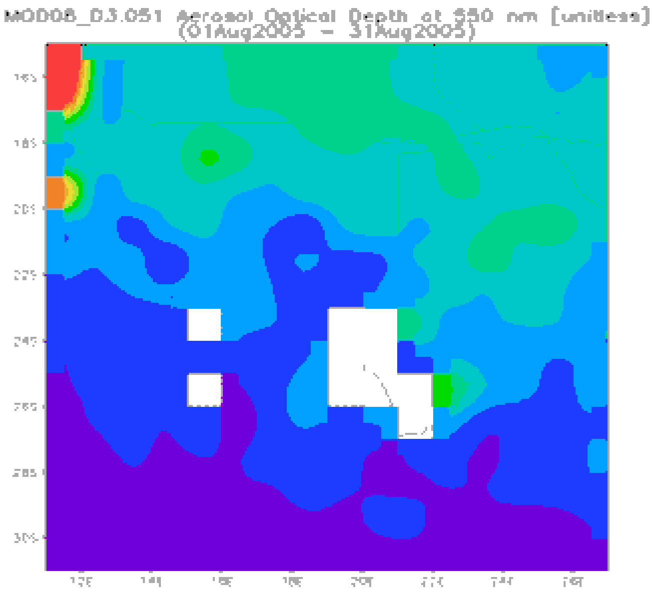
(a) Dust clouds on June 17, 2010

(c) White dust clouds on June 9, 2004 (looking south from the Kaokoveld Mountains)

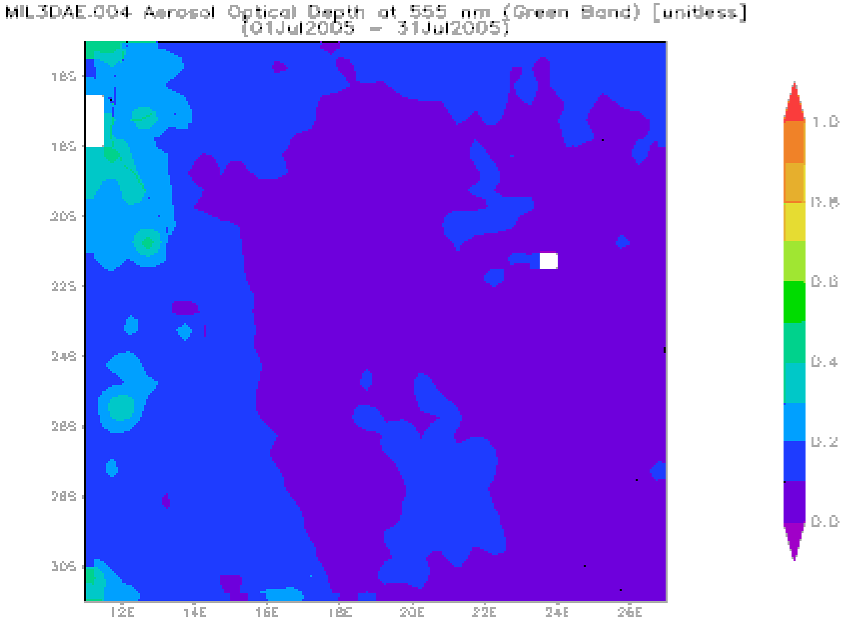
Source: MODIS/NASA.

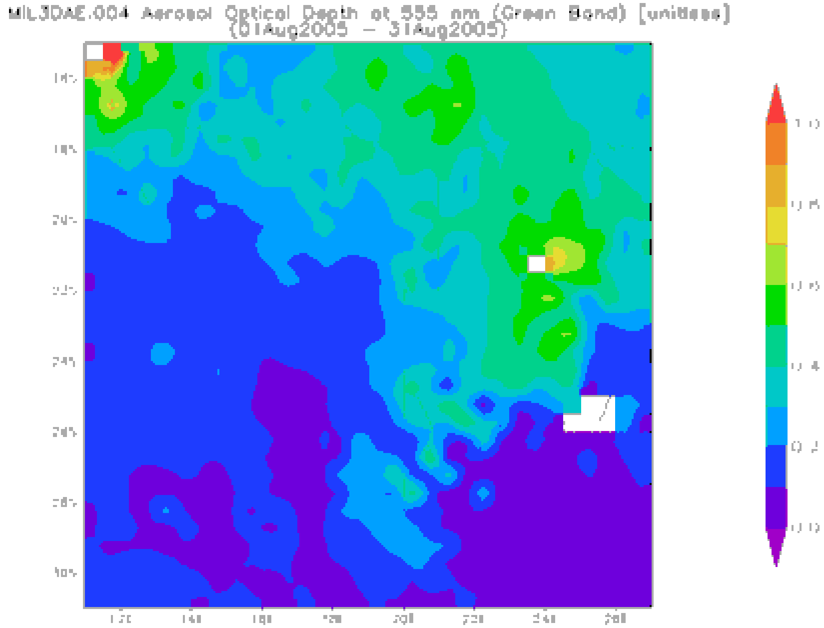
AEROSOL OPTICAL DEPTH (AOD) - SPACEBORN OBSERVATIONS (II/IV)

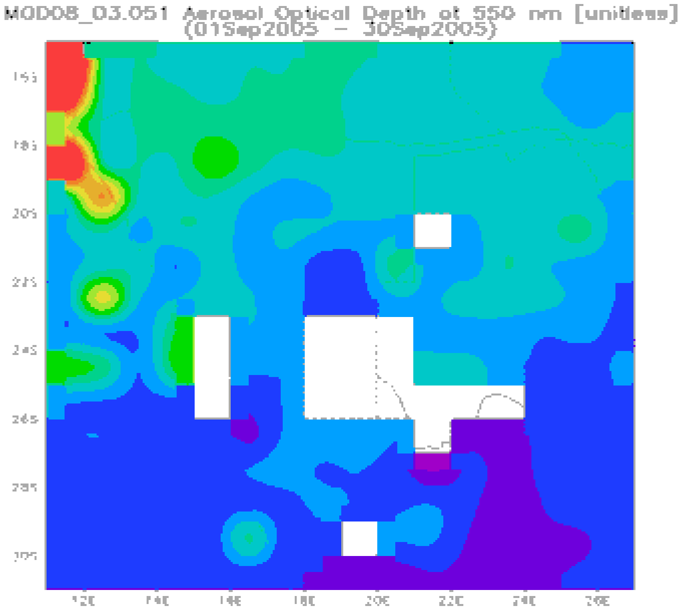


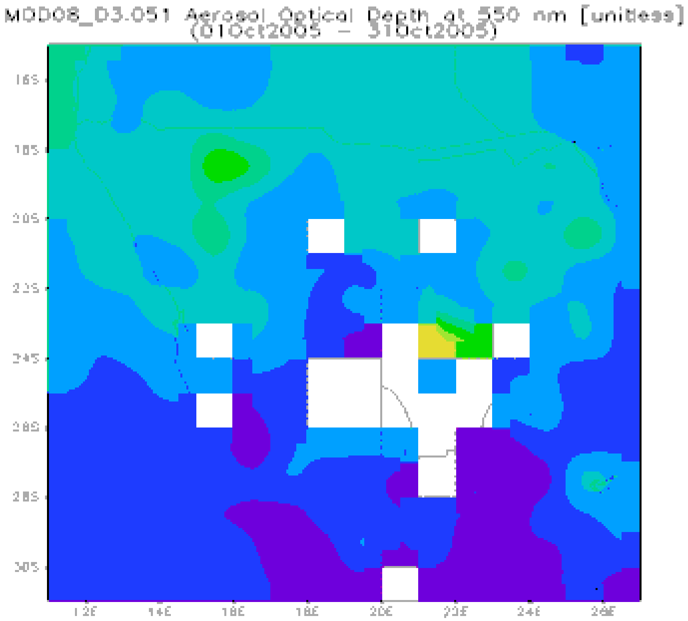


Monthly mean AOD at ≈550 nm as retrieved by MODIS (left plots) and MISR (right plots) during July and August of the 2005 fire season (top to bottom). Source: http://gdata1.sci.gsfc.nasa.gov/

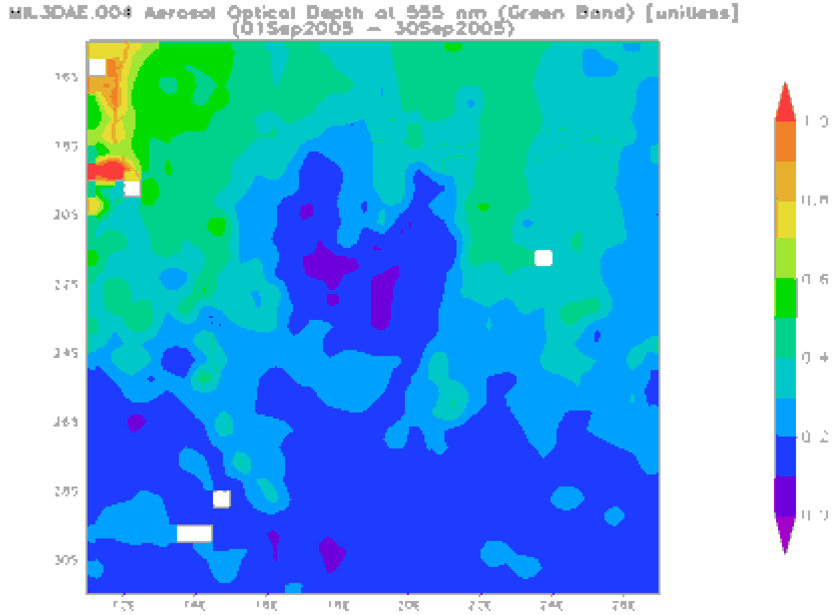


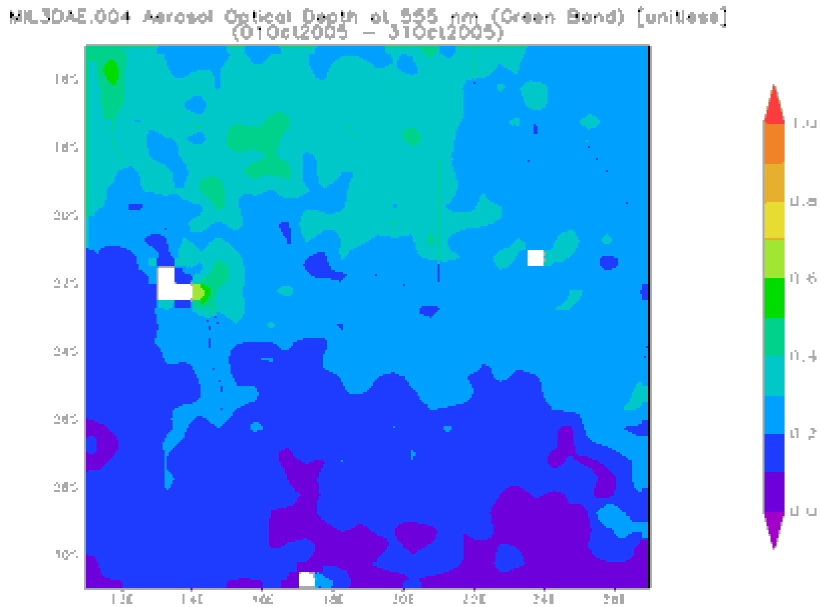






Monthly mean AOD at ≈550 nm as retrieved by MODIS (left plots) and MISR (right plots) during September and October of the 2005 fire season (top to bottom). Source: http://gdata1.sci.gsfc.nasa.gov/





AEROSOL OPTICAL DEPTH (AOD) - SPACEBORN OBSERVATIONS (IV/IV)

- These observations reveal that a strong north-south gradient can be expected from August to October, since most smoke clouds originate from areas north or northeast of Namibia.
- There are always missing data (white squares)
- There are large spatial and temporal gradients
- Two different instruments may yield significantly different results, even if observing the same region from the same satellite.
- MODIS and MISR provide daily data at high native spatial resolution (typically 1×1 km, depending on instrument and processing level; MODIS 1ºx1º and MISR 0,5ºx 0,5º). However, because their platforms are polar orbiters, and because AOD retrievals cannot be made over a cloudy scene, the daily AOD datasets contain a large fraction of missing pixels.
- Current spaceborne remote-sensing techniques cannot provide *hourly* AOD data, which would be desirable for CSP applications, and for computerized simulation of solar systems in general.

AEROSOL OPTICAL DEPTH (AOD) – AEROSOL/CHEMICAL TRANSPORT MODELS

- AOD is not observed directly, but is calculated by dynamically combining different models and sources of information:

  (i) estimated time-dependent emission data for various species of particles and aerosol precursors

  (ii) meteorological information (from general circulation models) related to their transport

  (iii) descriptions of the chemical processes involved in the formation, ageing and disposition of the different types of particles

- The uncertainties in the inventories of all aerosol precursors released in the past at any location and moment, as well as the complexity of all transport and chemical mechanisms involved, makes the modeled AOD results generally of lower accuracy than those from satellite observations. Moreover, the spatial resolution is coarser, and the AOD is generally derived at only one wavelength.
- Exception - MACC aerosol reanalysis and forecast system developed by the European Centre for Medium-Range Weather Forecasts (ECMWF) and it uses an assimilation of MODIS data

MODELING DNI

The accuracy of satellite-based DNI and GHI depends on that of the applied numerical models and of the data used as inputs to these models. More specifically, the overall accuracy of the modeled DNI and GHI depends on:

- The quality of the clear-sky model and its capability to properly characterize various states of the clear atmosphere
- The level of detail of the satellite-derived cloud transmittance algorithm, and particularly to what extent it can differentiate clouds or fog from snow or ice. Over arid zones, where the surface is predominantly bare and with a relatively high albedo, a critically needed feature of the radiative model is a correct simulation of the complex multidirectional albedo behavior for various sun-satellite geometries
- The universality of the diffuse/direct decomposition model
- The accuracy, temporal and spatial resolution of the model inputs: availability, geometric and radiometric corrections of satellite imagery, resolving occurrences of artifacts in cloud data, appropriate spatial/temporal resolution and quality of aerosol and water vapor data, etc.
- Spatial resolution and accuracy of the Digital Terrain Model (DTM).

SOLARGIS - GEOMODEL

First step consists in using the simplified SOLIS model to evaluate the ideal clear-sky irradiance based on the following parameters:

- Sun position determined by time and astronomical equations
- Variable (over space and time) concentrations of atmospheric constituents, namely aerosols, water vapor and ozone (delivered at a spatial resolution of about 125 km)
- Daily AOD from the MACC model is normally used (daily variability). For Namibia, the AOD obtained from the MACC dataset has been corrected to reflect the lower bias of the monthly AOD specially derived by SCS
- Water vapor is also highly variable in space and time, but has a lower impact on solar irradiance than aerosols (daily data GFS and CFSR)
- Ozone has only a minor effect on broadband solar radiation (monthly values)
- Cloudiness. Cloud extinction is expressed through a parameter called “cloud index”, based on meteorological geostationary satellites (MFG and MSG satellites; 4 x 4 km over Namibia). The cloud index is derived by empirically relating the radiance observed by the satellite in four spectral channels and the estimated surface albedo to the cloud optical properties. A number of improvements have been introduced to better cope with specific situations such as snow, ice, or high albedo areas (arid zones and deserts), and also with complex terrain.
- DNI is finally calculated

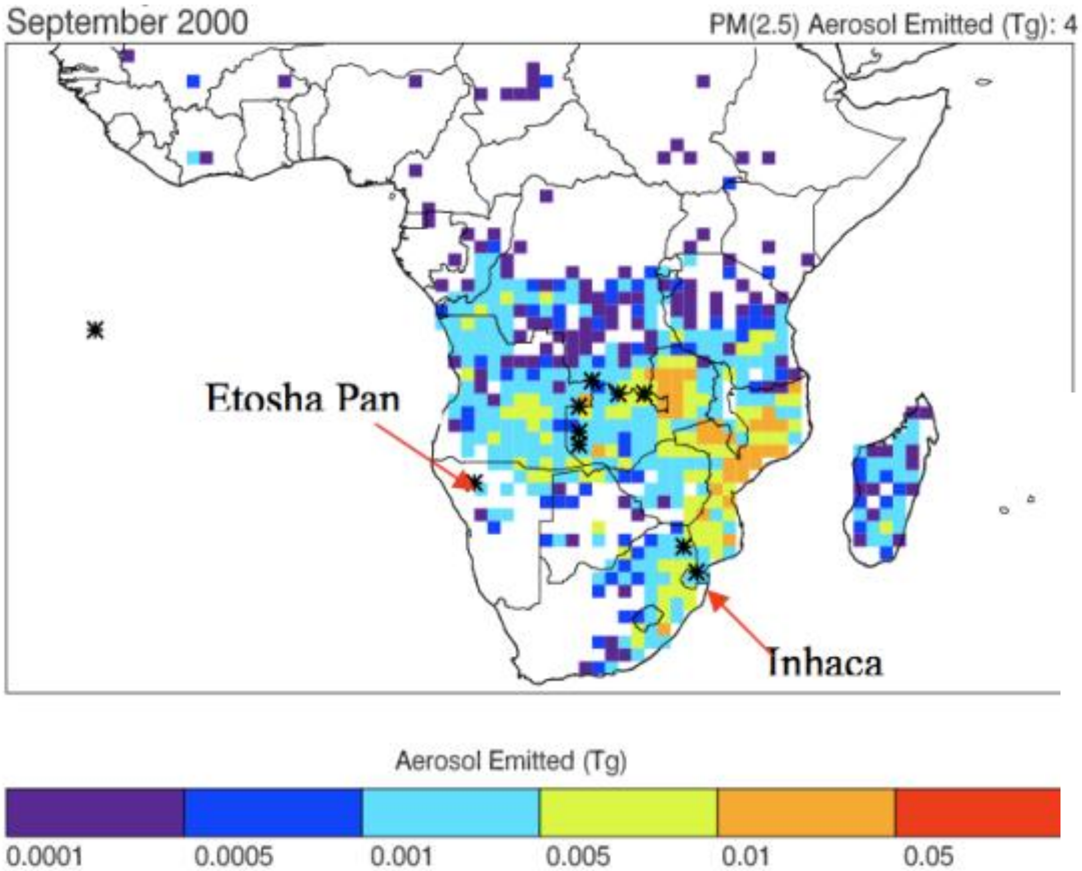
AEROSOL OPTICAL DEPTH (AOD) AND DNI – IMPACTS AND UNCERTAINTY (I/II)

- Radiative models used by solar resource data providers to obtain long-term irradiance time series at hourly or sub-hourly time intervals cannot be utilized optimally. In most cases, such time series are based on monthly-average AOD data, or even worse, on long-term monthly climatological AOD values
- Only average AOD data (from 2003–2011) can be used before 2003. This means that the modeled DNI data time series predating 2000 (or 2003, depending on implementation) will have a larger uncertainty than the more recent data. The magnitude of this pre-2000 or pre-2003 uncertainty is difficult to estimate due to the total absence of historical high-quality DNI data before 2003 in the region.
- The present AOD values also tend to be lower (by up to ≈0.05) than those of MACC, which means that the DNI maps based on the former dataset should be less conservative than those based on the latter. Over low-AOD and CSP-favorable areas in Namibia (i.e., where *ta*670 is lower than about 0.10 to 0.15), the typical error limits in the MACC AOD data normally used by GeoModel are estimated to be in the range –0.05 to +0.10. With the help of the current dataset, these limits should reduce to about ±0.05.
- A likely uncertainty of at least 5% in monthly-mean DNI caused by the inherent uncertainty in the AOD data *alone* can be expected over low-AOD (CSP prone) areas in the best possible resource maps or modeled datasets.

