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DC/AC inverter oversizing ratio – what is the optimal ratio for Australian solar farms?

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In This Presentation

- The need for this investigation
- Background on DC/AC ratio
- Methodology & investigations
- Results
- Future work

Photo source – author (confidential project)

The need for this investigation

- Australian solar farm industry is now becoming mature;
- Surprising lack of publicly available design guidelines or best practice;
- This investigation is both a call to arms and a start on an industry best practice for large scale solar PV design.

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But what are these then?

- Focused on the planning and approval process, not the electrical, structural or civil design process.

Left see https://www.planning.nsw.gov.au/Policy-and-Legislation/Renewable-Energy/Large-scale-Solar-Energy-Guideline
Right see https://www.planning.vic.gov.au/policy-and-strategy/solar-energy-facilities-design-and-development-guidelines

Why consider 'oversizing'?

- Real world performance of solar modules is typically lower than that of their STC rating;
- Temperature, age, soiling, cable losses, mismatch, etc all contribute to losses;
- So, if modules don't operate at their STC (nameplate) performance, can we have **y** MW (y<x) of inverters for **x** MW of solar modules.
- The question is – what is the 'best' y for any given x?

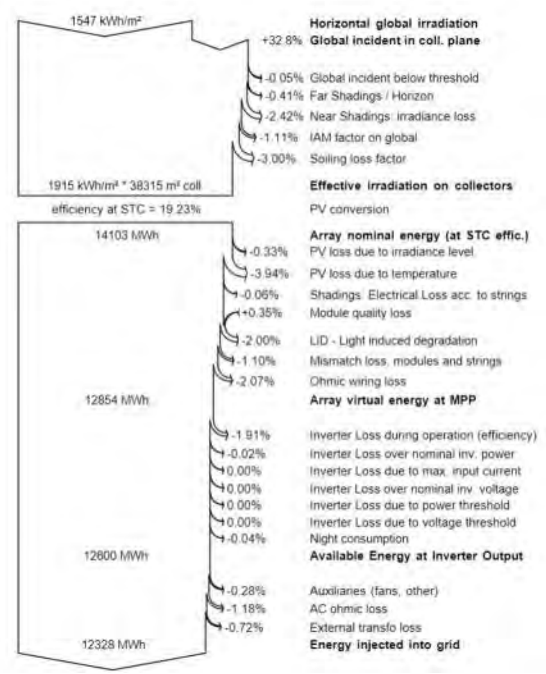

Photo source – example from PVSyst showing losses

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DC/AC ratio

- The ratio of the DC output power of a PV array to the total inverter AC output capacity.
  - For example, a solar PV array of 13 MW combined STC output power connected to a 10 MW AC inverter system has a DC/AC ratio of 1.30;
  - From the before, the oversizing ratio will be x/y
- Clean Energy Council (<100 kW) requires DC/AC < 1.33;
- But what about large-scale solar PV / solar farms?
  - Different manufacturers boast high oversizing ratio capability, but is this of value?

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Methodology & investigations

- Want to capture all ‘large-scale’ solar technologies;
- Three types of solar PV mounting for solar farms considered.

Single-axis Tracking

Fixed Tilt

High-density East-West

Photo source left & middle – author (confidential project)
Photo source right – https://5b.com.au/projects/

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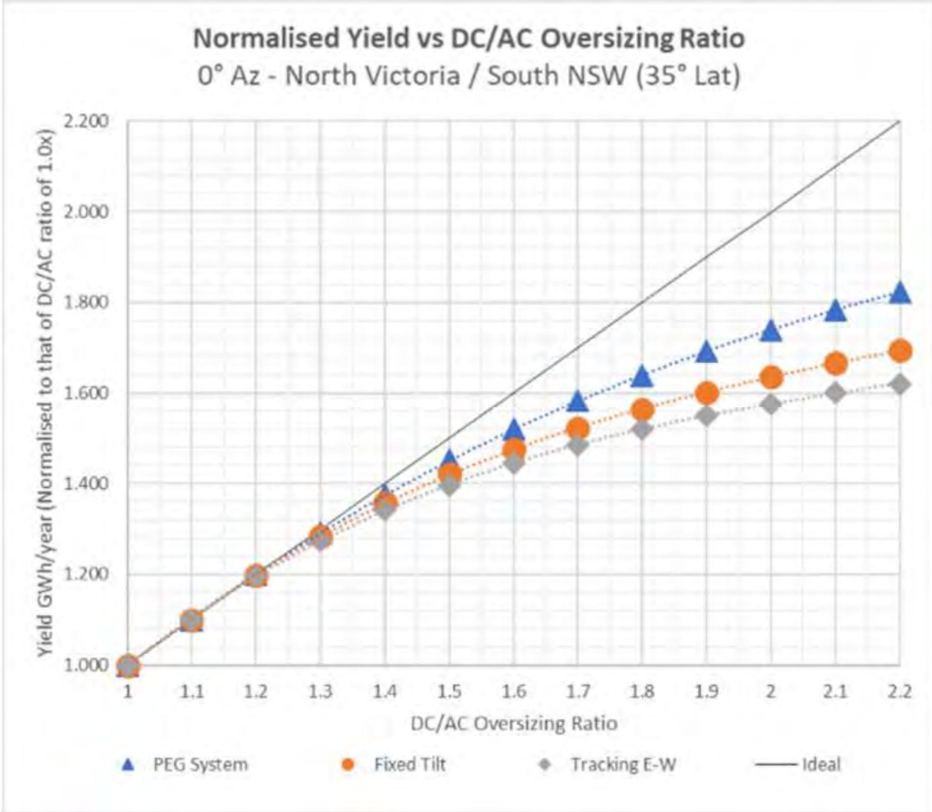
Diminishing Returns

- Used Helioscope software package – hourly resolution solar data;
- For each latitude, only varied DC (MWp i.e. number of modules), no increase to GCR;
- Can see 'diminishing returns' as DC/AC ratio gets larger.



