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# Solar energy meteorology: A Finnish-Nordic perspective

Research Professor
Anders Lindfors
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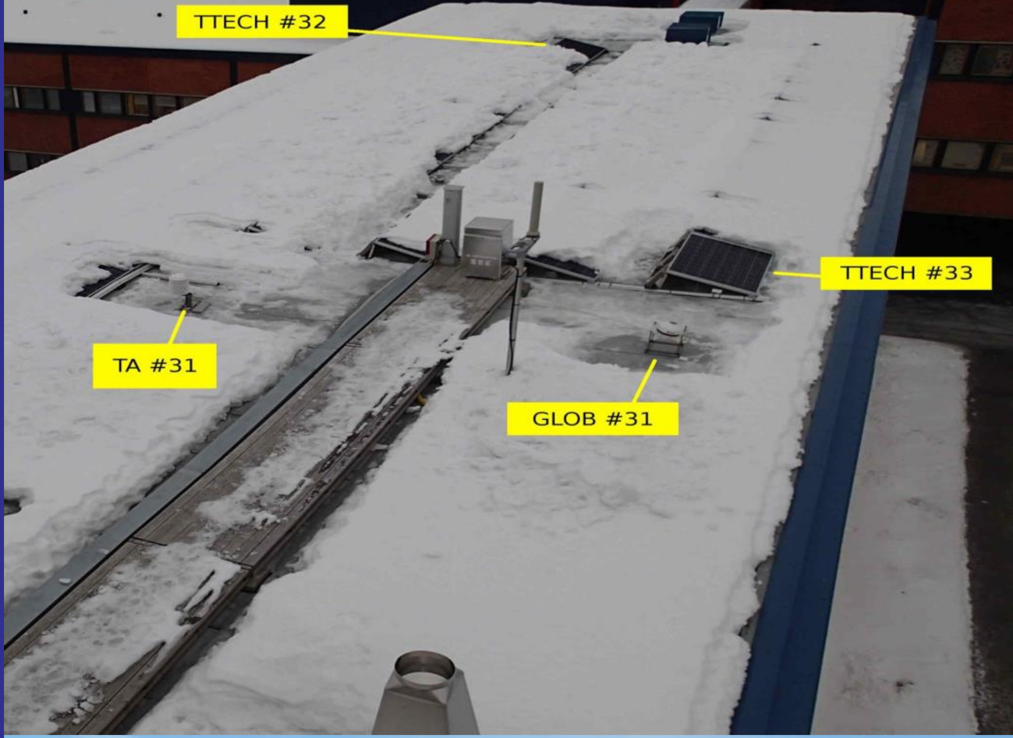


