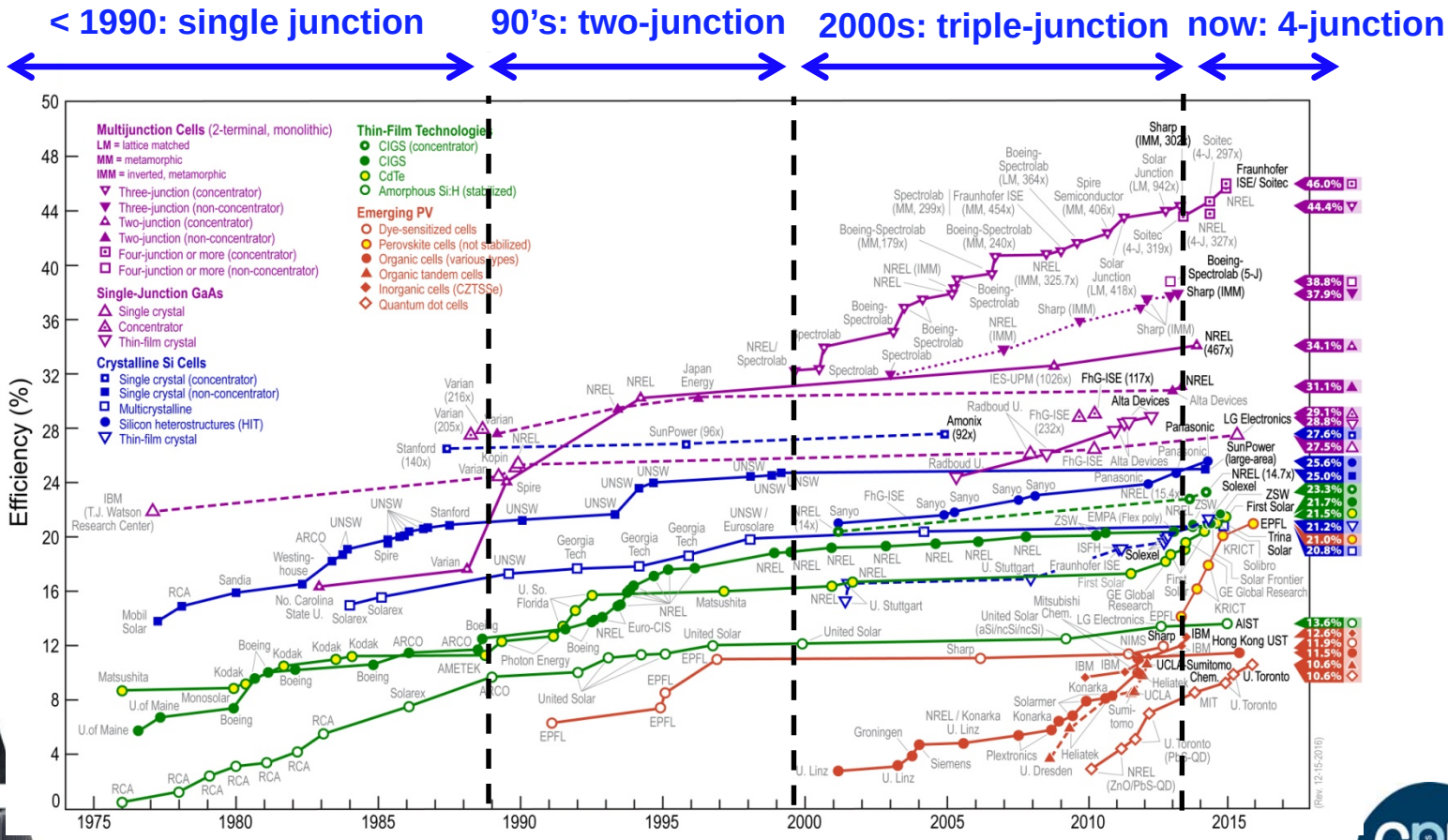
Optimizing the Energy Output of Multi-Junction Solar Cells: A theoretical assessment

