# Effects of Temperature Coefficients of Solar Cells on Grid Integration

Y. Riesen, C. Ballif, N. Wyrsch
yannick.riesen@epfl.ch / pvlab.epfl.ch

## Motivation

Solar cells are optimized for standard test conditions (STC, 1000 W m$^{-2}$, 25 °C, AM1.5g spectrum [1]). However, in real outdoor operation solar cells often operate at temperatures that are above 25 °C. Hence studying the temperature dependence of solar cell performance allows to assess the energy yield and its influence on grid integration.

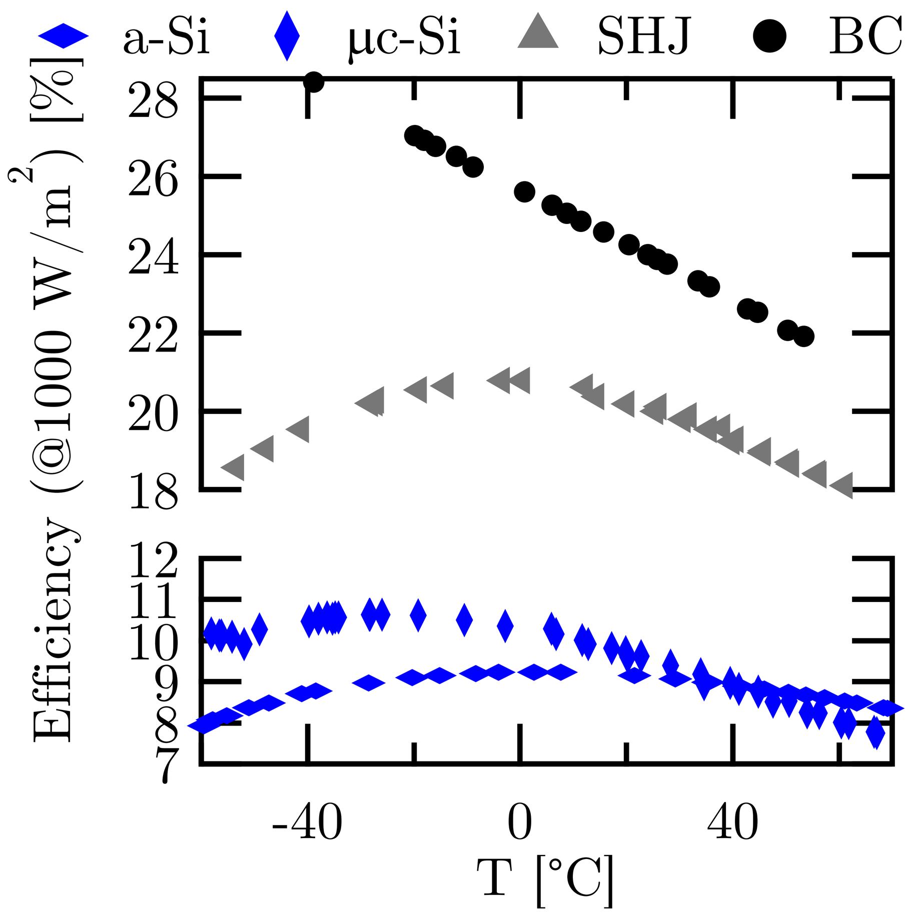
## Objectives

- Quantify the temperature coefficient ($TC$) and low irradiance performance impact on global energy production (maximizing kWh/Wp) of thin-film (TF) and crystalline silicon ($c$-Si) cells.
- Quantify the impact of cell technology with different $TC$ on grid integration of photovoltaic with a feed-in limit regulation.