# Grid-connected solar power capacity in Finland

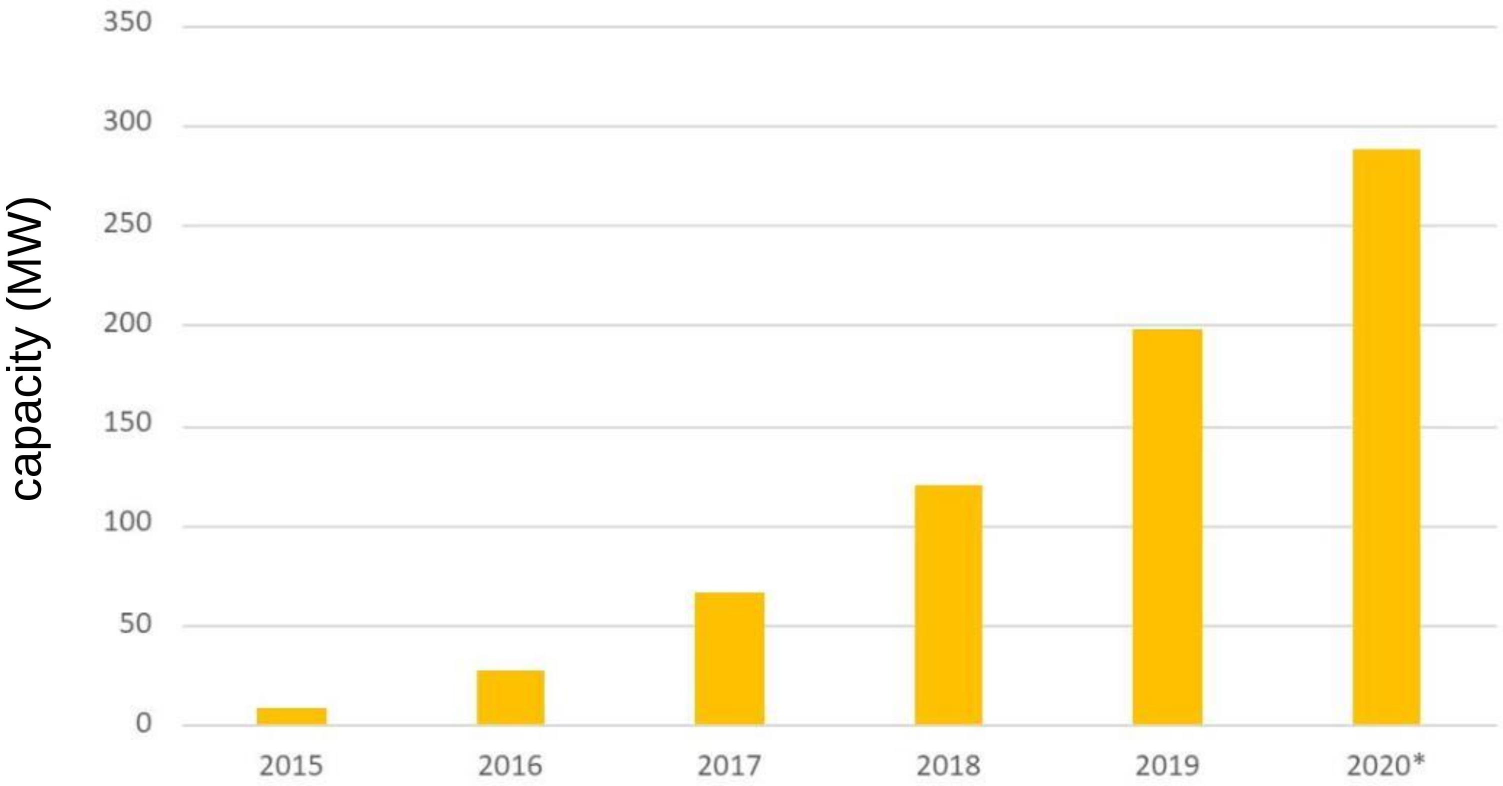


Figure courtesy: Energiavirasto

# Finnish electricity sources in 2021

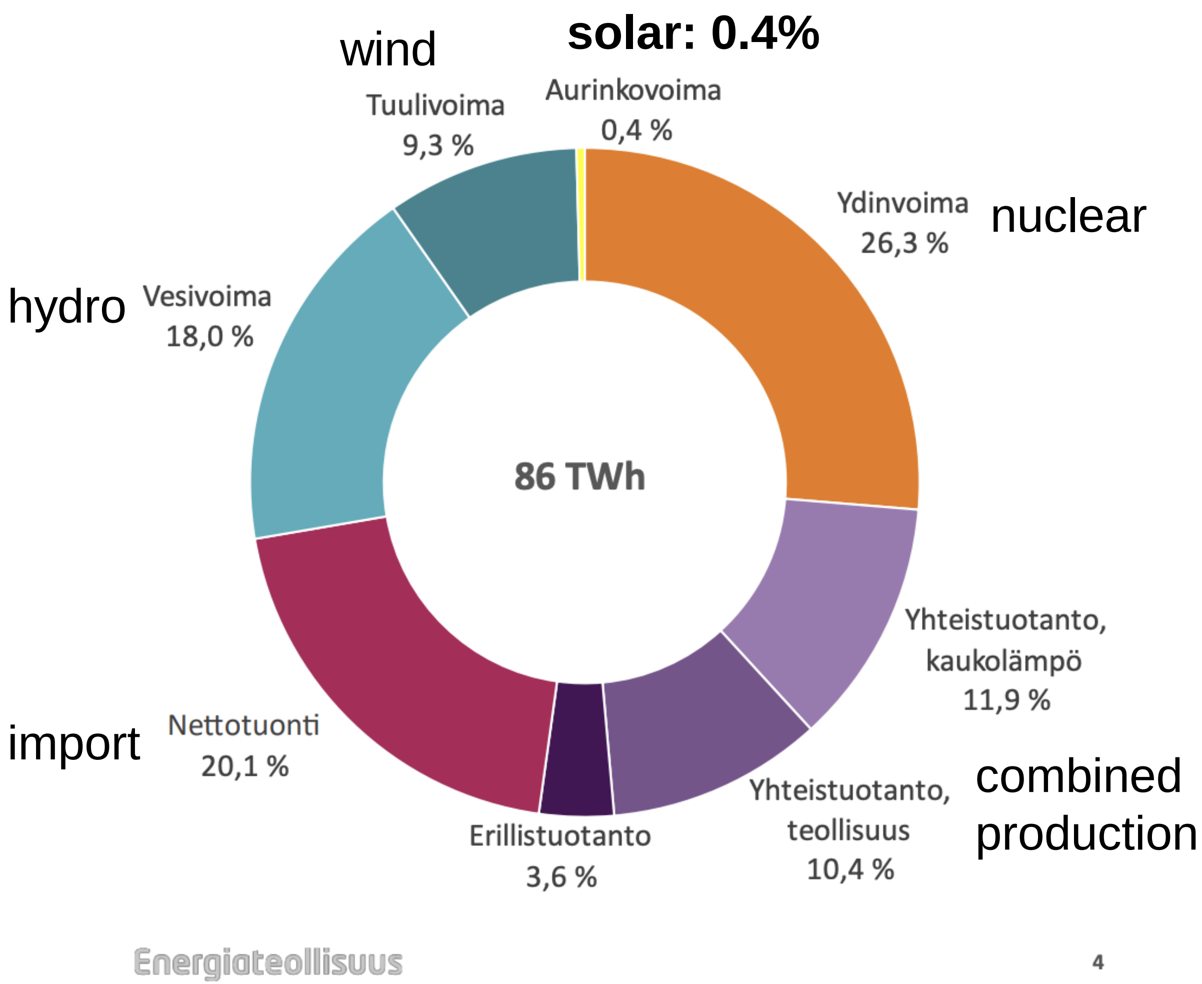




Figure courtesy: Energiavirasto

# Energy transition trends

- **Variable renewable energy on the rise**
- **Energy consumption is also weather-dependent**
- **Weather forecasts are of increasing importance**