Alexis Vossier[1], Laurène Parent[1], Alain Dollet[1], Daniel Chemisana[2], Chris Gueymard[3]

[1]CNRS-PROMES, Odeillo/Perpignan, France
[2]Université of Lleida, Spain
[3]Solar Consulting, Colebrook, NH, USA

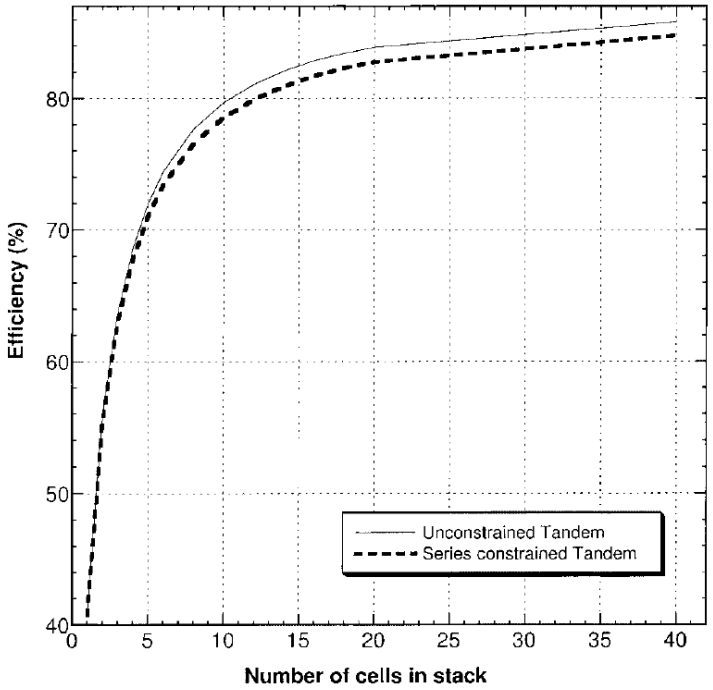
Increasing number of subcells in MJ cells: an historical trend

- **The typical number of subcells in world record solar cells steadily increased in the last 30 years.**



Alexis Vossier – 20th Sede Boqer Symposium on solar electricity production

Increasing number of subcells in MJ cells



A.S. Brown and M.A. Green, Prog. Photovolt: Res. Appl. 10, 299 (2002).

Motivations:

- **The efficiency gain increases proportionally to 1/n**
- **Increased number of *pn* junction → less R_s losses under concentrated sunlight**

Technological challenges:

- **Current and lattice matching, tunnel junctions…**

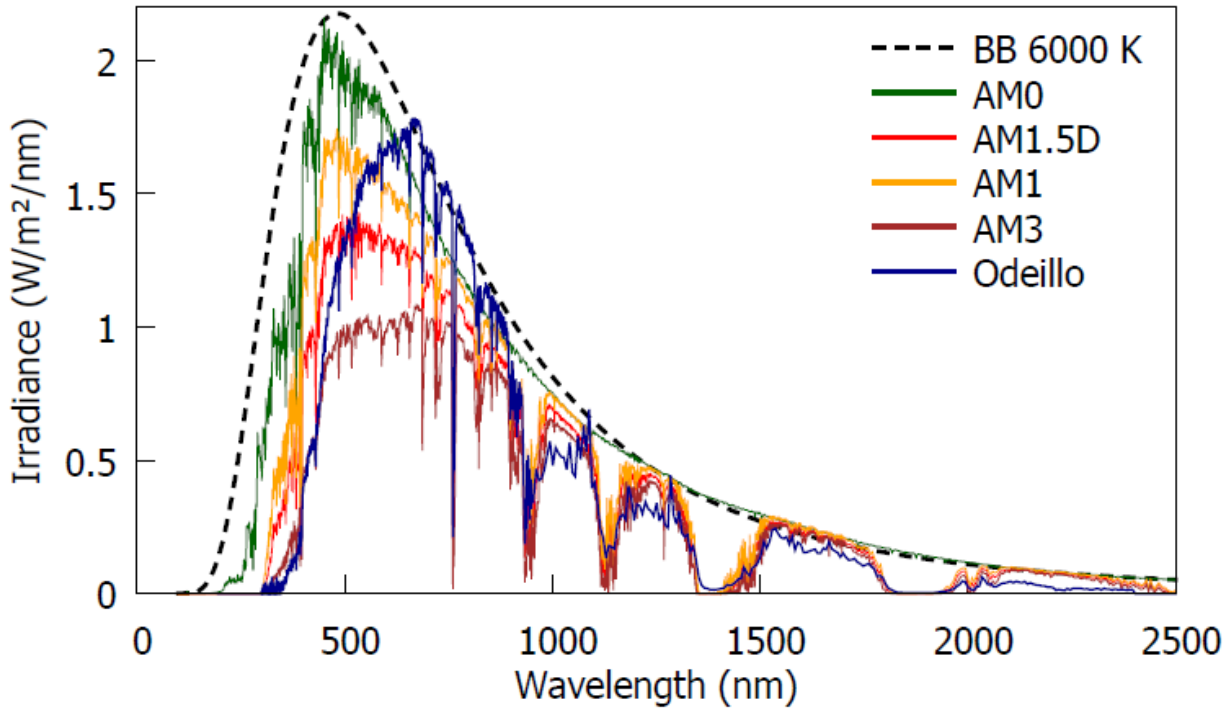
Practical issue:

- **Spectrum sensitivity**

Can advanced MJ solar cell architectures accomodate variations in the spectral distribution of light?

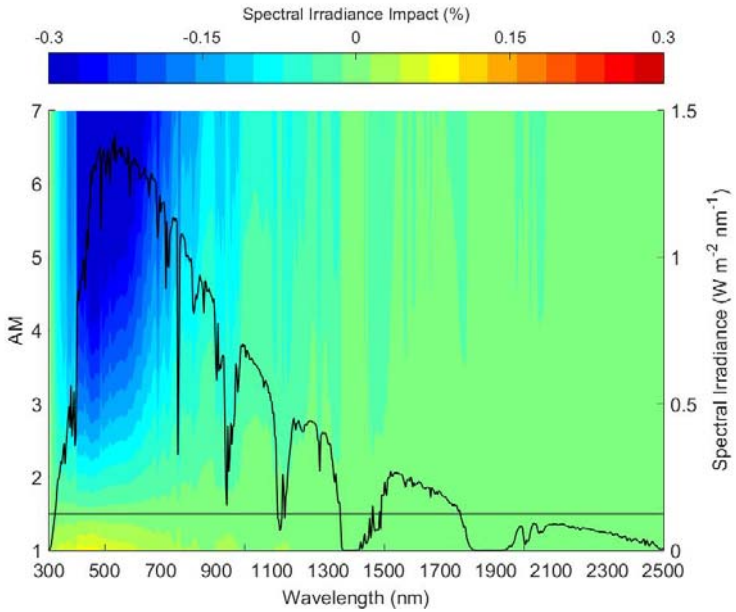
MJ solar cells: Influence of atmospheric parameters

- **Solar cells are usually designed according to the spectral content of AM1.5 solar spectrum**
- **In reality, the light distribution may change significantly from the design spectrum (AM variations, optical losses …)**