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A Dilemma – How to measure ‘value’?

- How can you capture the value of an increase in yield?
- Installing more PV modules to fully utilize a fixed inverter quantity will cost additional CAPEX but also provided additional revenue;
- Let’s go through an example

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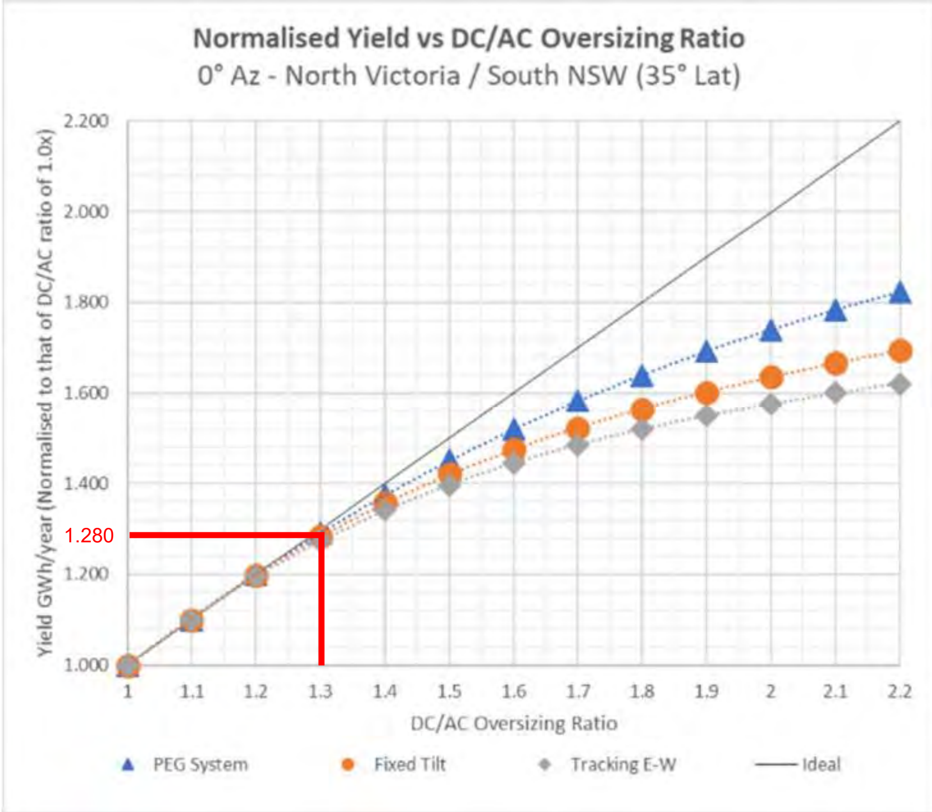
Example

- Two options:
  - Option 1 – DC/AC 1.00, cost of $20 million;
  - Option 2 – DC/AC 1.30, cost will be ***less than*** $26 million, say is $25 million;
- Option 1 will yield **x** MWh/year
- Option 2 will yield (from the right) ~1.28**x** MWh/year
- This means we generate 28% more per year for only 25% additional capital cost, which may be a better rate of return.



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Cost agnostic approach – Define **A**

- Define the ratio A, defining it as the proportion of the total solar farm capital spend which varies with the DC/AC ratio of a solar farm.
- Can perform a basic optimisation & normalisation. Let's also define the following:
  - R is the revenue from the solar farm;
  - δ is the DC/AC ratio (>1.00);
  - y is the solar farm's annual yield (based on the δ);
  - The subscript $_{\mathrm{Norm},\delta=1.00}$ means the associated value is normalised by the result for a DC/AC ratio of 1.00.

$$R_{\mathbf{Norm},\boldsymbol{\delta}=\mathbf{1.00}} = \frac{\mathbf{1} + A\boldsymbol{\delta}}{\left(\frac{y(\boldsymbol{\delta} = \boldsymbol{\delta}_{new})}{y(\boldsymbol{\delta} = \mathbf{1.00})}\right)}$$