- **Importance of understanding weather-related uncertainty**
- **Information flow, big data & IoT**
- **Modern algorithms (e.g., machine learning)**

**The carbon-neutral energy system needs weather forecasts!**

https://www.ilmastokatsaus.fi/2022/03/21/ilmastokatsaus-digilehti-helmikuu-2022/

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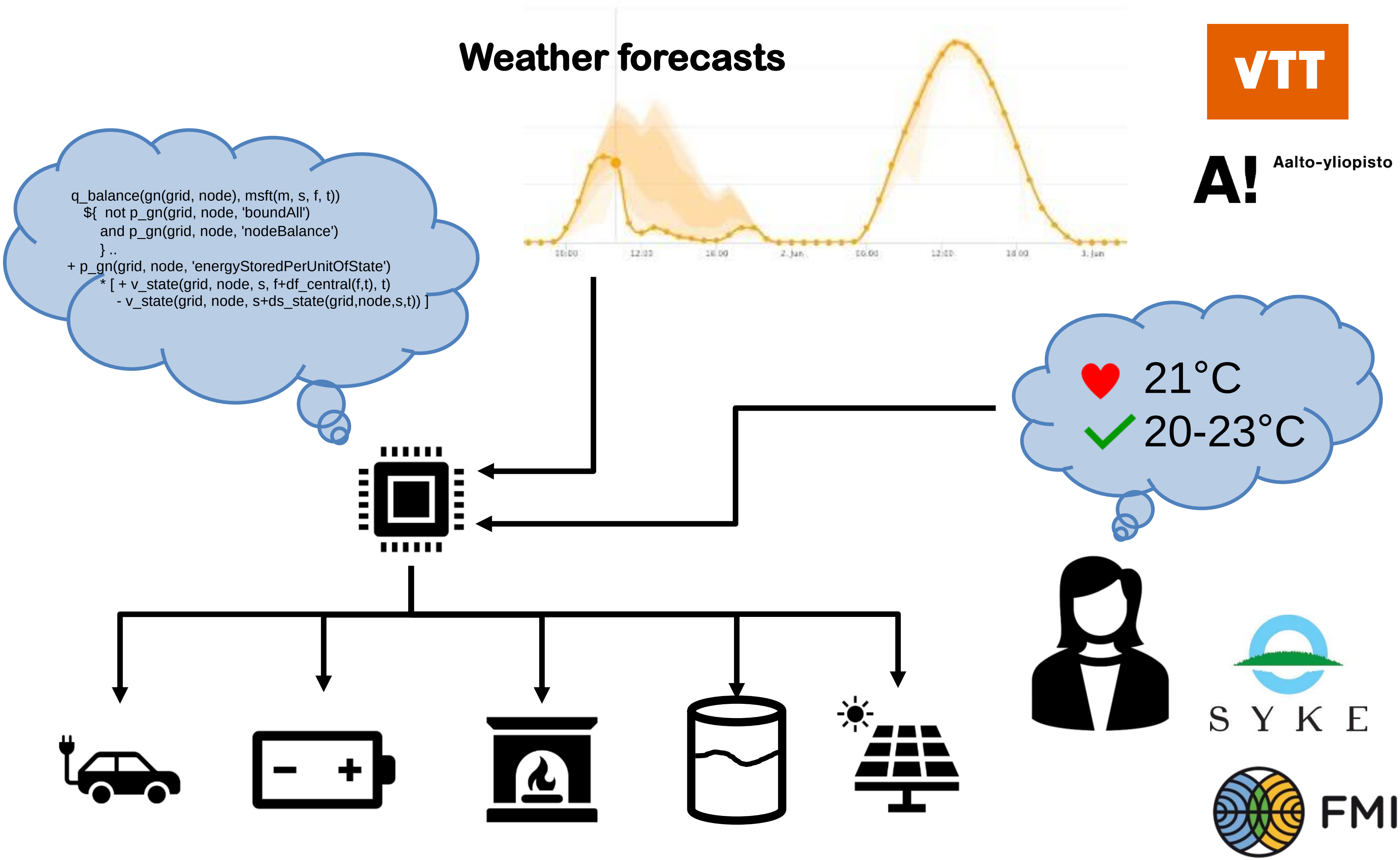
# EasyDR – easy demand-respons in households



