A Model for Efficient Shading Evaluation in Large-Scale PV Plants Based in Hemicube Geometry

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PV, DNV & SolarFarmer

- Independent engineers; assurance & risk
- Foundation, with Norwegian HQ
- 5% R&D re-investment
- Strategy goals: Decarbonisation & Digitalisation
- 250 PV Engineers & Scientists

- Software for bankable pre-construction yield estimates
- Industrial & utility scale projects
- 3D: complex terrain & shading
- Easy to use
- Enables scalability
Shading methods

Shading sources: Row-to-row, near scene obstacles (boundary structures, trees, buildings etc.) and terrain

2 approaches

• Geometric shading / View factors
  • Great for row to row shading on arrays laid on (tilted) planes; fast and accurate!
  • But not so easy for complex terrain or for arbitrary near shading obstacles

• Ray tracing
  • For beam shading, plot a line from each point on module to every solar position and loop over all the obstacles to evaluate whether or not that beam path is obscured
  • Great for accuracy but an intensive computation / computational efficiencies likely to be complex
  • … and, for diffuse, need to accumulate shading through weighted collections of paths over all of the sky

Is there an accurate enough method for complex terrain and arbitrary shading obstacles that’s faster, or simpler?
Hemicube finite element approach

• Established method in computer graphics for solving radiosity; rendering scenes with diffusely reflected light
  https://en.wikipedia.org/wiki/Radiosity_(computer_graphics)

• 3D surface polygons amalgamated into patches, then compute the light emitted and collected across all combinations of patch pairs. An efficient solution entails regularised patches and view factor computations

• SolarFarmer re-purposes just the first step; the so-called hemicube step…
Hemicubes for beam shading

Pre-compute step

• A virtual unit hemicube placed over each point on the module
• Grid each of the 5 faces, M * N pixels
• Evaluate beam shading for each pixel considering all shading obstacles; black = shaded
• Amenable to optimised graphics CPU/GPU instructions
• Store all these hemicube surfaces, for a fixed array they won’t change

Run-time

• For each solar position, just lookup the appropriate pixel in each hemicube; easy because the hemicube is regular
• Fast. Especially useful when you want to consider a lot of solar angles / small time steps
Hemicube silhouetting with multiple tilt angles

• To re-enforce how the hemicube works…

• … visualise how the shading from the row in front spreads up the hemicube side as the tilt angle increases

• All shading obstacles handled in a single method; row-to-row, near obstacles & terrain
Diffuse irradiance

- Hemicube method for beam shading also gets us the diffuse irradiance, almost for free
- Sky diffuse shading factor ≈ proportion of unshaded pixels
- Just needs a (pre-computed) pixel weighting map to compensate for hemicube perspective (i.e. it’s not a hemisphere) and module relative incidence angle
How many hemicubes?

• Investigate yield sensitivity to a range of hemicube placement scenarios; 1 per module through 9 per cell
• For a fixed tilt layout on simple terrain, so we can easily compare (the back row) with infinite sheds
• All methods similar at times of day without shade
• 1 per module assumption under estimates (row-to-row) shading towards each end of the day – underestimates shade
• 5/submodule, 1/cell, 9/cell: < 0.01% yield difference
• Compute time relative to the 1/module case for 5, 20 & 100MW sites; compute time \( \approx \)proportional to N hemicubes
  e.g. *4 increase from 5 per submodule to 1 per cell

**SolarFarmer defaults to 5 hemicubes per submodule**
Current status

• Core method proven & validated across multiple sites
  • 8 published, others confidential
  • Mixture of simple research sites and complex terrain commercial. Working on more validation for complex sites and near shading obstacles; striving for continuous validation
  • 11 SolarFarmer methodology & usage publications to date, 2 more this year…

• Run times on a modern PC typically a few minutes for 10MW, an hour or so for 100MW
  • Scales somewhere between $O(N)$ and $O(N^2)$
  • Hemicube pre-compute means small time step / multi-year calculations scale favourably
  • … or run the geometric / view factor methods in seconds (without variable terrain)

• API implemented on Azure Kubernetes cluster
  • Parallelised across many nodes; what took hours now takes minutes
  • Private Preview … while we keep working on the cluster scaling and queuing
Future Work

- More validation … continuously
  - Collaborations?
  - Comparisons with other 3D methods?

- More compute optimisations… explore more accuracy / compute time trade-offs

- Bifacial
  - 3D front side but currently using view factors for the backside - needs hemicubes on the ground and on the backside

- Multi-angle hemicube interpolation for trackers
See more at …

DNV’s Solar Energy Assessment Validation using SolarFarmer

Madison Ghiz, here, today @ 10:55!

DNV solar experts share the latest Solar Energy Validation Methodology, Webinar, 18th May 1pm ET
https://www.dnv.com/power-renewables/events

Uncertainty Considerations in Bifacial Photovoltaic Systems with High Albedo Seasonality, Javier Lorente Lopez, PVSC

Light and Shade – A Hemicube Approach for Efficient Shading Calculations in Utility-Scale PV Plants, Anja Neubert EU-PVSEC
Thank you

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