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Modelling of Single-axis tracking, applications to HET and IBC modules

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HERCULES Workshop – HZB - Berlin

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Outline

Introduction

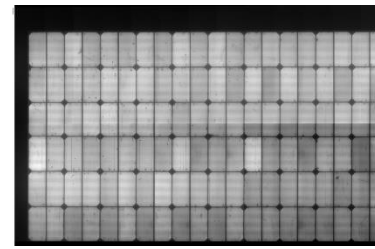
- High efficient modules
- Bifaciality
- Horizontal Single Axis Tracker (HSAT)

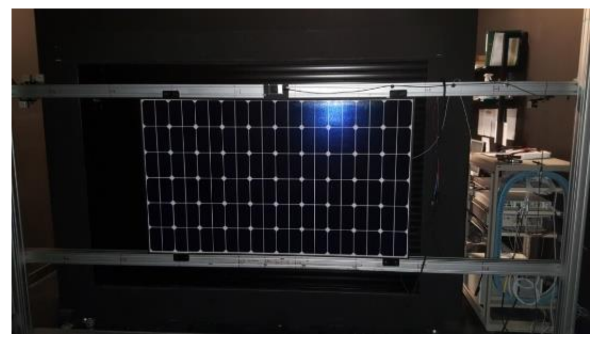
HSAT + Bifacial PV

- Interesting or not ?
- Modelling hypothesis
- Conclusions

HSAT + Bifacial PV + HET and IBC modules

- PV power plants hypothesis
- Modules data
- LCOE

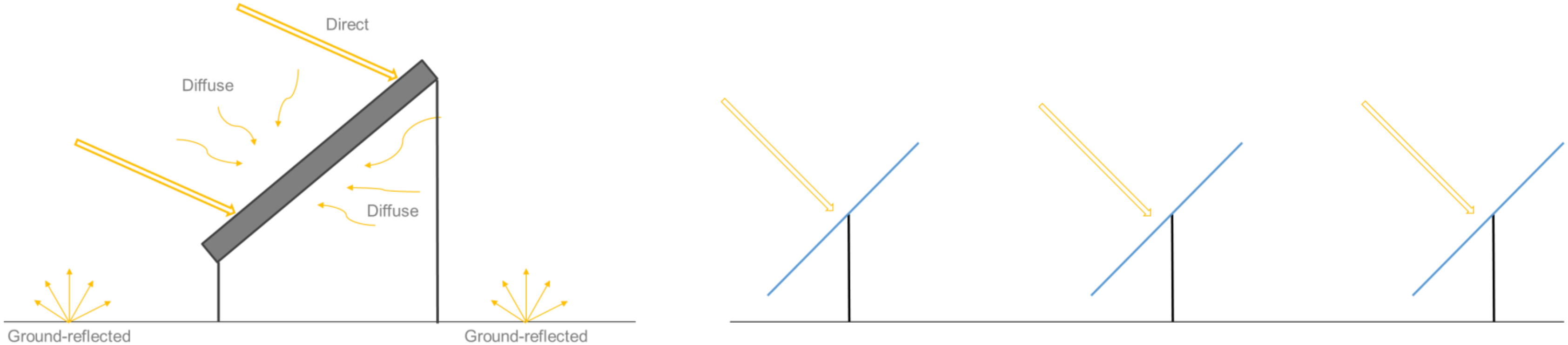




PV Lab @ EDF Lab Les Renardières

Three ways of increasing the output of a PV installation

- **High efficient modules** that convert more irradiance into electricity like HET or IBC technologies
- **Bifacial modules** that convert irradiance into electricity on both their front and rear sides*
- **Horizontal single-axis trackers** that unlock higher rates of PV production by following the position of the sun with a reasonable ground coverage ratio (compared to tilted-axis or dual-axis tracker)



* Bifacial gains between 5 and 15% for fixed-tilt PV installations and natural ground albedos (Key elements in the design of bifacial PV power plants, PV SEC 2015)

Modelling

HSAT + bifaciality

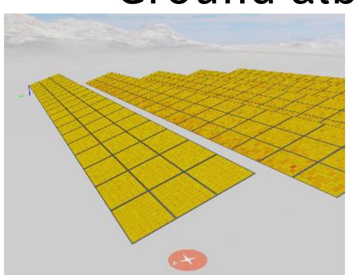
Combining bifacial PV and single axis tracking ?

Is it interesting to combine bifacial PV with horizontal single-axis trackers and under which conditions ?

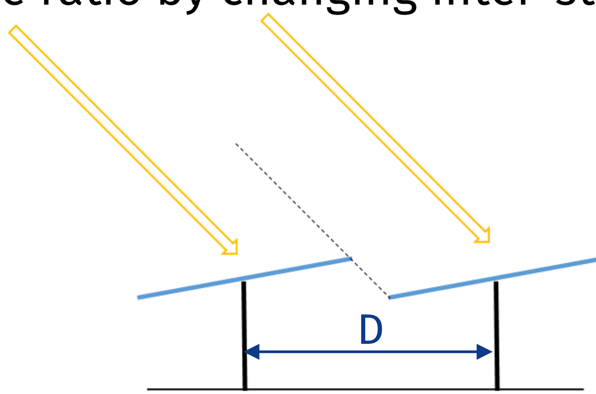
What bifacial gain can be achieved ?