# Solar photovoltaic (PV) electricity production and its dependence on meteorological conditions

# FMI's solar PV power plants

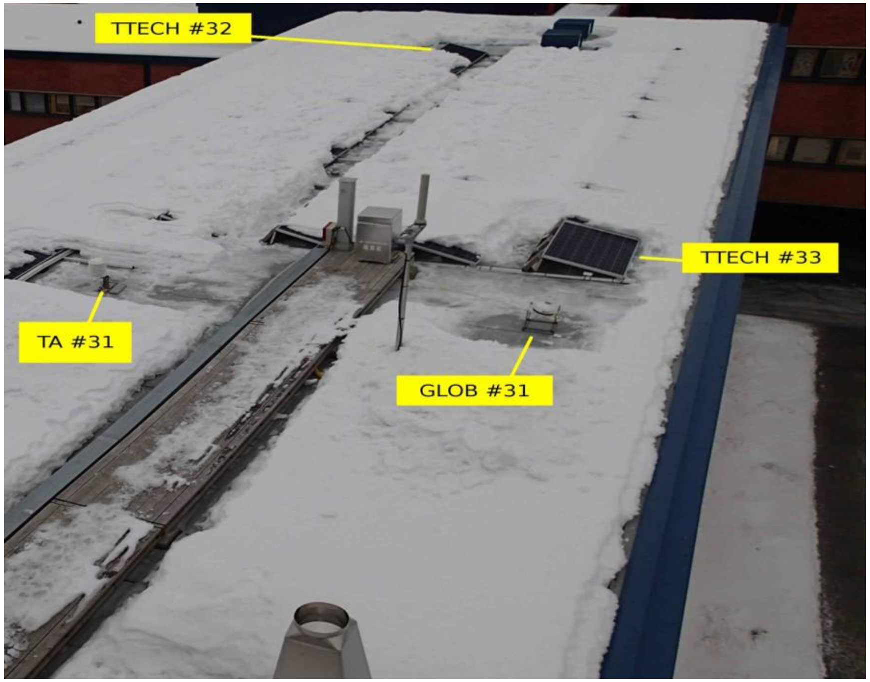
**Helsinki, 2015-**

- 21 kWp installation
- 84 panels, 250 W each
- facing: South-East
- inclination: 15 degrees
- measurements
  - electricity production, 2 strings
  - panel temperature
  - plane-of-array global solar irradiance
  - solar direct, diffuse, global radiation
  - wind and temperature

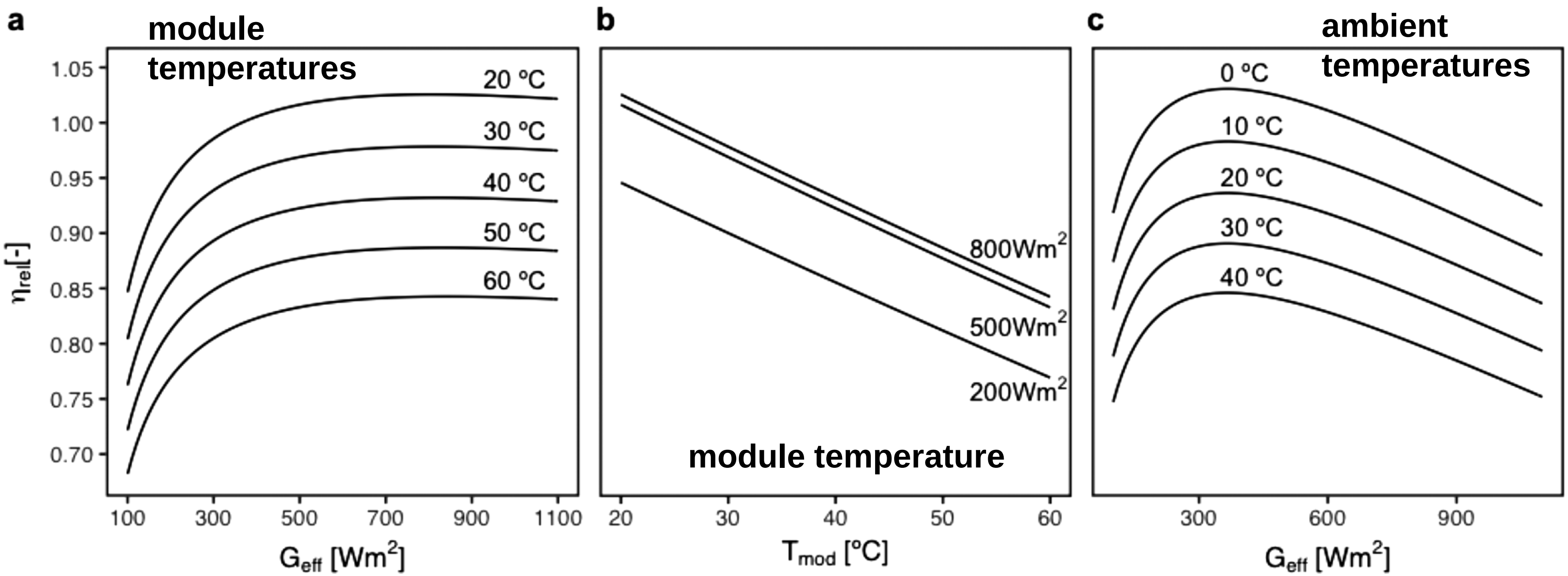
# FMI’s solar PV power plants

**Kuopio, 2016-**

- 20,3 kWp installation
- 82 panels, 260 W each
- facing: South-West
- inclination: 15 degrees
- measurements
  - electricity production, 2 strings
  - panel temperature
  - plane-of-array global solar irradiance
  - solar direct, diffuse, global radiation
  - wind and temperature



