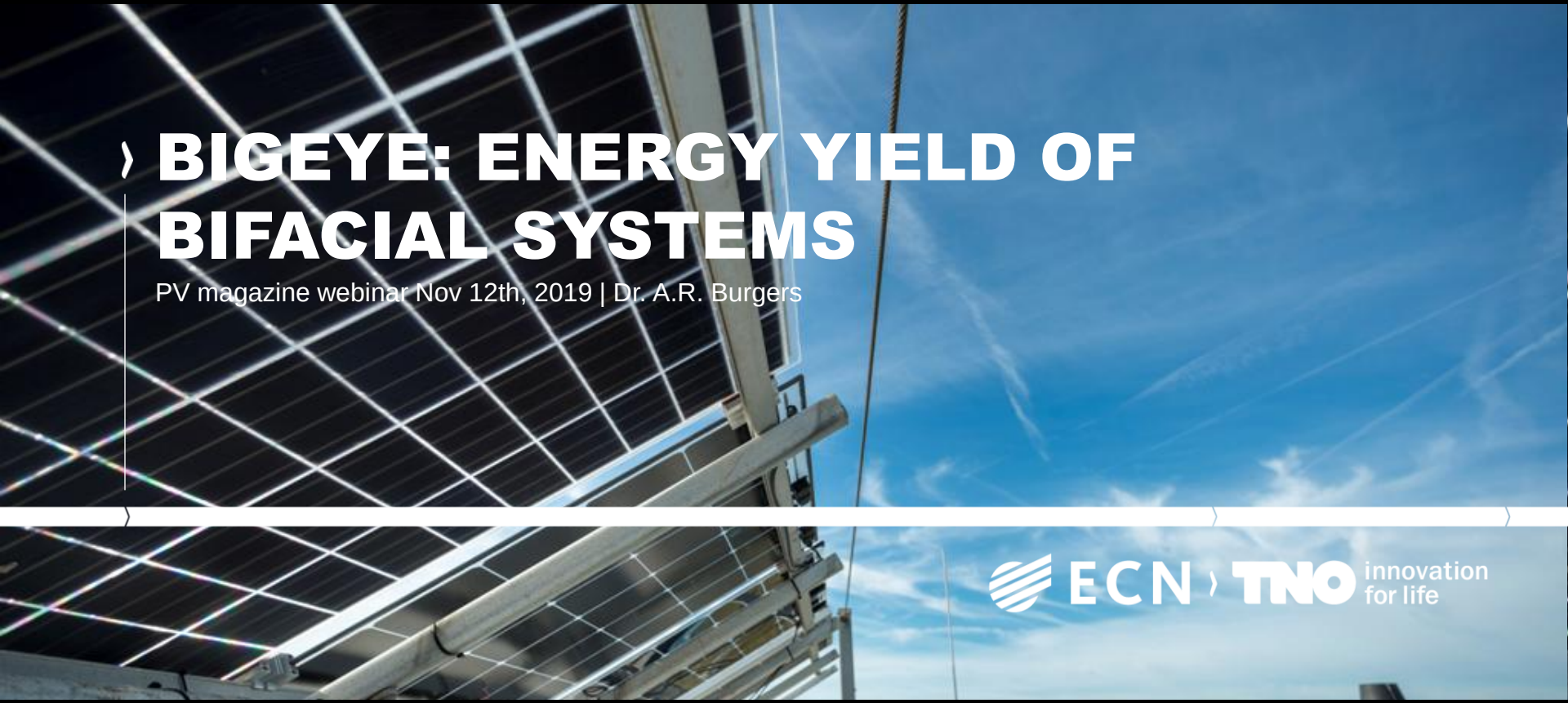


BIGEYE: ENERGY YIELD OF BIFACIAL SYSTEMS

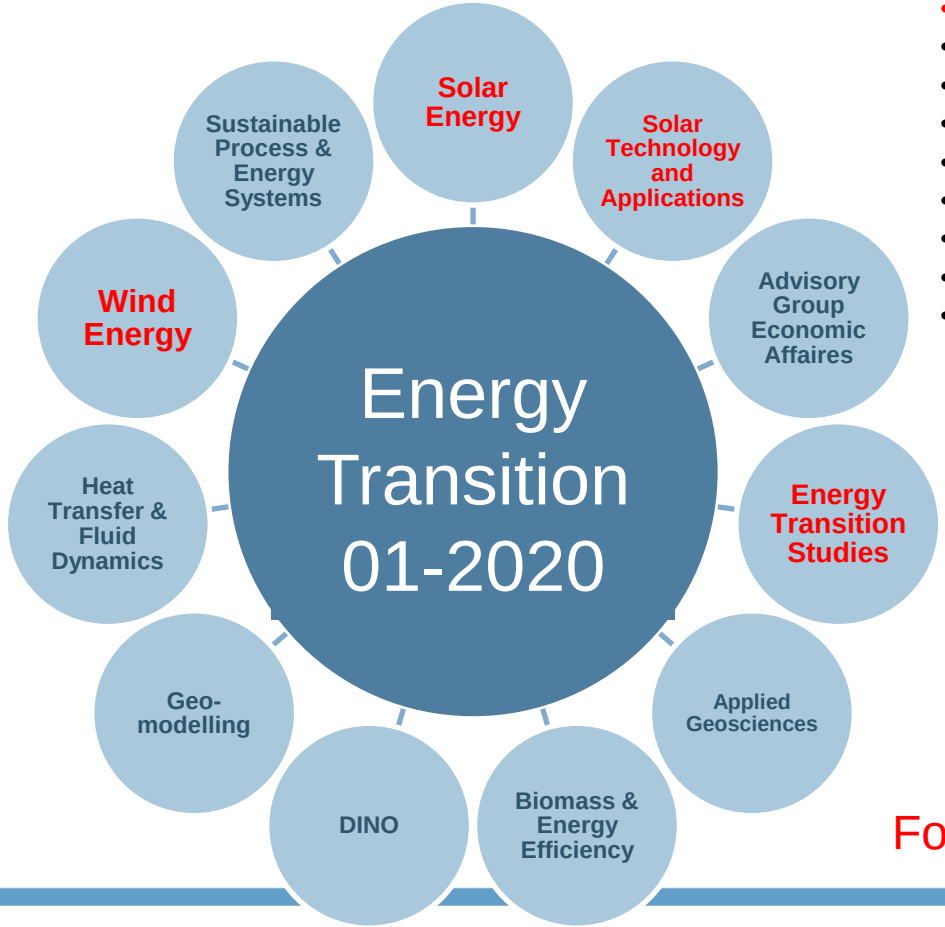
PV magazine webinar Nov 12th, 2019 | Dr. A.R. Burgers