→ Dymola Modelling + EDF R&D model library*

- Location : Cairo, DNI=1760 kWh/m²/year
- Variations on:
  - Ground coverage ratio by changing inter-stand distance
  - Ground albedo



Fixed tilt Incident Solar Irradiance

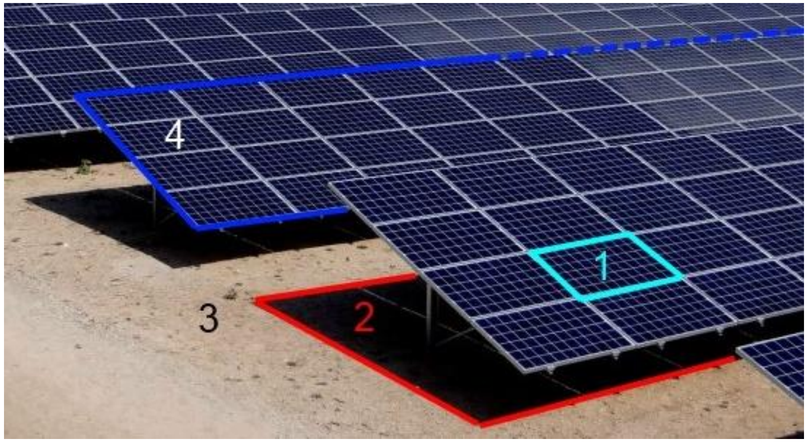


HSAT (http://article.sciencepublishinggroup.com)

**A. Lindsay et al. 32nd EUPVSEC*

Irradiance model
Rear irradiance

- **Calculates the rear irradiances based upon:**
  - 1) the position of the module within the stand
  - 2) the shadow cast on the ground
  - 3) the ground albedo
  - 4) the stand behind



$$I_{ground-reflected} = \alpha * GHI * VF_{module \rightarrow non-shadowed\ ground} + \alpha * DHI * VF_{module \rightarrow shadowed\ ground}$$

$$I_{diffuse} = DHI * VF_{module \rightarrow sky}$$

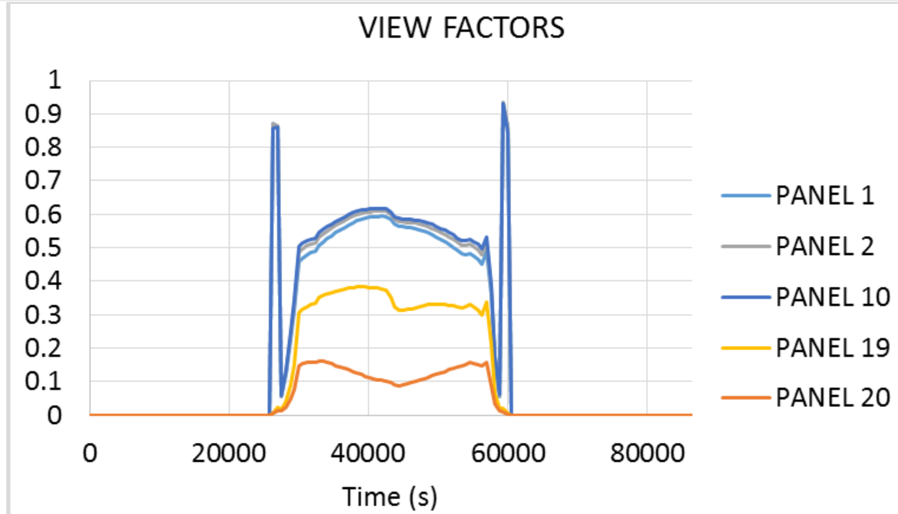
$$I_{direct} = \max(BNI * \cos(i), 0)$$

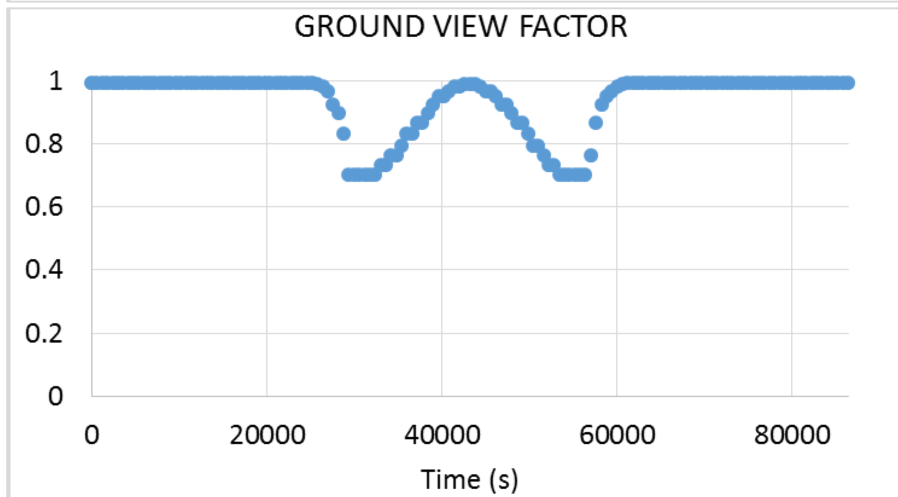
α: ground albedo ; VF: view factor ; GHI, DHI, BNI: Global Horizontal, Diffuse Horizontal and Beam Normal Irradiances ; i: incidence angle of beam