AEROSOL OPTICAL DEPTH (AOD) AND DNI – IMPACTS AND UNCERTAINTY (I/II)

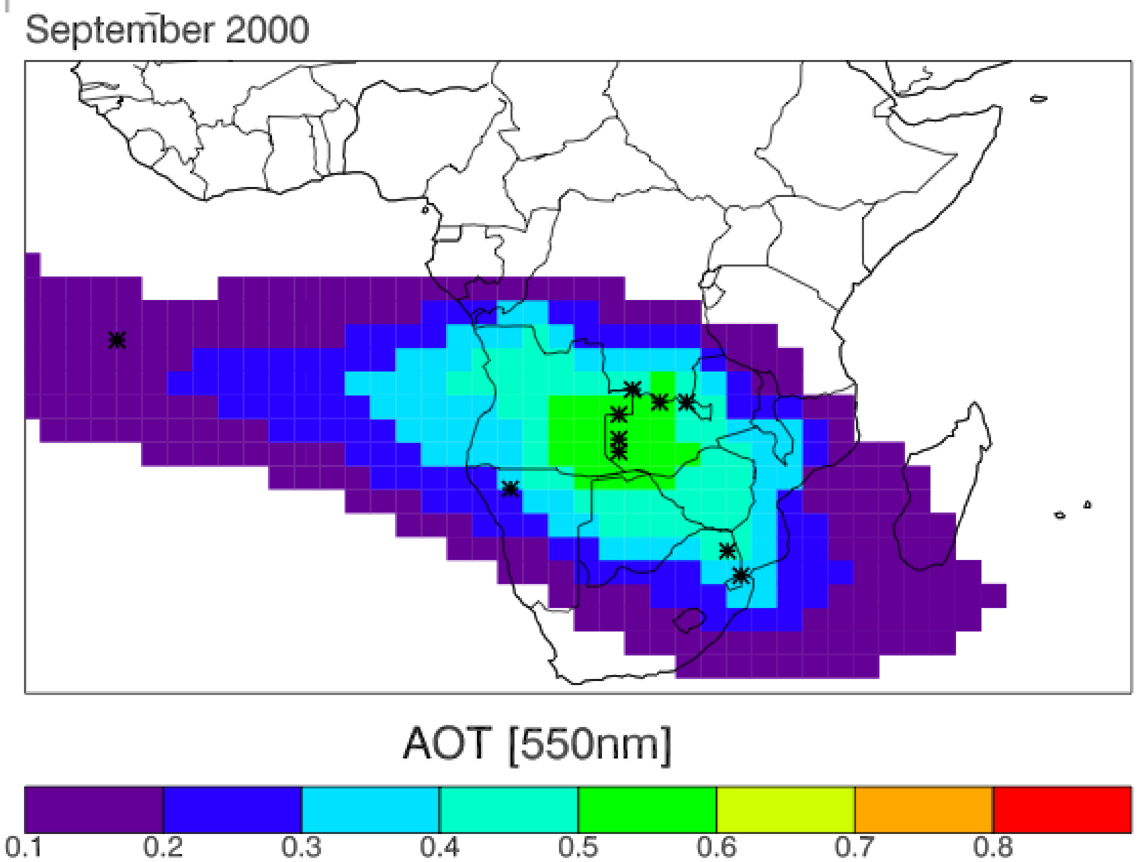
- In general, a typical aerosol-induced uncertainty of 10–15% in annual average DNI should be considered at sites with moderate aerosol load.
- Such effects cannot be sorted out without observations from local weather/radiometric stations specially designed for high-quality DNI measurements
- In the atmospheric and geographic conditions of Namibia, the inaccuracies of the aerosol data may account for more than half of the total uncertainty in solar irradiance.
- Over semi-arid and desert zones (which are widespread in Namibia), the accuracy of the modeled solar resource data is mainly determined by the parameterization of the atmosphere, especially the proper quantification of aerosol and cloud attenuation.
- The accuracy of the SolarGIS database, version 1.8, has been compared with high-quality ground observations at almost 100 stations worldwide. The SolarGIS database demonstrated its high reliability and its superior quality compared to other solar databases on the market in a recent IEA-SHC Task 36 data intercomparison study (Ineichen, 2011). -> error of 6 to 10% (we expect to have lowered these values)

AEROSOL OPTICAL DEPTH (AOD) DATA AND RESULTS (I/II)

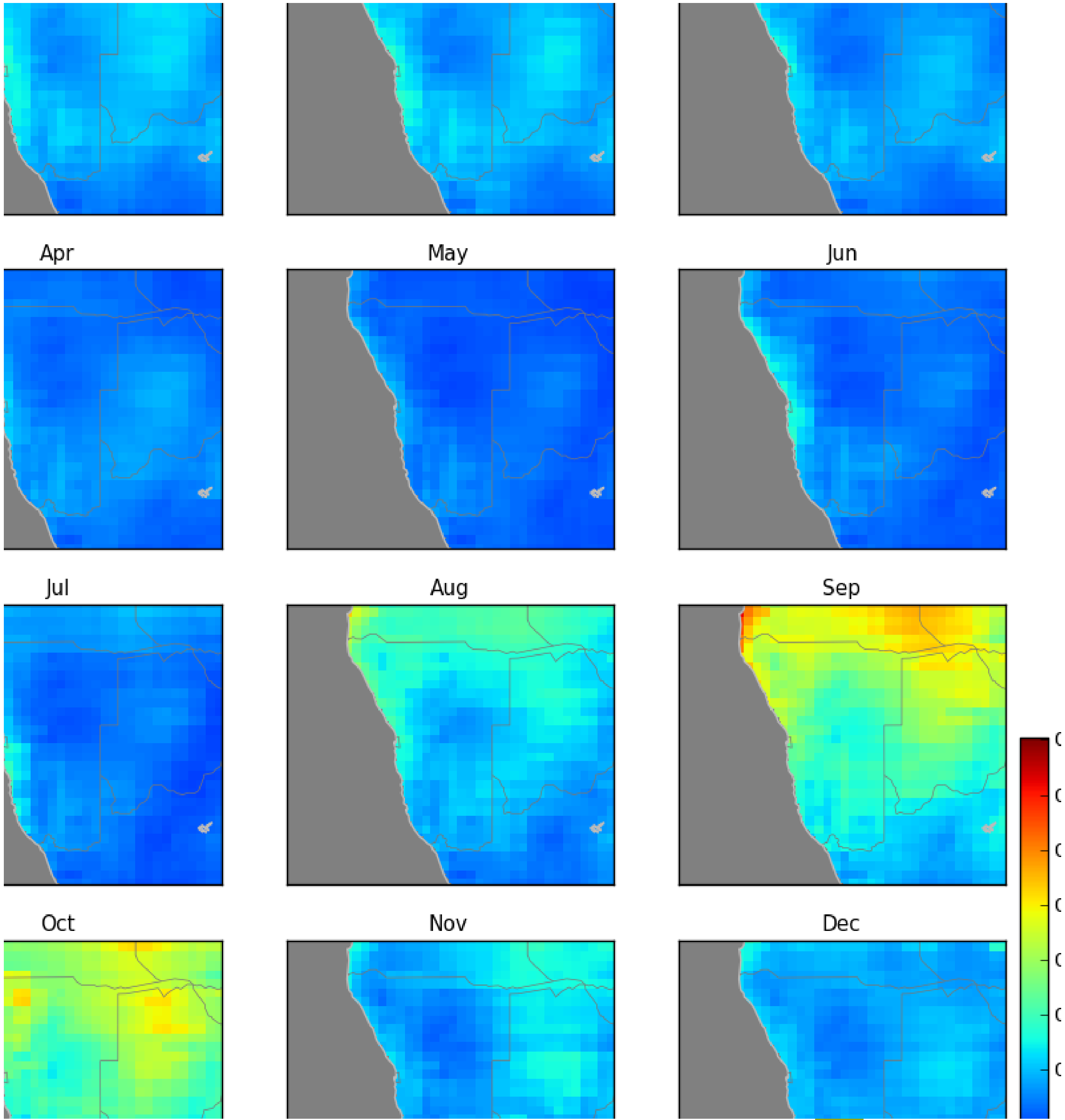


Monthly mean aerosol emissions (in Teragrams) over central and southern Africa during September 2000. Source: Matichuk et al., 2004.

Modeled monthly mean AOD at 550 nm for the month of September 2000. Asterisks identify AERONET sites. Source: Matichuk et al., 2004.



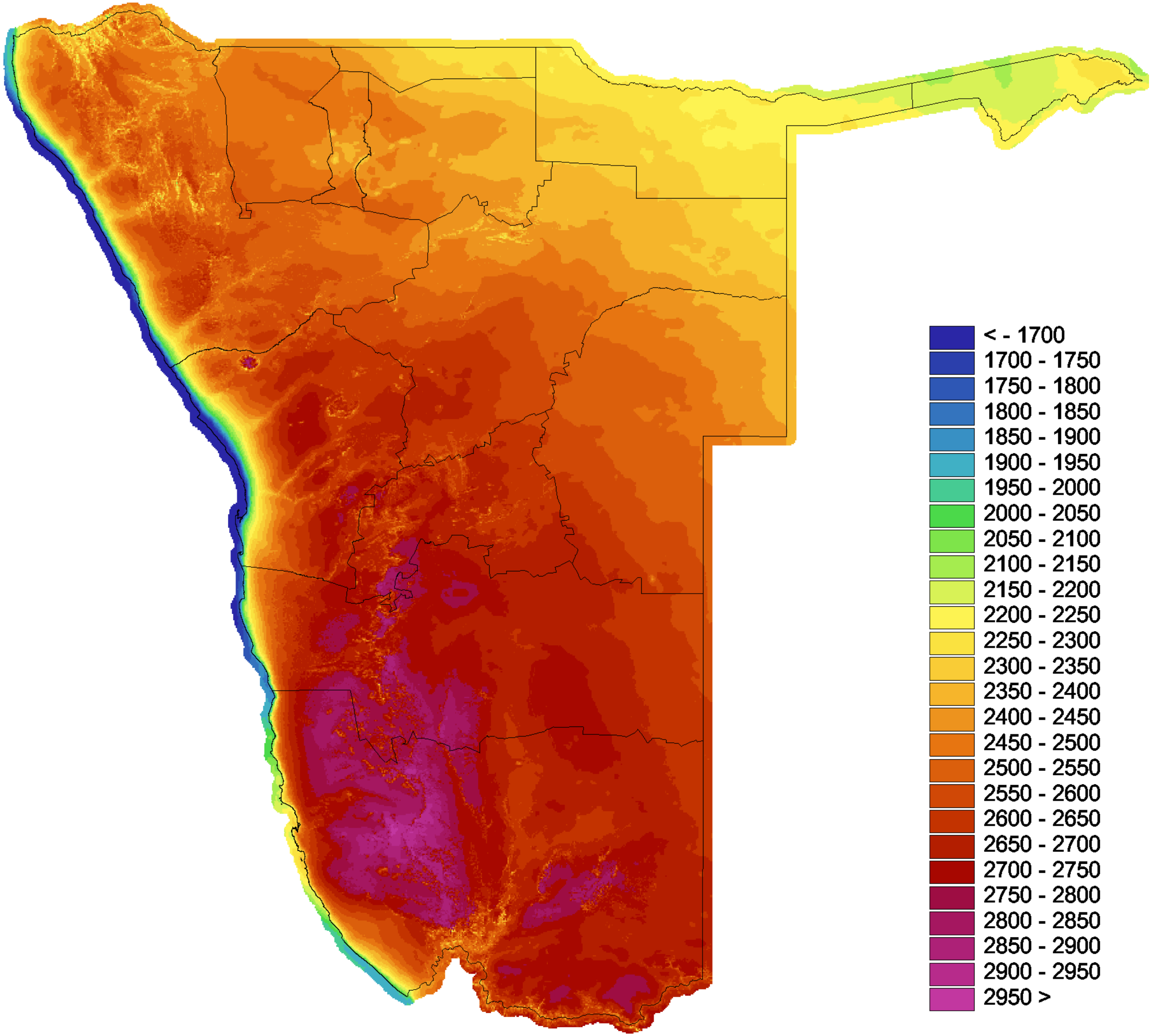
AEROSOL OPTICAL DEPTH (AOD) DATA AND RESULTS (II/II)



Long-term AOD monthly averages for the final dataset used in irradiance calculations for Namibia;

From January (top left) to December (down right)

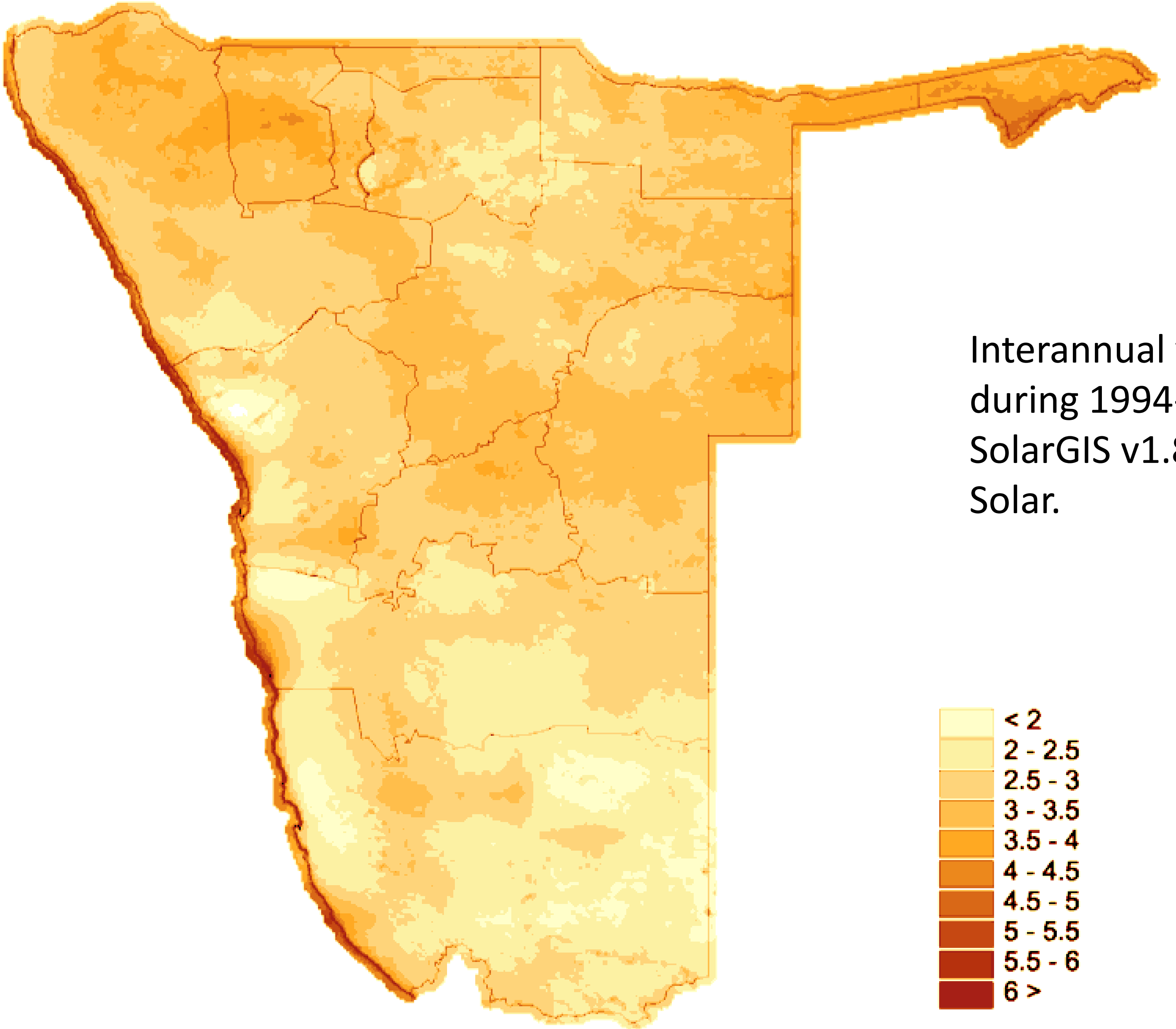
DNI MAPPING OF NAMIBIA - IMPROVED



Long-term annual average of DNI [kWh/m2] over the period 1994-2011, based on SolarGIS v1.8 © 2012 GeoModel Solar

For DNI, the bias reaches ±8.0% over arid areas, whereas the hourly Root Mean Square Difference (RMSD) is below 24.0%

DNI ANNUAL VARIABILITY IN NAMIBIA



Interannual variability (in %) of DNI during 1994-2011, obtained with SolarGIS v1.8 © 2012 GeoModel Solar.