# Solar PV effeciency: dependence on irradiance and temperature




$G_{eff}$ is the solar irradiance impinging on the PV panels

$\eta_{rel}$ is the relative energy conversion efficiency (if it is one, the panels will produce at nominal power)



Figure from Urraca et al (2018). https://doi.org/10.1016/j.solener.2018.10.065

# Modelling the PV output: Huld model (JRC, PVGIS)

1. Estimation of the solar radiation components impinging onto the PV module surface. *Transposition model, e.g. Perez et al. (1990).*

2. Calculation of reflection losses of the PV module surface and the amount of radiation eventually absorbing into the PV panel. *The more inclined solar rays will be more effectively reflected off the surface.*

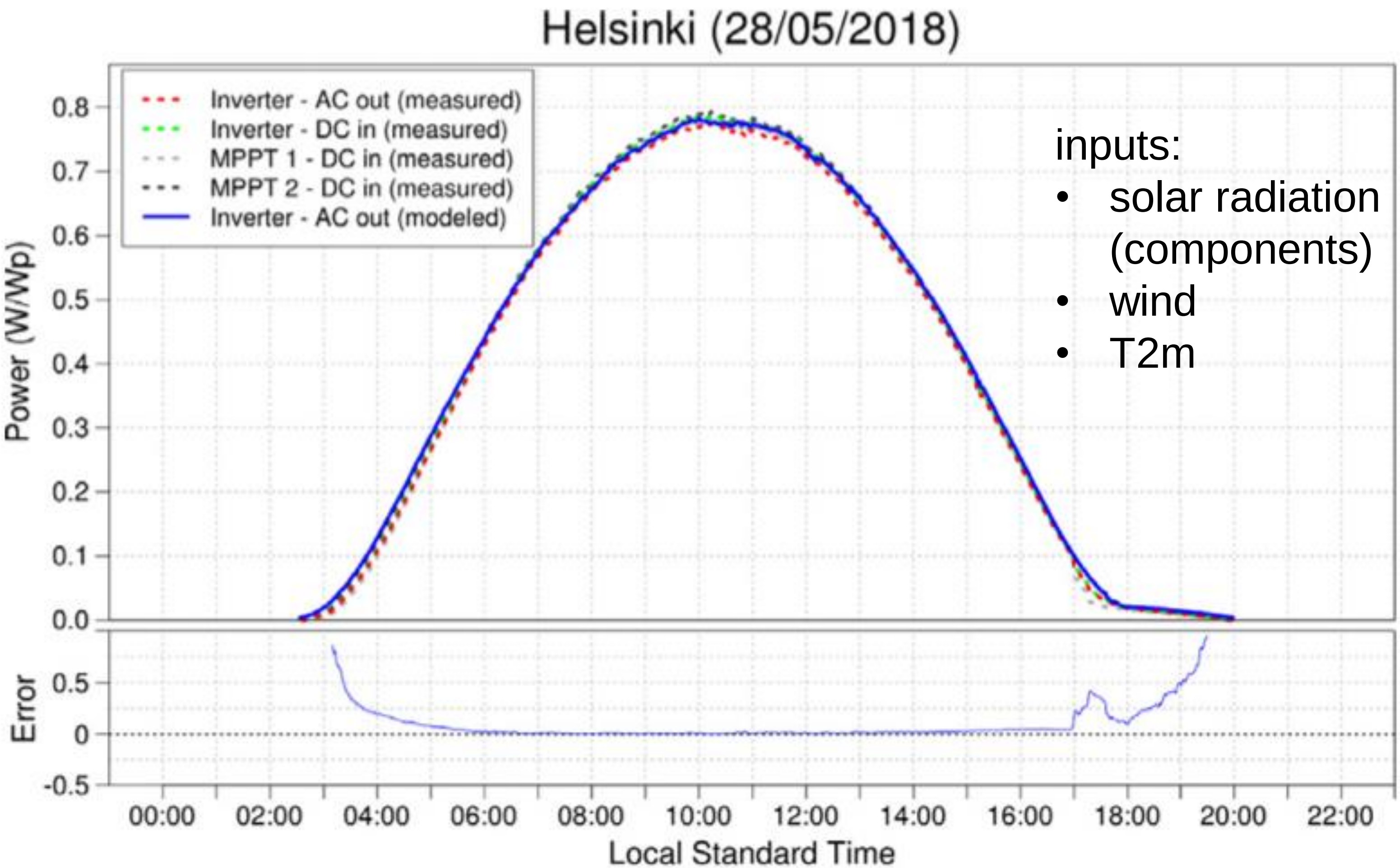
3. Modeling of the PV module temperature. *Taking into account air temperature, solar radiation, wind.*