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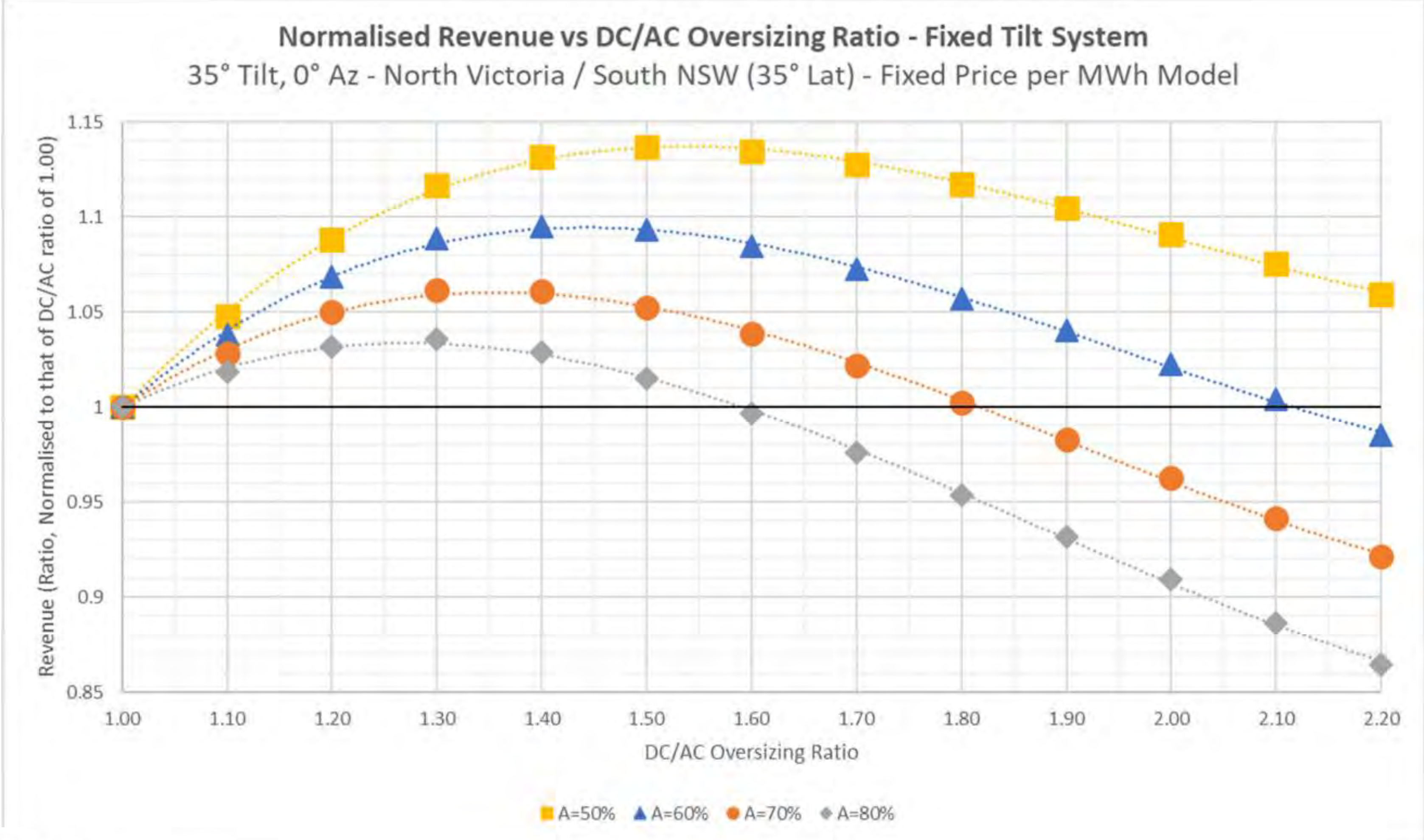