## Cell type

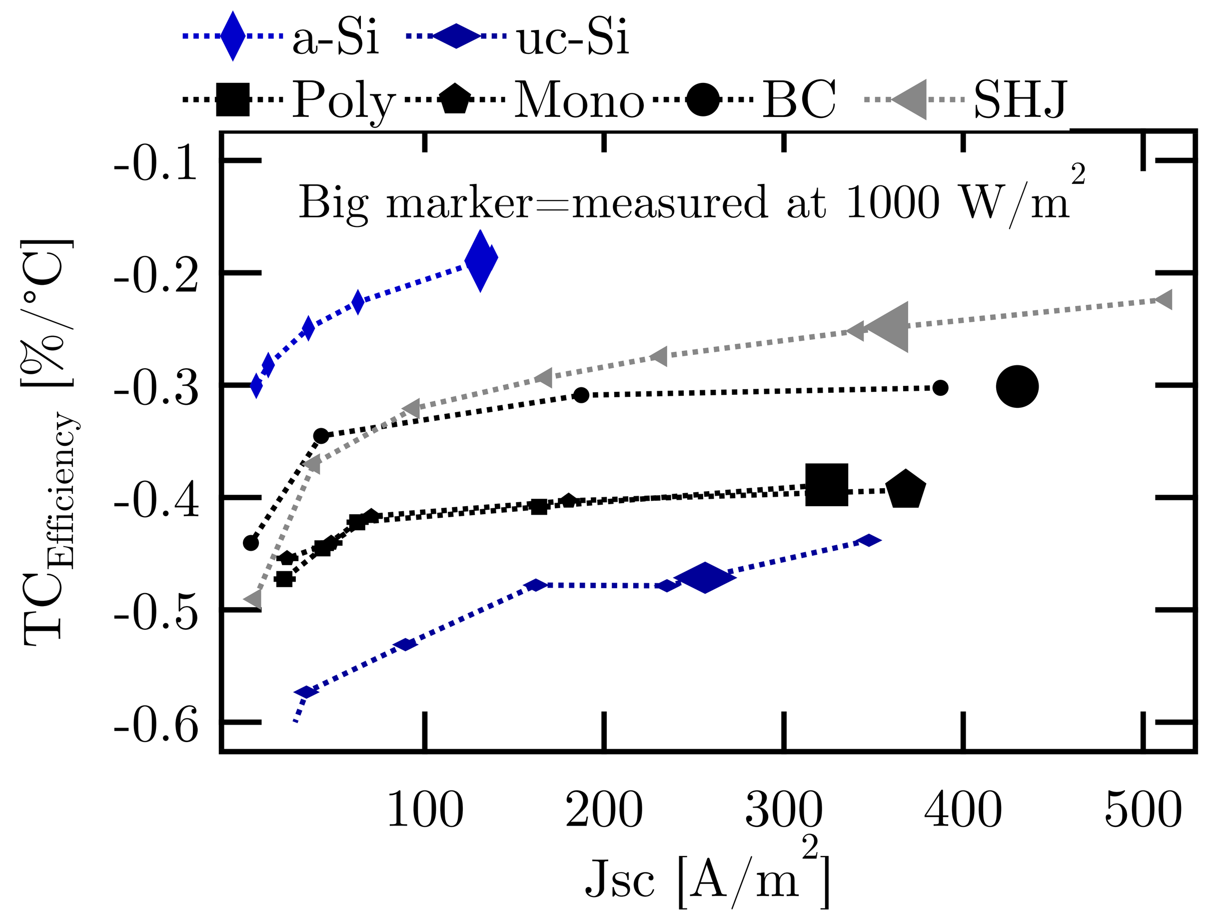
| Cell Type | a-Si | $\mu$c-Si | Poly | Mono | BC | SHJ |
|---|---|---|---|---|---|---|
| | Amorphous silicon cell (TF) | Microcrystalline silicon cell (TF) | Polycrystalline silicon cell | Monocrystalline silicon cell | Back-contacted monocrystalline cell | Silicon heterojunction cell |
| Efficiency | 9.1 % | 9.4 % | 15.5 % | 17.9 % | 24.0 % | 20.0 % |

## Temperature dependence




*Efficiency as a function of temperature*

- BC, Poly- and mono- $c$-Si solar cells have almost a linear temperature dependence in our measurement range.
- Thin-film silicon and SHJ cells have an efficiency maximum.




*$TC_{eff}$ as a function of the short-circuit current $J_{sc}$ (irradiance). The big markers correspond to STC conditions.*

- $a$-Si:H shows the best $TC_{eff}$, followed by the $SHJ$ cells. Those good values are mainly due to their maximum in the measurement range [2].
- The $TC$ increases slightly with irradiance. For cells with an efficiency maximum, this effect is stronger.