Ministry of Mines and Energy

CSP TECHNOLOGY OVERVIEW

NAMIBIA SOLAR RESOURCE AND DNI ANALYSIS

ENVIRONMENTAL ANALYSIS AND SITE SELECTION

TOP 5 SITES SELECTION AND FINANCIAL ANALYSIS

GROUND MEASUREMENTS

CSP DEVELOPMENT AND IMPLICATIONS FOR NAMIBIA

ENVIRONMENTAL ANALYSIS AND SITE SELECTION METHODOLOGY

Analysis inputs

1 Resource

- Direct Normal Radiation (DNI)
- DNI > 2400 kWh/m2/year

2 Feasibility

- Slope (<3%)
- Type of soils (Alluvium, gravel, calcisols, leptosols, etc)
- Electrical grid

Alternative business models

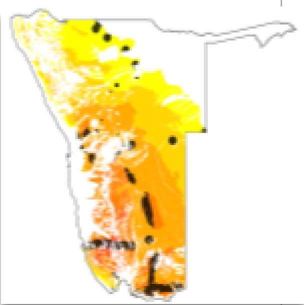
3

- Biomass hybridization
- Coal augmentation
- Gas hybridization
- Desalination
- Mines
- Solar/Wind Parks

Potential areas identification

4

- Potential areas identification
- More than 33.000 km^2 of potential areas for CSP development
- Total theoretical potential of more than 250.000 MW



- Projects identification and selection
- Selection of the best projects *(almost 40 projects selected)*

Best projects analysis (GIS analysis) **5**

Economic analysis

- Resource (DNI)
- Temperature
- Slope
- Distance to electric grid
- Roads distance

+

Environmental analysis

- Land use (agriculture, game parks, natural reserves, urban areas, etc)
- Endemic/protected species, soil erosion
- etc

+

Feasibility analysis

- Grid connection

+

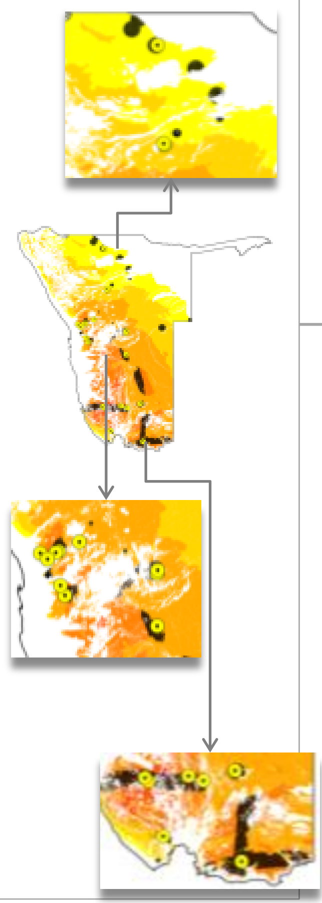
Alternative business models analysis

- Biomass hybridization
- Coal augmentation
- Gas hybridization
- Desalination
- Mines

TOP 20 sites selection

6

- Sites prioritization
- Selection of the 20 TOP sites



TOP 20 sites analysis **7**

GIS analysis

- Economic, environmental, business and deployment analysis
- Information layers:
  - Meteorological data (rain, fog, humidity, etc)
  - Protected areas
  - Aquifers productivity

Site visit (Feasibility and environmental analysis)

Site visit to TOP 20 sites:

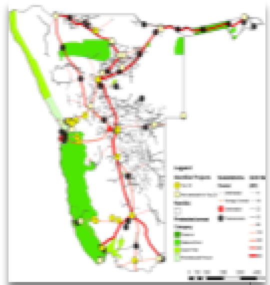
- Identification of potential barriers/shadings
- Soil analysis (terrain drainage and slopes)
- Access validation
- Landscape description
- Validation of endemic and protected fauna and flora
- Cultural values and social concerns
- etc

Potential for alternative business models

- Biomass hybridization
- Coal augmentation
- Gas hybridization
- Desalination
- Mines

TOP 5 sites selection

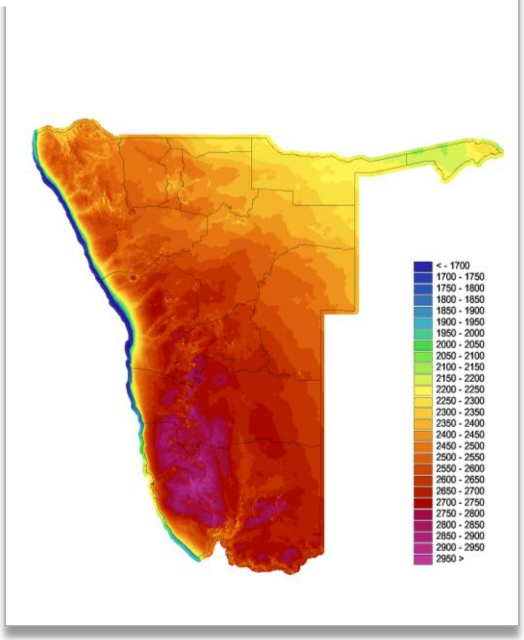
- **Prioritization of the 20 TOP sites**



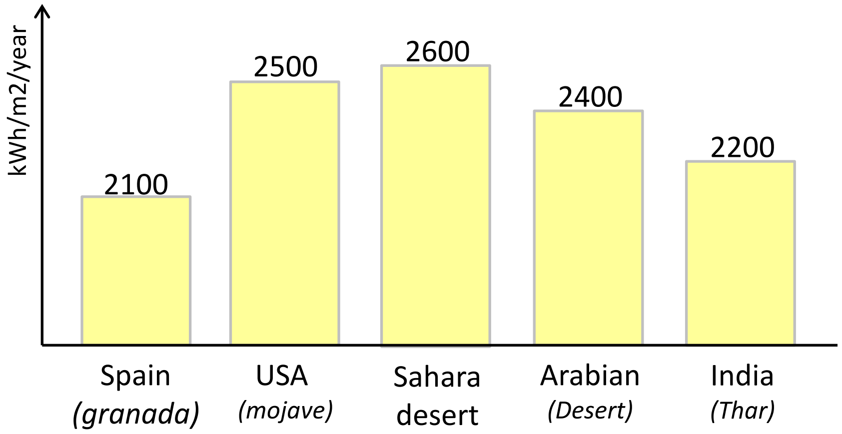
- **TOP 5 sites selection**

THE DIRECT NORMAL RADIATION (DNI), IS THE MOST RELEVANT VARIABLE IN CSP PROJECTS

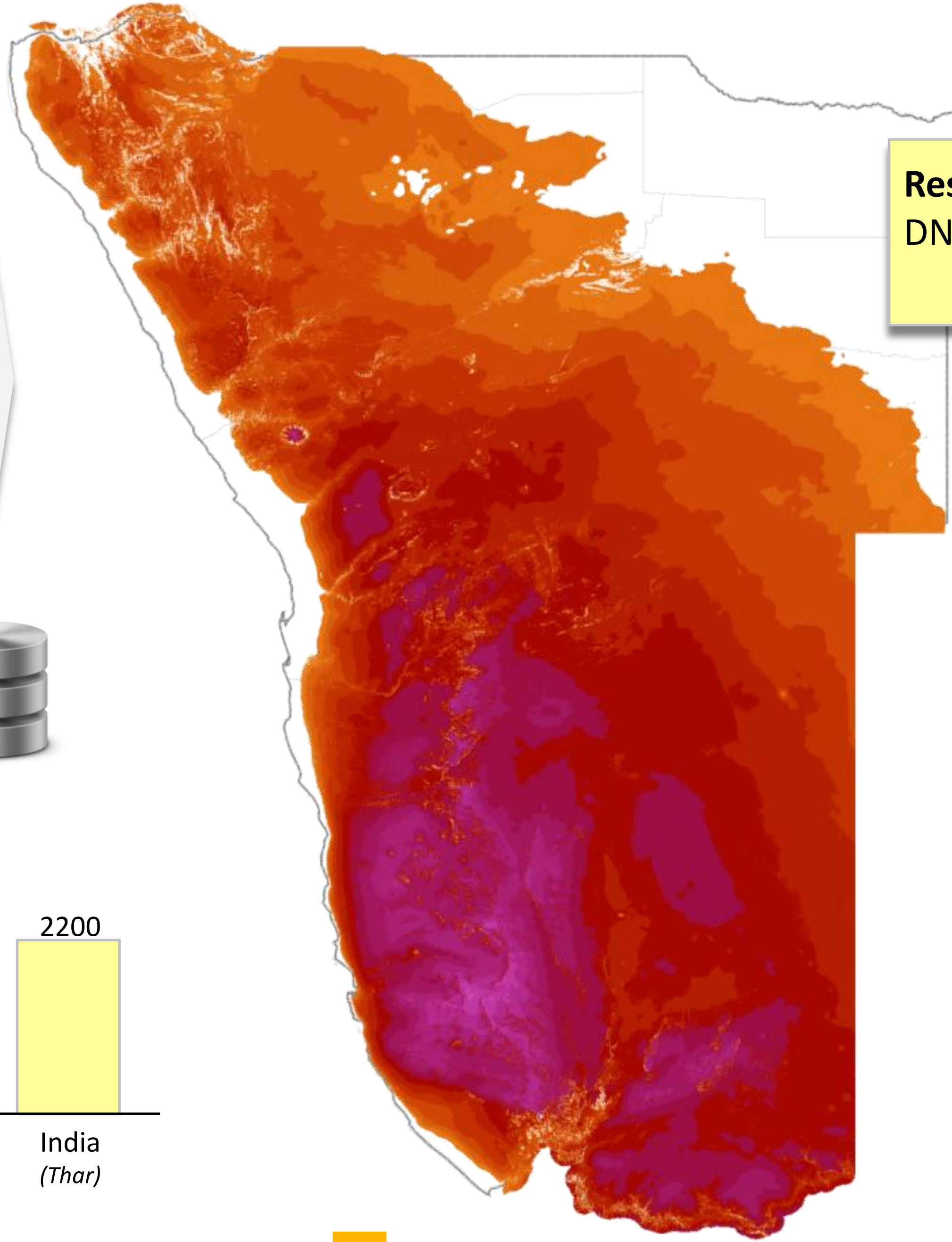
GeoModel SOLAR



- GIS integration
- Data reclassification



Source: Geomodel; NREL; SWERA



Resource criteria:
DNI > 2400 kWh/m2/year

Legend

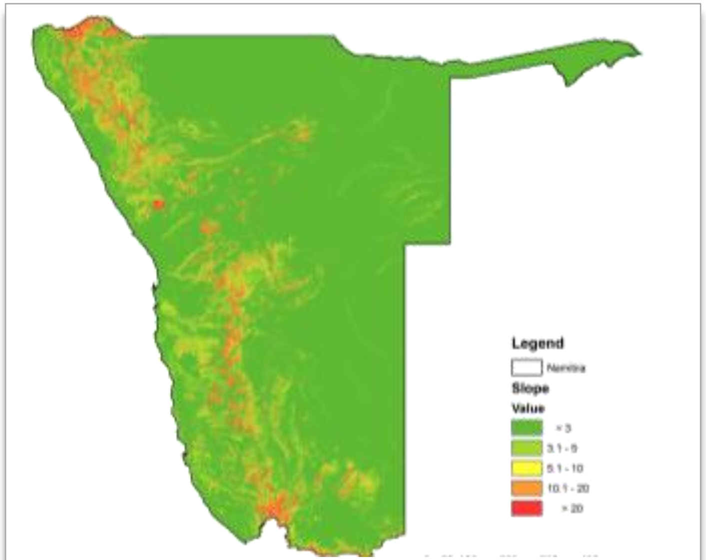
DNI - Year

Value

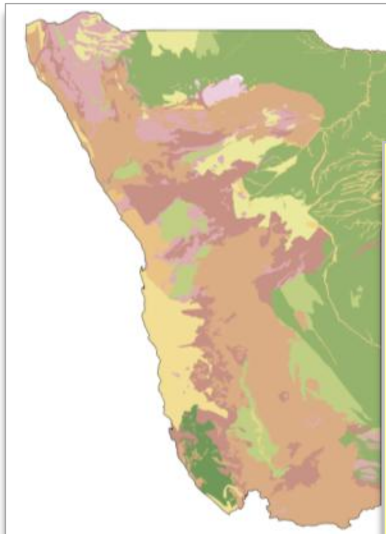
- 2.401 - 2.450
- 2.451 - 2.500
- 2.501 - 2.550
- 2.551 - 2.600
- 2.601 - 2.650
- 2.651 - 2.700
- 2.701 - 2.750
- 2.751 - 2.800
- 2.801 - 2.850
- 2.851 - 2.900
- 2.901 - 2.950
- 2.951 - 3.000

THE FEASIBILITY OF CSP PROJECTS DEPENDS MOSTLY OF THE SLOPE, TYPE OF SOILS AND DISTANCE TO ELECTRIC GRID/SUBSTATIONS

2

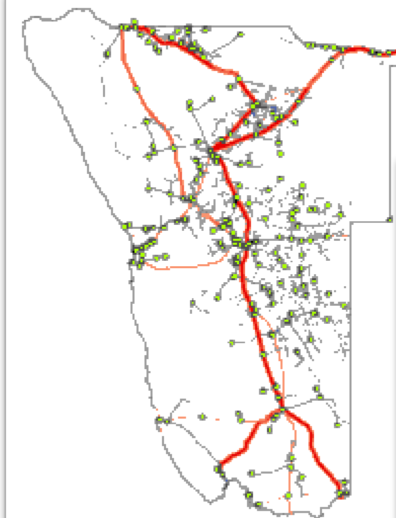


Slope criteria (< 3%)



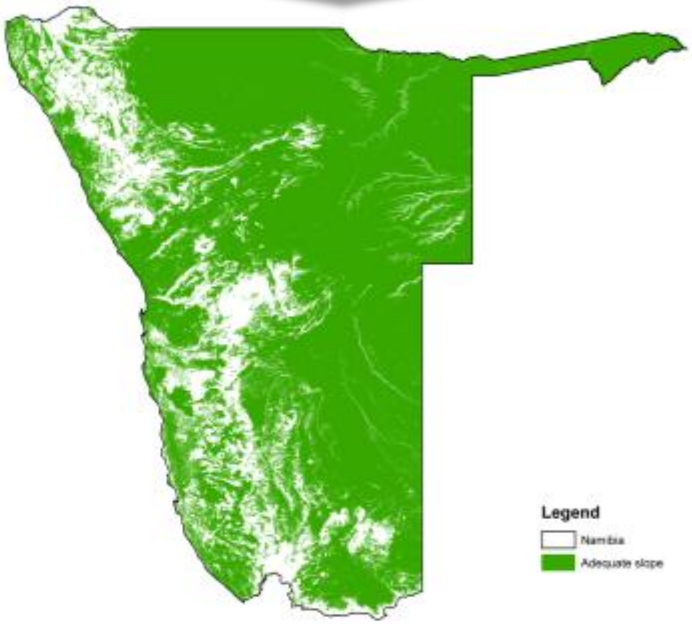
Soil selection:
- Alluvium
- San
- Gravel
- Calcrete Plains
- Arenosols
- Calcisols
- Fluvisols
- Leptosols
- Regosols

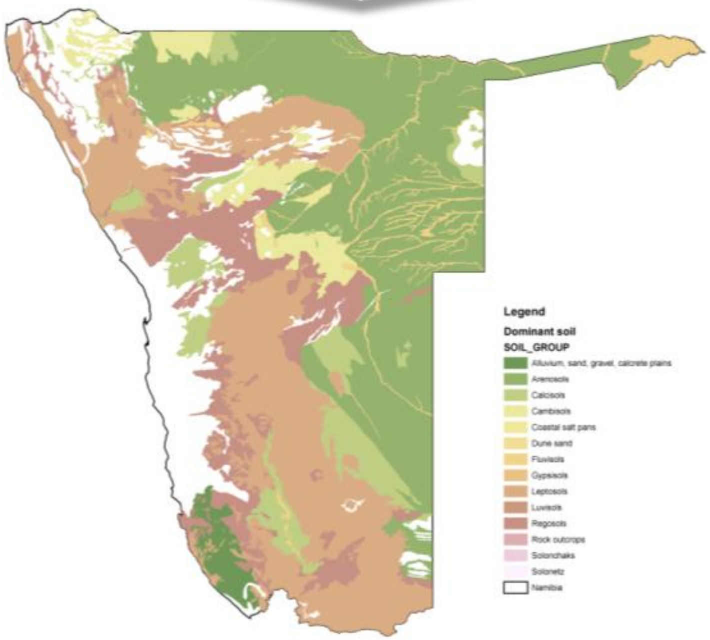
Soil selection criteria

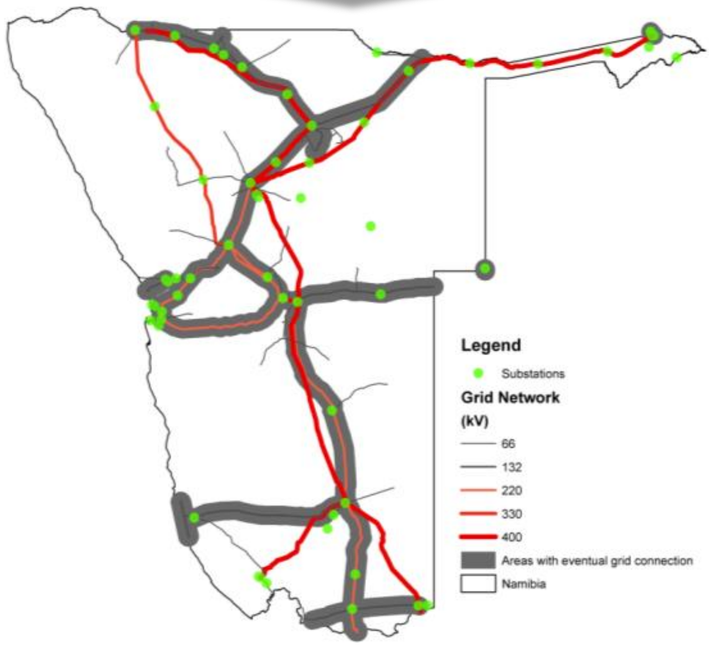


Selection criteria:
- 20 km to the electric grid
- 10 km to the nearest 132kV substation
- 5 km to the nearest 66 kV substation)

Distance to electricity grid







ALTERNATIVE BUSINESS MODELS WERE STUDY FOR THE DEVELOPMENT OF CSP IN NAMIBIA

Alternative business models

Biomass hybridization

- Addresses the use of biomass as a back up to the CSP power plant or as a booster to a biomass power plant

Coal augmentation

- Decreases the use of coal to generate power or augments the power generation capacity of the coal power plant by providing steam to the economizer of the coal thermal power plant

Gas hybridization

- Addresses the possibility of use the gas power plant as back-up to the CSP power plant

Desalination

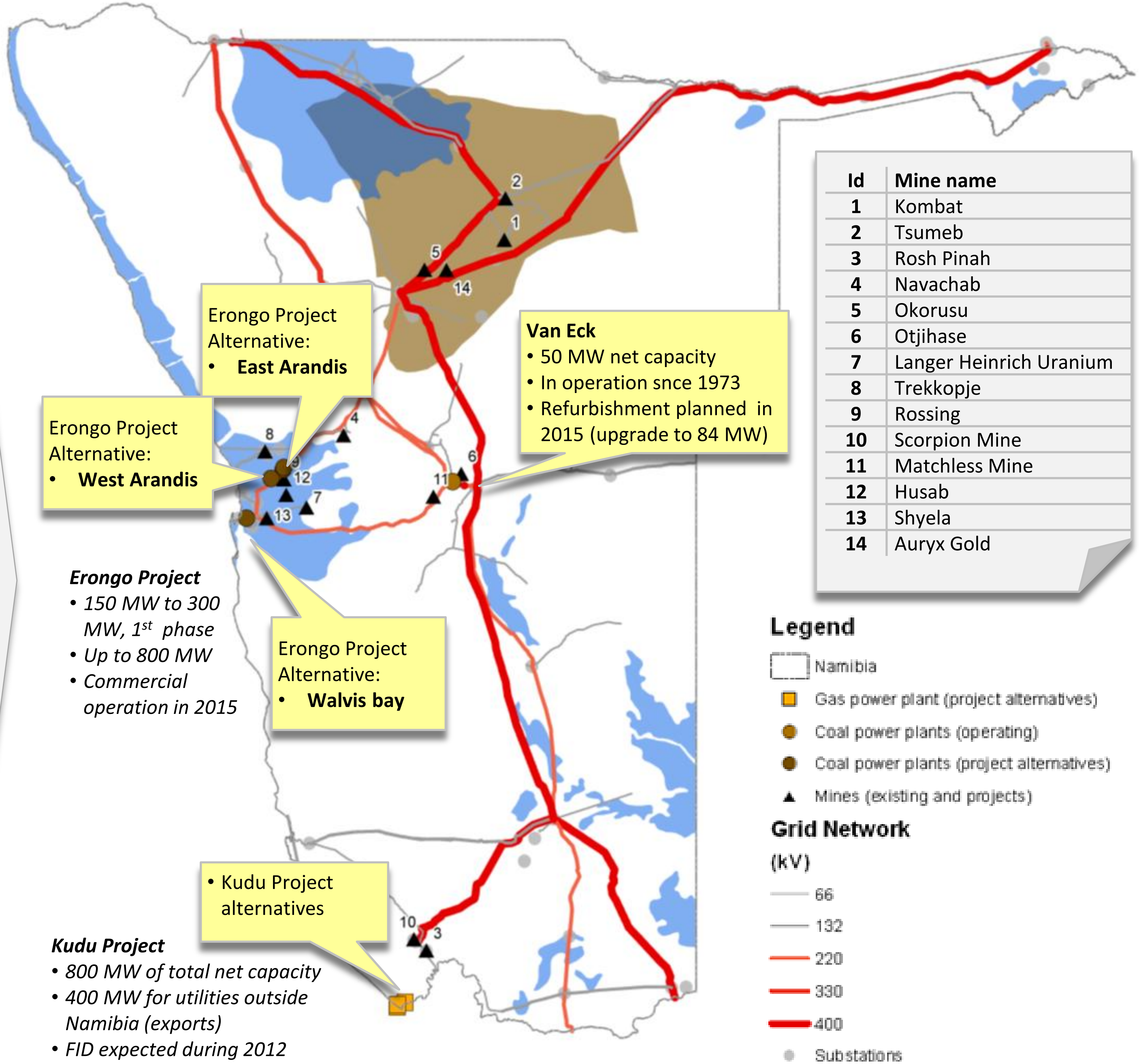
- Focus on locations with water scarcity . CSP can provide energy to produce desalinate water