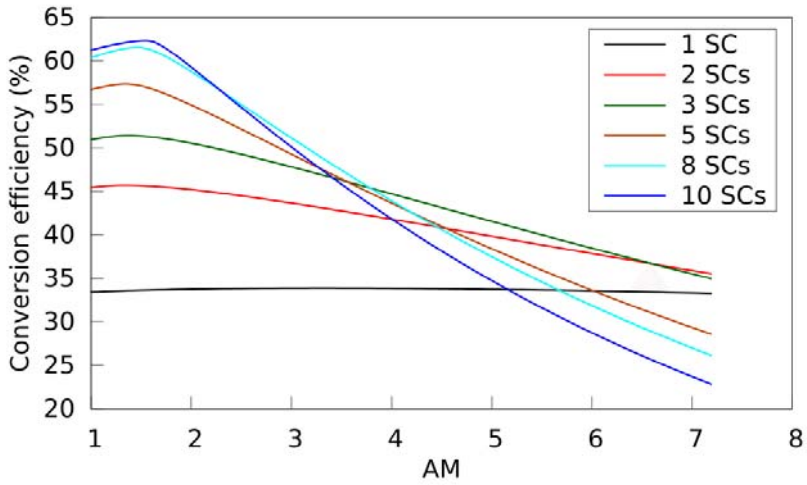
A. Vossier, E. Al Alam, A. Dollet, M. Amara, IEEE Journal of Photovoltaics 5, 1805 (2015).

MJ solar cells: Influence of atmospheric parameters



- **The decrease in the irradiance is particularly strong in the spectral region where the sun emits the highest power density**

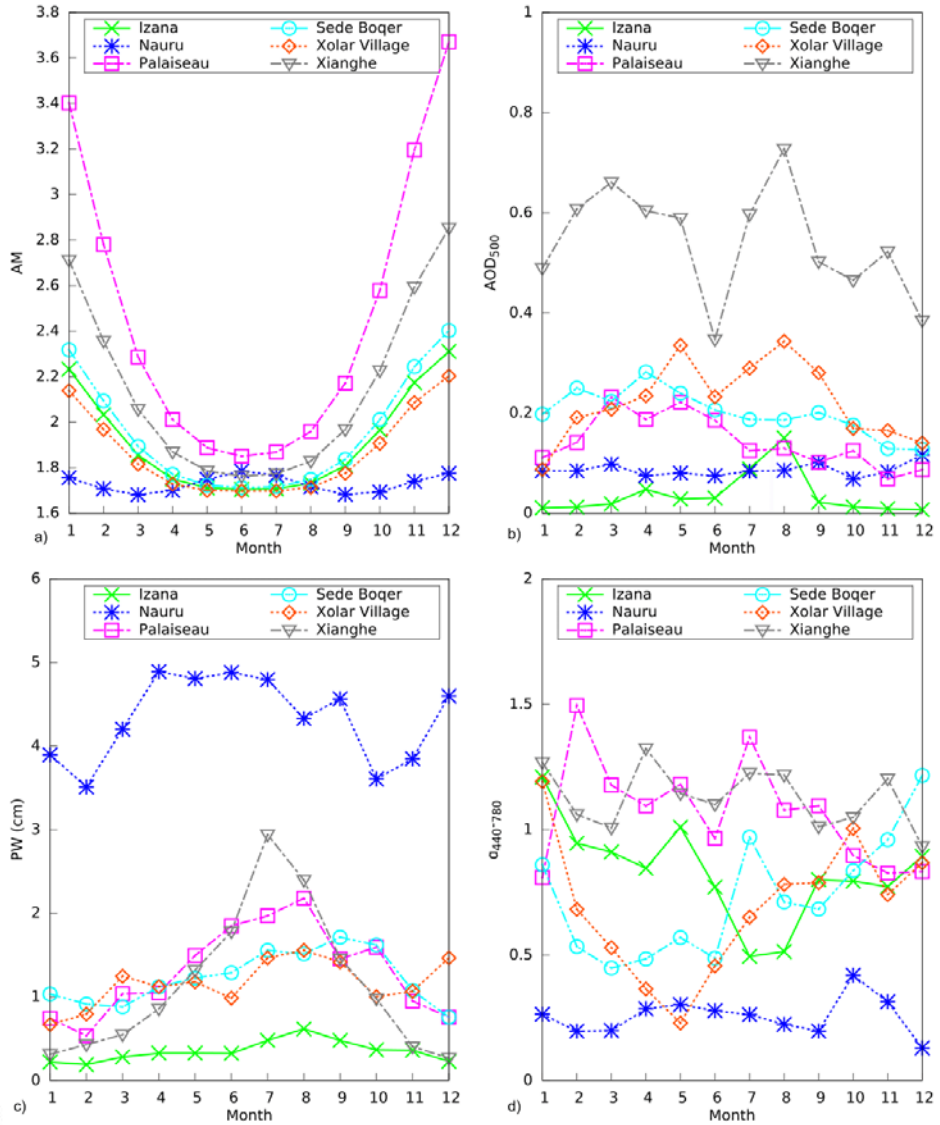
- **Single-junction cells show constant conversion efficiency as a function of AM**
- **MJ solar cells demonstrate a strong sensitivity to AM.**