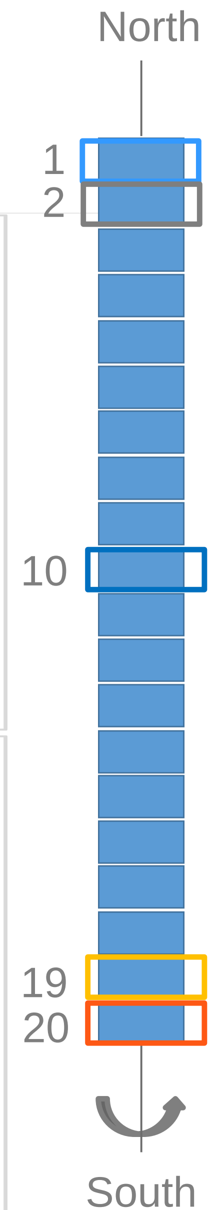
Irradiance model

View factors

- Illustrations for Cairo (DNI=1760 kWh/m²), albedo =0.2, D=6.5m (GCR=29%)
- Shadows view factors
- Other view factors depending on tilt angle for panel n° 10 :
  - ground view factor
  - inter-stand view factor
  - sky view factor

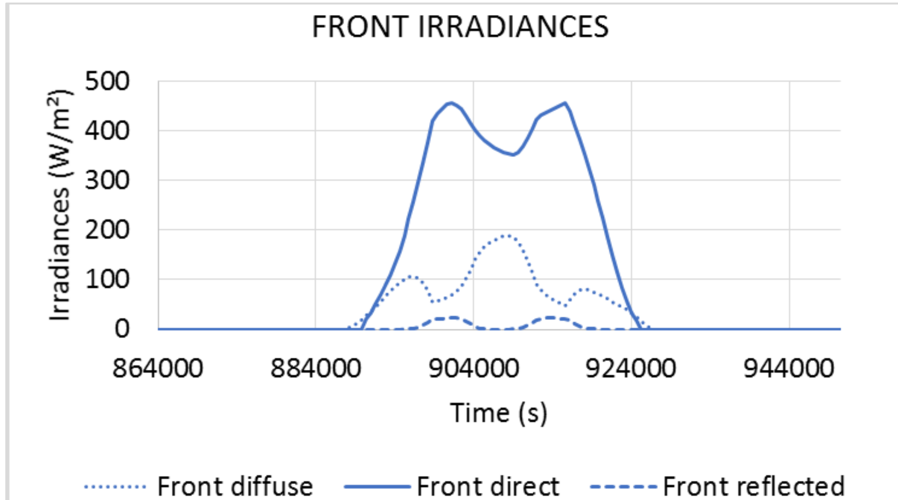


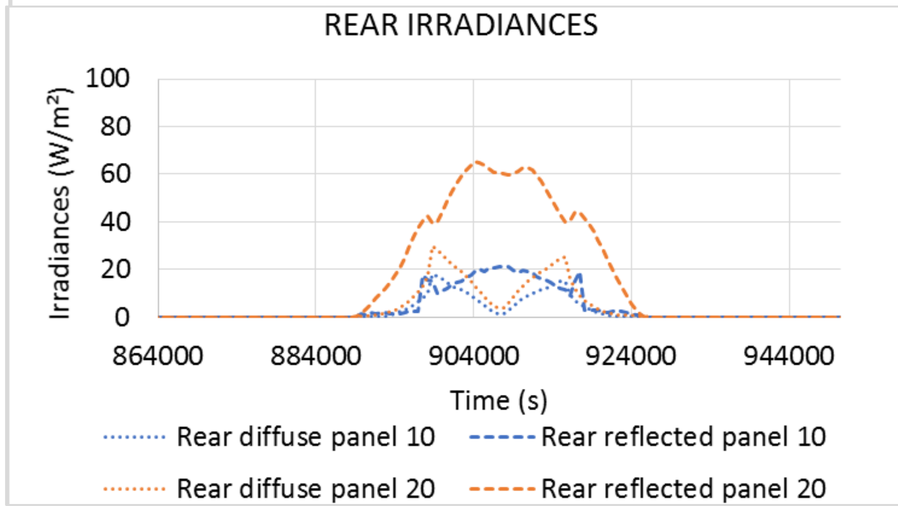


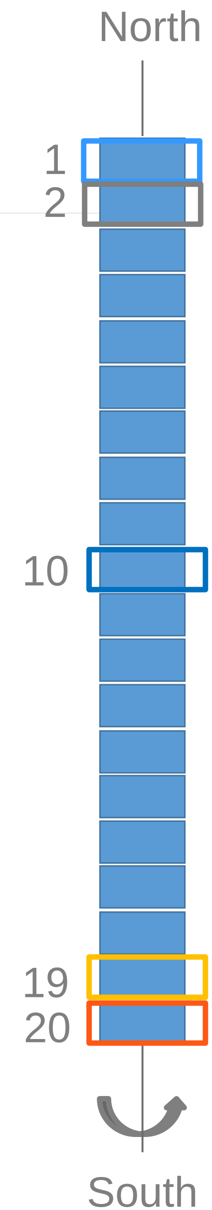


Irradiance model
Daily variation

- Illustrations for Cairo (DNI=1760 kWh/m²), albedo =0.2, D=6.5m (GCR=63%)
- Front irradiances
- Rear irradiances







