Albedo effects on PV yields

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Questions this presentation wants to answer

1. What is surface albedo?
2. How albedo affects solar yield?
3. Main aspects to consider concerning albedo & PV

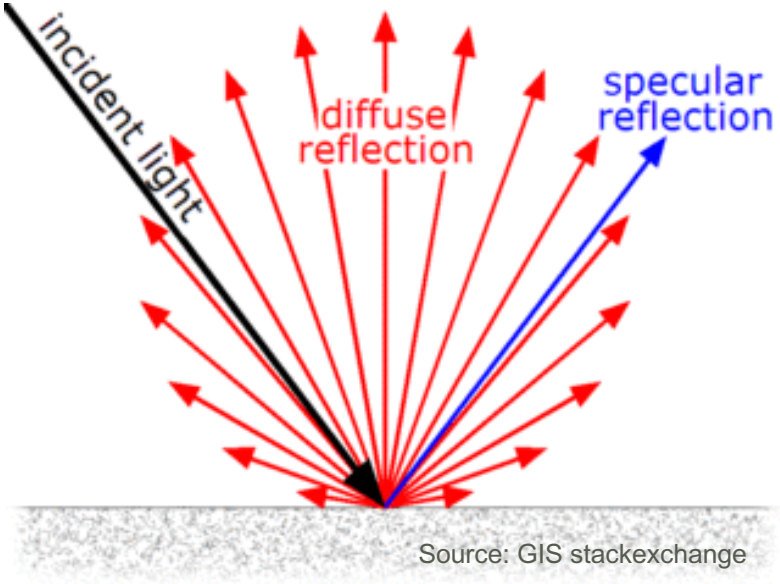
What is the meaning of albedo?

Albedo from Latin meaning “whiteness”

The albedo α of a surface is the fraction of the incident sunlight that the surface reflects.

Ratio of the total upwelling radiative flux F^+
to the downwelling solar flux F^-

$$\alpha = \frac{F^+}{F^-}$$

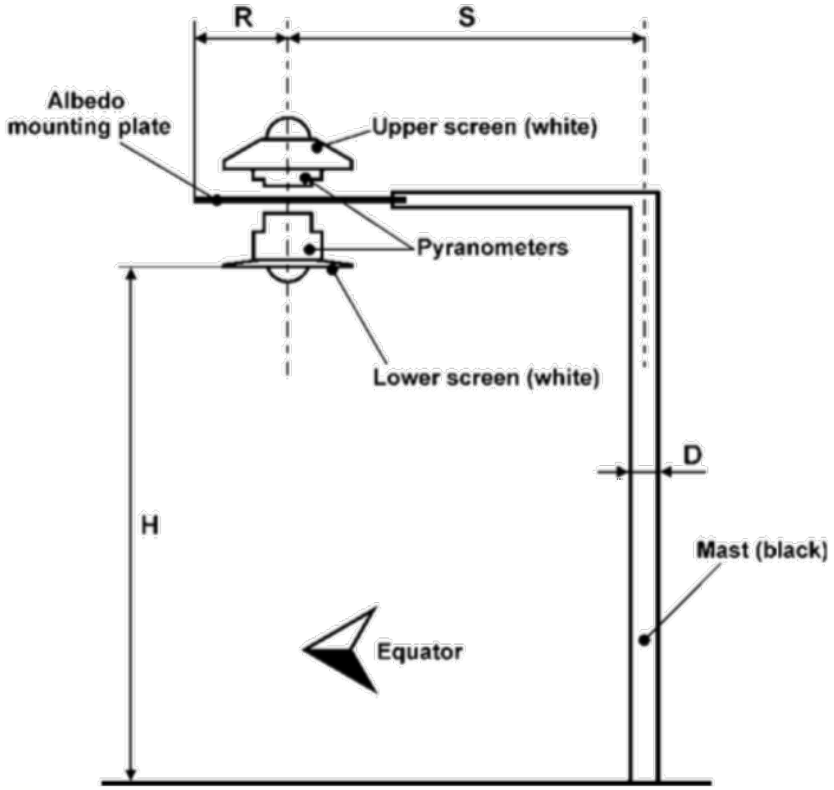


Source: GIS stackexchange

Simple view: isotropic reflection
= same in all directions.

Complex analysis: actually surface reflects differently in various directions:
Bi-Directional Reflectance Functions (BDRF)

How to measure albedo on the ground?



Albedo measurement construction

source: Kipp & Zonen

Albedometer using 2 pyranometers (Hukseflux SRA20 high quality albedometer)

source: Hukseflux

How to measure albedo on the ground?

source: Hukseflux

Albedometer using 2 pyranometers (Hukseflux SRA20 high quality albedometer)