MJ solar cells: Influence of atmospheric parameters

- **Systematic study aiming at a realistic estimation of the energy output of MJ-based concentrating photovoltaic (CPV)**

MJ solar cells: Influence of atmospheric parameters



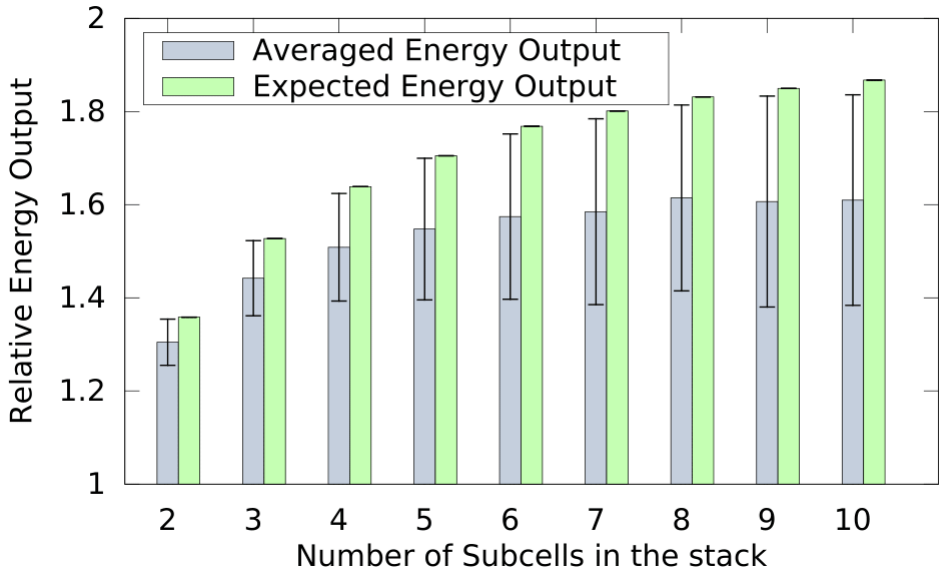
6 locations selected according to 3 criteria

(i) They should be representative of the large range of climatic conditions on the planet

(ii) They should provide high-quality data over an extended period of time

(iii) They should have co-located and simultaneous DNI measurements

MJ solar cells: Influence of atmospheric parameters



- **Globally, MJ solar cells involving between 2 and 6 subcells show a significant increase in the annual energy output**

- **On the contrary, cell architectures involving more than 6 subcells demonstrate a very modest increase in energy output**

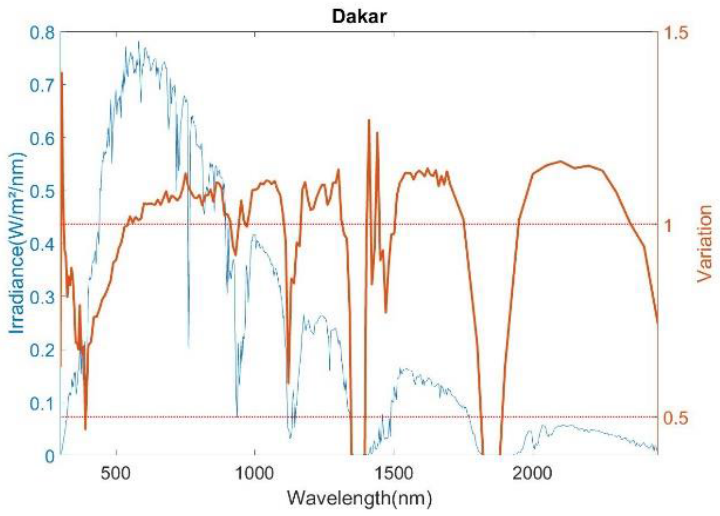
The gain in peak efficiency obtained by adding extra subcells does not necessarily translate in actual annual yield gains!