Mines

- Reflects the possibility of develop a CSP power plant to supply electric power to the mine plus heat for some industrial process (cogeneration)

Solar Wind parks

- Explores the possibility to couple wind and other solar technologies to better use power evacuation infra-structures



Id	Mine name
1	Kombat
2	Tsumeb
3	Rosh Pinah
4	Navachab
5	Okorusu
6	Otjihase
7	Langer Heinrich Uranium
8	Trekkopje
9	Rossing
10	Scorpion Mine
11	Matchless Mine
12	Husab
13	Shyela
14	Auryx Gold

NAMIBIA HAS MORE THAN 33.000 KM^2 OF POTENTIAL SITES FOR CSP, WHICH THEORETICAL IS EQUIVALENT TO MORE THAN 250.000 MW

Resource

Geographic processing

- Direct Normal Radiation (DNI)
- DNI > 2400 kWh/m2/year

Feasibility

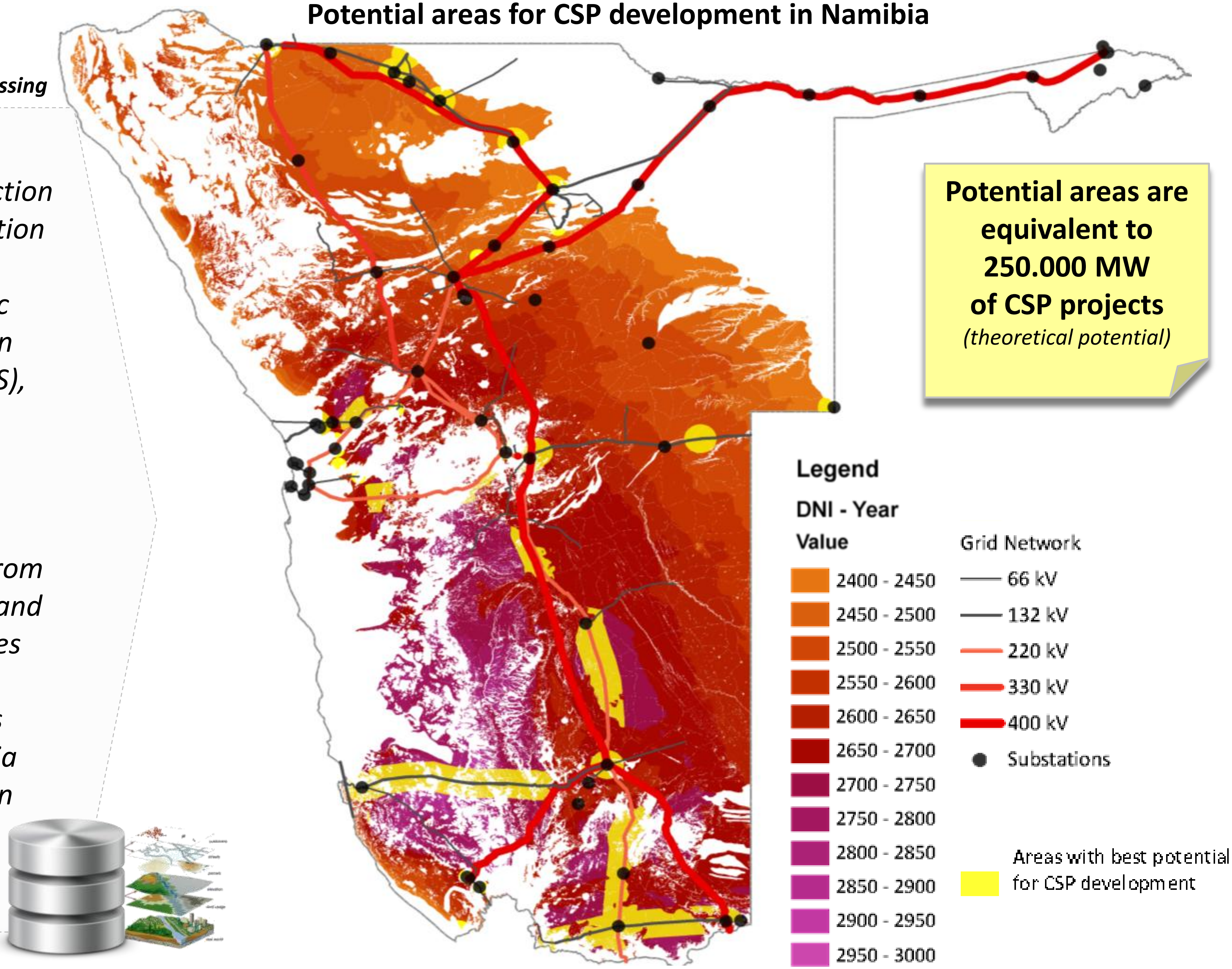
- Slope (<3%)
- Type of soils (Alluvium, gravel, calcisols, leptosols, etc
- Electrical grid

Alternative business models

- Biomass hybridization
- Coal augmentation
- Gas hybridization
- Desalination
- Mines

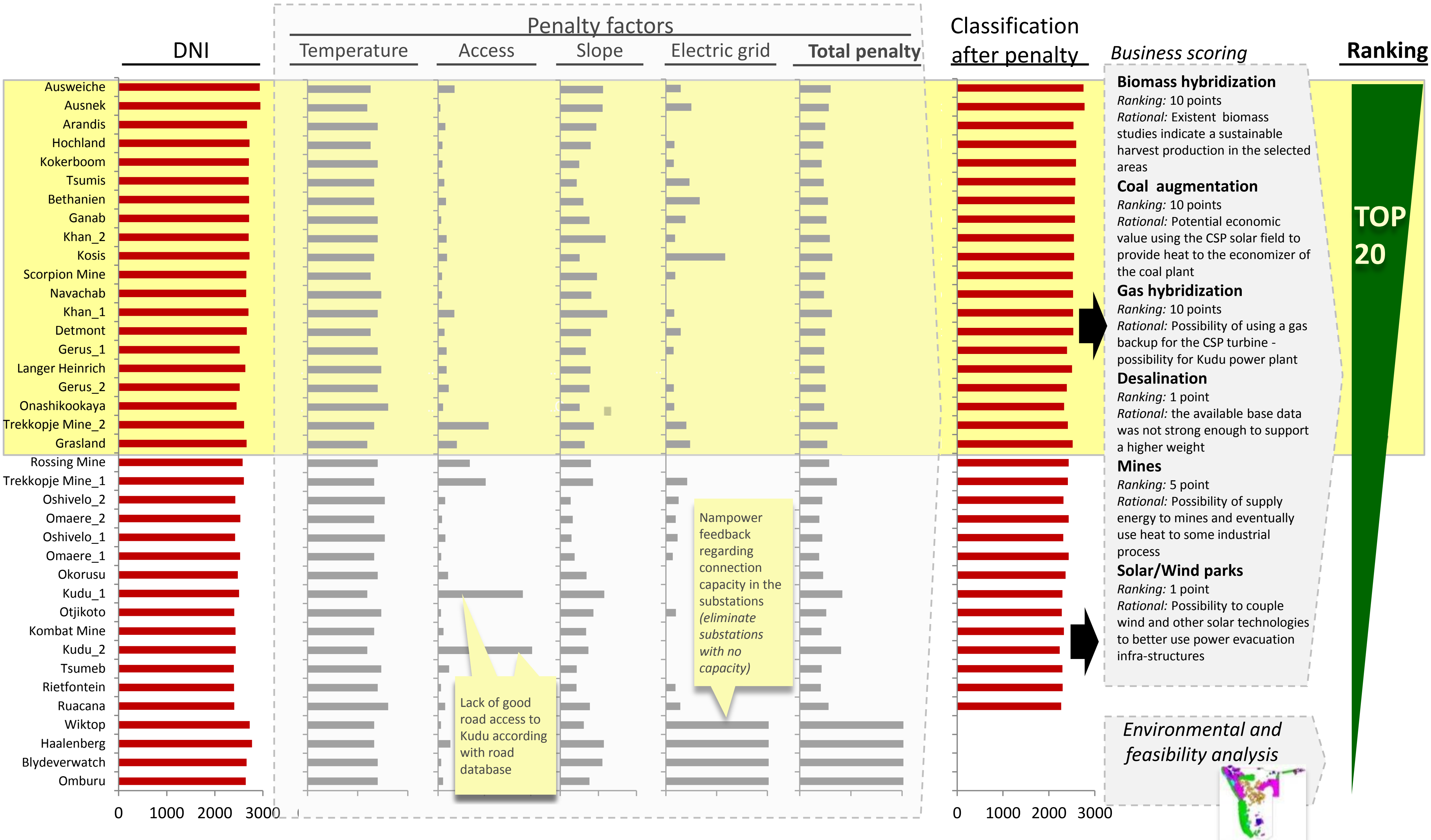
- *Data collection and validation*
- *Geographic information system (GIS), database design*
- *Attribute selection from the layers and data queries*
- *New layers with criteria Intersection*

Potential areas for CSP development in Namibia



Potential areas are equivalent to 250.000 MW of CSP projects
(theoretical potential)

TO SELECT THE BEST SITES, ECONOMIC, ENVIRONMENTAL, FEASIBILITY AND ALTERNATIVE BUSINESS MODEL WERE ANALYZED



NATURAL PROTECTED AREAS & POTENTIAL ENVIRONMENTAL IMPACTS OF CSP TECHNOLOGY

About 46% of the territory is protected area…

Land Use

The main land use in Namibia is agriculture. There is abundant area with this profile, reason why the use of such areas shouldn't be considered relevant.

Cultural and socio-economic values

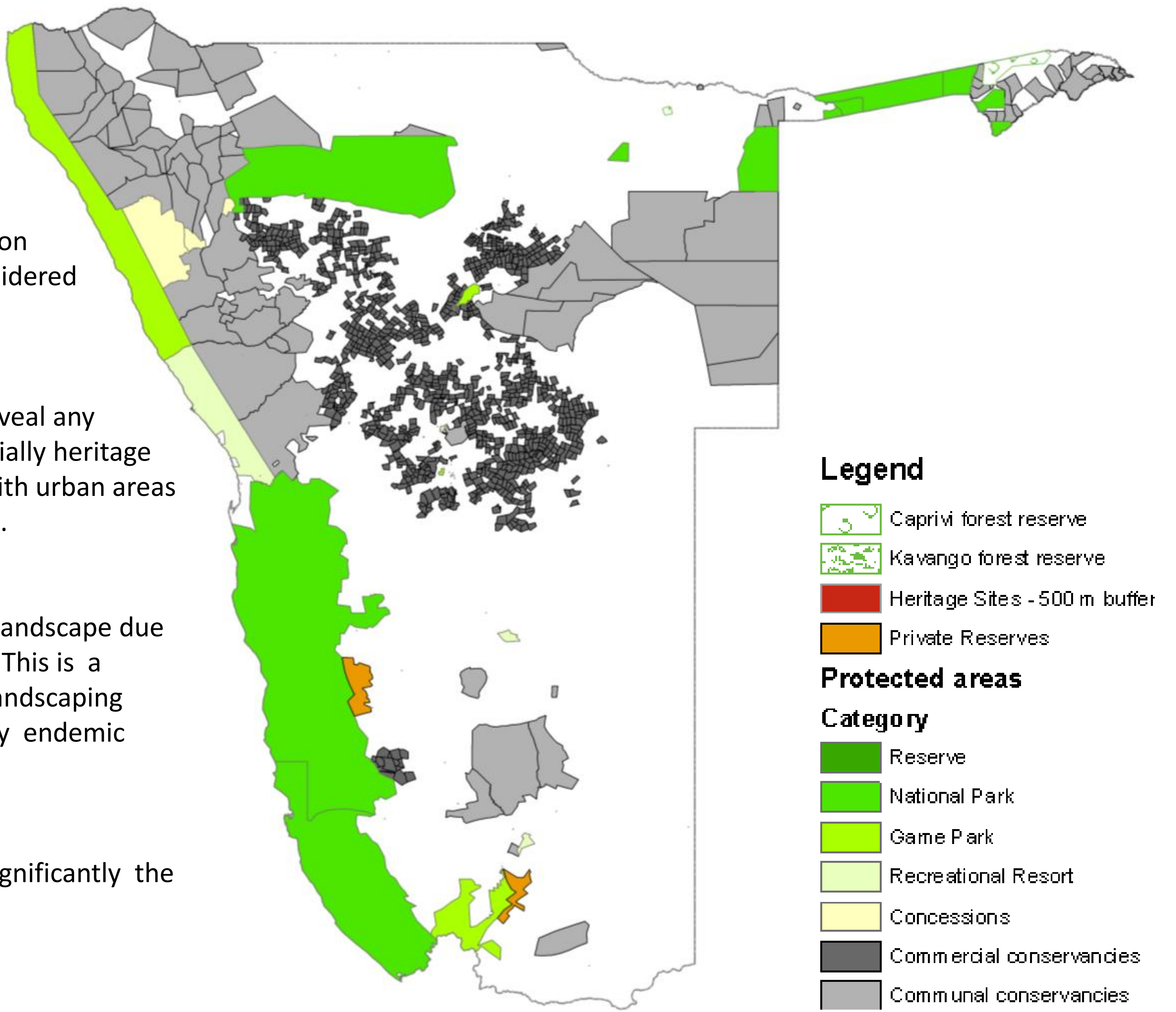
The field works and desktop studies didn't reveal any potential conflicts with cultural values, especially heritage sites. Also, it's not expectable any conflicts with urban areas from what was reported from the field works.

Landscape

This projects constitute great change on the landscape due to the large size area that will be committed. This is a impact that can be mitigated with recovery landscaping measures, such as, natural barriers created by endemic flora.

Fauna and flora values

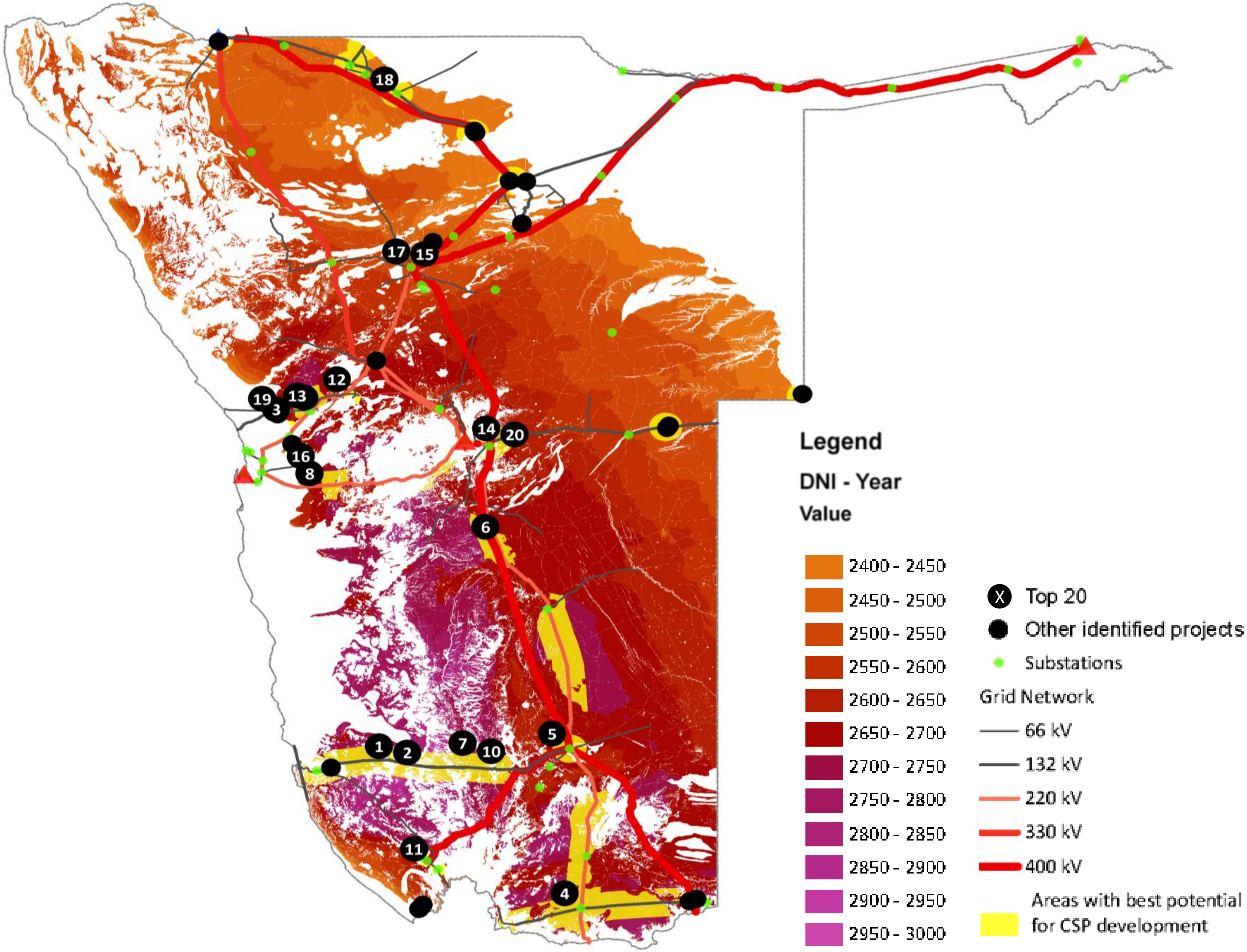
The abundance of natural habitats reduces significantly the impact on Namibia's fauna and flora values.