### TC at STC and energy yield

| | $TC_{efficiency}$ | Energy yield |
|---|---|---|
| a-Si | −0.19 %/°C | 1163 kWh/KWp |
| Poly | −0.39 %/°C | 1137 kWh/KWp |
| SHJ | −0.25 %/°C | 1148 kWh/KWp |

The energy yield is calculated according to the PV production simulation described below.

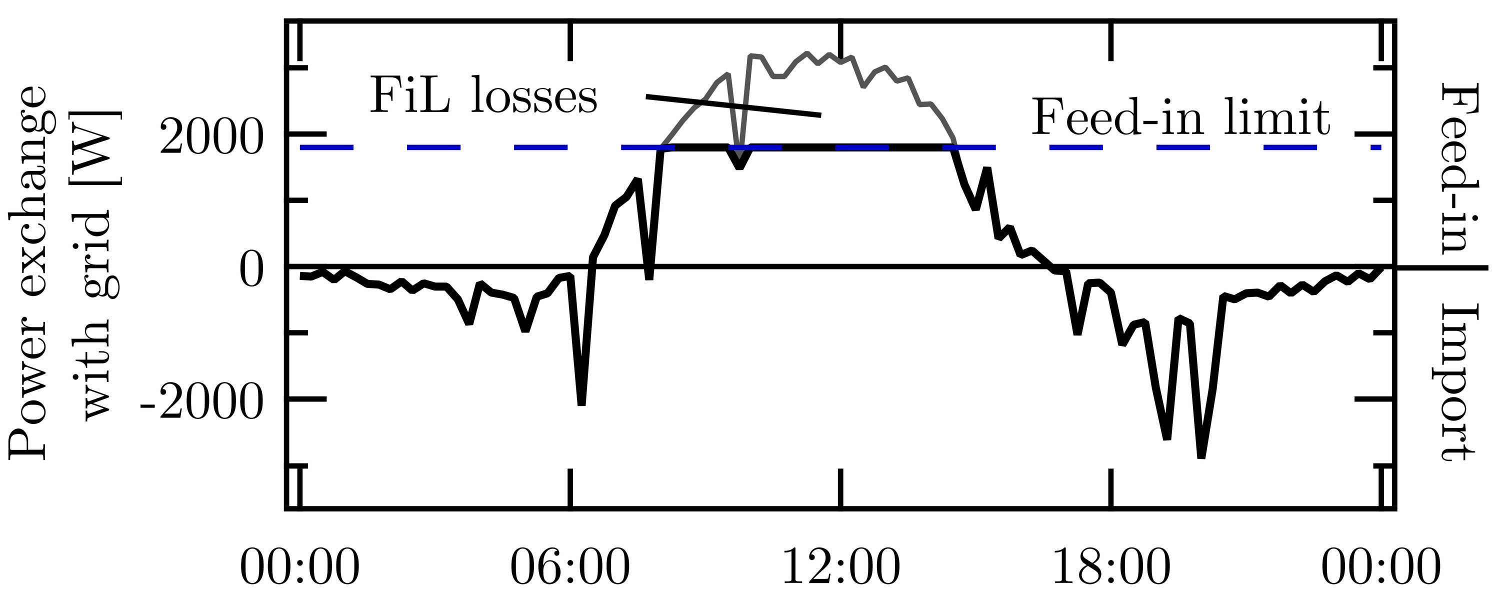
- As expected, cells with more favorable temperature coefficient have a better energy yield.
- The influence on the energy yield of low irradiance performance is lower than the influence of the temperature dependence.