source: Suntrace

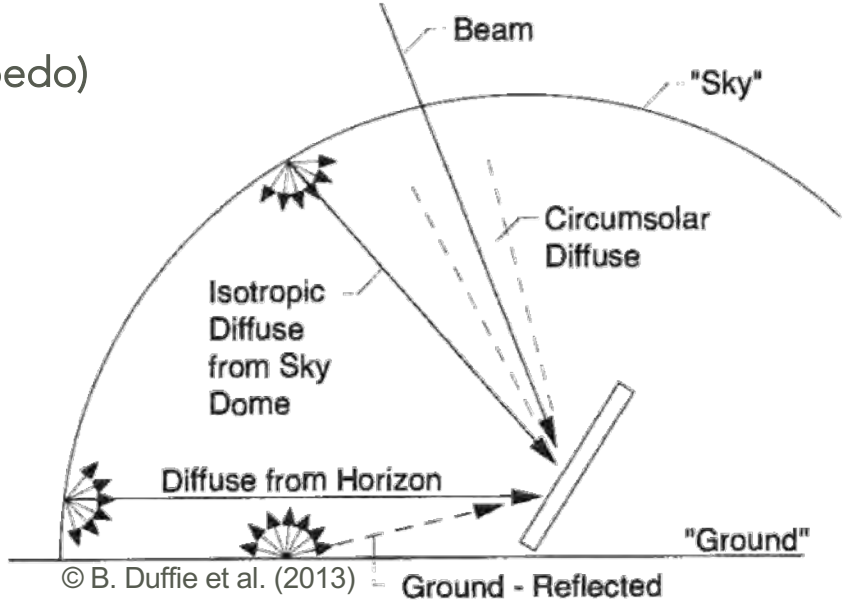
Albedometer using photodiode sensors

Global irradiance on the tilted surface (GTI) of PV modules

GTI or Plane of Array (POA) irradiance

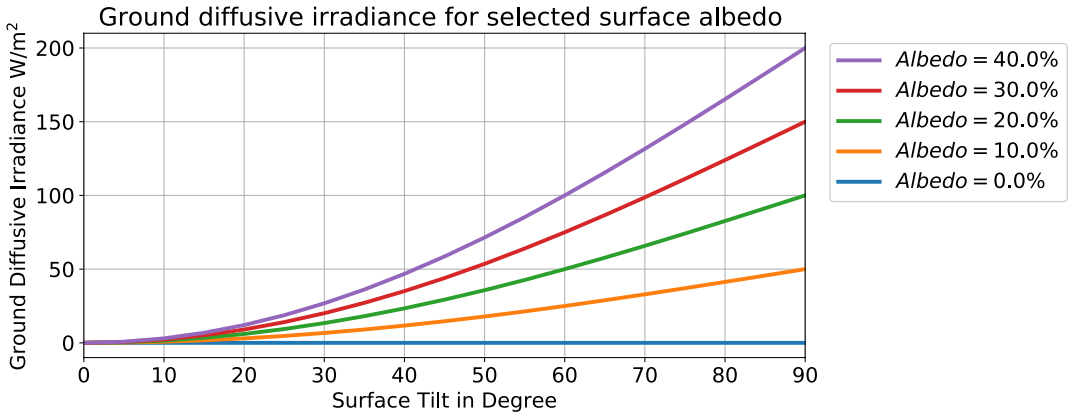
is calculated from Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI), terrain albedo, and instantaneous sun position.

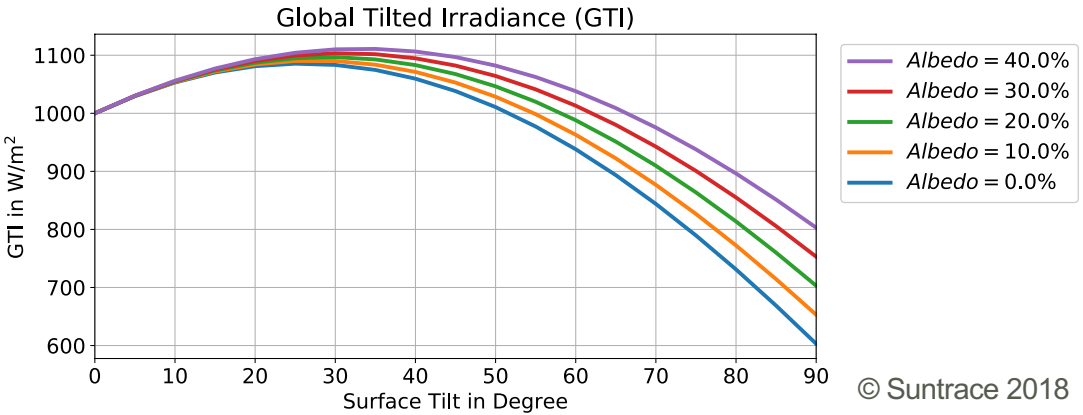
GTI = f (GHI, DNI, SE, SA, Albedo)



Beam, diffuse, and ground-reflected radiation on a tilted surface.

Calculations for Global Horiontal Irradiance GHI = 1000 W/m² & Diffuse Horizontal DHI= 200 W/m², solar zenith angle $\theta_z = 25°$





Typical values of surface albedo

The reflectance properties are highly variable for different surfaces. Albedo values can largely vary from site to site

Some examples:

Natural surface types	Typical albedo values
Forest	5% – 15%
Grassland	10% – 25%
Sand	15% – 40%
Snow	50% – 95%
Water	5% – 12%