ECN | TNO innovation for life

CONTENTS

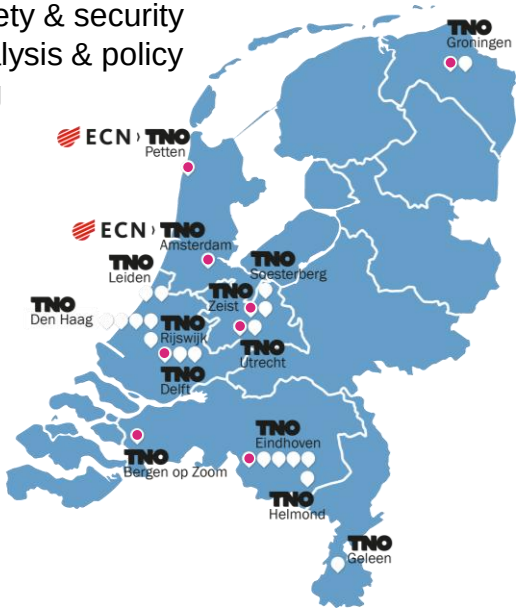
- About TNO energy transition
- Recent material
- Yield calculation for bifacial systems
  - Issues & design options
  - Approaches
- ECN.TNO's BIGEYE:
  - description
  - validation
  - Bifacial energy gain in different configurations

EXPERTISE GROUPS



TNO units (~3000 p)

- **Energy transition (~700 p)**
- Buildings, infrastructure and maritime
- Information & communication technology
- Circular economy & environment
- Traffic & transport
- Industry
- Defence, safety & security
- Strategic analysis & policy
- Healthy living

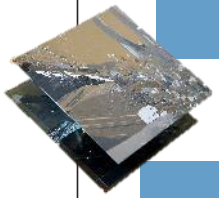


Former ECN

TNO innovation for life

INNOVATION THROUGHOUT THE PV VALUE CHAIN

Materials | Module design & production x-Si and thin film based | System design & production | Integration & application



Cell design&manuf.

Outdoor testing

Module design &manuf.

Field testing

Cell and module characterisation

Module reliability testing and diagnostics

Power electronics testing and diagnostics

Yield modelling and simulation

RECENT MATERIAL

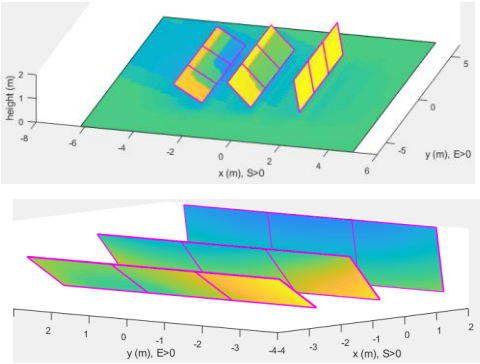
- Bifacial workshop 2019:
  - http://bifipv-workshop.com/index.php?id=amsterdam-2019-program

  - History of bifacial PV
  - Bifacial (silicon crystalline) PV technologies
  - Impact of the system design on the achievable yield
  - Yield prediction software

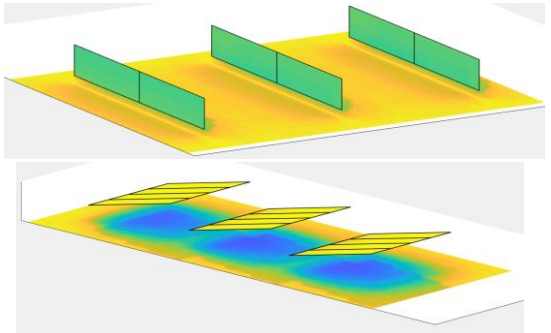
ISSUES IN BIFACIAL SIMULATION

- Technical issues:
  - Inhomogeneous irradiance on rear side
  - Edge effects
  - Support structures: shading and scattering
  - Obtain ground irradiance