THE TOP 20 SITES

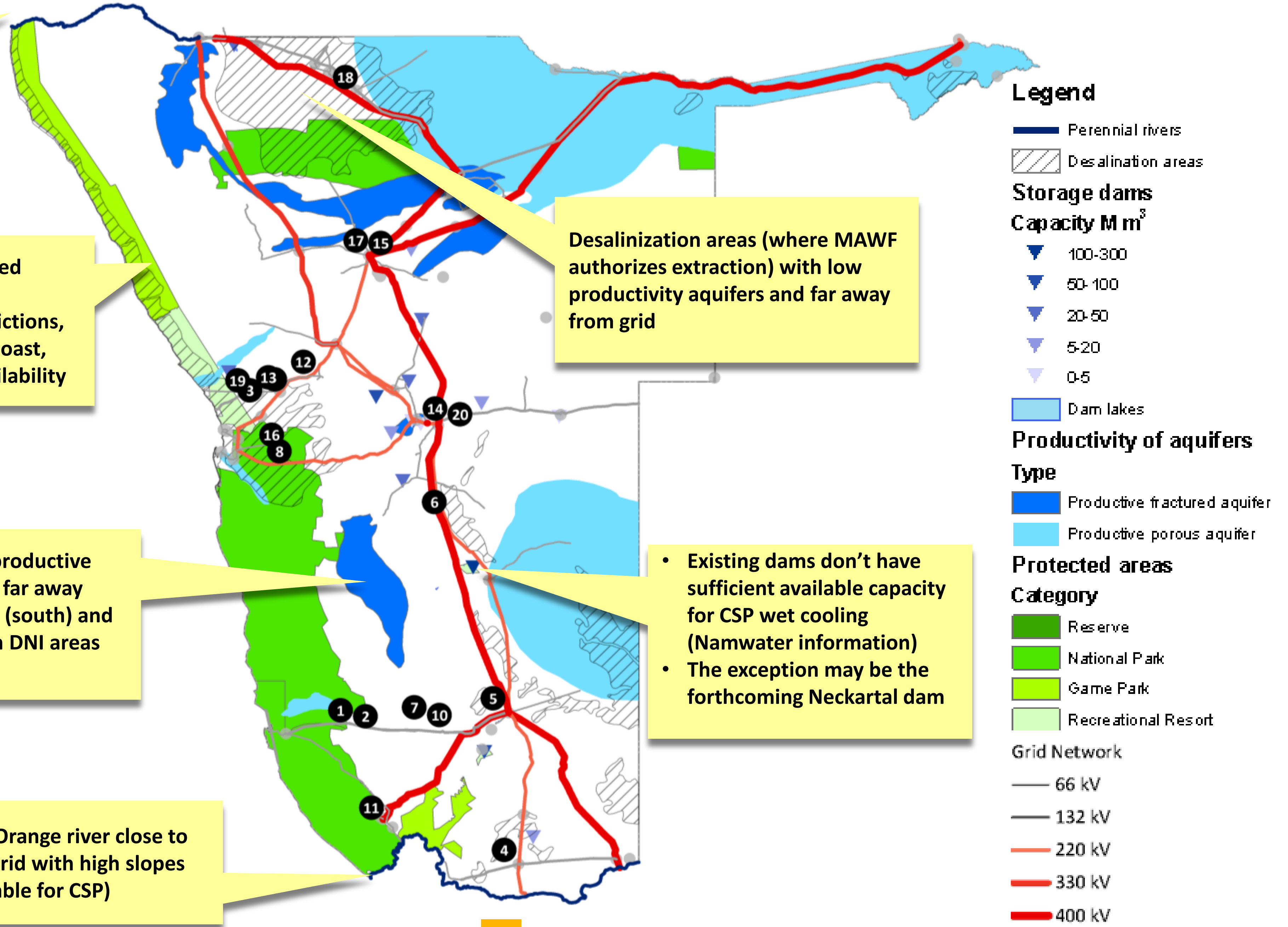
TOP 20 SITES

1 Ausweiche
2 Ausnek
3 Arandis
4 Hochland
5 Kokerboom
6 Tsumis
7 Bethanien
8 Ganab
9 Khan_2
10 Kosis
11 Scorpion Mine
12 Navachab
13 Khan_1
14 Detmont
15 Gerus_1
16 Langer Heinrich
17 Gerus_2
18 Onashikookaya
19 Trekkopje Mine_2
20 Grasland



POTENTIAL FOR WET COOLING HAD NO IMPACT ON SCORING GIVEN LOW AVAILABILITY OF WATER ACROSS NAMIBIA

6



International Kunene river far away from grid

Sea water cooling limited because of:

- Environmental restrictions,
- Lower DNI close to coast,
- and limited grid availability

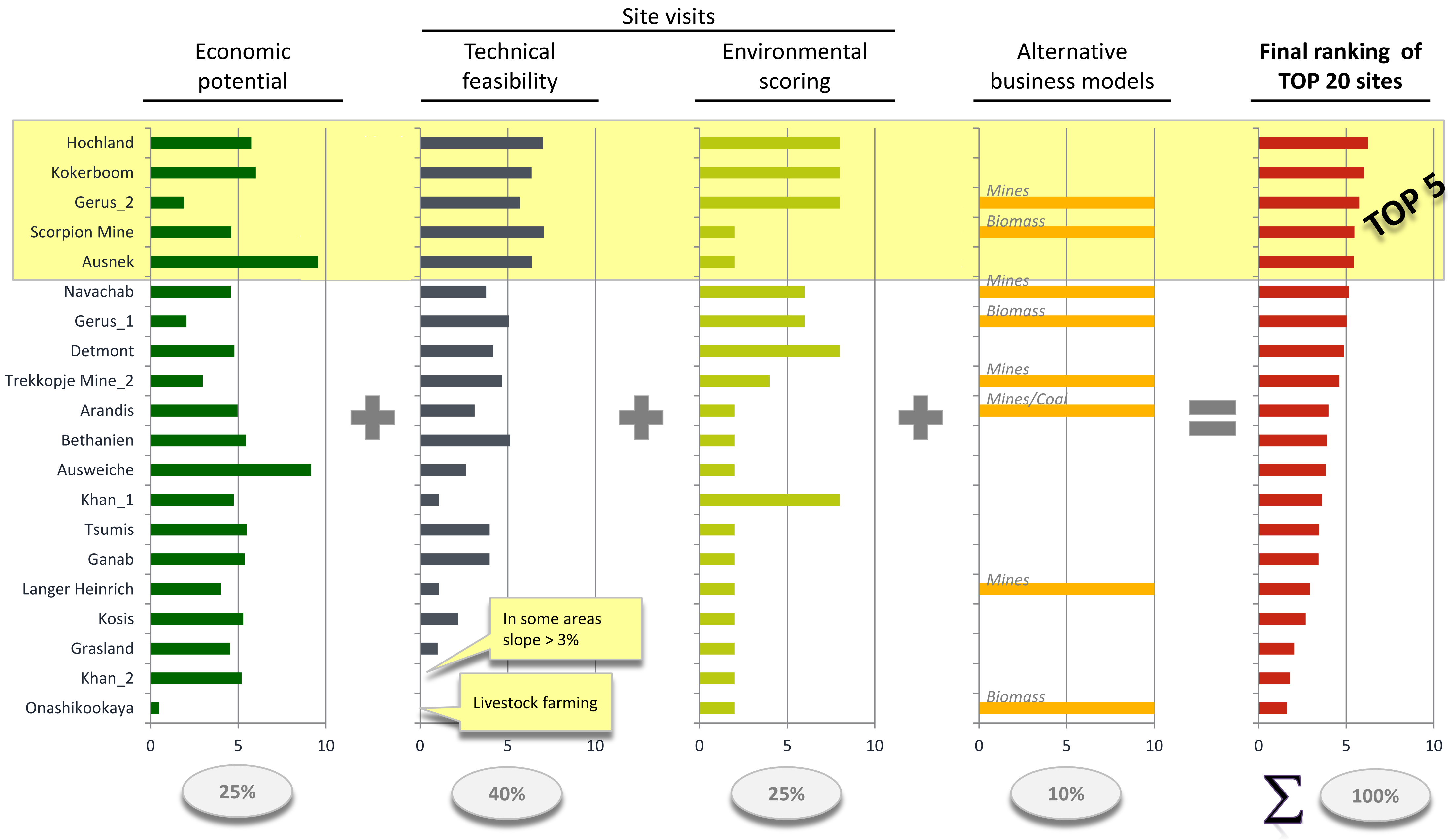
Desalinization areas (where MAWF authorizes extraction) with low productivity aquifers and far away from grid

Existing productive acquifers far away from grid (south) and from high DNI areas (north)

- Existing dams don't have sufficient available capacity for CSP wet cooling (Namwater information)
- The exception may be the forthcoming Neckartal dam

Areas in Orange river close to existing grid with high slopes (not suitable for CSP)

THE SELECTION OF TOP 5 SITES WAS BASED ON MULCRITERIA ANALYSIS WITH THE GIS STUDY, SITE VISITS AND ENVIRONMENTAL RESTRICTIONS



POLYTECHNIC OF NAMIBIA

Ministry of Mines and Energy

EEP

Gesto ENERGY SOLUTIONS

Solar Consulting Services

CONSULTING SERVICES AFRICA

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CSP Services
Concentrating Solar Power Services

CSP TECHNOLOGY OVERVIEW
NAMIBIA SOLAR RESOURCE AND DNI ANALYSIS
ENVIRONMENTAL ANALYSIS AND SITE SELECTION
TOP 5 SITES SELECTION AND FINANCIAL ANALYSIS
GROUND MEASUREMENTS
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TOP 5 SITE SELECTION

Location	Hochland	Scorpion Mine	Ausnek	Kokerboom	Gerus_2
Land *Ownership (Government, Communal, private)*	Private	Private	Private	Private	Government
Use (grazing, game park, agriculture, reserve, park, urban, resettlement)	Agriculture	Agriculture	Agriculture	Agriculture	Agriculture research
Any barriers/shadings	no	Surrounded by mountains which will cast some shadows in the early morning and late afternoon.	No	no	No
Any limitations for CSP technologies	The connection to the Harib SS may require some underground cabling due to the layout and the power corridors.	no	No	no	No
Others	In front of Harib SS	New location is required	Traces of man made fire may pose an issue to the DNI.	In front of KokerboomSS	Full of biomass

	Hochland	Scorpion Mine	Ausnek	Kokerboom	Gerus_2
Soil analysis					
Type (according to FAO World Reference Base for Soil Resources)	Alluvium, sand, gravel, calcrete plains	Leptosols	Leptosols	Regosols	Regosols
Visual inspection	open and clean, started to be sandy, not very hard, and then it turned out to be full of rocks (sedimentary). The site seems to be shifting sand from one side to the other so some places display soft sand while others are full of rocks. Low bushes with scattered medium size ones. Animals roam around and tracks are visible. Land nearer to the road may be very similar and easier to obtain.	Both sides of the road display the same features. Sandy soil, low bushes, some cactus and species that require analysis.	clean, open site, on a prairie, next to the road, bordered by mountains and with some clouds hovering. Sandy soil, no rocks or stones, few bushes and very small, grazing ground. No signs of soil erosion, due to deep sandy soils and low rainfall.	Low bushes, sandy soils. Low grazing. No serious signs of soil erosion. Soil compaction was observed is some parts. Some gravel found on the top-soil, indicating that the soil underneath will have stoney characteristics. Limestone appear to be the dominant subsurface stone.	Similar to site 15, but without any traces of rocks or stones. Low density of bushes, better access, some acacias
Slope (average)	1,60	1,92	2,22	0,99	1,53
Slope (maximum)	3,86	5,98	5,52	2,70	4,81
Visual inspection	Slope is fine, but the rock/sand creates some higher grounds.	Soil is flat.	Very flat all around, with a slight slope towards the east and north-east	Flat with a slight tilt to the north, but there are areas which can be even flatter.	Slope is flat, but with the trees and bushes it is hard to tell whether it undulates.

TOP 5 SITE SELECTION

	Hochland	Scorpion Mine	Ausnek	Kokerboom	Gerus_2
Solar radiation					
DNI - Direct Normal Irradiation	2721	2655	2945	2709	2517
Source - Geomodel					
GHI - Global Horizontal Irradiation	2261	2278	2386	2318	2291
Source - Geomodel					
Ambient temperature					
Average	19-20	16-17	17-18	20-21	21-22
Source – Atlas NAmibia					
Humidity					
Maximum	60	70	50	50	70
Minimum	10	20	10	10	10
Source - Atlas NAmibia					
Wind speed					
Average	6,50	7,50	8,00	6,50	6,00
Source - 3 tier					
Wind direction					
Average	163	176	151	166	178
Source: Geomodel					
Rainfall					
Average	50-100	50-100	50-100	100-150	400-450
Source – Atlas Namibia					

TOP 5 SITE SELECTION

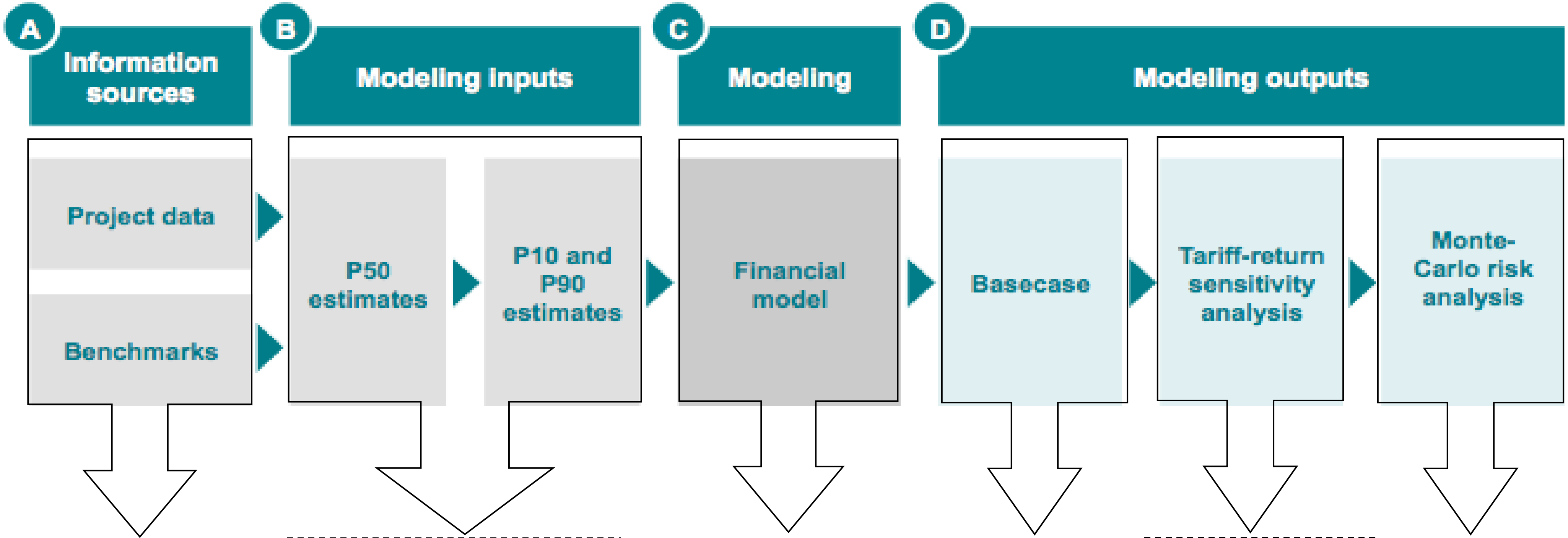
	Hochland	Scorpion Mine	Ausnek	Kokerboom	Gerus_2
Populations nearby? *Number of people (5 km radius)*	0.01-1	0.01-1	1-5	0.01-1	0.01-1
Endemic/protected fauna in the site *Spotted* *Verification required (mention the source)* *List of the endemic or protected species*	None spotted	Verification required	Verification required	None spotted	None spotted
Endemic/protected flora in the site *Spotted* *Verification required (mention the source)* *List of the endemic or protected species*	None spotted	There are four succulent species spotted. 3 not listed in red data list, but the distribution range is restricted. 1 in the red list: Endemic and rare Sarcocaulon patersonii, Augea capensis, Mesembryanthemum sp, Euphorbia namibensis	There is one succulent species spotted and verified Namibia Red data list Euphorbia namibensis, endemic and rare	None spotted	None spotted

TOP 5 SITE SELECTION

	Hochland	Scorpion Mine	Ausnek	Kokerboom	Gerus_2
Environmental and social concerns					
Landscape	The area is very remote, no major impact on landscape is expected. The site is next to a sub station.	An acess road transporting staff and mining products passes through the middle of the site. It is expected that the holder of the mining license and staff could have a issues with the proposed development.	Site is near the road and it is a scenic place, so there may be a negative impact on tourism and related activities due to the CSP power plant. If no tourism activities are being carried out, no major issues.	No major impact on landscape is expected. It is next to a sub station.	No major impact on landscape is expected. The site is near a sub-station in a bush encroached area.
Soil use	Low impact sheep farming observed.		Low impact livestock farming observed and springbok seen on site	Low impact sheep farming observed. Two water points were seen near the site.	High impact livestock farming observed.
Displacement	The site is on private land, hence very low human density. No infrastructures were observed.	The site fall within a mining concession. There are no human settlements on site, nor are livelihood activities are carried out on the proposed site.	The site is on private land, hence very low human density. Some buildings were observed near site. The buildings included housing and water infrastructure for maybe herders.	The site is on private land, hence very low human density. Except for the water points, no other infrastructures were observed.	The site is on private land, hence very low human density. No infrastructures were observed.

	Hochland	Scorpion Mine	Ausnek	Kokerboom	Gerus_2
Wildlife impact	Small mammals such as hare and steenbok were observed during the rapid site assessment. Aardvark burrow and lots of animals spoors also observed.	No wildlife observed	Springbok were seen, termites mounts and aardvark burrows observed. Displacement of wildlife will take place with minimal long-term impacts since the similar habitat in the surrounding area	No wildlife was observed during the rapid site assessment.	There are wildlife spoors/ tracks in the site.
Local population	The site appeared not to have any cultural values during the rapid assessment. Since it is part of a private land, the likelihood of any special utilisation for cultural and traditional activities is very low.	The site appeared not to have any cultural values during the rapid assessment. Since it is part of a private land, the likelihood of any special utilisation for cultural and traditional activities is very low.	The site appeared not to have any cultural values during the rapid assessment. Since it is part of a private land, the likelihood of any special utilisation for cultural and traditional activities is very low.	The site appeared not to have any cultural values during the rapid assessment. Since it is part of a private land, the likelihood of any special utilisation for cultural and traditional activities is very low.	The site appeared not to have any cultural values during the rapid assessment. Since it is part of a private land, the likelihood of any special utilisation for cultural and traditional activities is very low.
Others	Soil erosion, soil pollution, fires, poaching and livestock theft during construction and operations.	Soil erosion and soil pollution, during construction and operations; and decrease in aesthetic value of area depending on technology selected.	Soil erosion, soil pollution, fires, poaching and livestock theft during construction and operations; decrease in aesthetic value of area depending on technology selected.	Soil erosion, soil pollution, fires, poaching and livestock theft during construction and operations.	Soil erosion, soil pollution, fires, poaching and livestock theft during construction and operations.

FINANCIAL ANALYSIS



CAPEX, OPEX, plant lifetime, construction period, net energy yield, Insurance, Water, Rents & Licenses, Inflation, Market risk premium, Loan duration, Minimum DSCR, EPC payment schedule, debt ratio, equity raising, WACC.

Three data points were produced for each input: P50 (an average estimate, for which there is an equal probability that the actual value is above or below the estimate); P90 (a conservative estimate, with a 90% probability of underestimation); and P10 (an aggressive estimate, with a 10% probability of underestimation).

The financial model's main output is the LCOE (Levelized Cost of Energy, in USD/MWh). LCOE is calculated individually for each project under a *Basecase* scenario, assuming the P50 data points for all modeling inputs.

LCOE is the average cost at which the plant will produce energy during its lifetime, and is calculated by driving the NPV (Net Project Value) to zero

Calculates the tariff (per MWh) required for the project's equity investor to achieve a given eIRR (equity Internal Rate of Return, in %/year) and NPV. This is done under the *Basecase* scenario.

Predicts how the *Basecase* scenario will be affected by error estimates, technological risks, economical and financial uncertainties as well as others.