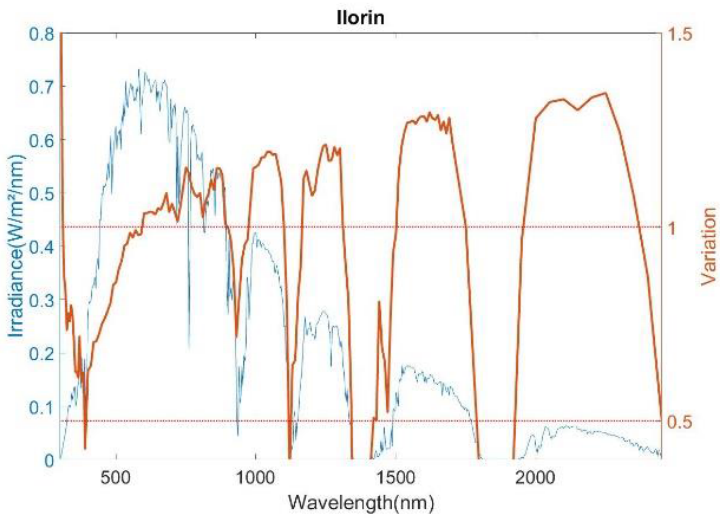
Can we do better?

Fine-tuning of MJ solar cells is often mentionned as a promising strategy to increase the energy yield of MJ-based CPV systems

- ***Basic motivation:***

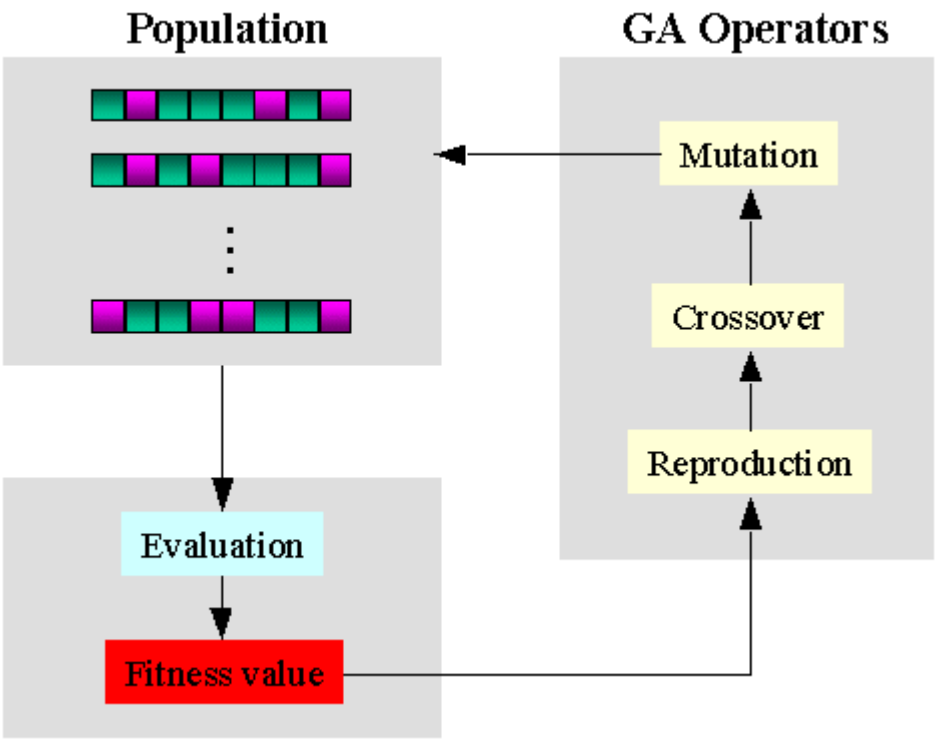
Instead of tailoring solar cells to the AM1.5 spectrum, we consider a mean solar spectrum taking into account the yearly variation of the spectral distribution of light