- Design options
  - Dual ground use
  - DC/AC ratio
  - Single axis tracking

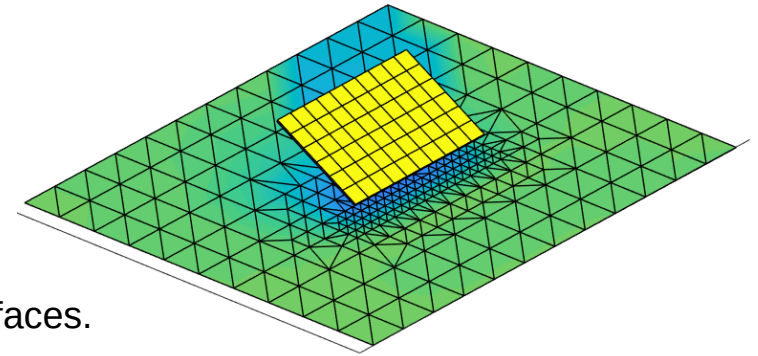


BIGEYE simulation



MODELLING APPROACHES

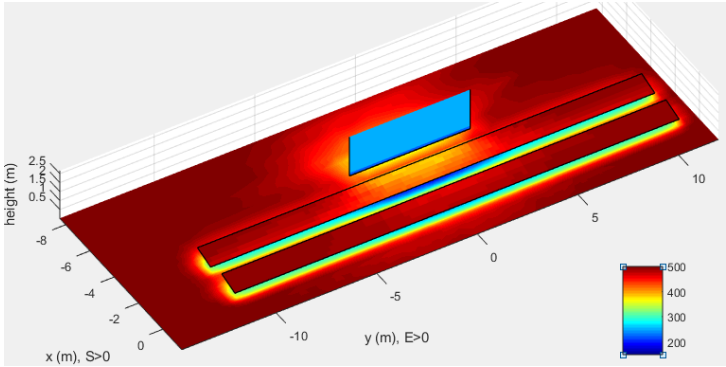
- Ray-tracing
  - Statistical method
    - Track (many) rays through system until error is below certain threshold
    - Contingent on parallel processing
  - bifacial_radiance (NREL)



- View factors
  - Linear algebra based:
    - meshing (adaptive) of surfaces
    - matrices represent radiative exchange between surfaces.
  - MoBiDIG (ISC Konstanz) quasi-3D view factors
  - PVsyst
    - assumes infinitely long sheds or SAT trackers, at same pitch
    - inhomogeneous illumination effects to be captured by user in “mismatch loss factor”

ECN.TNO BIGEYE FEATURES

- Designed from onset with bifacial systems in mind
  - 3D irradiance model
    - View factor based
    - Used for both front- and rear side, no approximations for rear side
    - Sub-cell spatial resolution (beam shade)
  - Flexible in geometry, provides SAT
  - optical and thermal models adapted for bifacial.
  - Development hand-in-hand with applications → validation
- From inhomogeneous irradiance to IV of string of modules
  - Series connection
    - Cell IV curves (accounting for shading)
    - Module IV (bypass diodes) → string of modules
    - Mismatch accounted for implicitly
- Design-of-Experiments
  - scan multiple configurations, parameter ranges

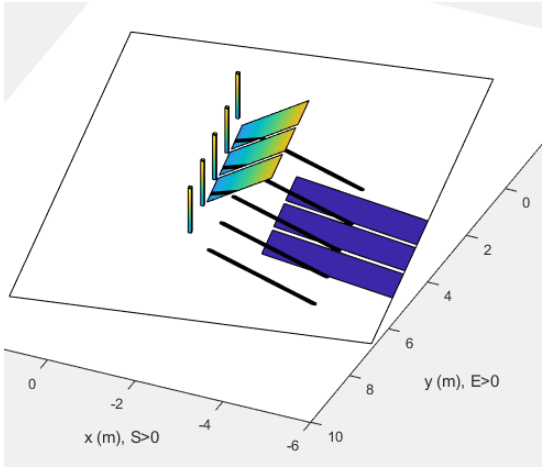


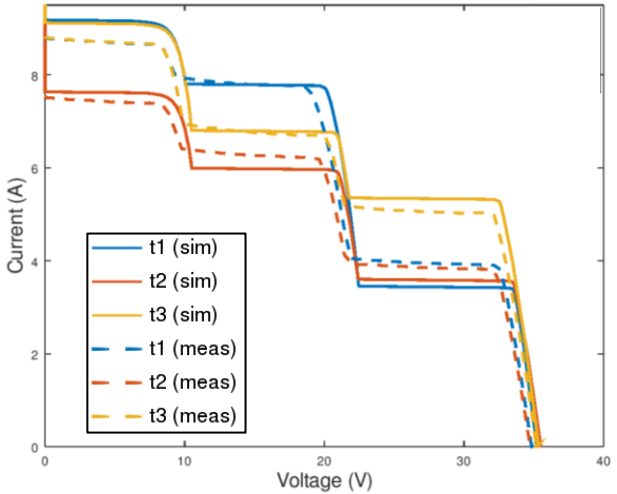
Two sheds before a diffusely reflecting wall

VALIDATION: USING FULL IV CURVES

- Test rig at ECN.TNO
  - Intentional shading
  - measure full IV curves

- Allows to validate BIGEYE IV curve modelling.