4. Conversion of the effective solar radiation and PV module temperature into PV electricity output. *Following the relationships shown in previous slide.*



See also Böök et al. (2020). https://doi.org/10.1016/j.solener.2020.04.068

# Modelled and measured PV output




inputs:

- solar radiation (components)
- wind
- T2m

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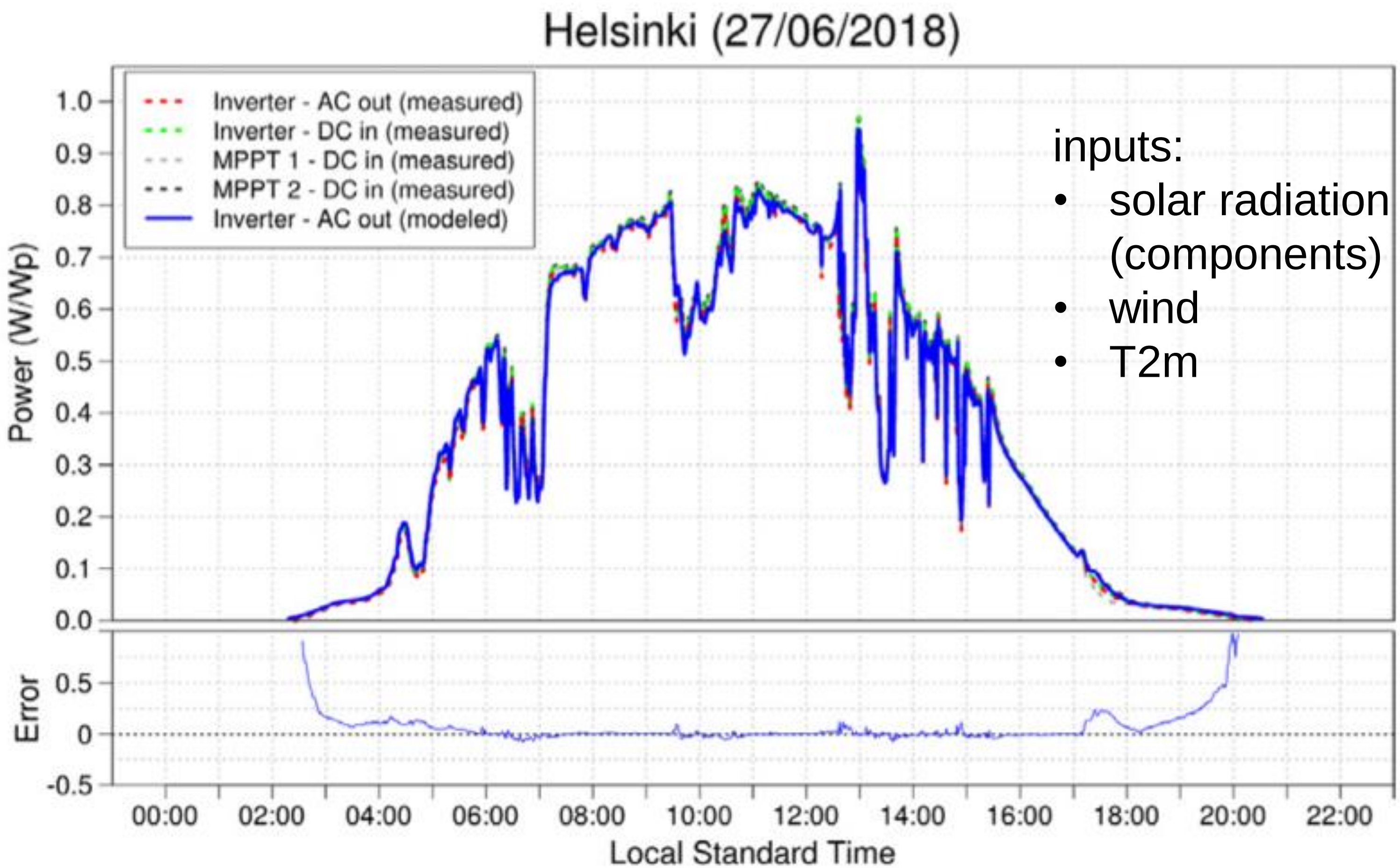
From Böök et al. (2020). https://doi.org/10.1016/j.solener.2020.04.068

# Modelled and measured PV output




inputs:

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From Böök et al. (2020). https://doi.org/10.1016/j.solener.2020.04.068