Surface albedo can have signifcant seasonal variability

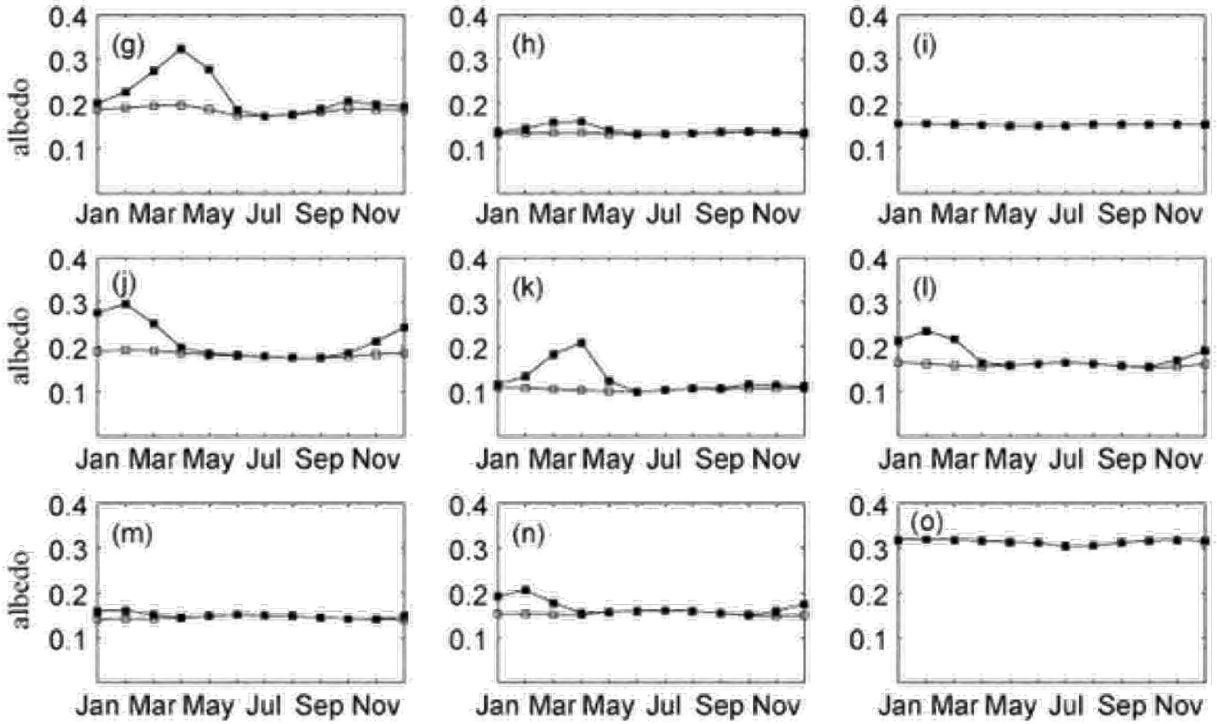
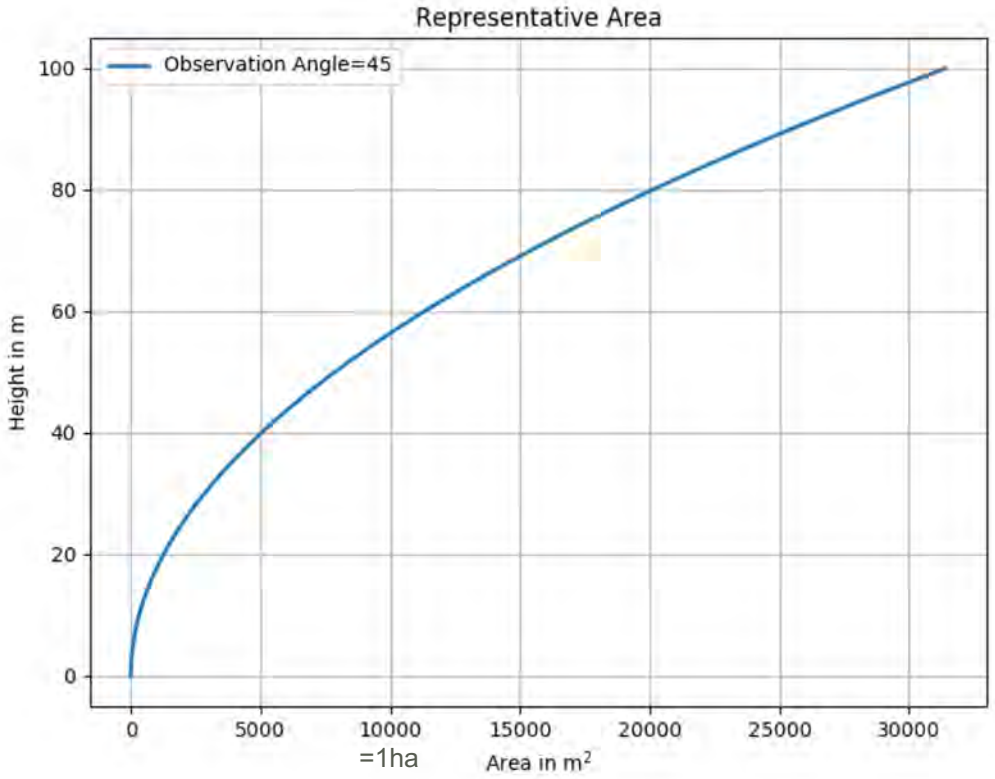


Fig. 7. Nine complete years (2000–2008) of Global shortwave monthly-average albedos seasonal variation for different IGBP land surface under snow-covered and snow-free conditions. The filled-square represents snow-covered conditions, and the unfilled-square represents snow-free conditions. (a) Evergreen Needleleaf forest. (b) Evergreen Broadleaf forest. (c) Deciduous Needleleaf forest. (d) Deciduous Broadleaf forest. (e) Mixed forest. (f) Closed shrublands. (g) Open shrublands. (h) Woody savannas. (i) Savannas. (j) Grasslands. (k) Permanent wetlands. (l) Croplands. (m) Urban and built-up. (n) Cropland/Natural vegetation mosaic. (o) Barren or sparsely vegetated.

source: Zhang et al. (2010)

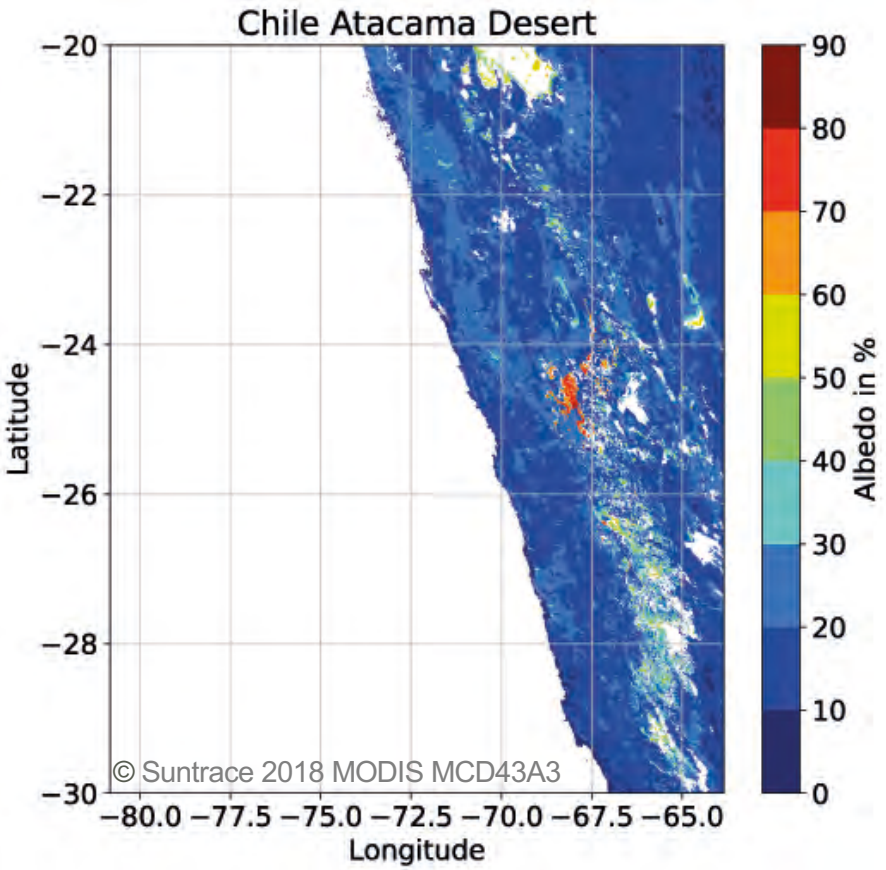
Practical issues of ground measured albedo