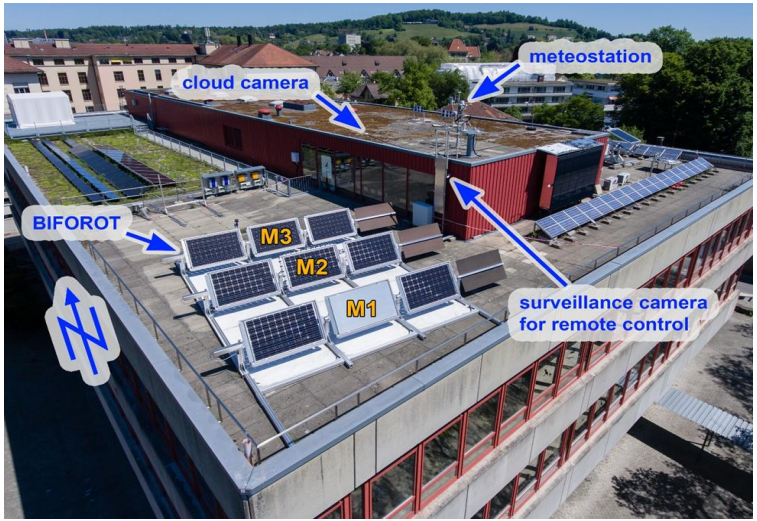


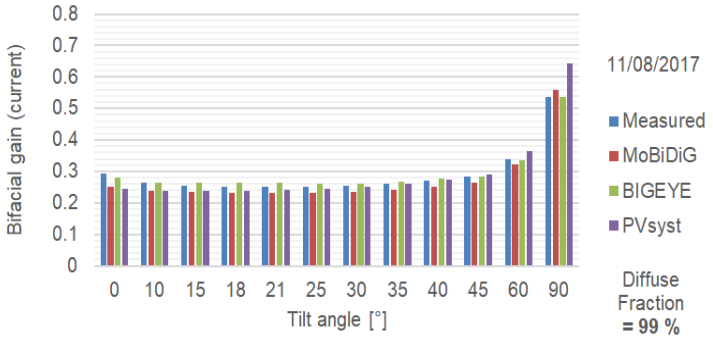


VALIDATION: BIFOROT

- Set-up at Zurich University of Applied Science
- Simulation programs
  - Pvsyst, MoBiDig (ISC), BIGEYE

- Conclusions from the comparison [1]
  - The three simulation tools
    - give similar results
    - are in agreement with the experiment
  - bifacial yield modeling is reaching a stage of maturity.





[1] Accuracy of Simulated Data for Bifacial Systems with Varying Tilt Angles and Share of Diffuse Radiation, Hartmut Nussbaumer et al, submitted to Solar Energy

BIGEYE VALIDATION: HOPEWELL (NC)

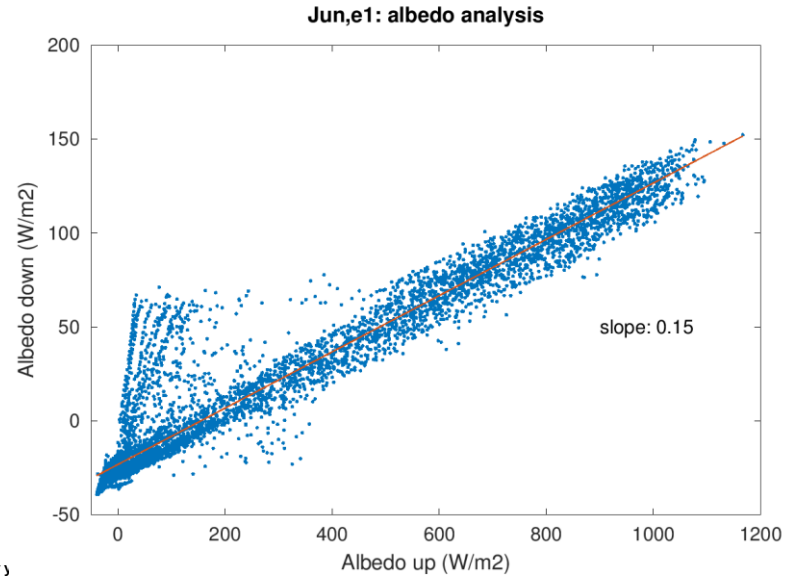
- 1 MW commercial bifacial SAT site
  - More details talk Jenya Meydbray, bifacial workshop 2019 (available for download)
  - Realized by Cypress Creek Renewables (CCRE) for Randolph Electric Membership Corporation
  - US DoE grant: additional instrumentation for validation
    - GHI, T_{module}, albedo, $G_{POA,fr}$, $G_{POA,re}$
    - 5 minute time resolution
    - PV Evolution Labs, CCRE

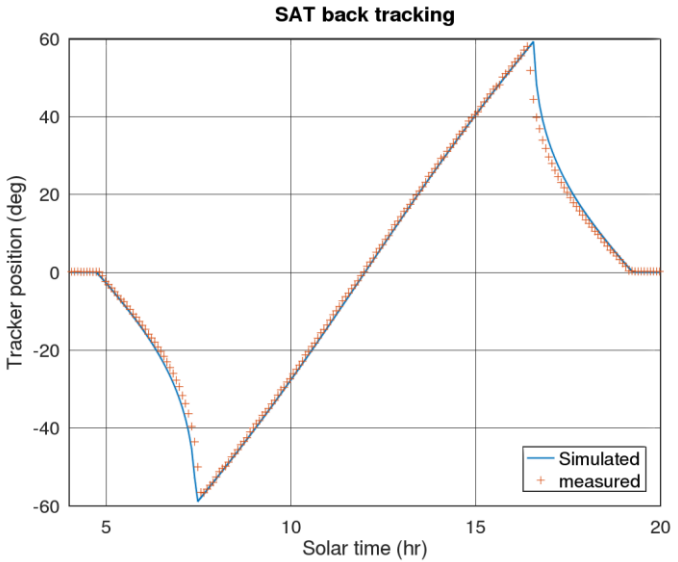
- Monitoring started in January 2019
- Early results, pending full report.