# Climatological solar energy resource – solar radiation climate

# Where and when can you find the maximum of the daily solar radiation at the top-of-the-atmosphere?

The answer is: at the South Pole, on the day of the summer solstice

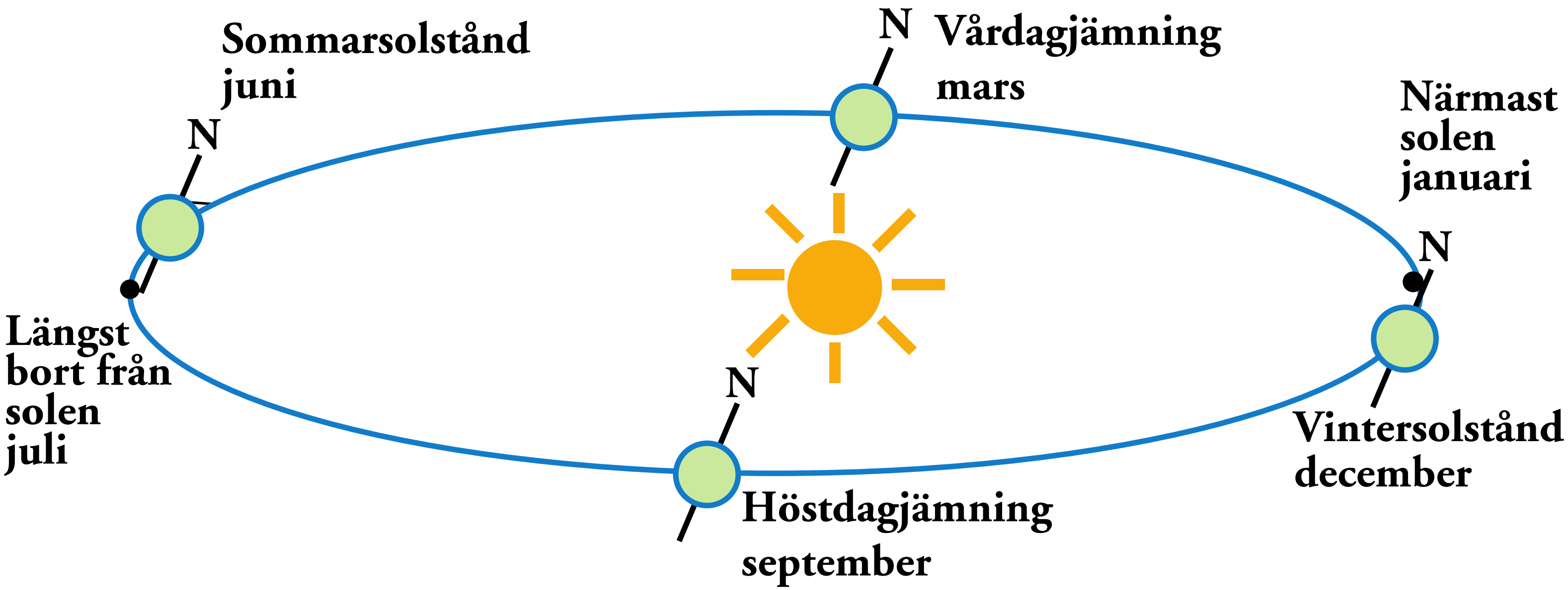


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**Figure:** Josefsson, W., Solstrålning, SMHI, Faktablad nr. 37, 2007.

# Solar radiation climatology: Helsinki & Rostock

**Probability of sunny summer day**

Hampuri: ~27%

Berliini: ~28%

Frankfurt: ~36%

Göteborg: ~35%

Norrköping: ~34%

Vaasa: ~40%

Helsinki: ~43%

**Source:** CMSAF, Sunny Days, EUMETSAT

EUMETSAT CLARA-A1 (polar orbiting)