**Question**

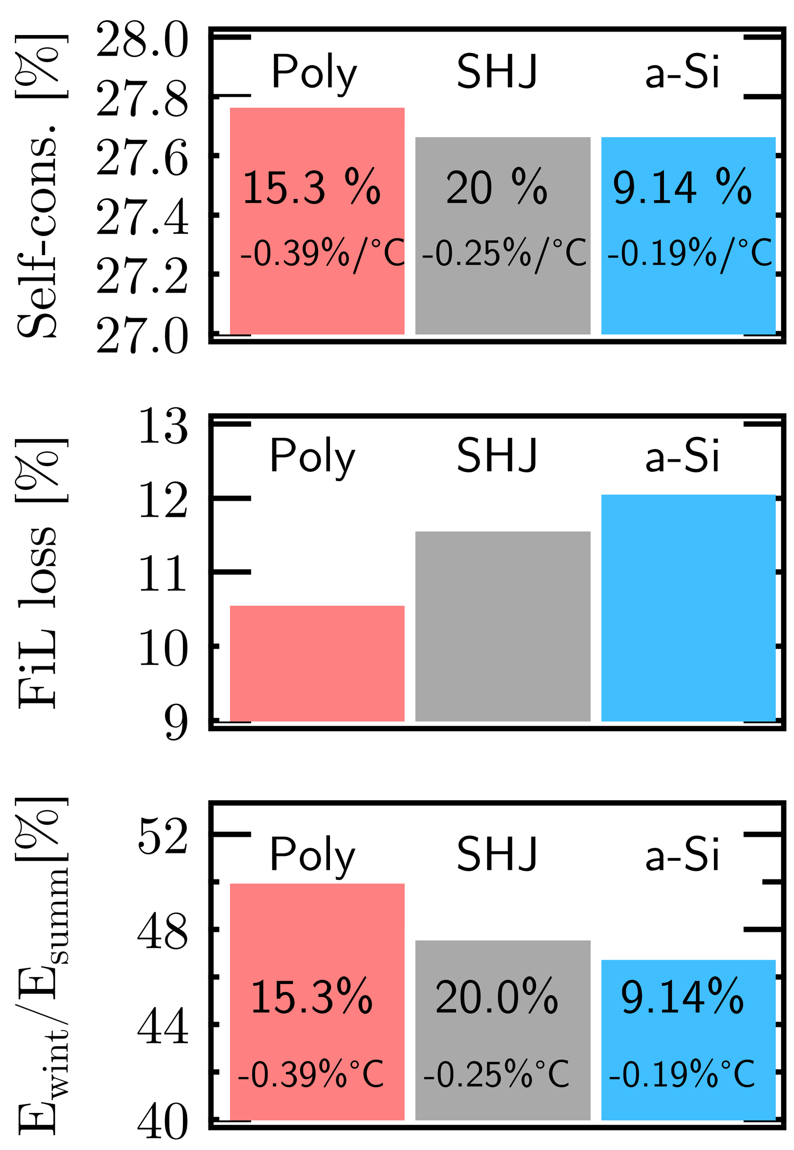
What is the influence of those $TC$ on grid integration parameters such as self-consumption, losses due to a feed-in limit and winter over summer production?

## Grid integration: Simulation input

- The PV-production was simulated by interpolating indoor I(V) measurement data of the cells at different temperatures and irradiances. Measured irradiation and module temperature data for one year in Neuchâtel was used as input.
- Electrical load of a family house.
- Yearly PV production = Yearly electricity consumption.
- Feed-in limit of 50 % of the nominal PV power. If injection (PV − load) is higher than this limit, the excess is loss (FiL loss).




## Grid integration: Results




As during high production period the module temperature is generally also high, the peak production is reduced for cells with low (non-favorable) $TC$.

- Self-consumption does not change significantly.
- The losses due the feed-in limit are reduced (1.5 %) with the $Poly$ cell with a non-favorable $TC$ (−0.39 %/°C).
- Same effect leads to 3.5 % higher winter over summer production ratio for cells with non-favorable $TC$.

## Conclusion

- The temperature dependencies of silicon heterojunction (SHJ) and thin-film silicon cells ($a$-Si:H and $\mu c$-Si:H) differs from standard crystalline silicon solar cells. This leads to better temperature coefficients for those cells ($e.g.$ −0.19 %/°C for $a$-Si:H solar cells).
- The type of solar cell technology has a limited (1 %-3.5 % in absolute) but not negligible impact on system output compared to other influences (such as inverter sizing or electricity management).

### Bibliography and acknowledgement

[1] IEC 60904-3: Photovoltaic devices - part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data, 2008.

[2] Yannick S. Riesen. *Energy Yield and Electricity Management of Thin-Film and Crystalline Silicon Solar Cells.* PhD thesis, EPFL, Lausanne, 2016.

This work was supported in part by EOS Holding, by the Swiss Federal Office of Energy under Grant SI/500750-01, by the CTI (SCCER FURIES) and Swisselectric Research (DURSOL project, www.dursol.ch).