VALIDATION: ALBEDO AND TRACKING

- System provided with an albedo meter (up+down looking pyranometer)

- Verification of logged tracking angles and measured tracking angles.
  - Follow sun, but avoid casting shade on neighbouring tracker (back-tracking)

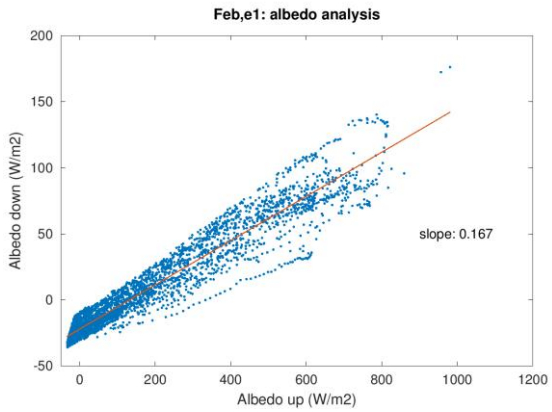


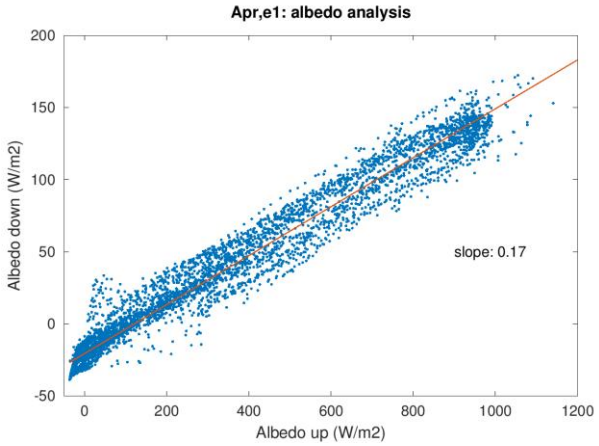


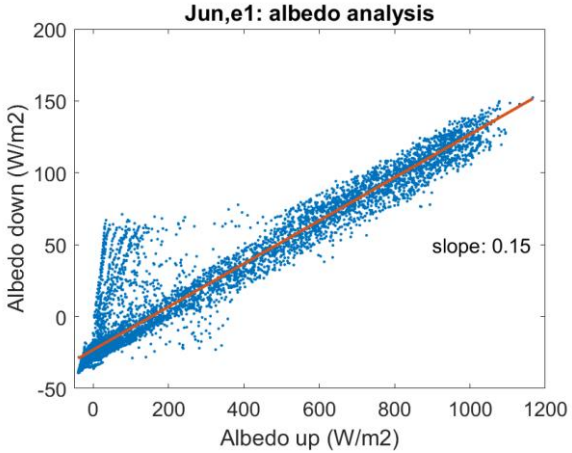
ALBEDO OVER TIME

- High correlation up/down facing
- Small spread over period observed

month	slope
Jan	9.8%
Feb	16.7%
Mar	17.1%
Apr	15.6%
May	17.0%
Jun	15.0%
Jul	15.6%

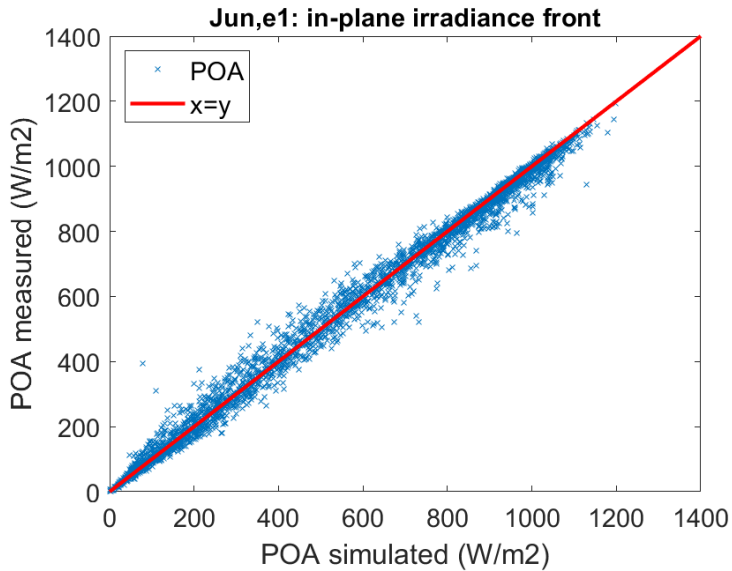


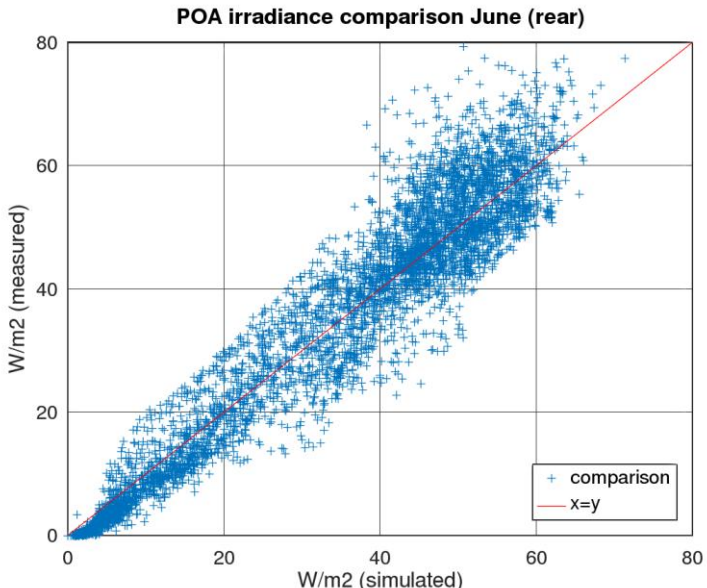




VALIDATION: POA IRRADIANCE

- Pyranometer mounted on both front- and rear side, with tracking
- POA irradiance calculated from:
  - GHI, measured albedo, time.
- Note: scale difference front/rear irradiance, spread.