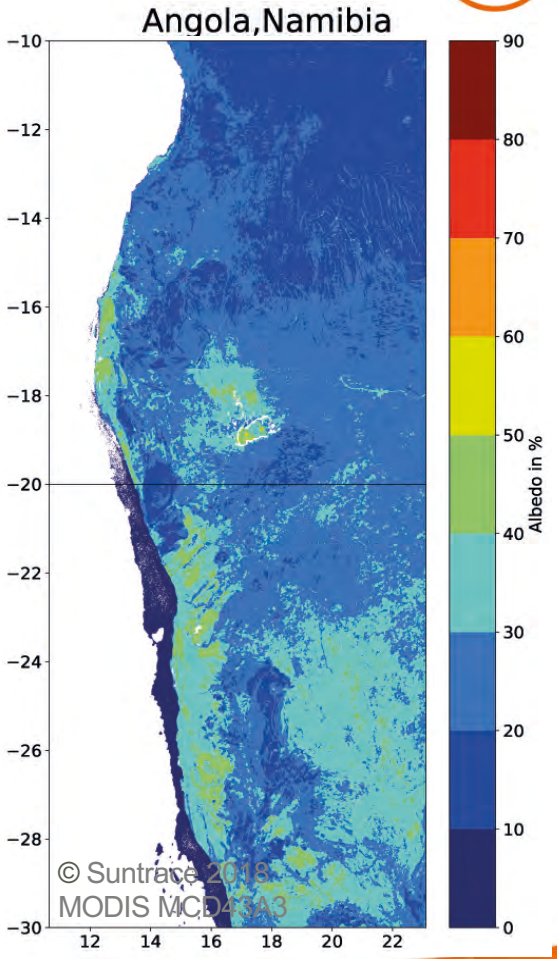
Practical issues of albedo ground measurements



- For representative measurements, installation heights of >> 10 meters recommended. But leads to difficulties with installation & regular cleaning!
- Surface can be quite heterogenous within one PV lot covering many km^2
- Disturbing objects can influence the measurement result
- You cannot measure back into time!

Satellite-derived albedo can build on long archives and covers all sites on Earth

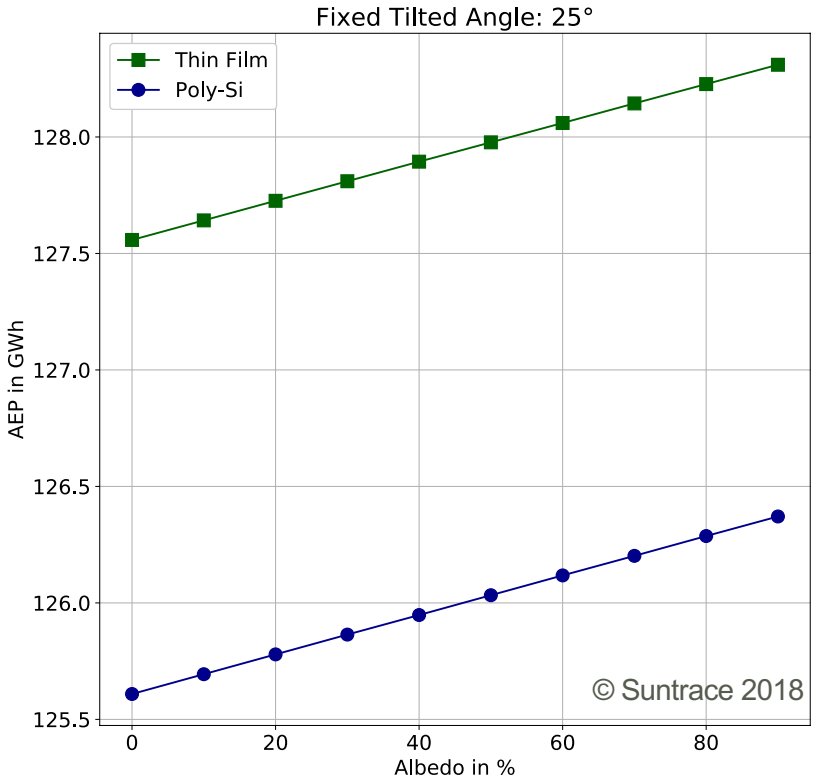




How does albedo affect PV yield?

GTI is enhanced by high ground albedo

⇒ higher yields also for conventional PV (without gains from backside)



Bifacial modules taking advantage of harvesting the also illuminated backside.

⇒ may lead to much stronger effects.

Which software tools calculate albedo effects?