Can we do better?

- **We use a Genetic Algorithm to tailor the cell architecture to the mean spectral distribution of each investigated location**



Population

combination of electronic gaps associated with each *pn* junction

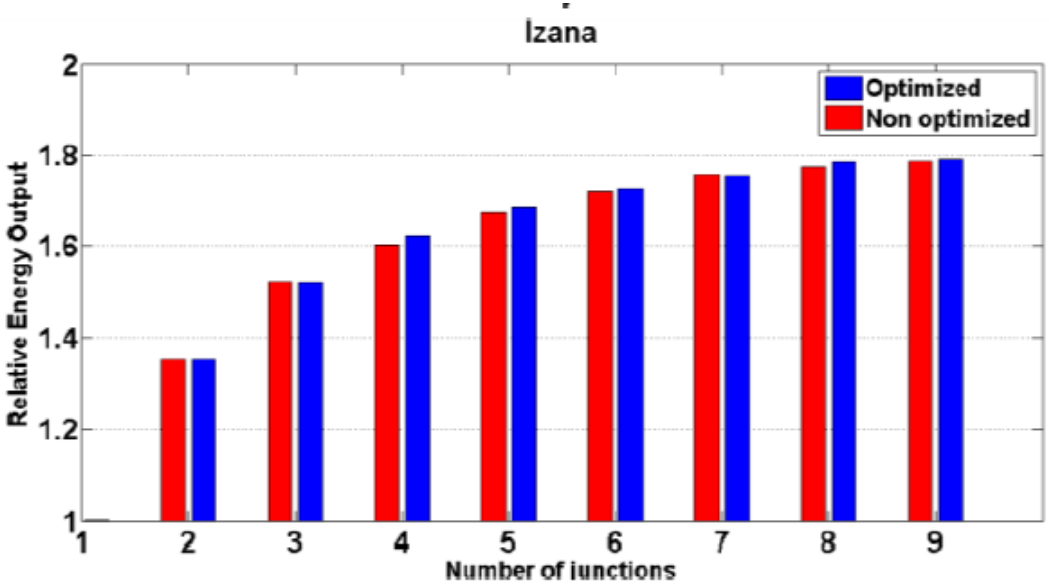
Fitness function to be minimized

$1-\eta$

Can we do better?

Best case scenario: Izana (Spain)

- **High solar resource**
- **Mean annual spectral distribution close to AM1.5 Spectrum**