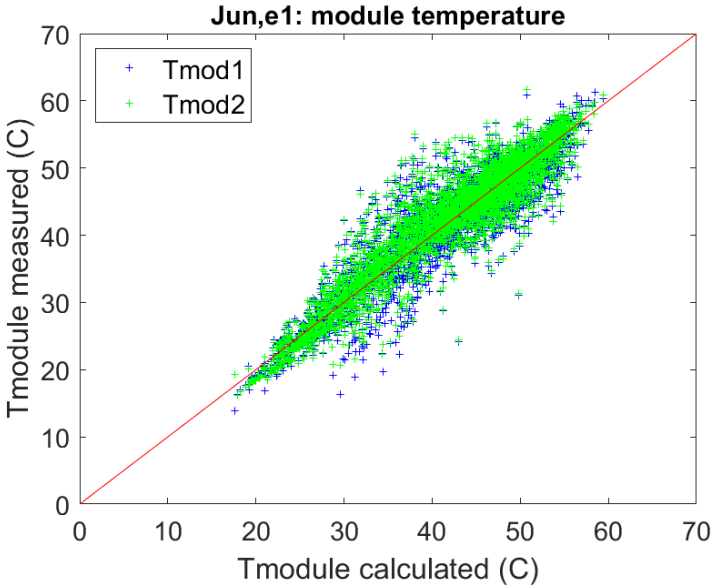




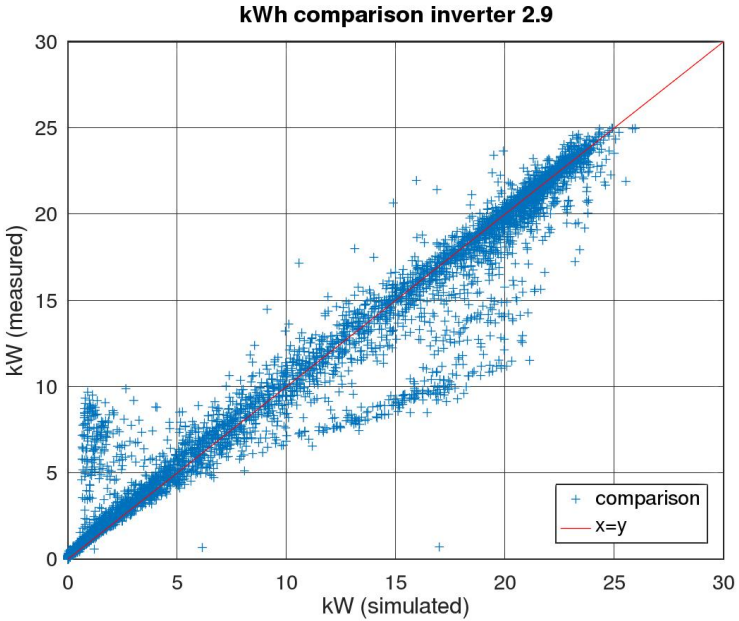
BIGEYE VALIDATION: HOPEWELL (NC)

Module temperature measured for 2 modules

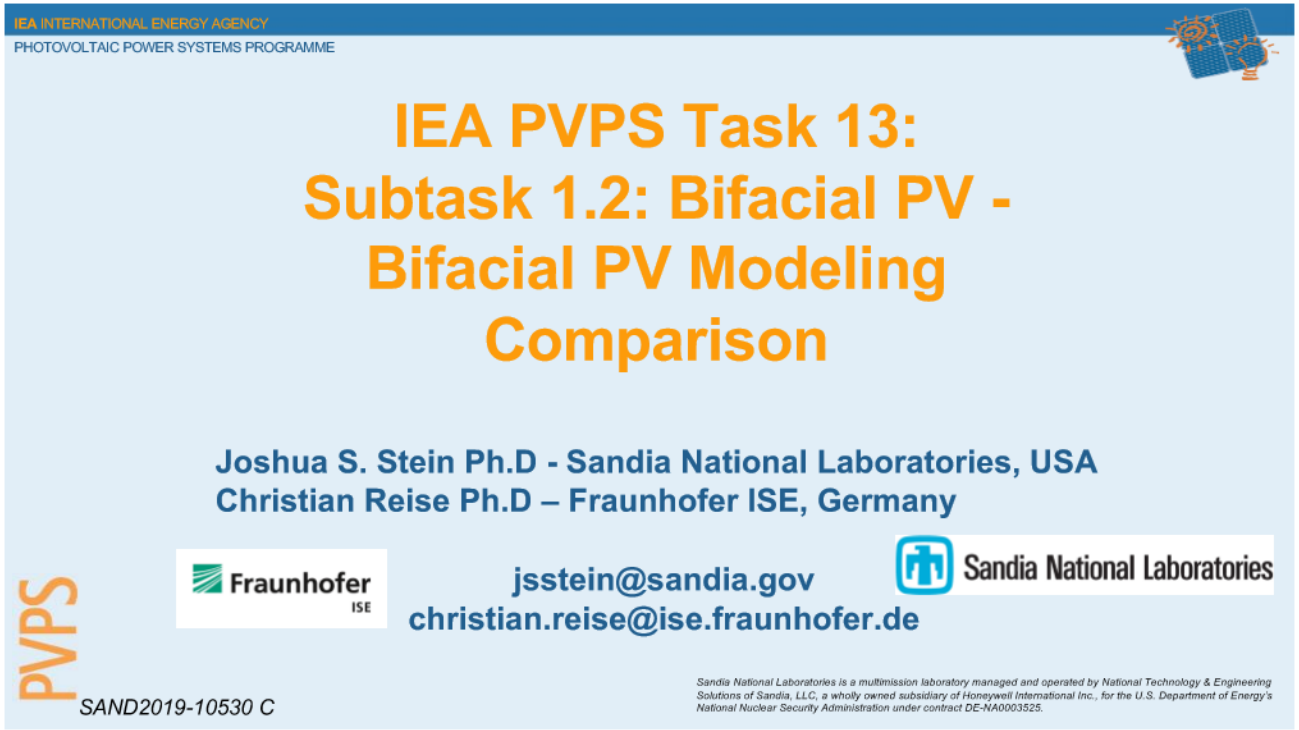
- Comparison with calculated (day time)