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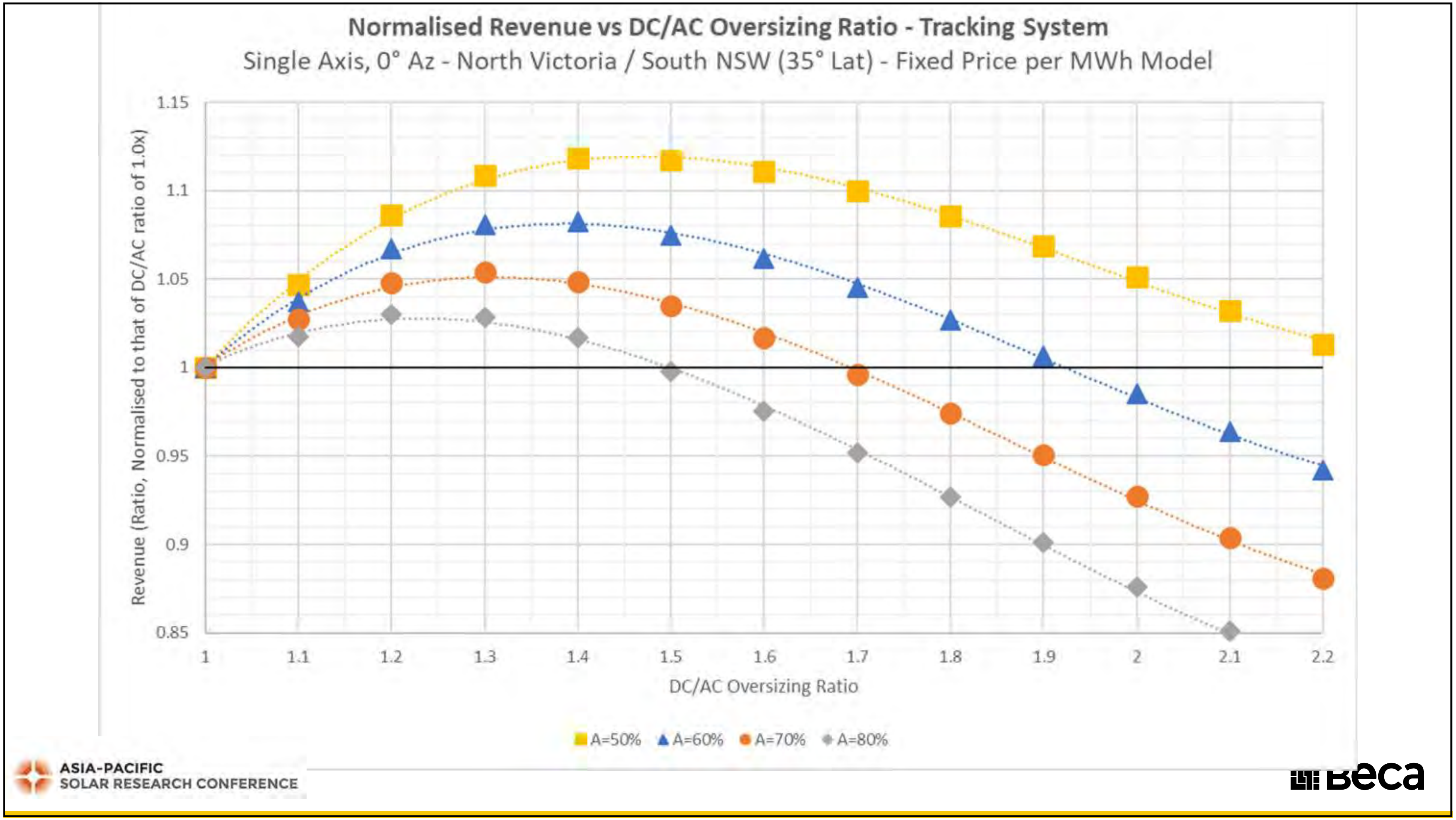
Normalised Revenue vs DC/AC Oversizing Ratio - Tracking System
Single Axis, 0° Az - North Victoria / South NSW (35° Lat) - Fixed Price per MWh Model
Revenue (Ratio, Normalised to that of DC/AC ratio of 1.0x)
1.15
1.1
1.05
1
0.95
0.9
0.85
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
DC/AC Oversizing Ratio
A=50%
A=60%
A=70%
A=80%
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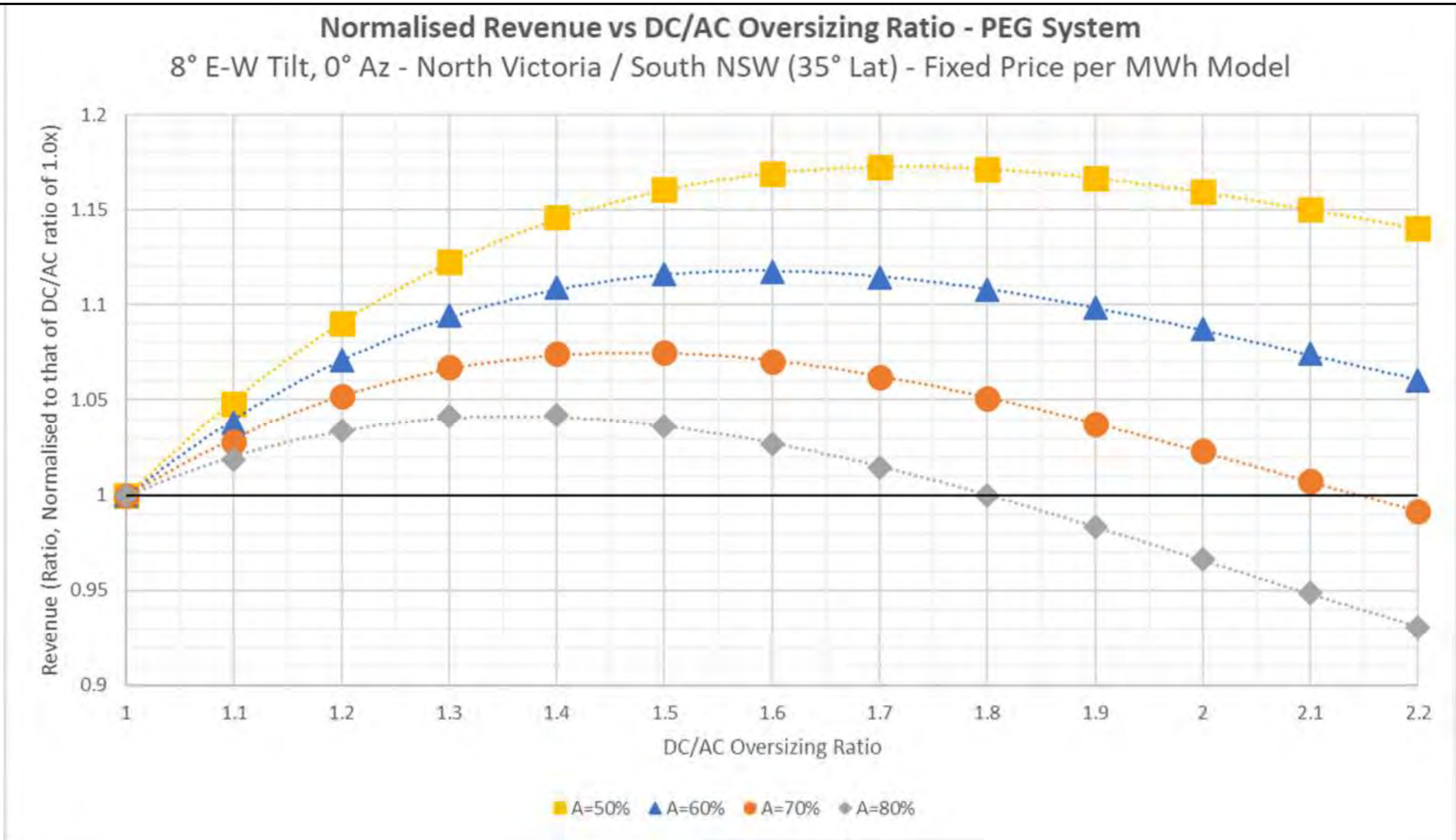

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Results (Continued)

- The lower A, the optimal DC/AC ratio tends upwards;
- High-density east-west systems appear benefit the most from ‘large’ oversizing ratios – but they also generate the lowest kWh / kWp / year (specific yield);
- Decreasing the latitude (moving north) decreases the optimal DC/AC ratio (more sun causing more clipping).