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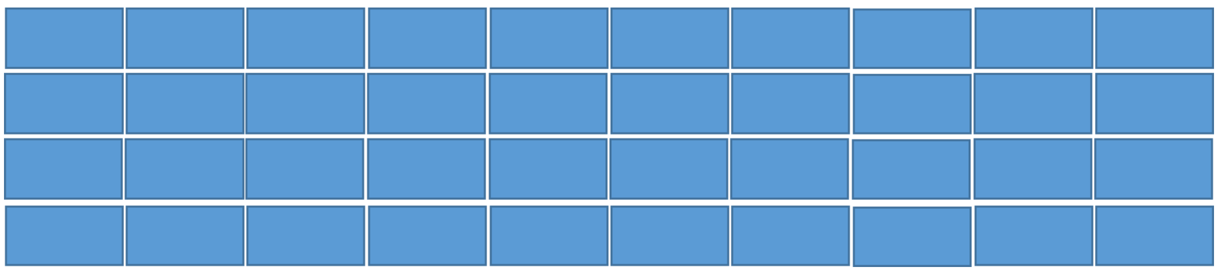
Irradiance model
Rear irradiance heterogeneity

- Rear side irradiance heterogeneity for HSAT or fixed-tilt (kWh/m²/year)



239	165	131	120	116	116	120	131	165	239
214	138	109	101	98	98	101	109	138	213
188	111	90	84	82	82	84	90	111	187
185	116	106	103	101	101	103	106	116	184

176
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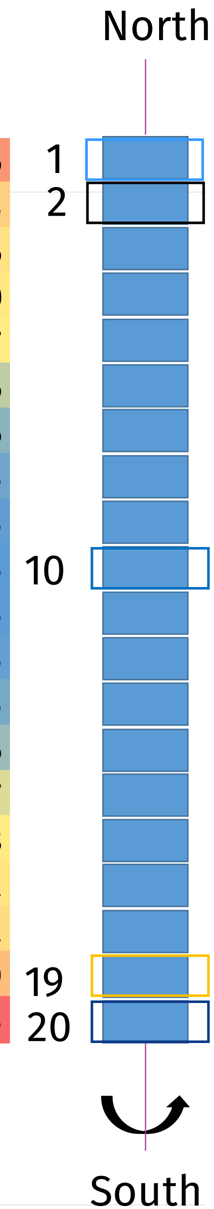
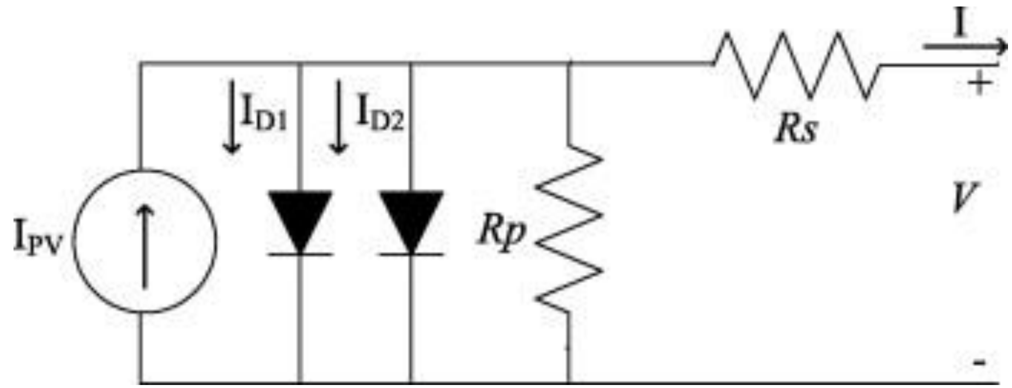


- Illustrations for Cairo (DNI=1760 kWh/m²), albedo=0.2, equivalent GCR=63%, fixed-tilt=30° , elevation=60cm