- Energy production



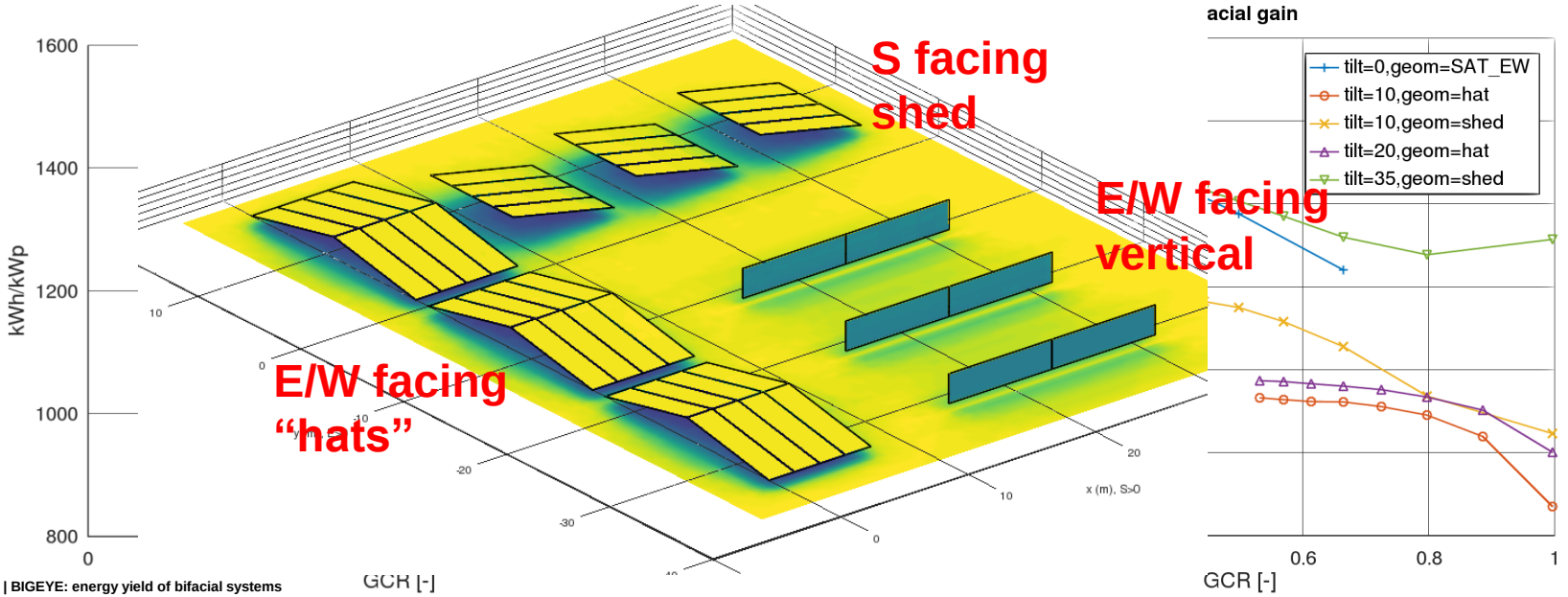
OTHER VALIDATION EFFORTS



BIGEYE: SYSTEM DESIGN

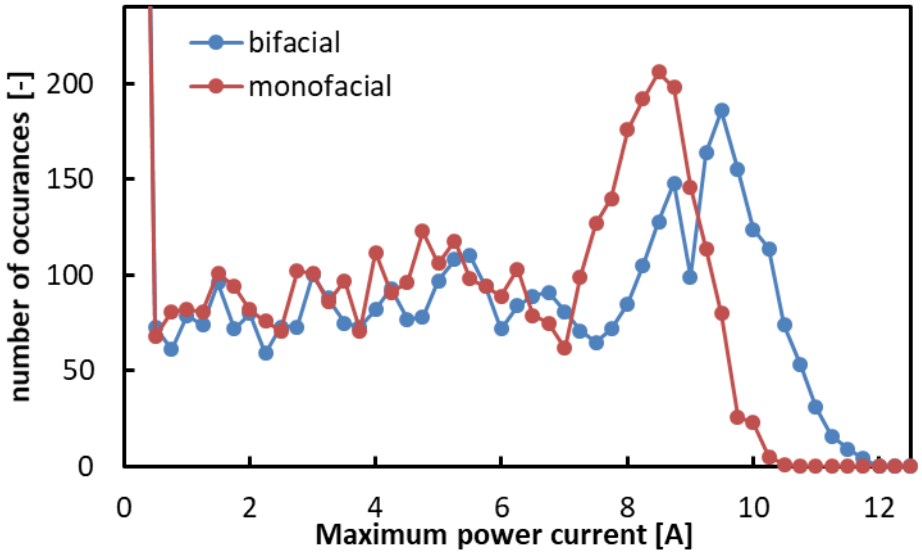
- Site layout
  - Design e.g. for kWh/m^2, kWh/kWp, ground irradiance
  - With edge effects
  - As function of e.g. ground albedo, geometry, module transparency