Most PV performance simulation tools consider enhanced GTI through albedo since long

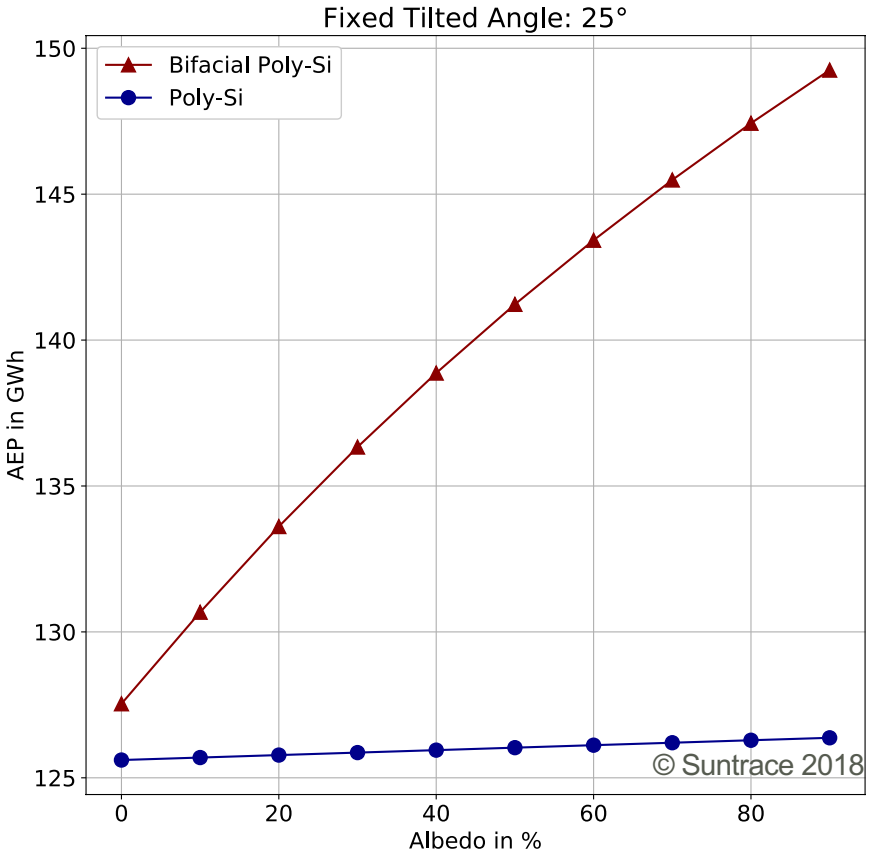
Effects on bifacial modules are new for many:

- *SAM* updated last week to consider also bifacial modules.
- *PVSOL* updated recently for bifacial modules.
- *pvlib* has a basic code, which is under improvement.
- *PVSyst* has been offering bifacial module services for quite some time now.

All these tools only consider isotropic albedo – none BDRF.
But this shortcoming is sufficient for most PV applications.

The following case studies are based on simulations using *PVSyst*.

Annual Energy Production (AEP) of various PV technologies signifcantly increases with higher albedo