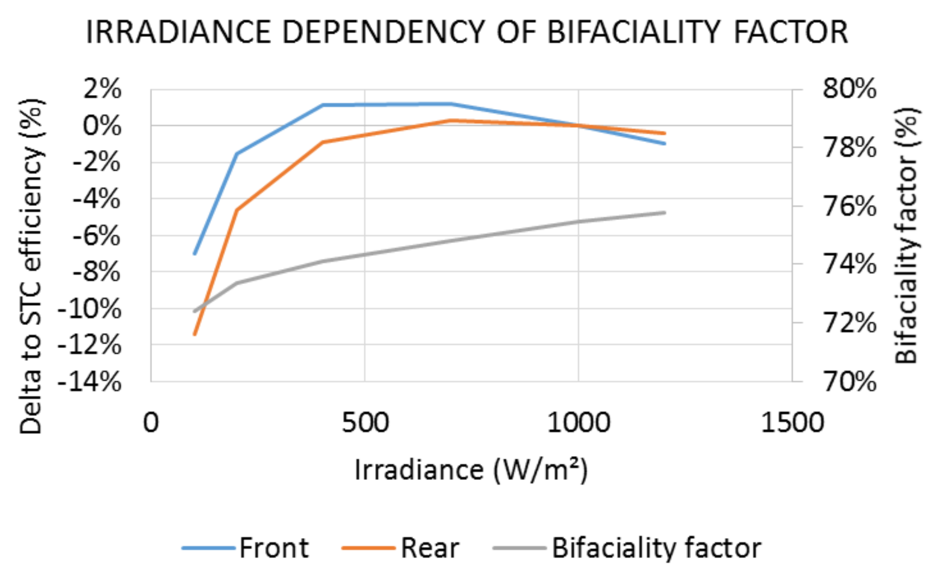
Electrical model

- 2 diodes model



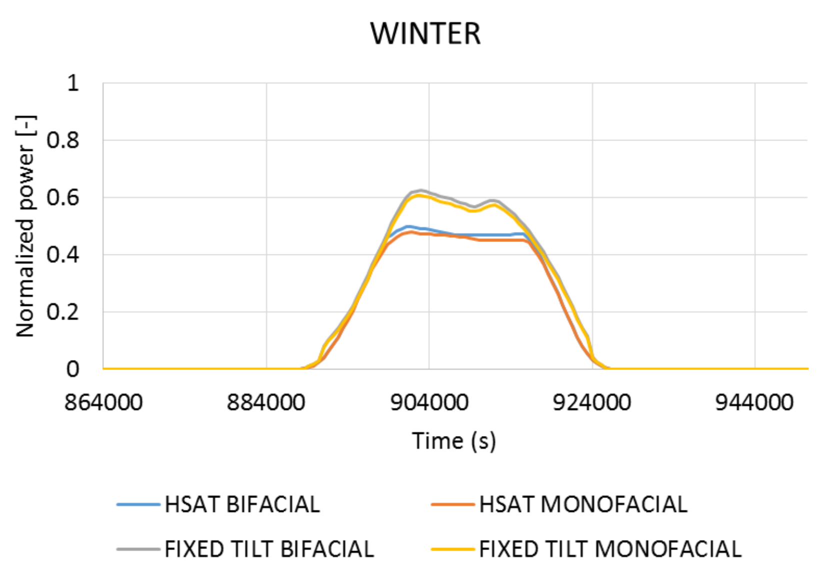
- Bifaciality factor

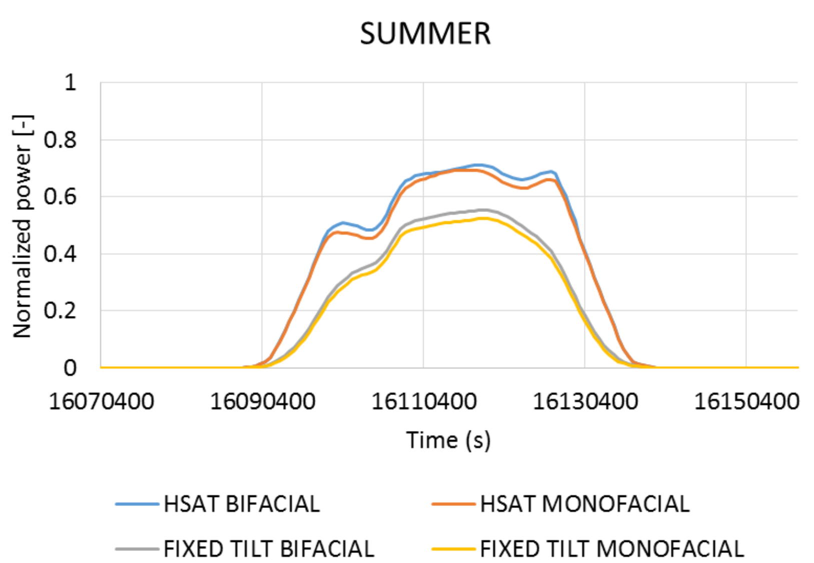
$$BFF(G) = \frac{\eta_{front,25°C,AM1.5}(G)}{\eta_{rear,25°C,AM1.5}(G)}$$



Results
Seasonality impact

- **Power comparison**
  - Horizontal single axis tracker vs. fixed-tilt 30° South
  - Bifacial vs. monofacial