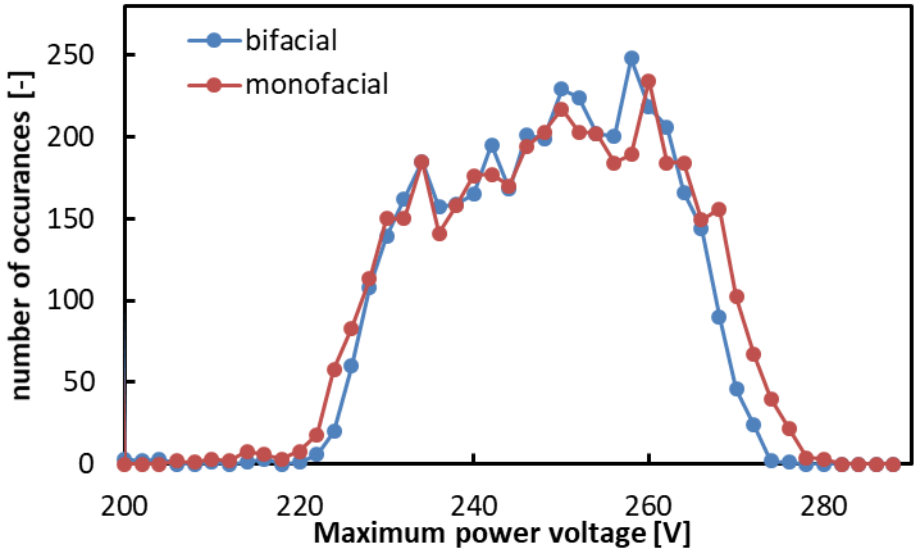
GCR: m^2 PV/m^2 area



DISTRIBUTION OF V_MPP AND I_MPP

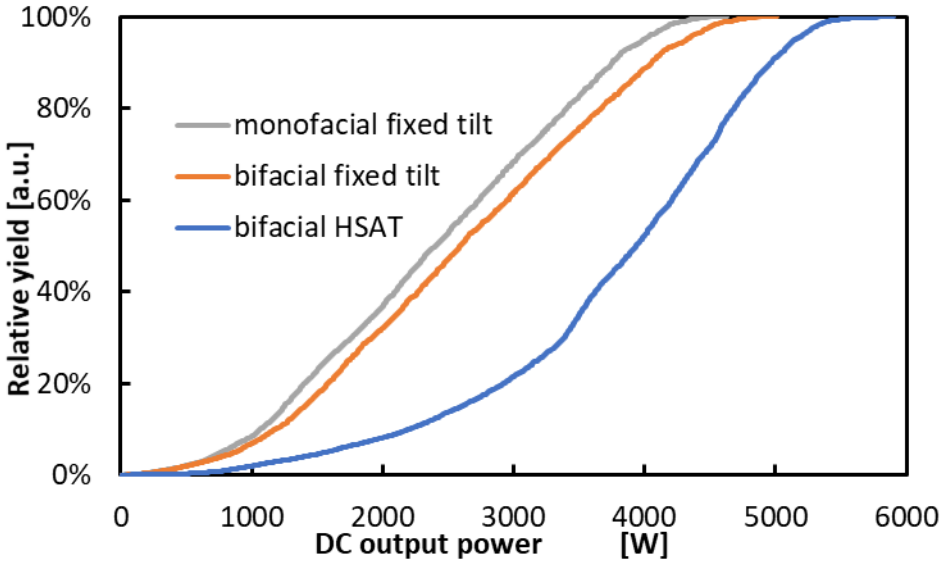
- bifacial HSAT, 4900 Wp system
- Bifacial gain is evidenced by shift in current distribution, but 98% <10 A
- Typical inverter limitations will not frequently be breached by this I_MPP distribution
- hardly any difference in voltage distribution, slightly narrower for bifacial both at low and high end of distribution!

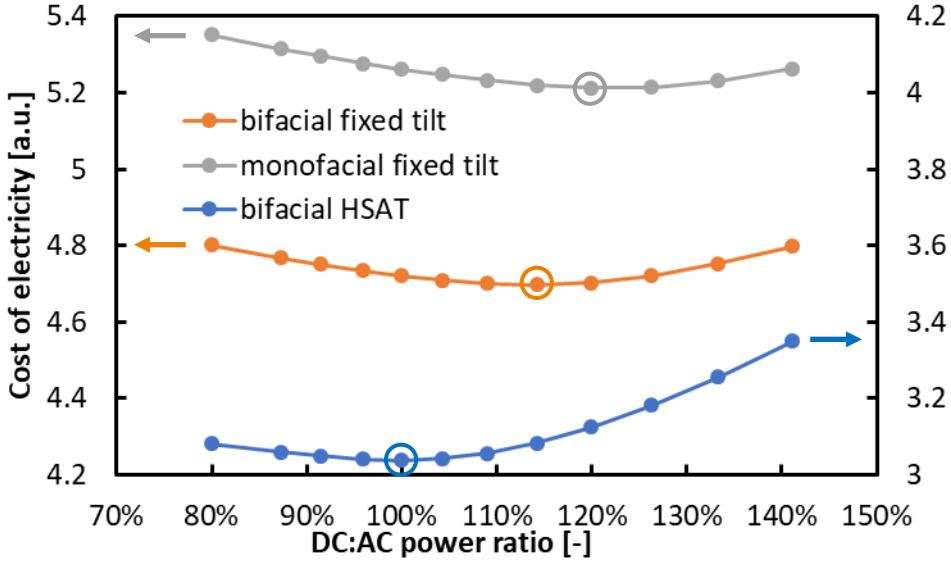




SHIFT DC OUTPUT POWER EFFECTS DC:AC RATIO

- If the AC power limitation is surpassed, the output power is clipped
- For HSAT low power situations rare as sun is tracked (hardly ever poor angles) in sunny climate!
- Circled cost points are optimal DC:AC ratio for this system and our cost assumptions





SUMMARY

- Bifacial energy yield modelling is maturing
  - Multiple programs
  - Multiple validation efforts

- System design:
  - Energy yield an important input
  - But for LCOE: subsidies/tariffs, m^2 prices, climate, building constraints, …

- BIGEYE:
  - Developed for bifacial systems and general geometries
    - Inhomogeneous illumination mismatch implicitly calculated
  - Significant effort put in validation, leading to confidence in results.