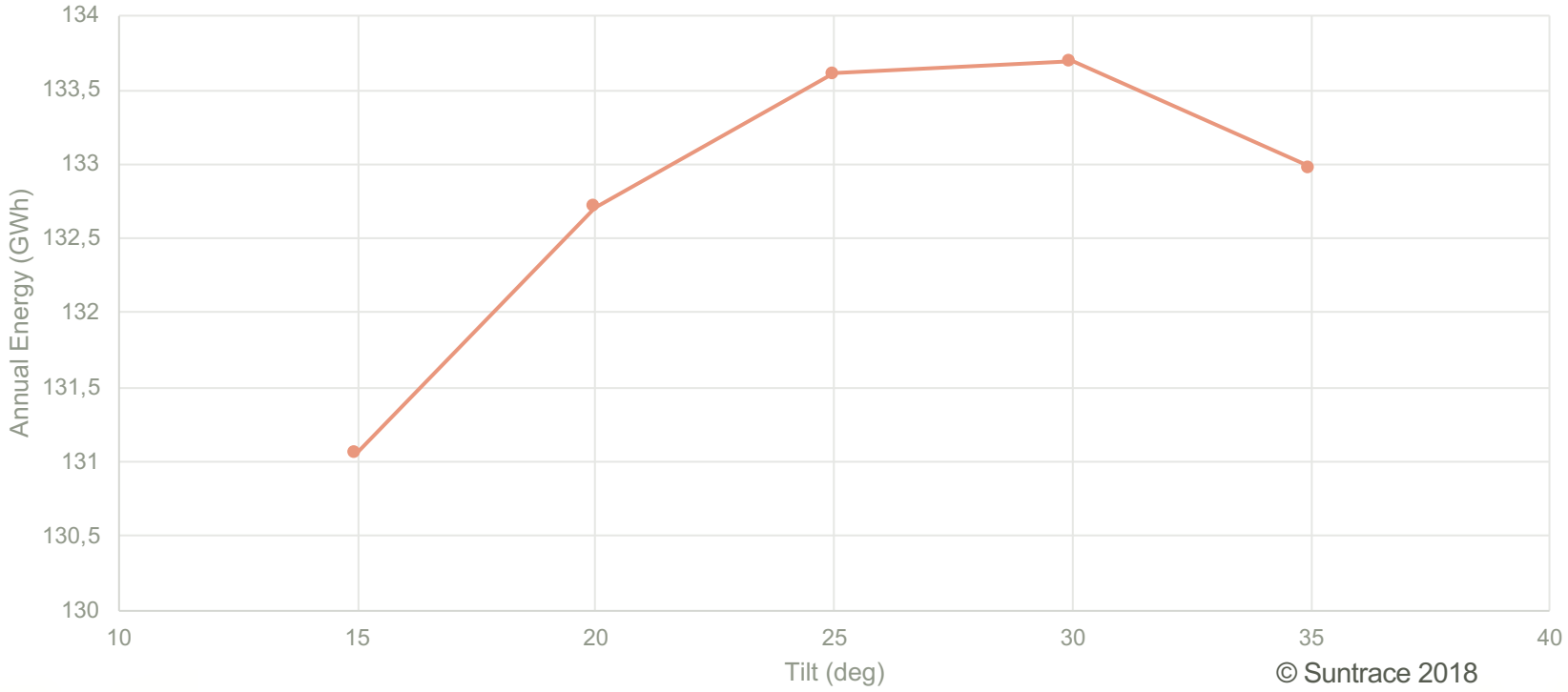
Example 50 MW AC plant in Tunesia

AC/DC = 1.3

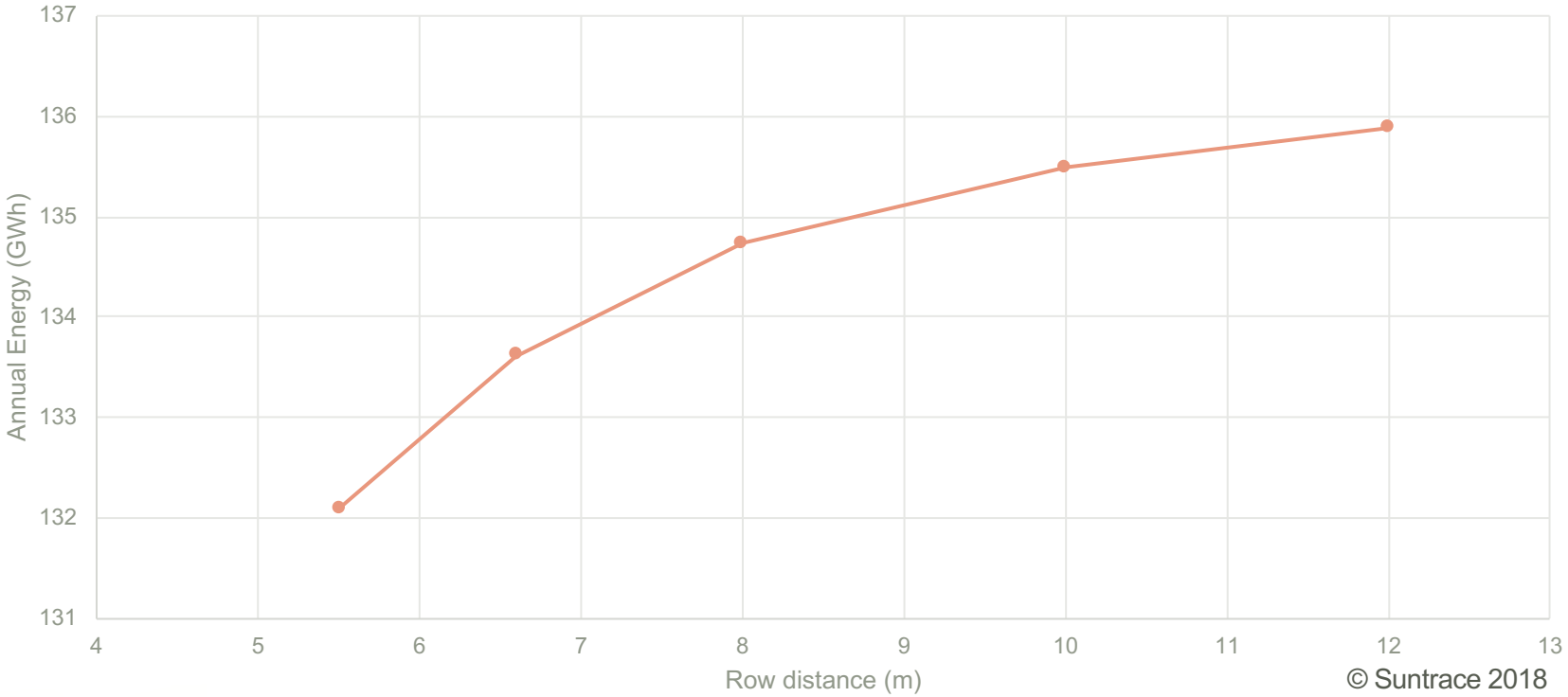
Gain of AEP per % albedo: ΔAEP/Δα

Albedo Range	Thin Film	Poly-SI	Bifacial Poly-SI
0-10%	8.4 MWh/%	8.5 MWh/%	314 MWh/%
10-20%	8.4 MWh/%	8.5 MWh/%	294 MWh/%
20-30%	8.4 MWh/%	8.5 MWh/%	272 MWh/%

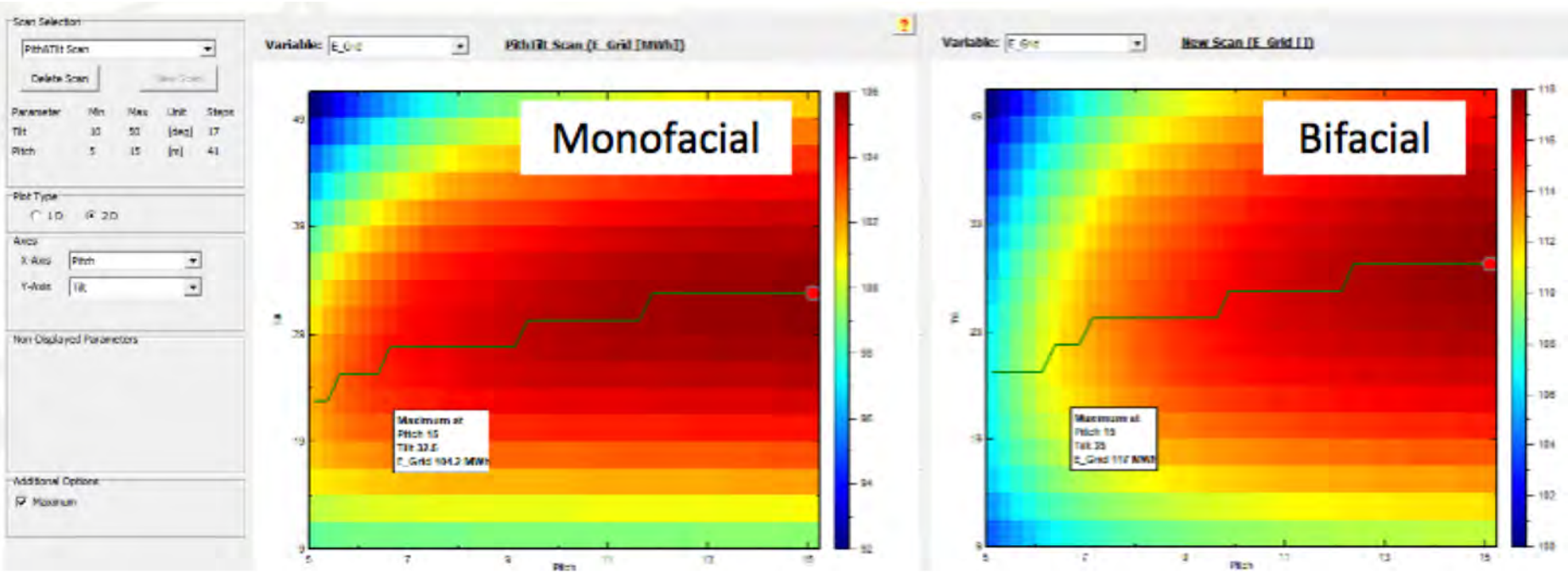
Bifacial modules quite sensitive on tilt angle



Bifacial takes good advantage of high pitch = large distance between rows



Optimization of PV layouts should consider tilt angles together with row distance!