Single-axis Tracking

Fixed Tilt

High-density East-West

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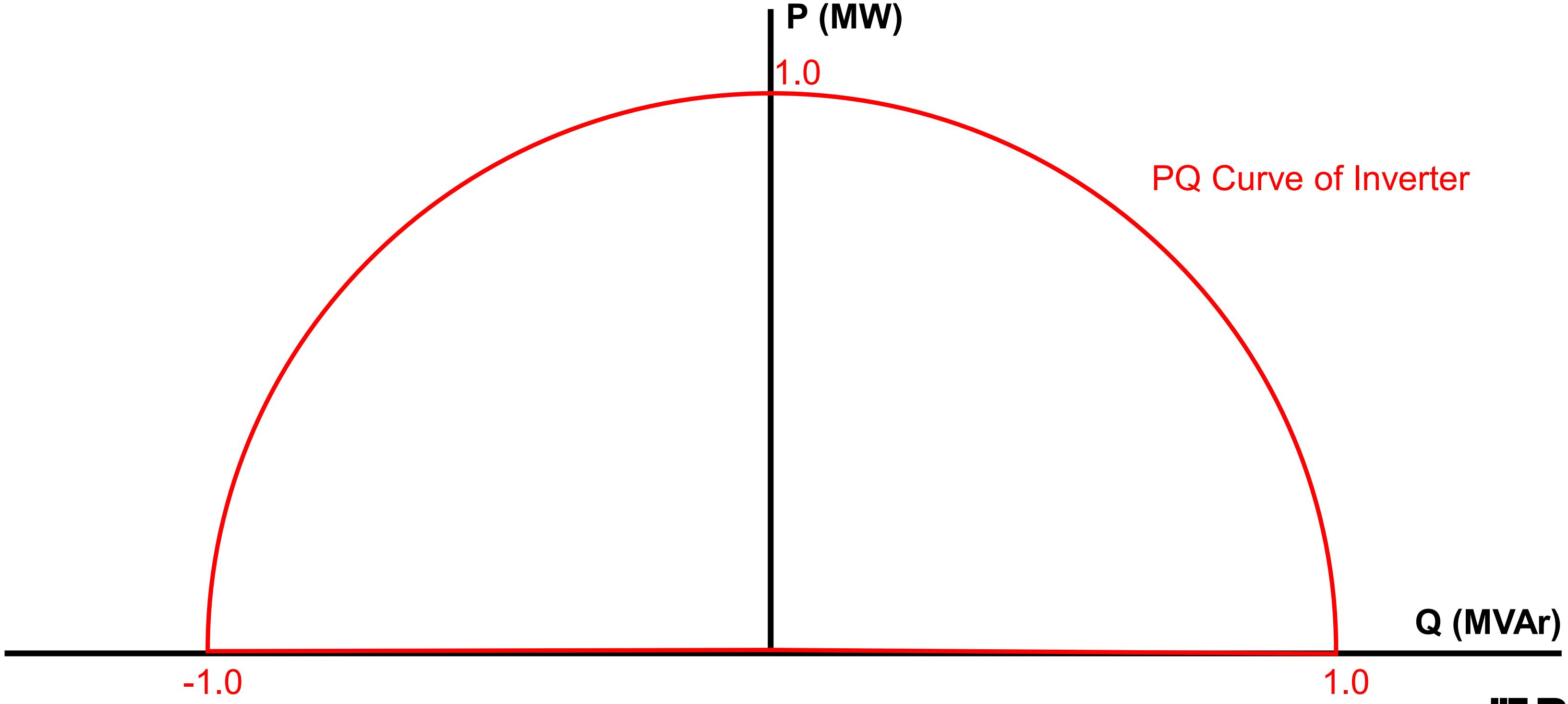
Grid-connection requirements

- Large-scale solar farms must comply with S5.2.5.1 of the NER (GPS);
- This rule requires the ability to supply and absorb MVAr equal to 39.5% at any output power;
- We may need *another* oversizing ratio?
- Easiest to explain the impact / outcome with an example.