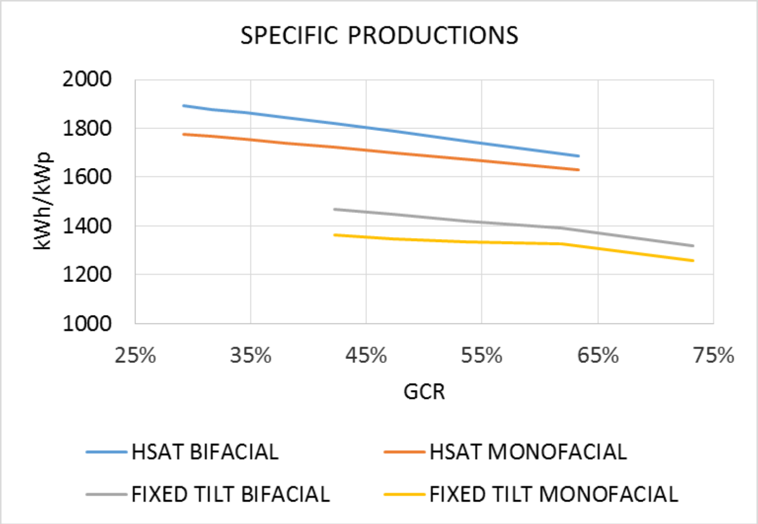


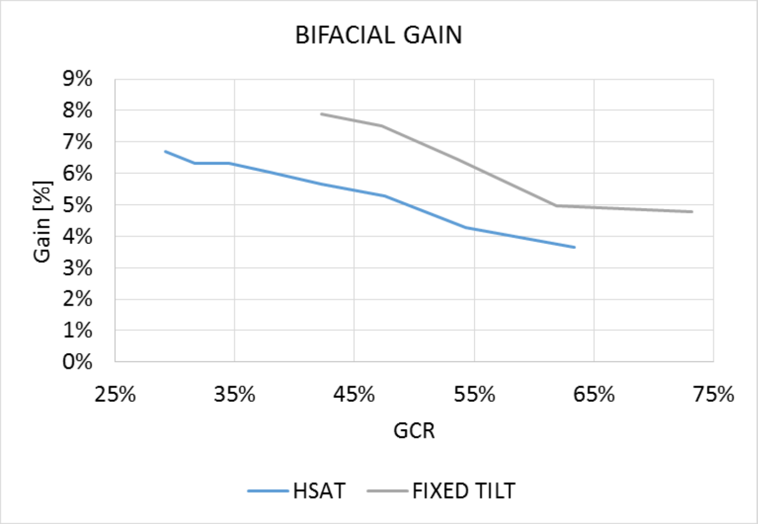


- **Seasonality of tracking gain** (or loss) **and of bifacial gain**

Results
Tracking gain

- Location : Cairo, DNI=1760 kWh/m²/year
- Variations on ground coverage ratio by changing inter-stand distance and ground albedo





- **Tracking gain higher for monofacial (23-27%) than for bifacial (21-24%)**
- **For equivalent ground coverage ratios, the bifacial gain is higher for fixed tilt** than for horizontal single axis tracking

Modelling

HSAT + bifaciality + high efficient modules

High efficient modules VS single axis tracking VS bifaciality
Hypothesis

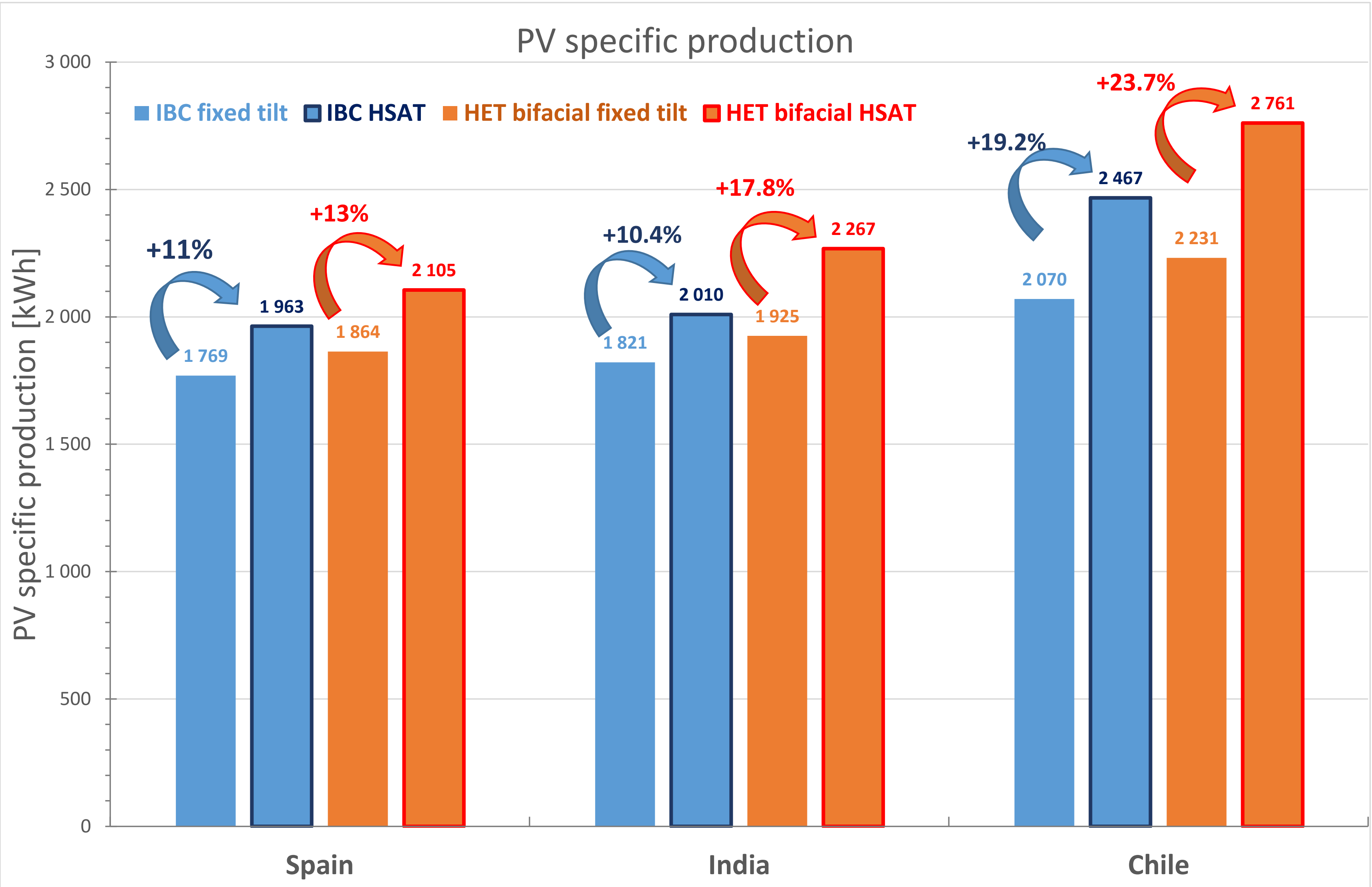
- **High efficient 60 cells modules with 300 Wp efficiency**
  - Bifacial Heterojunction solar cell based modules
  - Monofacial Interdigited back contact cells based modules
- **50 MWp ground mount PV system**
  - Fixed tilt installation : GCR = 67%
  - Horizontal Single Axis Tracking : GCR = 42%
- **Three Localization**
  - Spain (Malaga)
    - DNI = 1952 kWh/m²/year & Albedo = 0.25 (dry light soil)
  - India (Jodhpur)
    - DNI = 1929 kWh/m²/year & Albedo = 0.35 (sandy desert)
  - Chile (Calama el loa)
    - DNI = 2887 kWh/m²/year & Albedo = 0.30 (stony desert)