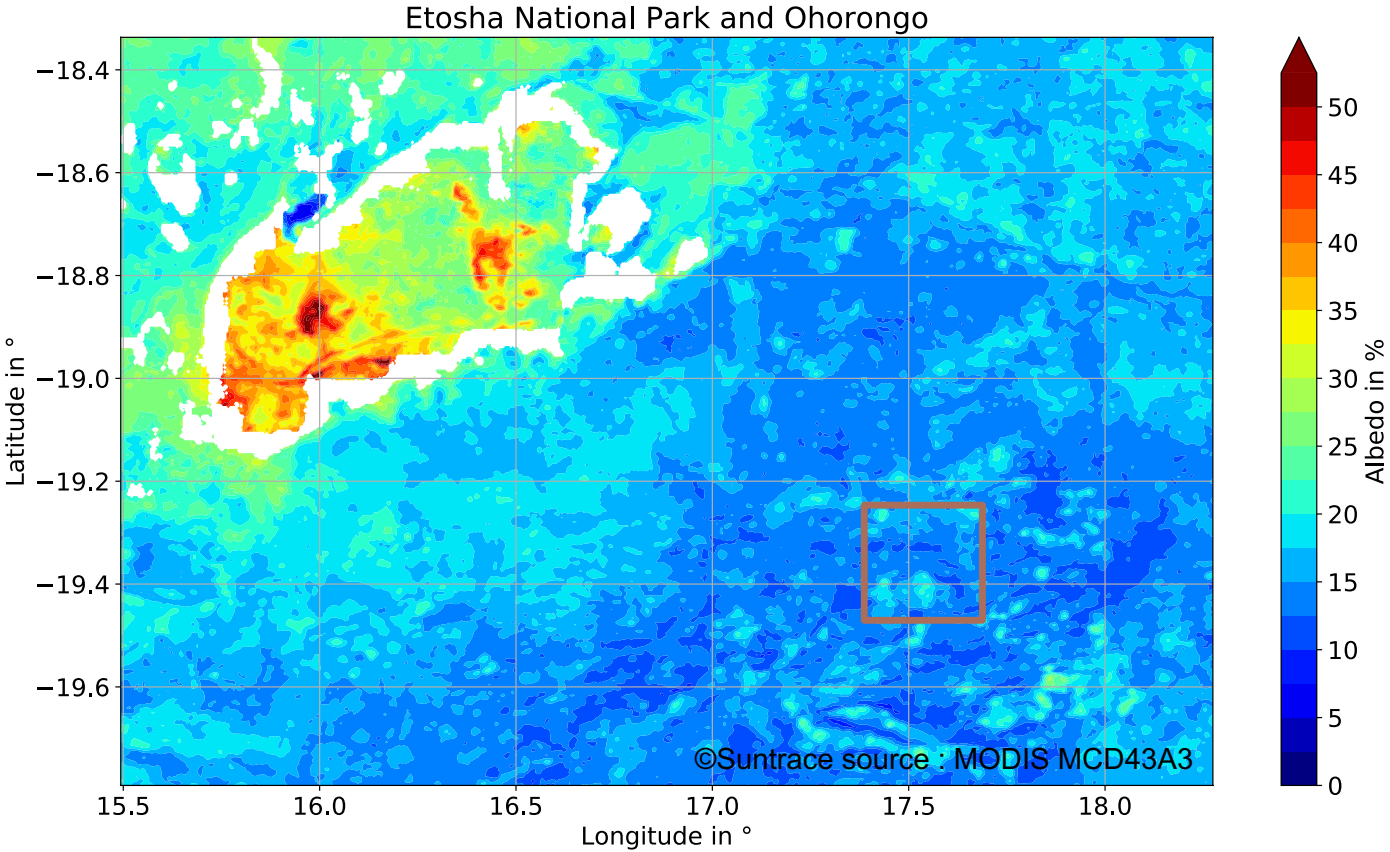


Bifacial layouts show optimum at slightly higher tilt than monofacial.

Example for strong albedo differences in Namibia

Source: Google Earth

Example for strong albedo differences in Namibia



Albedo at PV-site: 19.0%

Albedo differences within area of 25 km x 25 km around PV site:

- **Mean: 14.7%**
- Max: 22.4%
- Min: 10.7%

- **Spread: 11.7%**

Translated for the case in Tunisia & albedo increase of only 10%

Albedo increase of 10% for the 50 MW AC plant with bifacial poly-Si modules

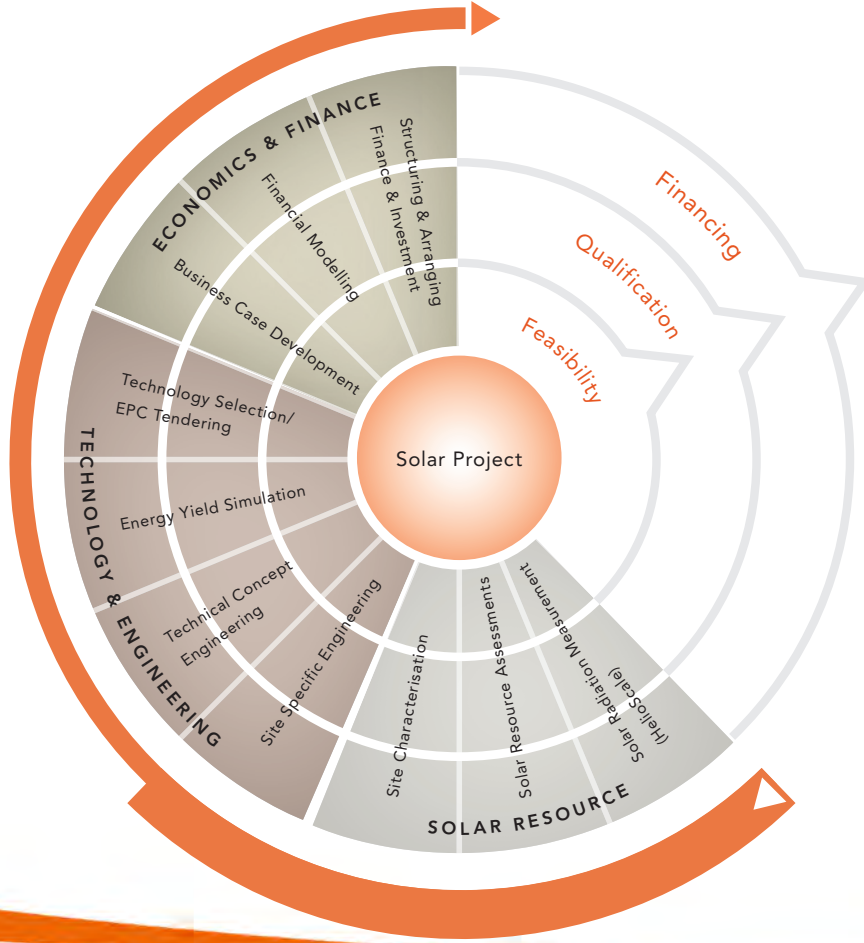
⇒ additional yield may reach almost +3%.

⇒ +161 kUSD additional yield each year assuming 55 USD/MWh!

Main apects to consider for albedo & PV

- Albedo of the ground depends strongly on soil type, and vegetation:
  - One site can be more favourable than the other, and
  - within one lot there might be substantially brighter and darker regions:
    might earn >100 kUSD per year for a 50 MW plant when placing bifacial in bright regions.
- Ground albedo at a site varies temporally:
  - changes with soil moisture – even more throughout the vegetation period.
  - can change strongly at a PV site due to land change with erecting the PV plant!
- Albedo tricky to measure on the ground, not easy also from satellite.
- Albedo generally increases the diffuse radiation component => favourable for PV
  - High albedo shows some positive effect on conventional PV modules.
  - Albedo increase has a strong gain for bifacial modules
- Suntrace measures albedo with HelioScale solar measurement stations,
  combines it with satellite-derived albedo in advanced solar resource assessments, and
  provides PV yield assessments & techno-economic optimization considering albedo.

Thanks for your attention & feel free to contact us



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Suntrace supports solar projects
from initial concept to full realization
with a holistic view through combining
meteorological | technical | financial
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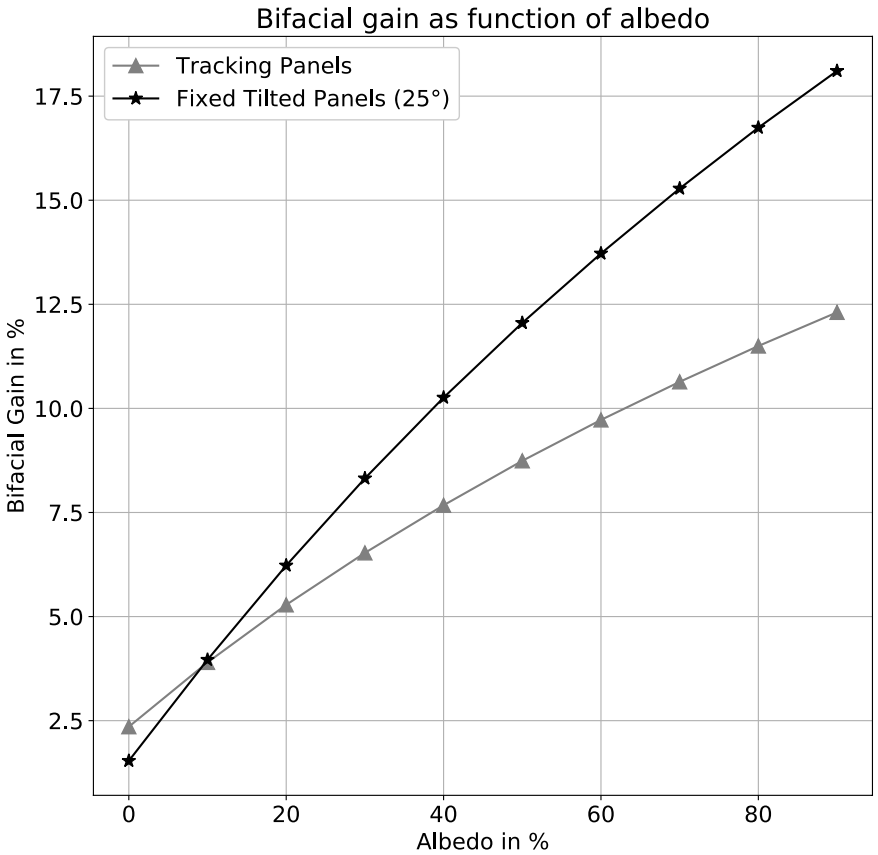
Instrument options offered with Suntrace HelioScale stations

Type	2 x Si-photodiodes	2 x moderate qual. thermopile	2 x high quality thermopile pyranometer
ISO 9060:1990		First Class	Secondary Standard
Uncertainty	5 %	3 %	1.5%
Broadband uncertainty	7%	4.2%	2.2%
Estimated PV-specific albedo uncertainty	4%	5 %	3 %

Fixed PV parks profit more by bifacial modules



Impact of height of PV panels on energy production