FINANCIAL ANALYSIS

Sites	Scenario	Generation	Time	Load profile	Technologies	Cooling
Ausnek	Nearest term	12 hours	8h30-13h; 14h-21h30	Nampower load	Towers, Troughs	Dry
Kokerboom	Nearest term	12 hours	8h30-13h; 14h-21h30	Nampower load	Towers, Troughs	Dry
Hochland	Nearest term	12 hours	8h30-13h; 14h-21h30	Nampower load	Towers, Troughs	Dry
Skorpion Mine	Mines	8 hours	8h-13h; 18h-21h 7h-12h; 17h-20h	TOU Peak tariff	Towers, Troughs	Dry
Gerus	Biomass hybrid	12 hours	8h30-13h; 14h-21h30	Nampower load	Tower, troughs, Linear Fresnel	Dry

The cost of the CSP power plant was obtained by separating the main costs:

solar field (m2)	USD / m2	power (MW)	M USD / MW	Storage	Biomass Boiler (MUSD /MW)	Eng & Const	CAPEX (M USD)	per MW (M USD)	per MW (M N$)
	100		1,8	10%	1,2	20%			
	150		1,8	10%	1,2	20%			
	200		1,8	10%	1,2	20%			

Sites (dry cooling)	Mirrors (m2)	Plant size (Hect)	Storage (hours)	Generation (hours)	CAPEX (M USD)		Yield (GWH)	
Ausnek – tower	647000	194	6,58	12	197	286	190	212
Ausnek - troughs	700000	210	5,66	12	204	301	190	212
kokerboom - tower	700000	210	6,49	12	204	301	190	209
kokerboom - troughs	760000	228	5,46	12	212	317	190	210
Hochland - tower	713000	214	6,83	12	206	304	193	214
Hochland - troughs	778000	233	5,82	12	215	322	194	215
Skorpion - tower	520000	156	4*	8	176	245	128	142
Skorpion - troughs	553000	166	4*	8	180	253	129	143
Gerus - troughs	432000	130	0	5	231	283	85	95
Gerus - Fresnel	602000	120	0	6,5	252	324	100	117
Gerus - towers	370000	111	0	4	224	268	68	76

* - Storage is done in the afternoon when the power plant is not generating to the grid

FINANCIAL ANALYSIS – SOFT CURRENCY SCENARIO

- 2 year plant construction time;
- EPC payment schedule: 40% in Year 1, 60% in Year 2.
- Loan duration: 15 years + 2 years of grace period during construction
- Interest rate: 11%
- Debt arrangement fee: 1,5% of debt (considering recourse financing)
- Equity/debt ratio: 50/50 (in order to maintain an average DSCR of 1,4 – with exception of the first 1/2 years of operation that may be below this, but always above 1)
- Investor cost of capital: 15%;
- WACC: 13%
- Inflation: 7%
- Tax on profits: 34%
- Autoconsumption: 4%

FINANCIAL ANALYSIS – LCOE VALUES

Projects	CAPEX		Yield		LCOE (USD/KWh)		LCOE (ND/KWh)	
	Min	Max	Min	Max	Min	Max	Min	Max
dry cooling								
Ausnek – tower	197	286	190	212	0,169	0,220	1,27	1,65
ausnek – troughs	204	301	190	212	0,175	0,231	1,31	1,73
Kokerboom – tower	204	301	190	209	0,175	0,235	1,31	1,76
kokerboom – troughs	212	317	190	210	0,182	0,246	1,36	1,84
Hochland - tower	206	304	193	214	0,174	0,231	1,30	1,74
Hochland - troughs	215	322	194	215	0,181	0,244	1,35	1,83
Skorpion - tower	176	245	128	142	0,224	0,281	1,68	2,11
Skorpion - troughs	180	253	129	143	0,227	0,288	1,70	2,16
Gerus - troughs	231	283	213	223	0,211	0,240	1,58	1,80
Gerus - Fresnel	252	324	200	217	0,234	0,269	1,75	2,02
Gerus - towers	224	268	214	222	0,210	0,234	1,57	1,76

FINANCIAL ANALYSIS – HARD CURRENCY SCENARIO

- 2 year plant construction time;
- EPC payment schedule: 40% in Year 1, 60% in Year 2.
- Loan duration: 15 years + 2 years of grace period during construction
- Interest rate: 6%
- Debt arrangement fee: 1,5% of debt (considering recourse financing)
- Equity/debt ratio: 40/60 (in order to maintain an average DSCR of 1,4 – with exception of the first 1/2 years of operation that may be below this, but always above 1)
- Investor cost of capital: 15%;
- WACC: 9%
- Inflation: 7%
- Tax on profits: 34%
- Autoconsumption: 4%

FINANCIAL ANALYSIS – LCOE VALUES

Projects	CAPEX		Yield		LCOE (USD/KWh)		LCOE (ND/KWh)	
	Min	Max	Min	Max	Min	Max	Min	Max
dry cooling								
ausnek - tower	197	286	190	212	0,127	0,165	0,95	1,24
ausnek - troughs	204	301	190	212	0,131	0,173	0,98	1,30
kokerboom - tower	204	301	190	209	0,131	0,176	0,98	1,32
kokerboom - troughs	212	317	190	210	0,136	0,184	1,02	1,38
Hochland - tower	206	304	193	214	0,130	0,174	0,98	1,30
Hochland - troughs	215	322	194	215	0,135	0,183	1,02	1,37
Skorpion - tower	176	245	128	142	0,168	0,211	1,26	1,58
Skorpion - troughs	180	253	129	143	0,170	0,216	1,28	1,62
Gerus - troughs	231	283	213	223	0,158	0,180	1,19	1,35
Gerus - Fresnel	252	324	200	217	0,175	0,202	1,31	1,51
Gerus - towers	224	268	214	222	0,157	0,176	1,18	1,32

CSP TECHNOLOGY OVERVIEW
NAMIBIA SOLAR RESOURCE AND DNI ANALYSIS
ENVIRONMENTAL ANALYSIS AND SITE SELECTION
TOP 5 SITES SELECTION AND FINANCIAL ANALYSIS
GROUND MEASUREMENTS
CSP DEVELOPMENT AND IMPLICATIONS FOR NAMIBIA

BEST PRACTICES IN GROUND MEASUREMENTS GUIDELINES

- Proper site selection is one of the most important issues during project development and the planning of a large-scale solar power installation
- Due to the high capital investment, potential sites should be thoroughly analyzed for their solar resource as solar radiation is the fuel for solar power plants
- Aerosols, water vapour or dust strongly influence the amount of available radiation and are known to vary widely in spatial and temporal dimension.
- This affects especially direct radiation, used in Concentrating Solar Power applications, and causes high intra-annual and inter-annual variability.
- Long-term irradiation data with high quality are necessary but usually not available
- Satellite data may serve as alternative due to their availability also for past decades. However, their accuracy is usually inferior to properly taken ground measurements
- Combination of accurate ground measurements and long-term satellite data including site-specific correlations within a contemporaneous period of at least one year is recommended for financial purposes or technical design of solar power installations on sites where no high quality long-term irradiation data is accessible.

Solar resource assessment at a given site include the following tasks and activities:

- Selection of a suitable ground measurement spot close to (<3 km distance) or on the project site
- Acquisition of on-site ground measurement data with an appropriate measurement system
- Acquisition of long-term solar irradiation data from satellites
- Combination and cross-correlation of satellite and ground measurement data for a period of at least one entire year
- Assessment of data quality and data uncertainty
- Derivation of expected long term averages (P50), solar resource variability and expected worst-case scenario (P90 or P95)

TYPES OF SENSORS FOR SOLAR IRRADIATION (I/III)

Thermopiles – Pyrheliometers

Use a thermoelectric sensor unit with a black coating that allows measurement of nearly the complete solar spectrum.

Pyrheliometers measure only **direct normal irradiation** (DNI, beam, within an aperture angle of approximately 1°) and therefore have to be pointed towards the sun, requiring a two-axis tracking system.

TYPES OF SENSORS FOR SOLAR IRRADIATION (II/III)

Thermopiles – Pyranometers

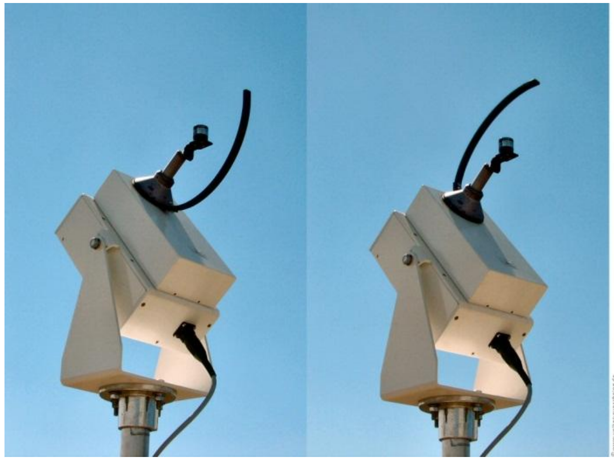
Use a thermoelectric sensor unit with a black coating that allows measurement of nearly the complete solar spectrum.

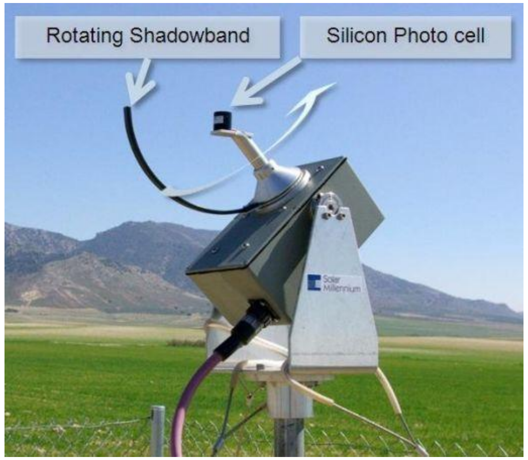
Pyranometers have a hemispherical opening angle and thus determine global (GHI) or diffuse (DifHI) radiation. For the latter case, a shading device blocking the sun is necessary.

Photodiode Sensors:

convert sunlight via the photoelectric effect to an electric signal which is approximately proportional to the irradiance. Their response time is within milliseconds; however their spectral sensitivity is not flat and usually does not cover the full solar spectrum. This yields systematic deviations of their response which needs to be corrected in order to get usable measurements.

To obtain Diffuse and Direct Radiation Measurements (DifHI, DNI), they are used in Rotating Shadowband Irradiometers (RSI).





TYPES OF STATIONS (SOLAR IRRADIATION)

Examples of thermopiles (High precision) Stations
left: Eppley Tracker
right: Kipp&Zonen
Cost: 35,000–55,000 USD

Examples of RSI stations.
left: Irradiance, Inc.
right: MDI, CSP Services G
Cost: 13,000–25,000 USD

RECOMMENDED EQUIPMENT (I/II)

-**Thermopiles:**

+ highest nominal accuracy
+ Standardized instruments (ISO 9060)
- more expensive, additionally need of a tracking system with high power consumption
- High maintenance effort to reach their higher accuracy. Especially pyrheliometers are notably affected by soiling, requiring daily maintenance on sites exposed to dust.

- **Photodiode sensors:**

+ less sensitive to soiling
+ designed as self-sufficient remote system with an independent power supply
+ Cheaper
+ Inherent systematic measurement deviations can be corrected
- Less nominal accuracy than thermopiles
- Not standardized yet

RECOMMENDED EQUIPMENT (II/II)

- RSI sensor type is recommended for measurements with the purpose of Solar Resource Assessment at an unattended and remote site where daily maintenance of the irradiance sensors is not possible. There is a large track record of projects successfully financed based on RSI sensor measurements.

→ recommended for project site analysis and operation monitoring of solar power plants

- The use of high precision instruments is only recommended when daily cleaning can be secured and a permanent grid power supply is available. Their use is also reasonable for quality assurance of remote station sensors in a parallel measurement setup at a supervised site

→ recommended for sensor calibration, performance measurements and scientific purposes

SPECIFICATIONS AND MINIMUM MEASUREMENT REQUIREMENTS

	Measured value	Unit	Accuracy	Range
DNI	Direct Normal Irradiation	W/m^2	instantaneous values: < ± 3.5 %, annual sum: < ± 2 %	0 to 1500 W/m^2
GHI	Global Horizontal Irradiation	W/m^2	instantaneous values: < ± 4 %, annual sum: < ± 3 %	0 to 1500 W/m^2
DHI	Diffuse Horizontal Irradiation	W/m^2	instantaneous values: < ± 10 %, annual sum: < ± 5 %	0 to 800 W/m^2
Measured value		**Unit**	**Accuracy**	**Range**
Ambient Temperature		°C	± 0.4 °C (range: + 5 to 40°C) ± 0.9 °C (range: - 40 to 70°C)	-40 to + 70°C
Relative humidity		%	± 2 % (range: 10 to 90%) ± 4 % (range: 0 to 95%)	0 to 100 %
Wind speed		m/s	0.1 m/s (range: 5 to 25 m/s)	1 to 96 m/s
Wind direction		°N	<5° installed	0 to 360°N
Barometric pressure		hPa	1.0 hPa (range: 0°C to 40°C)	600 to 1100 hPa
Precipitation		mm	2 % (< 50 mm hr^{-1})	0 to 700 mm/hr, (-40°) 0°C to 70°C

RSI AND THERMOPILE REQUIREMENTS

Measurement equipment

- All peripheral auxiliary equipment shall be provided stored safely and easily accessible for maintenance and inspection purposes in a weather-proof box.
- Measurement data sampling rate shall be at 1 Hz with 1 minute and 10 minute resolution for duration of at least one year.

Power supply

- The Automatic Weather Stations for the unattended remote sites must provide their own power source through a solar panel and backup battery.

Grounding and shielding

- The equipment should be properly grounded to prevent from lightning damage and shielded to prevent from radio frequency interferences.

Communication and data transfer:

- The equipment must be capable of GPRS or 3G data transfer or optionally via satellite connection (if no GSM or 3G net is available on the site).

Environmental conditions:

- The box containing data logger and electronics must be lockable to protect from theft and vandalism.
- All parts accessible from outside should be safe against bite damage by animals
- The entire equipment shall be made of stainless materials, cables and other equipment must be UV resistant

FURTHER GUIDELINES

Calibration

- Certificates should be traceable to a certified international reference calibration device or by an internationally recognized institution (like NREL, DLR, CIEMAT, etc.)
- Detailed description of the calibration method and period should be available.
- Regular repetitions of calibration according to the manufacturers recommendations should be performed to maintain a high level of data quality and reliability

General requirements for the area

- Dimensions should be at least 10×10 m^2, recommended free area of 25×25 m^2
- Surface should be horizontally leveled firm ground
- Accessibility should be granted by car, but not open for public access
- For remote data transmission a landline connection or mobile phone network is required
- No power lines should cross the site, either underground or above ground

Additional requirements for measurement of solar radiation:

- Locations free from any obstruction above the plane of sensing element (2 m off ground)
- No shade on sensor at all times of the day and year.
- No reflections on the sensor at all times of the day and year.
- No artificial light source.

Ministry of Mines and Energy

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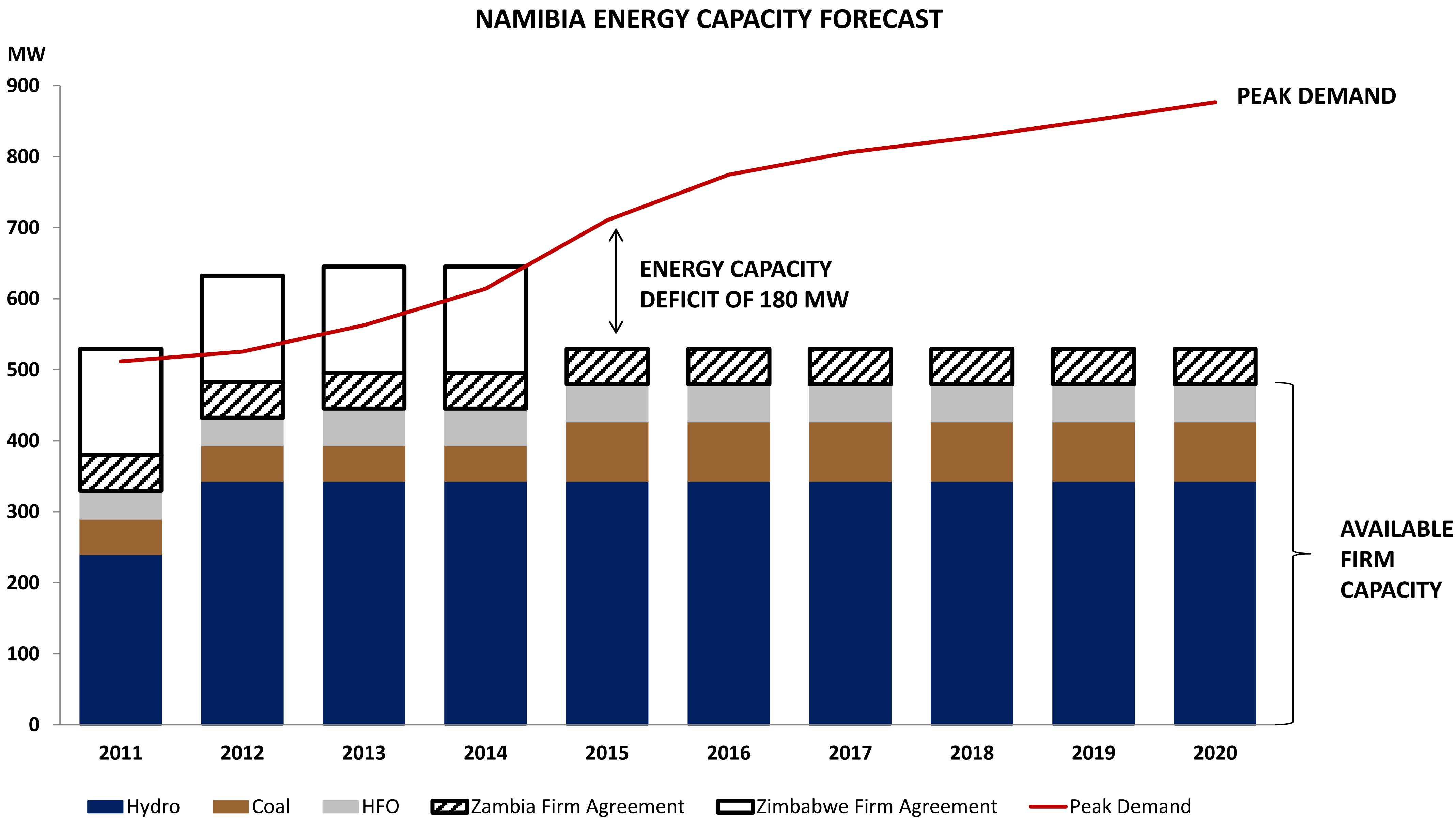
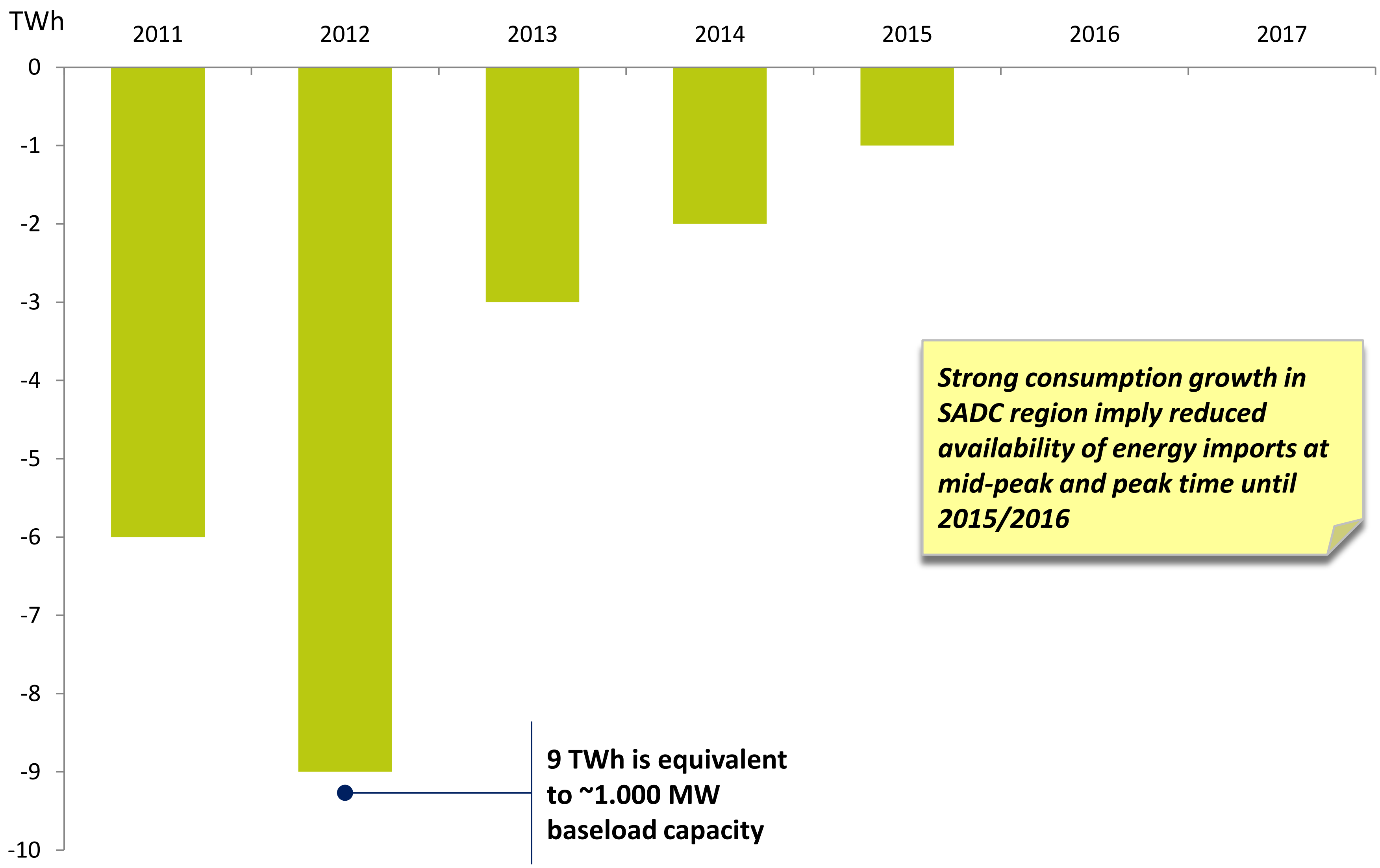
NAMIBIA FACES A CAPACITY DEFICIT FROM 2015 ONWARDS