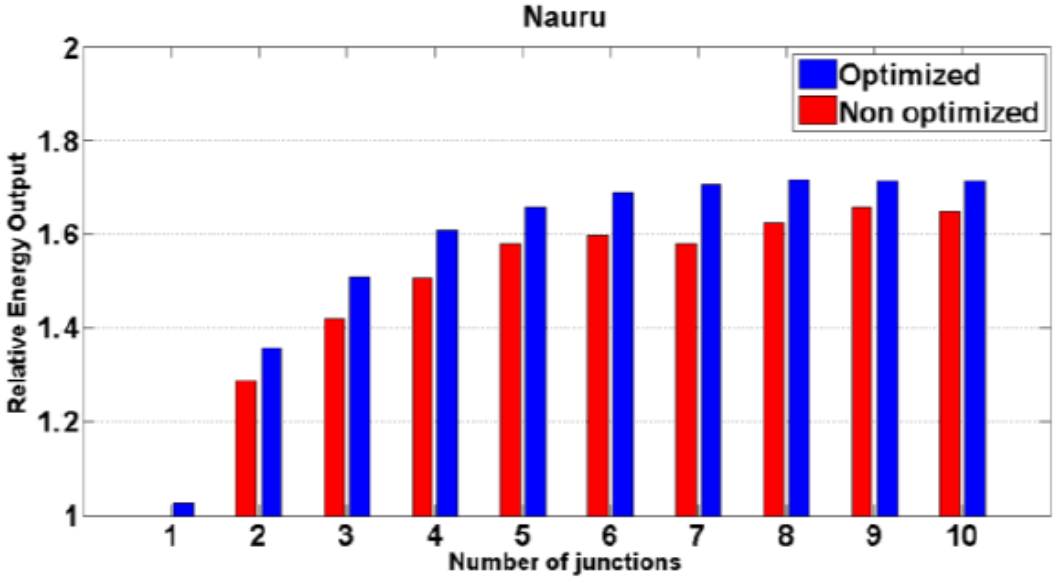


No benefit for fine-tuning

Can we do better?

Nauru (Pacific Islands)

- High solar resource
- Noticeable deviation in the spectral distribution of light

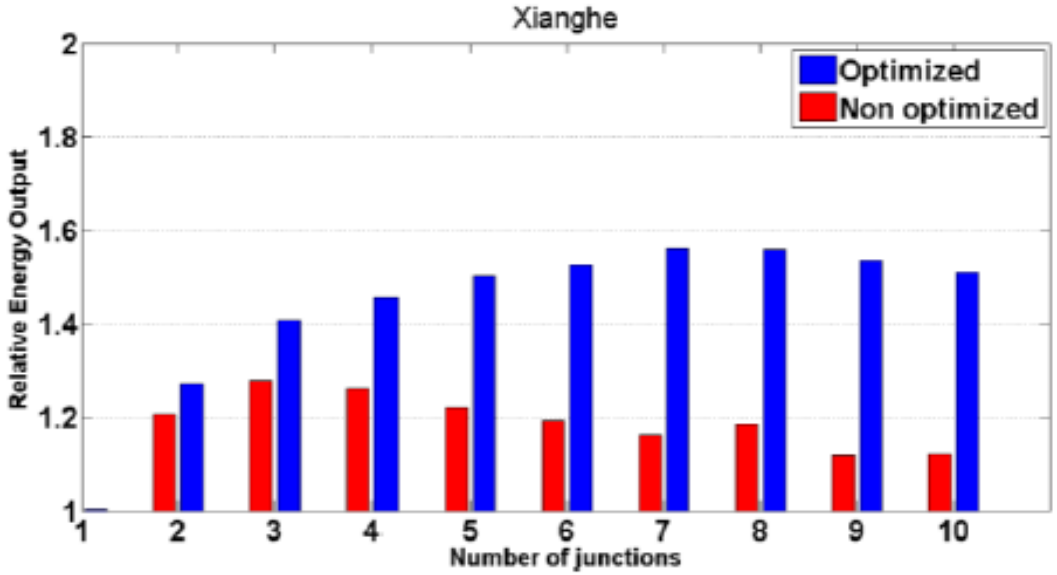


Moderate benefit for fine-tuning

Can we do better?

Worst case scenario: Xianghe (China)

- **Low solar resource**
- **Noticeable deviation in the spectral distribution of light**



Important benefit for fine-tuning

Conclusions

- **The use of MJ cells involving 4 subcells or more does not guarantee a higher annual energy output.**

- **The gap between the simulated annual energy output and the expected (theoretical) energy output grows steadily when the number of subcells increases in the stack, even at sites with the most favorable solar resource**

- **Benefit for fine-tuning of MJ cells largely depends on both the spectral distribution of light and the annual typical DNI of any particular site**

- **We suggest that conversion efficiency should not be considered as the sole indicator of the cell ability to convert light into electricity for MJ cells involving 4 subcells and more**