High efficient modules VS single axis tracking VS bifaciality
Modules parameters

Technology		HET	IBC
Mechanical & electrical features			
Module area	[m²]	1,65	1,62
Cell To Module Ratio	[%]	95%	98%
Cell number per module		60	120 (half cells)
Power per module	[Wp]	300 / 275	305
Bifacialité factor		0,92	-
Temperature coefficients			
a or TK(Isc)	[%/K]	0,039	0,039
b or TK(Voc)	[%/K]	-0,24	-0,29
d or TK(Pmpp)	[%/K]	-0,260	-0,385
Lifetime & degradation			
Module Lifetime	[y]	25 - 30	25-30
PID+LID 1st year	[%]	0,0%	0,0%
Long-Term degradation	[%/y]	0,35%	0,35%

High efficient modules VS single axis tracking VS bifaciality

Yield results



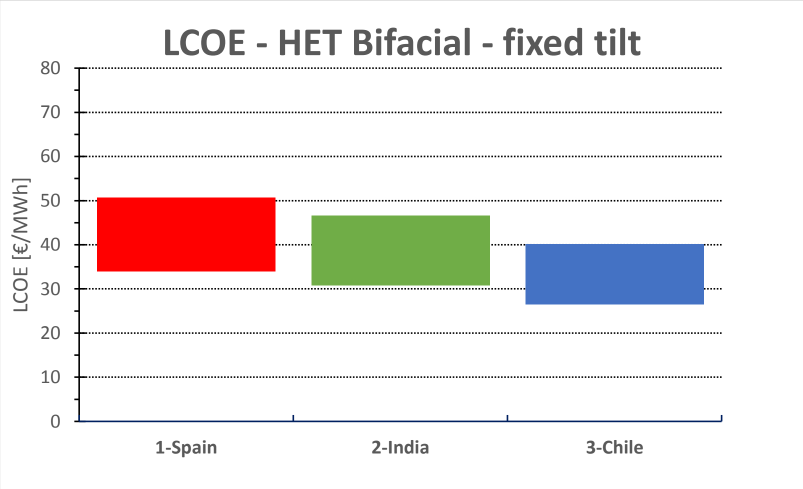
High efficient modules VS single axis tracking VS bifaciality
Yield conclusion

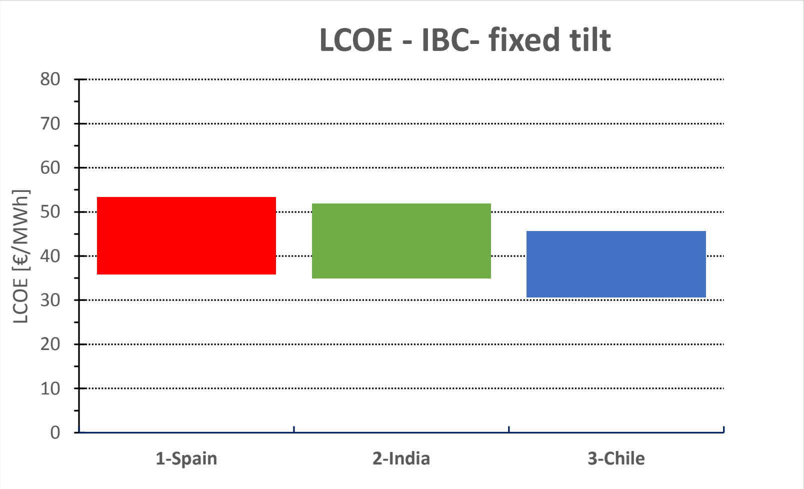
- **Going for HSAT for high efficient modules is beneficial**
  - Gain of 10-19% for IBC
  - Gain of 13-24% for HET
- **Higher gain for HET bifacial modules compared to IBC monofacial**
  - High albedo region (0.25-0.35)
  - Low thermal coefficient
  - Good bifaciality coefficient
- **Slightly higher bifacial gain for bifacial HET than in Cairo modelling due to higher albedo**
  - 5-8% for fixed tilt HET
  - 7-12% for HSAT HET