Source: *Hatch Planning Parameters and Generation Options Draft Report – April, 30 2012; Gesto Analysis*

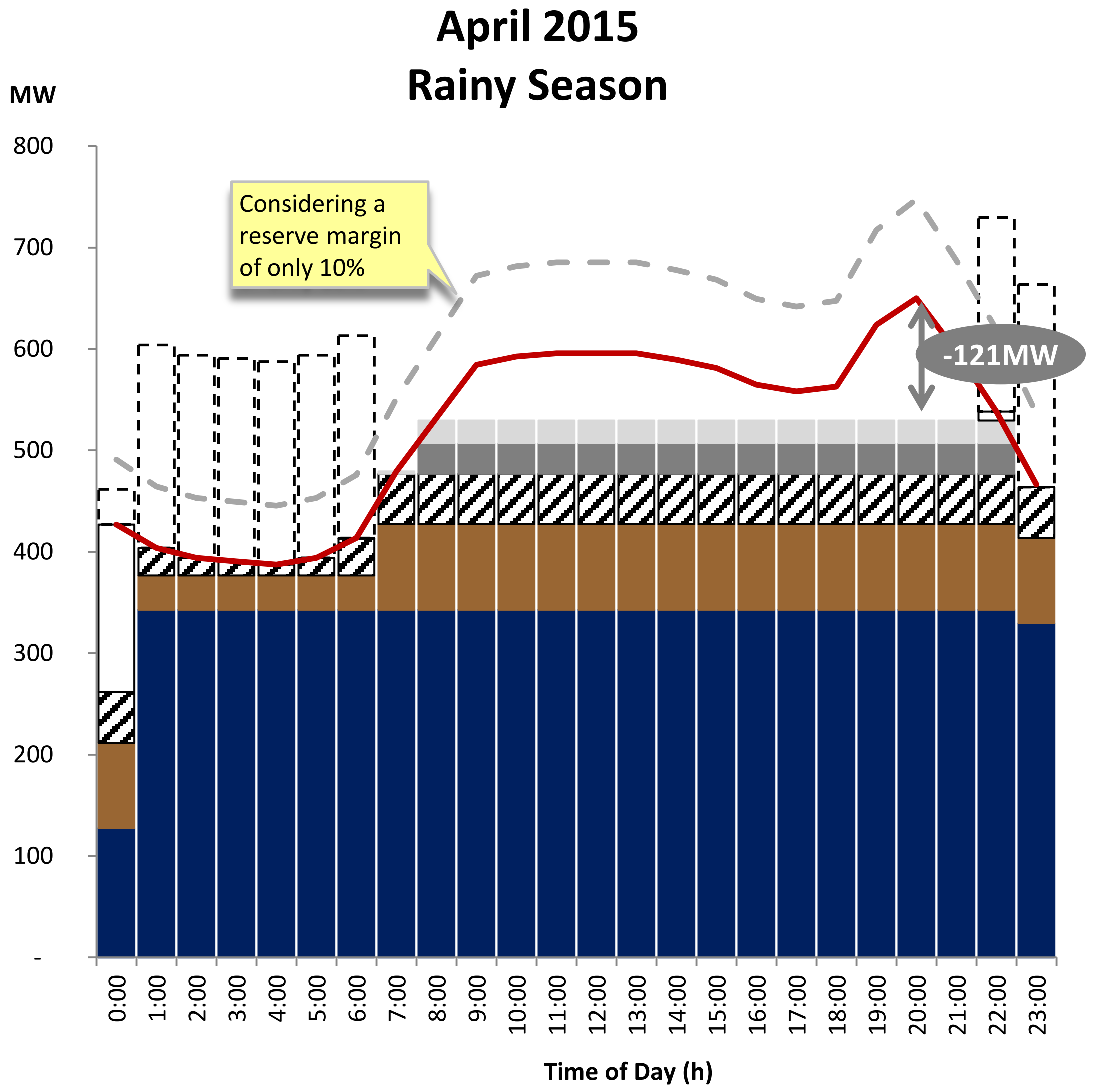
DUE TO SOUTH AFRICA'S ENERGY CRISIS, THE BILATERAL AND SUPPLEMENTAL CONTRACT MAY NOT BE AN OPTION FOR NAMIBIA'S ENERGY GAP

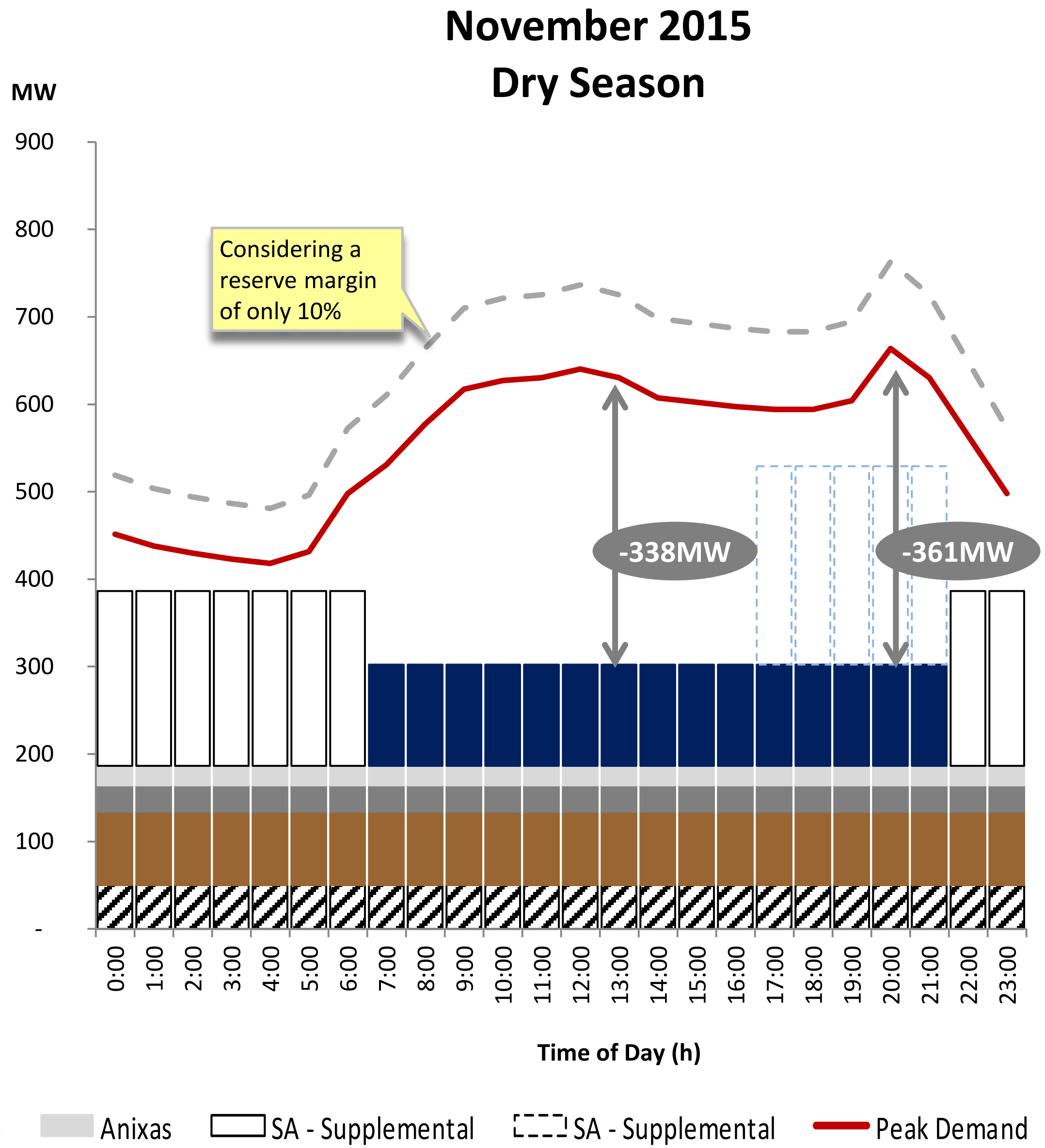
ELECTRICITY SUPPLY-DEMAND BALANCE IN SOUTH AFRICA



***Source:** The outlook up to 2017 is based on the Integrated Resource Plan (IRP) "moderate demand" scenario*

LACK OF WATER AVAILABILITY DURING DRY SEASON INCREASES ENERGY DEFICIT

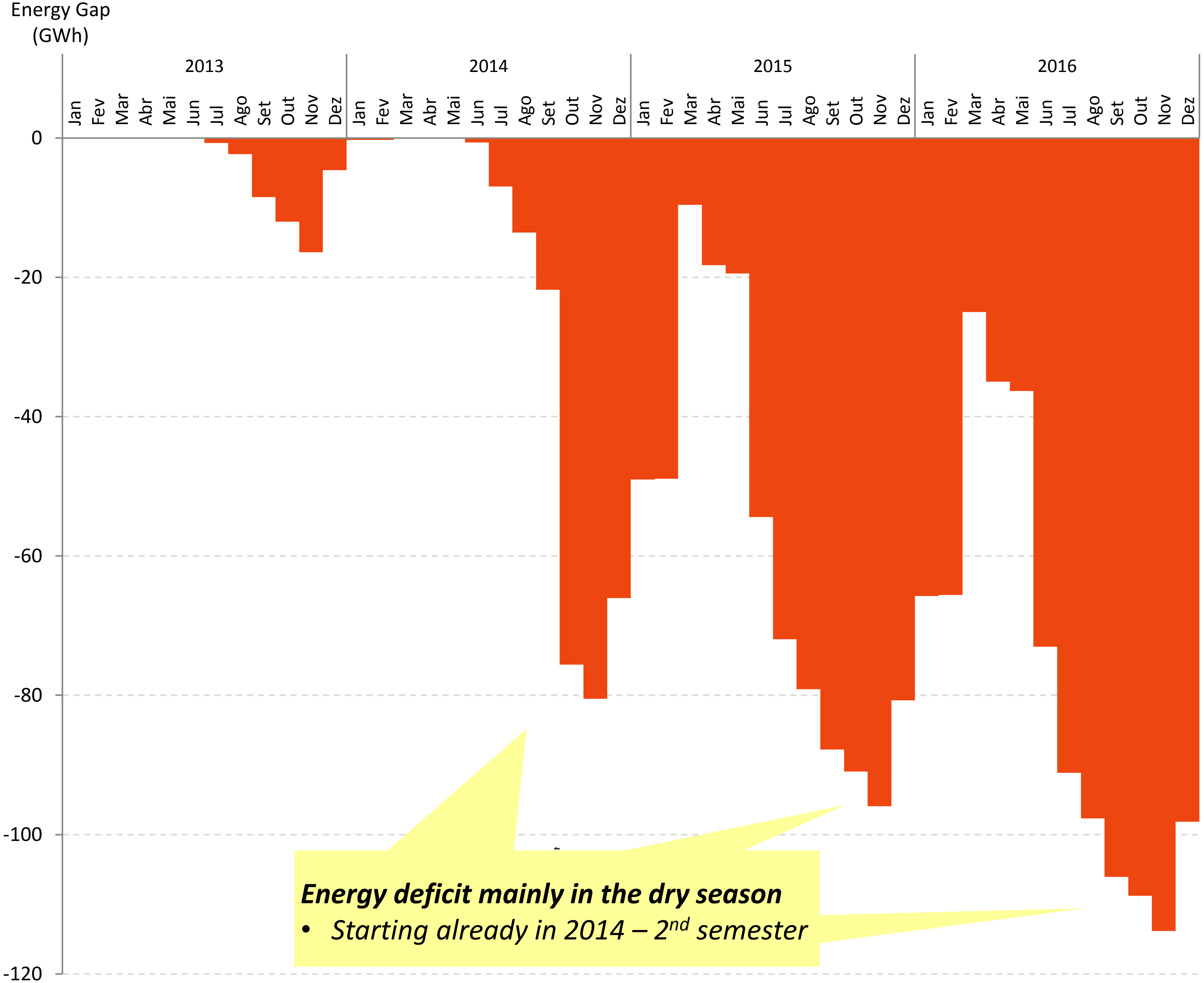




Source: *Hatch Planning Parameters and Generation Options Draft Report – April, 30 2012; Gesto Analysis*

WITHOUT SHORT TERM INVESTMENTS NAMIBIA MAY FACE A COST OF N$6.377M

ESTIMATED ENERGY GAP UNTIL 2016



Source: *Hatch Planning Parameters and Generation Options Draft Report – April, 30 2012; Gesto Analysis*

…may represent a +$6.377M cost for Namibia

Estimated total gap of 1,932 TWh between 2013 and 2016

- considering only peak and mid-peak periods

Without short term investments in power generation the gap will most probably be met with rental diesel

- Tanzania recently signed large contracts with Aggreko and Symbion
- Botswana had a 70 MW rental diesel unit operating until 2012

Tanesco estimated cost with Aggreko and Symbion rented diesel in 2012 amounts to $3.500M

- ~$3.300ND/MWh

If 75% of the Namibian energy gap is met using rental diesel this will represent a total cost for Namibia of N$ 6.377M

THREE SHORT TERM ALTERNATIVES TO RENTAL DIESEL

	1 HEAVY FUEL OIL	2 SOLAR CSP	3 SOLAR PV / WIND & BACKUP DIESEL	4 RENTAL DIESEL
Minimum Lead Time	**1,5 years**	**2 years**	**PV & Diesel – 1 year** **Existing wind – 1 year** **Other Wind – 2 years***	**6 months**
Investment ($N/MW)	**~$10M to $15M**	**~$40M**	~$16-18M (PV or Wind) ~$2-4M (Diesel) **Total: ~$20M**	**~0**
Operating Cost (Fuel + O&M - $N/MWh)	**~$1.200**	**~$250-$400**	**~$150 – 200 (PV) or** **~$100 – 150 (Wind) or** **~$2800 (Diesel)**	**~$3.300** *(based on Tanzania contracts with Aggreko and Symbion)*
Total Cost ($N/MWh)	**~$1.640 – 1.860** (@40% utilization)	**~$1.400** *(Devpt. Banks)* **~$1.720** *(IPP)*	**Solar PV & diesel: $1.780** (IPP) **Wind & diesel: $1.050** (IPP) *Considering only Diesel capacity & South Africa Refit results*	**~$3.300**

** Wind parks already with 1 year wind measurements and environmental impact assessment can be built in 1 year*

Notes: *a 5 year tax exemption was considered. Average project IRR of 15% and 11% in case of commercial and development financing, respectively.*
Source: *HFO: Hatch Planning Parameters and Generation Options Draft Report – April, 30 2012; CSP: SUNBD; Solar PV & Wind: South Africa Gesto Analysis*

ALL OTHER COST COMPETITIVE ALTERNATIVES BEING STUDIED IN THE NAMIBIAN IRP WILL NOT COME UP ON TIME

	1 NATURAL GAS	2 COAL	3 HYDRO BAYNES (600MW)	4 HYDRO ORANGE RIVER (100MW)
Minimum Lead Time	5 years (?)	5 years	9 years	6 years
Investment ($N/MW)	~$6M – 12M	~$21M	~$30,5M	~$28,6M
Operating Cost (Fuel + O&M - $N/MWh)	~$635 *(will depend on Kudu exploration agreement)*	~$559	~$50	~$50
Total Cost ($N/MWh)	~$850 - 1060 (@50% utilization)	~$1.080 (@70% utilization)	~$1.356 (@40% utilization)	~$1.275 (@40% utilization)