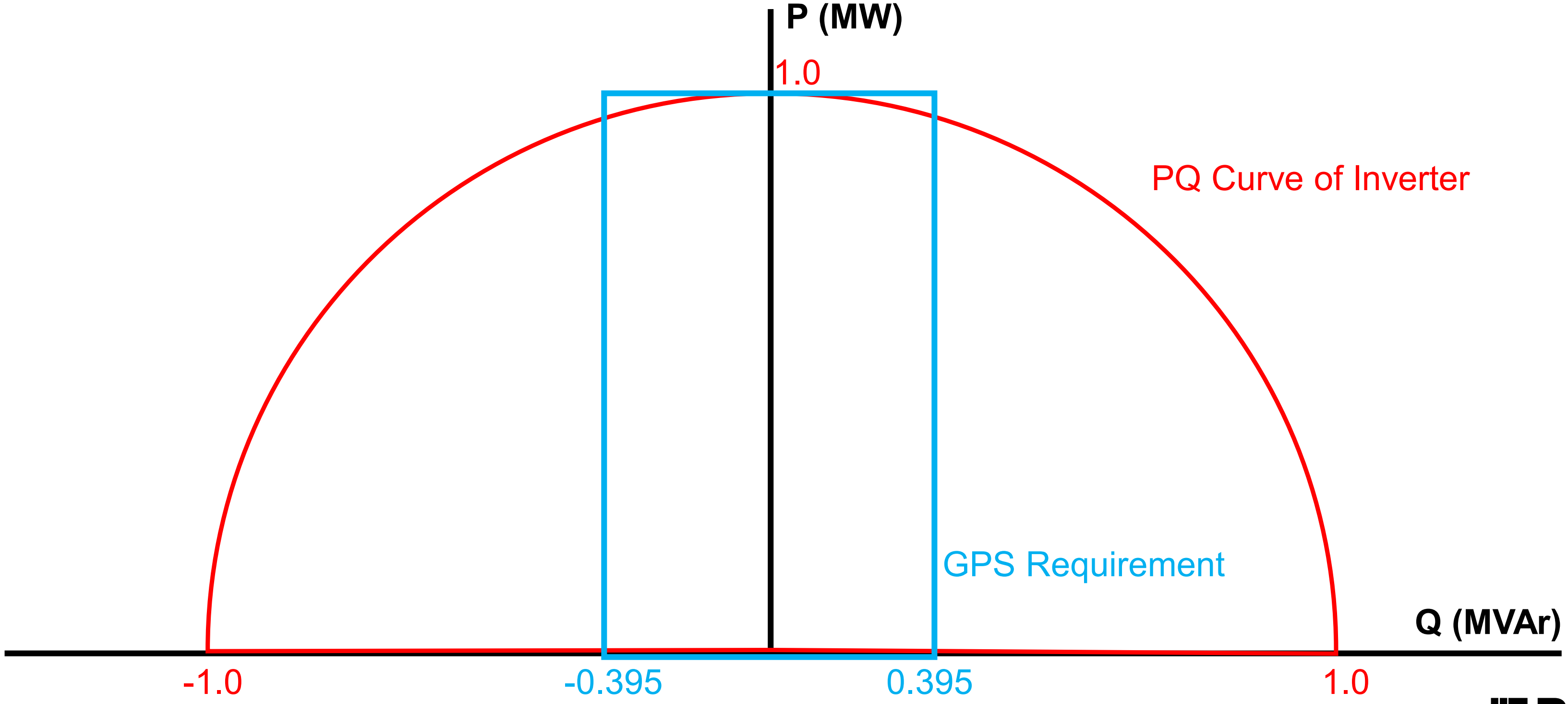
S5.2.5.1 Example

Consider a single 'ideal' 1.0 MVA Inverter



S5.2.5.1 Example

39.5% Reactive Power Requirement



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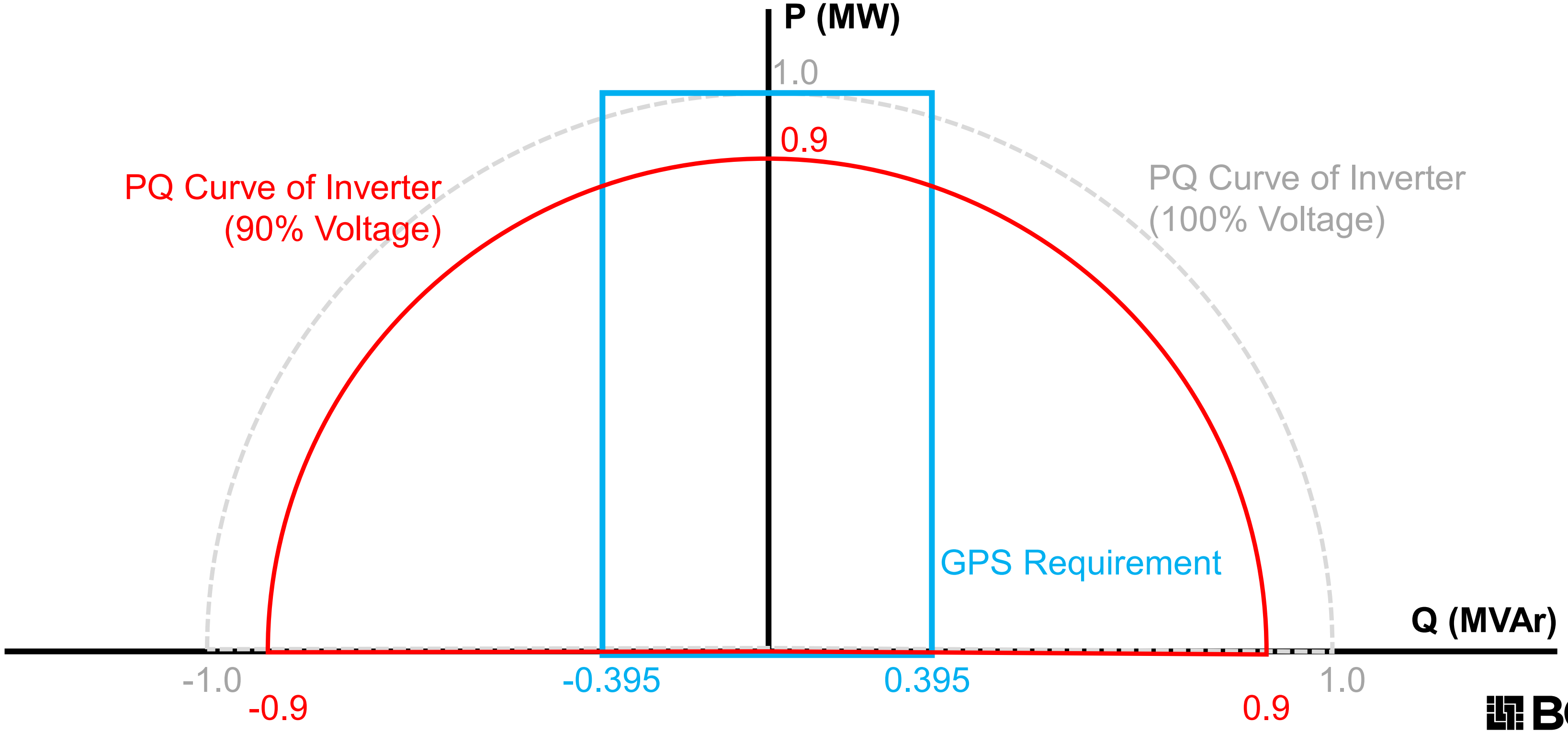
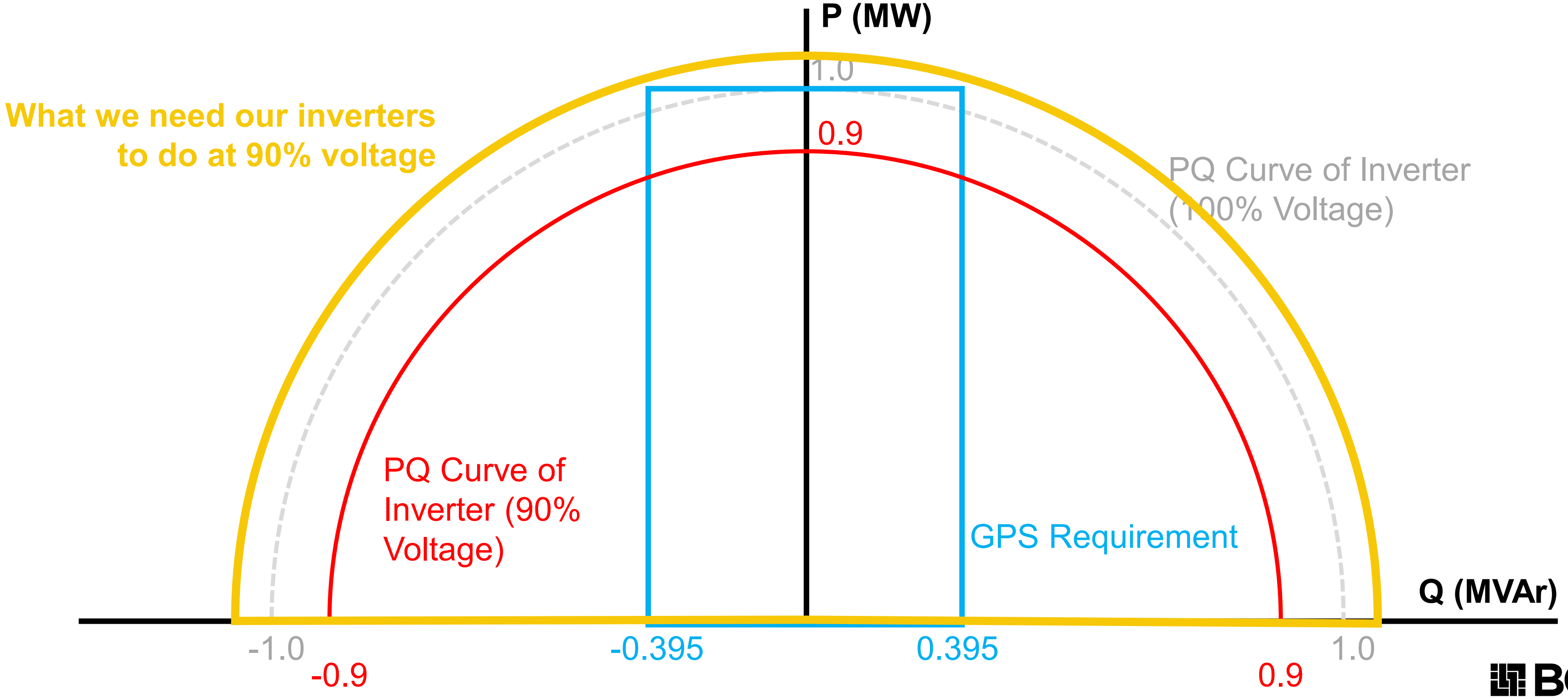
S5.2.5.1 Example

Must achieve performance at 90% voltage



S5.2.5.1 Example

Need to 'oversize' inverter so can meet the requirement



S5.2.5.1 Requirements - Discussion

- For an 'ideal' inverter with a semi-circular PQ capability, the absolute minimum MVA / MW_{AC} ratio is ~1.20;
  - Disclaimer – be careful as losses from transformer may skew the PQ curve and be careful with temperature derating at high ambient operating temperatures;
- This is a minimum – inverters with less than the 'ideal' performance will require a higher MVA / MW_{AC} ratio;
- So what does this all mean?

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Results (so far)

Single Axis Tracking	Fixed Tilt	High Density East-West
If you want a 10 MW AC solar farm, assuming A = 70%, in south NSW, the best yield-to-cost ratio is: Install **between 12.0 MW and 14.0 MW of modules** (DC/AC 1.20 – 1.40) Install **inverters with a total nameplate of at least 12.0 MVA** (MVA / MW_{AC} 1.20) with the inverters limited in software to 10.0 MW output power.	If you want a 10 MW AC solar farm, assuming A = 70%, in south NSW, the best yield-to-cost ratio is: Install **between 13.0 MW and 15.0 MW of modules** (DC/AC 1.30 – 1.50) Install **inverters with a total nameplate of at least 12.0 MVA** (MVA / MW_{AC} 1.20) with the inverters limited in software to 10.0 MW output power.	If you want a 10 MW AC solar farm, assuming A = 70%, in south NSW, the best yield-to-cost ratio is: Install **between 13.0 MW and 16.0 MW of modules** (DC/AC 1.30 – 1.60) Install **inverters with a total nameplate of at least 12.0 MVA** (MVA / MW_{AC} 1.20) with the inverters limited in software to 10.0 MW output power.