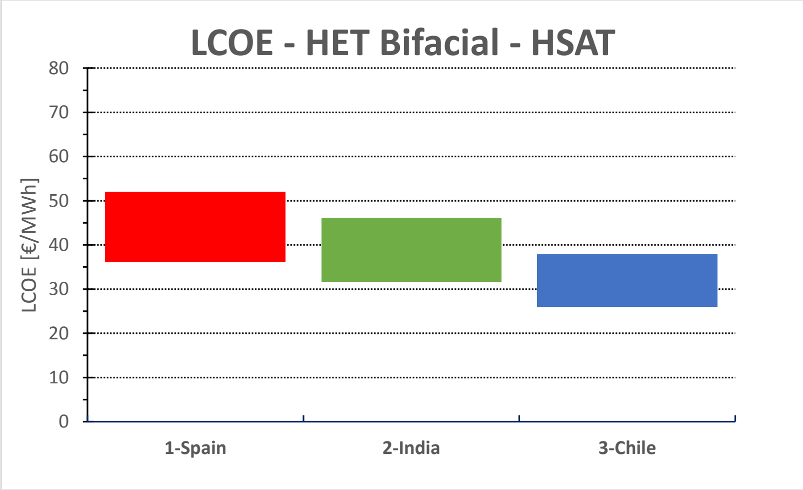
Economic Assessment
LCOE hypothesis

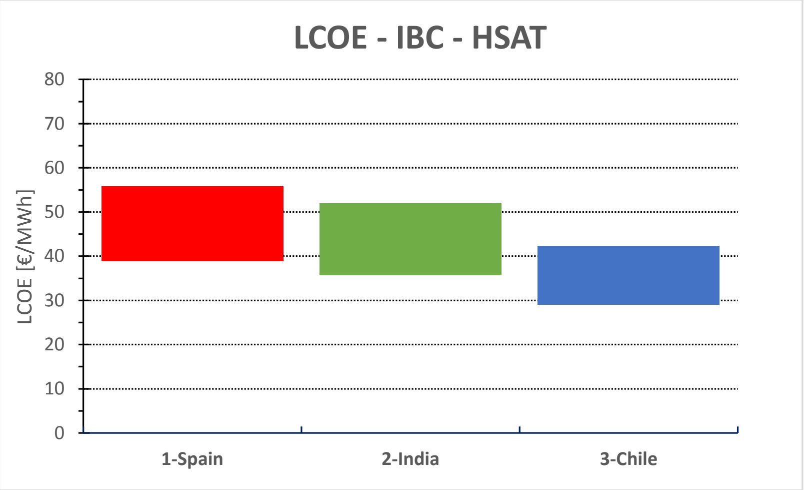
- **Modules prices**
  - Project HERCULES cost objective at 0.4€/Wp
  - 25% margin taken : 0.5€/Wp for both technology
- **HSAT versus fixed tilt BoS cost**
  - References : AGORA, ADEME, IHS, GTM, Bloomberg
  - Fixed tilt : 0.36 €/Wp ; HSAT : 0.41 €/Wp
    - Higher Structural BoS cost for HSAT
- **Others**
  - WACC= 4 to 6%
  - Inflation = 1.3%
  - PV installation Lifetime = 25 to 30 years
  - Discount factor = 4.9 to 6.8%
  - OPEX (Operation & Maintenance)
    - 2.0 to 2.5 % of the CAPEX for fixed tilt (+0.5% for Spain)
    - 3.0 to 3.5 % of the CAPEX for HSAT (+0.5% for Spain)

Economic Assessment
LCOE results









Economic Assessment
LCOE results

- **LCOE between 26 and 36€/MWp achievable**
  - In the range of state of the art LCOE
- **HSAT may only be an interesting option in Chile**
  - Low module cost entails higher relative difference in LCOE due to BoS
  - Production gain is absorbed by BoS cost

LCOE [€/MWp] HET bifacial				LCOE [€/MWp] IBC monofacial			
Fixed tilt	**1-Spain**	**2-India**	**3-Chile**	**Fixed tilt**	**1-Spain**	**2-India**	**3-Chile**
min	34,1	30,7	26,5	min	35,9	34,9	30,7
max	50,7	46,6	40,2	max	53,4	51,9	45,6
HSAT	**1-Spain**	**2-India**	**3-Chile**	**HSAT**	**1-Spain**	**2-India**	**3-Chile**
min	36,2	31,6	26,0	min	38,9	35,7	29,1
max	52,0	46,1	37,8	max	55,8	52,0	42,3

- **Some case studies show nearly identical results**
  - More precise parameters are required to confirm HSAT interest
  - HSAT show continuous price decrease making it more and more appealing

Conclusion

- **We have developed a simulation tool for precise estimation of large-scale bifacial PV installation yield**
  - Fixed-tilt or horizontal single axis trackers (HSAT)
  - Precise modelling of rear irradiances
  - Irradiance dependency of bifaciality factor
- **Modelling shows that HSAT clearly increases the producible…**
  - 10% to 24% increase
  - Higher gain for bifacial modules due to high albedo and good temperature coefficients
- **… but not always enough regarding LCOE in our studied cases**
  - LCOE between 29 and 39c€/Wp achievable
  - But producible gain remain too low to justify HSAT except in Chile

Acknowledgements

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Thank you ! Any questions?