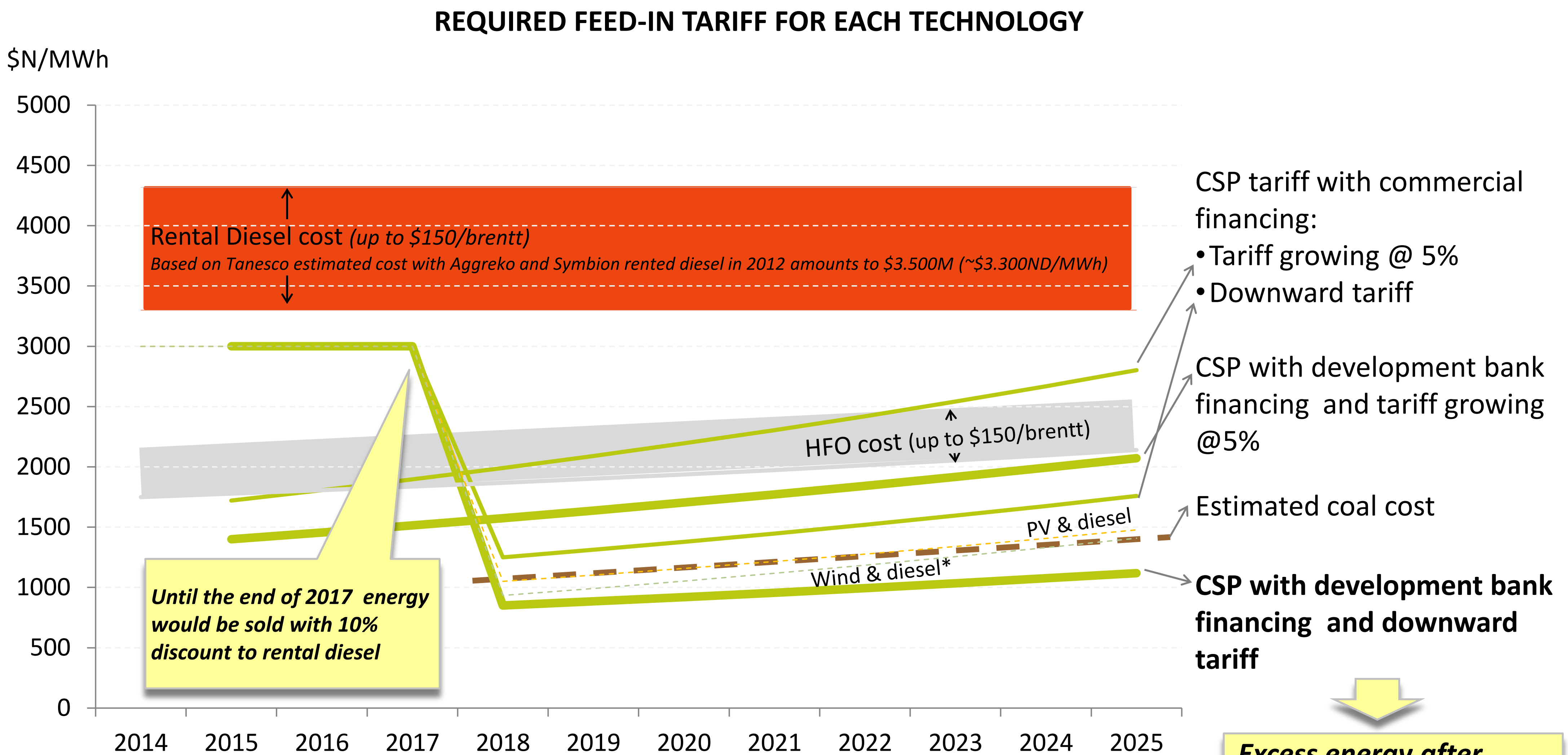
Coal seems to be the most reliable medium term alternative given Kudu timing uncertainty

Natural gas is the most adequate alternative in terms of investment, cost and fit with hydro.
However uncertainty on Kudu timeline undermines this option

Note that: *Taxes were not considered. Capex was annualized using a 15% weighted average cost of capital with equal payments (no inflation)*

CSP WITH DEVELOPMENT BANK FINANCING IS THE PREFERRED OPTION

A 2 step downward tariff allows renewables to be exported after coal is installed…



* Tariff for wind calculated considering that 40% of the energy will be sold at off-peak hours at $350/MWh throughout the period

Excess energy after 2017 can be exported to SADC with profit

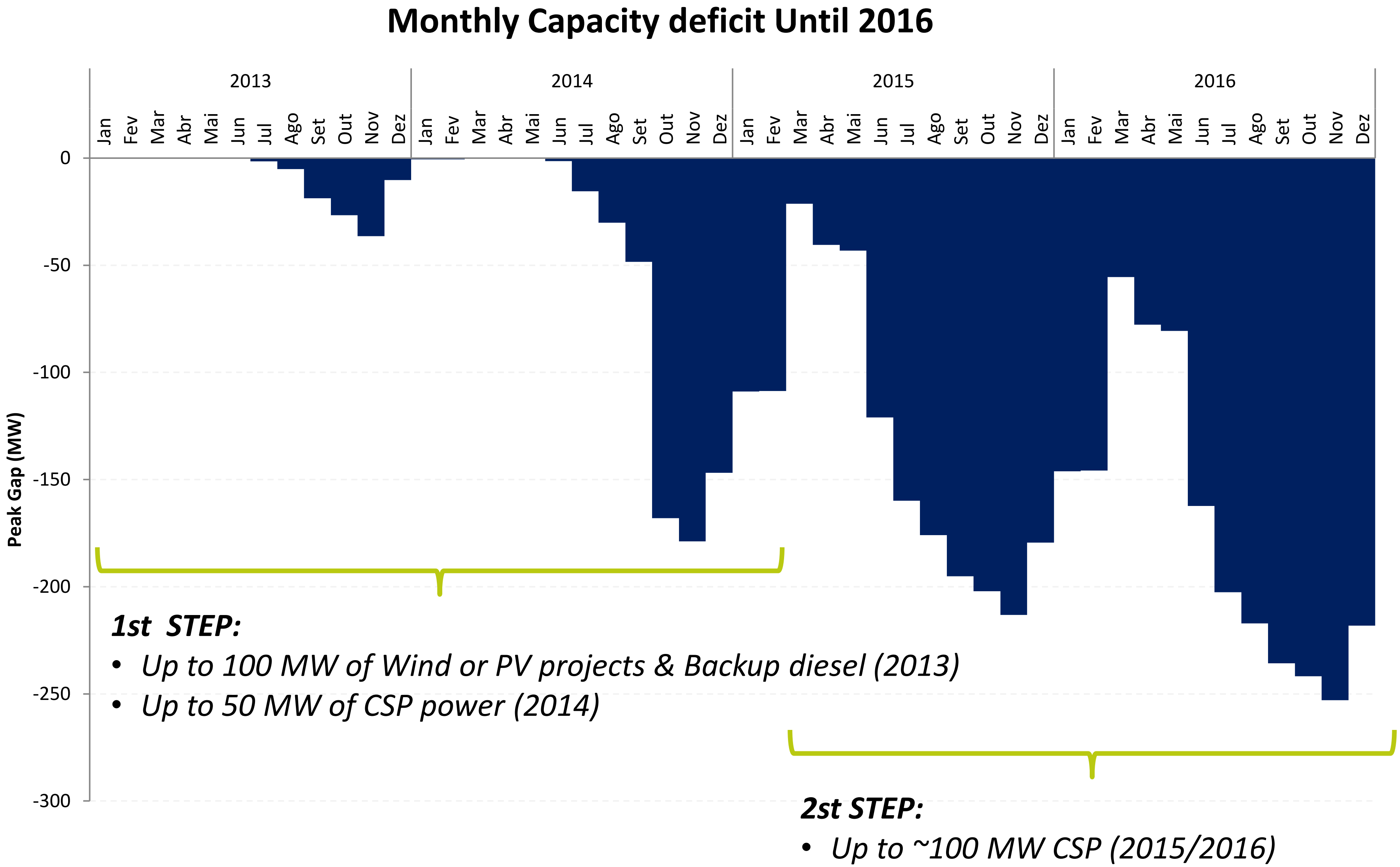
Source: *Hatch Planning Parameters and Generation Options Draft Report – April, 30 2012; Gesto Analysis*

FOUR MAIN ALTERNATIVE BUSINESS MODELS STUDIED FOR NAMIBIA

		Development banks	Downward negotiated tariff (IPP)	Refit with auction	Market price + Fixed Premium
Description		• CSP project developed by Nampower or Strategic private partner + Government institution (ex. REEEI) • Government support for low cost debt from development institutions	• Negotiated IPP and PPA contract with private investors • Recommended for PV and Wind projects	• Pre-established maximum Renewable feed in tariffs • Tariff auction (downward from maximum tariff) • Similar to South Africa Refit program	• Recommended only in the medium term given higher risk for investment • Multi-buyer bilateral agreement + fixed premium • Bilateral agreements with mines for market price
Incentive system		• Negotiated Fixed tariff • Debt incentives • Tax exemptions	• Negotiated Fixed tariff • Tax exemptions	• Auction based Fixed tariff • Tax exemptions	• Market price + premium • Tax exemptions
Tariff design	**Currency**	• US Dollars (preferred)	• Most likely Namibian dollars • US Dollars (preferred)	• Namibian dollars	• US Dollars (energy) • Namibian dollars (premium)
	Duration	• 20 years	• 20 years	• 20 years	• 20 years
	Time structure	• Downward (preferred) • Growing with inflation (alternative)	• Downward (2 step approach) • 2nd step growing at fixed rate	• Growing with inflation or at a fixed rate	• Downward premium
	Counter-part	• Nampower as buyer with state guarantee	• Nampower as buyer with state guarantee	• Nampower as buyer with state guarantee	• Multi buyer • ECB paying the premium

Recommended alternatives for Namibia in the short term (Development banks; Downward negotiated tariff (IPP))

GIVEN TECHNOLOGY LEAD TIMES WE PROPOSE A 2 STEP APPROACH



Note that: *based on Namibia's Energy Policy, a 75% coverage of peak demand with internal resources was considered. The capacity of Ruacana was equally distributed between mid-peak and peak hours according to average water availability*

Source: *Hatch Planning Parameters and Generation Options Draft Report – April, 30 2012; Gesto Analysis*

THIS APPROACH CAN SOLVE NAMIBIA'S ENERGY SHORTFALL WITH THE LEAST COST

2012 – 2nd Semester | 2013 – 1st Semester | 2013 – 2nd Semester | 2014 – 1st Semester | 2014 – 2nd Semester | 2015 – 1st Semester | 2015 – 2nd Semester | 2016 – 1st Semester

1st STEP

Up to 100 MW of Wind or PV & Backup diesel
+
Up to 50 MW of CSP

Negotiate PPA under IPP regime

All renewable promoters required to install and transfer(?) to Nampower diesel backup engines

Delivery and installation of Diesel backup engines

Operation startup (up to 100 MW)

Installation of wind and solar PV projects
(only wind projects with measurements can provide energy in the required time frame)

Operation startup reducing diesel oil consumption

Feasibility study

Environmental screening

Negotiation with Development institutions

Selection of implementing agency

EPC procurement

Financial closing

Environmenta l clearance

Installation of CSP project (50 MW)

Operation startup of the first 50 MW CSP project

2nd Step

Up to 100 MW of CSP

Installation of the second phase (100 MW)

Operat ion startup

CSP SOLAR PROJECTS HAVE SIGNIFICANT ADVANTAGES FOR NAMIBIA

Namibia has one of the best solar resources for CSP in the world enabling a competitive source of energy

- If there is an initial period of 3 years with higher PPA tariffs (taking into account that rental diesel is the existing short term alternative), CSP can become a competitive source of energy (relative to coal) with export potential

CSP in Namibia can have access to development funding for renewable energies in Africa

- Increasing access to available financing (important given strong investment requirements until 2017)
- Significantly decreasing the cost of debt and increasing the required tenors, which results in lower tariffs

CSP is a renewable source of energy with zero CO2 emissions contributing to climate change and improving Namibia's international image and visibility

CSP is a reliable technology with more than 1 GW of projects already deployed

- Spain with +750 MW installed and the USA with +440 MW installed
- Energy storage already tested and deployed in many projects around the world

CSP can guarantee dispatchable peak power even for the night peak time

- With storage or hybrid with biomass

CSP does not need to produce at off-peak periods when the value of energy in the region is very low

A CSP technology transfer program will enhance the renewable competences of Namibian research and education institutions

CSP has a strong potential for local job creation

- Which may significantly be increased in case of biomass hybridization

A TECHNOLOGY TRANSFER PROGRAM FOR CSP WOULD ENHANCE EXISTING COMPETENCES AT THE POLYTECHNIC OF NAMIBIA

POLYTECHNIC OF NAMIBIA

The Polytechnic of Namibia (Polythec) is industrial sector skills, business and management, engineering, communications, natural resources and tourism.

In the field of renewable energy the Polytechnic of Namibia focuses its work specifically **on solar home systems and feasibility studies for the utilization of wind generators as well as the analysis of new technology approaches.**

Research in the field of energy efficiency. Sustainable energy technologies have been reviewed as well. **Simulation of hot water systems**.

Renewable Energy & Energy Efficiency Institute

The Renewable Energy and Efficiency Institute (REEEI) represents the Polytechnic of Namibia as contact for questions regarding renewable energy and energy efficiency.

Project NEEP has its main focus on energy efficiency improvement in buildings

Master plan for the provision of electricity in off-grid/pre-grid areas by means of the establishment of so-called Energy Shops in June 2011.

Project Soltrain

Training and capacity building as well as the implementation of small and medium enterprises in Renewable Energies

UNIVERSITY OF NAMIBIA

The UNAM is a public institution with main focus on:

- *Natural resources*
- *Economics*
- *Management sciences*
- *Others allocated in the corresponding faculties.*

Capacity building in the field of renewable energy and/or sustainable energy does not take place and would have to be established

Technology transfer initiatives at UNAM may be difficult to implement given absence of faculty with know how on renewables

PRELIMINARY STRUCTURE FOR CSP TRAINING AT POLYTECHNIC OF NAMIBIA (I/II)

General Trainings on Power plant engineering and Solar radiation
(Prior to CSP specific technology course)

This should include the following topics and should be taught, if possible, prior to the CSP technology course, which may be seen as a specialization comparable to gas fired or coal fired specific power plants

Power plant engineering:
- Boilers / steam generators and heat exchangers
- Feedwater tank and deaerator assembly
- Condensers
- Steam turbines
- Gas turbines
- Cooling technology
- Water treatment facilities, and water and steam quality
- Electric generators

Before teaching CSP topics, the basics of solar radiation and additional small topics:
- Solar radiation
- Solar radiation for CSP power plants

Specialization course on CSP technology should include the following topics

Parabolic trough power plants:
- Parabolic trough types, designs, sizes and applications
- Heat collector elements
- Heat transfer fluids
- Descriptions of existing plants
- New technology outlook
- Operation experience from existing commercial plants

Power towers:
- Heliostat field
- Receiver types
- Heat transfer fluids
- Descriptions of existing and planned plants
- New technology outlook
- Operation experience from existing commercial and demonstration plants

Linear Fresnel reflectors:
- Linear Fresnel reflector types, designs, sizes and applications
- Absorber tube and secondary concentrator
- Heat transfer fluids
- Descriptions of existing plants / market analysis
- New technology outlook
- Operation experience from existing commercial and demonstration plants

Dish systems:
- Stirling cycle and Stirling engine
- Dish system sizes and designs
- Descriptions of existing plants / market analysis
- New technology
- Operation experience from existing commercial and demonstration plants

Thermal energy storage systems:
- Thermal energy storage systems for sensible heat
- Latent-heat storage system
- Steam accumulator
- Thermo-chemical energy storage
- Solar multiple
- Storage capacity

Maintenance of CSP plants and Quality control

Hybridization of CSP plants

Augmentation of CSP power plants

Economic comparison of the CSP technologies / comparison to other renewable energy technologies

PRELIMINARY STRUCTURE FOR CSP TRAINING AT POLYTECHNIC OF NAMIBIA (II/II)

Training courses for construction, operation and maintenance personnel should also be developed

Preliminary list of required skills and knowledge for operational workers:

- Safety instructions should be given whenever a worker is assigned with a task which could involve danger of injury or death to the worker or others
- Be able to read power plant systems diagrams and get to know all the locations of the components, valves etc.
- Handling of valves etc.
- Receive instructions on how to handle the components (steam turbine, boiler…)
- Know how to repair/maintain broken solar field components (heat collector elements, mirrors, tracking motors, electronics…) and some power block components (gauges, valves…)
- Operate the plant from the process control system
- Understand the interconnection between plant systems and components
- Know of the danger of heat transfer fluids, be aware of the danger of fluids like oils and chemicals to the environment and human body
- Understand the danger associated with pressurized systems also with regard to maintenance
- Be aware of the dangers of concentrated solar irradiation to components and the human body if handled inappropriately
- Maintenance of the meteorological measurement station
- Refilling of fluids

150 MW CSP POWER COULD REPRESENT MORE THAN 100 O&M DIRECT JOBS AND 1.700 DIRECT JOBS DURING THE CONSTRUCTION PHASE

Temporary jobs during construction

- Assembly of metal frames by welding
- Fixing of mirrors
- Optics measurements
- Alignment of the drive system
- Fixing of receiver elements
- Installation of tracking system
- Filling of the system with heat transfer fluid
- Good repairing skills required for:
  - Assembly of metal frames
  - Welding of pipes
- Electrical and electronic works by technicians and engineers

Permanent jobs during operation

- General operation
- Permanent tests of the components
- Change of heliostats and receiver elements

Job-years in parabolic trough power plants
(in operation)

- Average construction job-years per MW_e (gross): 11.3
- Average annual O&M jobs per MW_e (gross): 0.7

Job-years in power tower plants
(in operation)

- Average construction job-years per MWe (gross): 37.3
- Average annual O&M jobs per MWe (gross): 2.3

- *Parabolic trough technology is longer on a commercial state than power towers*
- *More experience with parabolic troughs has been gathered with respect to efficient construction and mass production*
- *The lack of experience requires more personnel in power towers*

PRELIMINARY LIST OF NAMIBIAN COMPANIES WITH POTENTIAL FOR SUPPLYING THE CSP VALUE CHAIN

Companies	CSP area
Valco Sales & Service CC	pumps, fittings, heat transfer, heat exchangers
Nirosta	Steel, pressure vessels
Pupkewitz Metalworx	very large group of companies, may be able to supply components
Kurose (Pty) Ltd	water, heat exchanger, pipes, tanks
Ohorongo Cement (Pty) Ltd	foundations
RMB bank	CSP experience in SA
PG Glass	tempered glass
Africa Glass Industries Namibia	Not clear whether they manufacture tempered glass
Burbridge Glass CC	Not clear whether they manufacture tempered glass
Suremix	Foundations
Brick & Concrete Industries (Pty) Ltd	Foundations
City Concrete (Pty) LTD	Foundations
Concretech industries	Foundations
Concrete-Simply In	Foundations
NAMSLAB	Foundations
COASTAL PRECAST & PAVING	Foundations
WIBEKU CC	Foundations
Deamaru Group CC T/A Desert Iron & Steel	Steel structures
Kraatz Steel (Pty) Ltd	Steel structures
Steel & Industrial Supplies	Steel structures

More than 40 companies identified already…

Companies	CSP area
Namibia Engineering Corporation	Steel structures
Pro-Edge Steel	Steel structures
Coastal Steel Works	Steel structures
Okahandja Wire & Steel	Steel structures
Stainless Engineering	Steel structures
Exacto Engineering CC	Steel structures
Invo Stahlbau CC	Steel structures
Steel & Wire	Steel structures
Steel Force CC	Steel structures
Suresteel	Steel structures
Steeldale Reinforcing & Trading (Namibia)	Steel structures
Aurecon	Engineering
Burmeister & Partners	Engineering
EMCON	Engineering
CSA	Engineering
CMB Namibia Ltd	Engineering
Precast Walls	Foundations
Namibia Garden & Cement Product CC	Foundations
Coupar Contrete (Pty) Ltd	Foundations
SOnnex Precast Concrete Industries	Foundations
Barloworld Concrete Industries	Foundations

POLYTECHNIC OF NAMIBIA

Ministry of Mines and Energy

EEP

Gesto ENERGY SOLUTIONS

Solar Consulting Services

CONSULTING SERVICES AFRICA

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CSP Services
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