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Future Work

- Hourly resolution is very likely too coarse. Larger DC/AC ratios require investigation of MPPT tracking delays and minute- or second-resolution data;
- Large DC/AC ratios push inverters harder, elevated temperatures etc – difficult to quantify impact to project cost and lifecycle, but should be considered;
- Bifacial gains & impact on oversizing ratio and ‘rules-of-thumb’?
- Effects of GCR – this investigation assumed sufficient land, if land is constrained what is the best DC/AC?

Photo source – author (confidential project)

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Key Takeaways

- The ideal oversizing ratio varies based on location and module mounting type;
- Two oversizing ratios:
  - Module STC to inverter nameplate/size; **and**
  - Inverter nameplate/size to maximum AC power
- Based on this work, a DC/AC ratio above 1.00 almost always appears to be worth the investment. DC/AC ratios above 1.50 may be viable when **A** is low or high-density east-west mounting systems used;
- Discuss increased DC/AC ratio effects with the inverter OEM;
- 'Rules-of-thumb' are no substitute for a detailed solar farm modelling (PVSyst etc);

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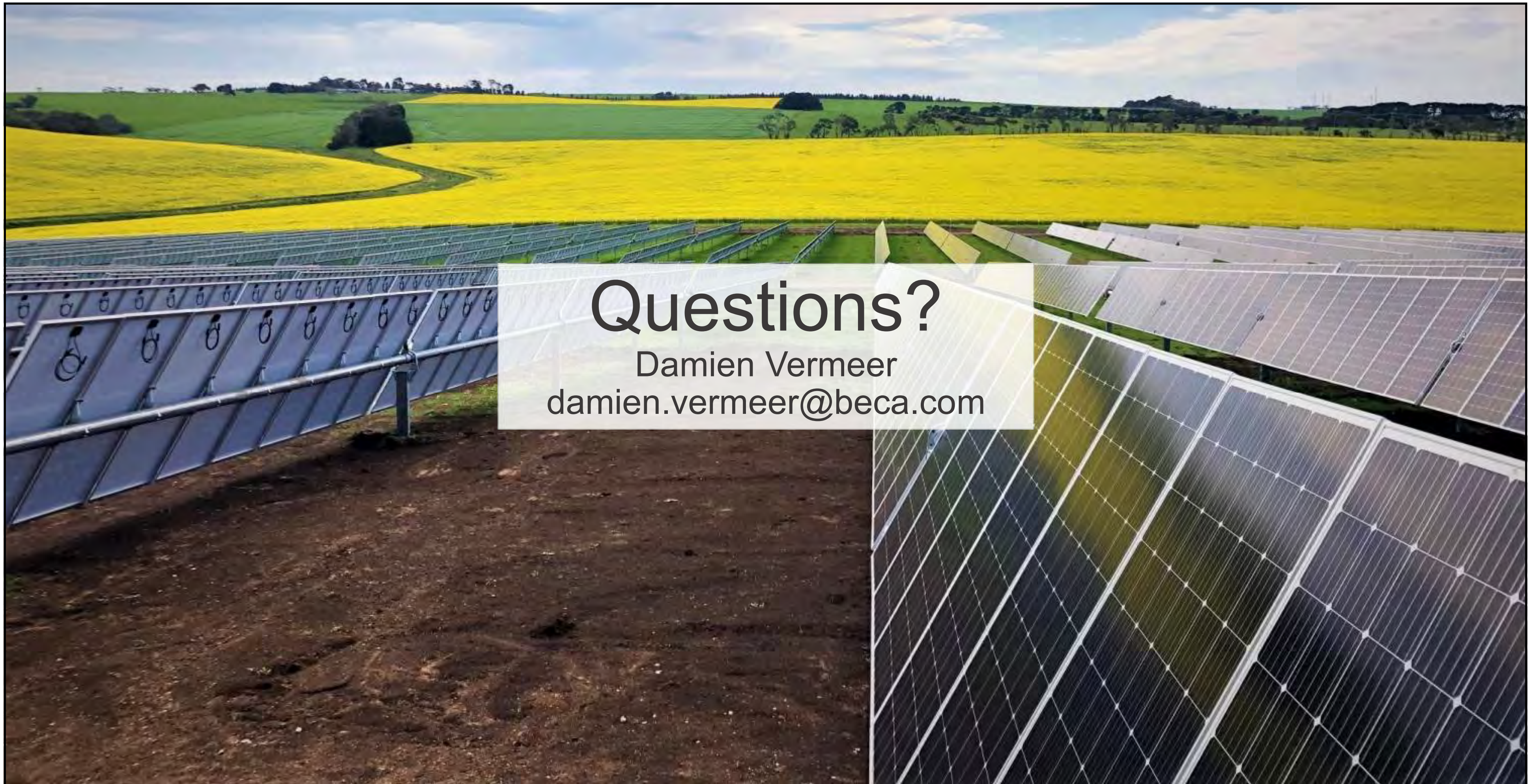

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