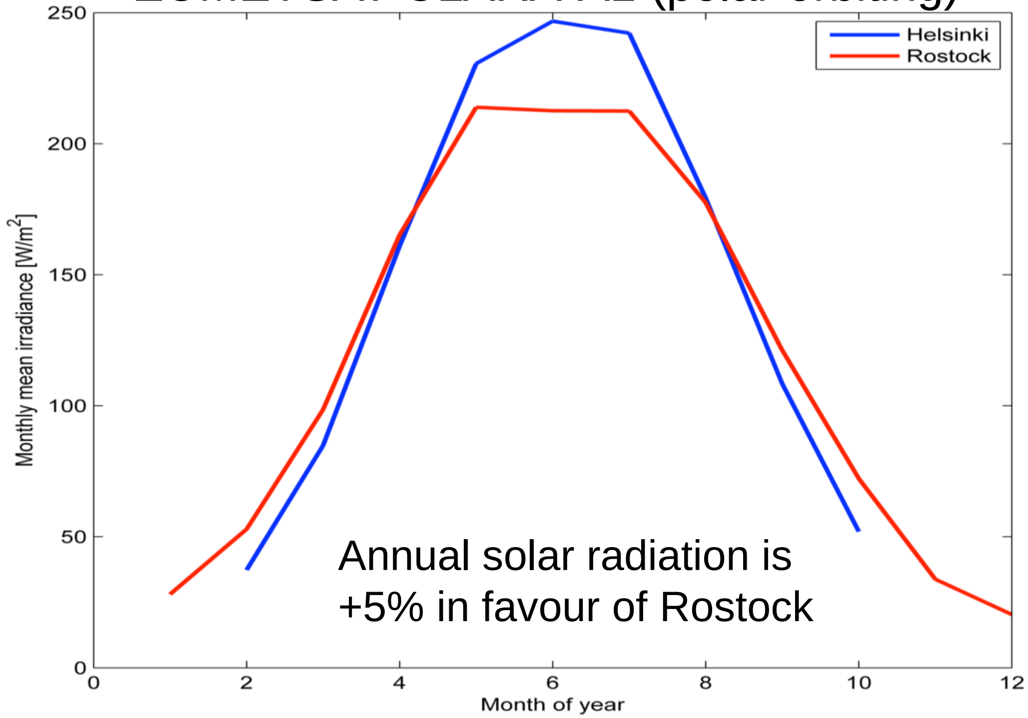


Figure from Lindfors et al. (2014).
https://helda.helsinki.fi/handle/10138/135830

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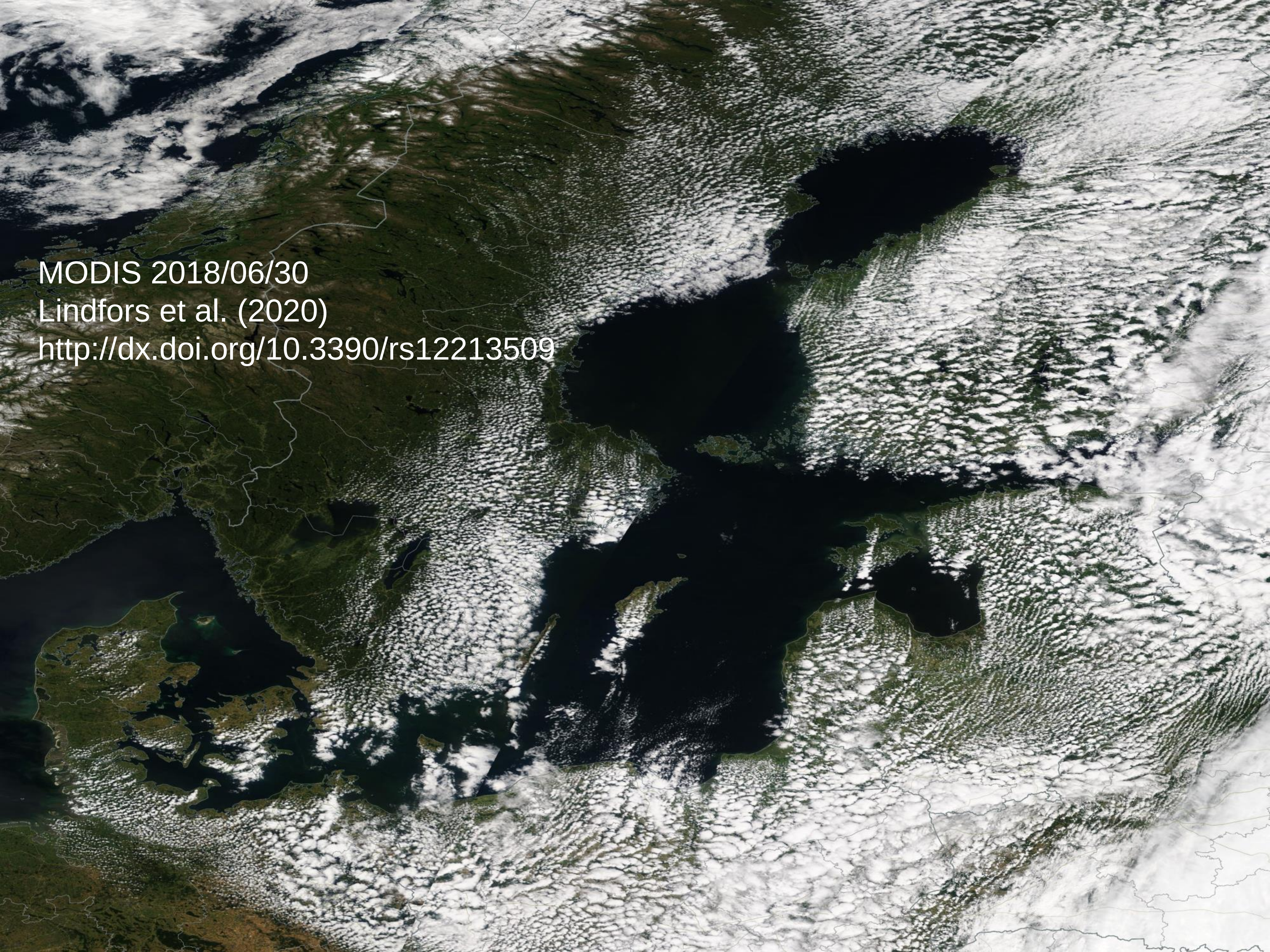
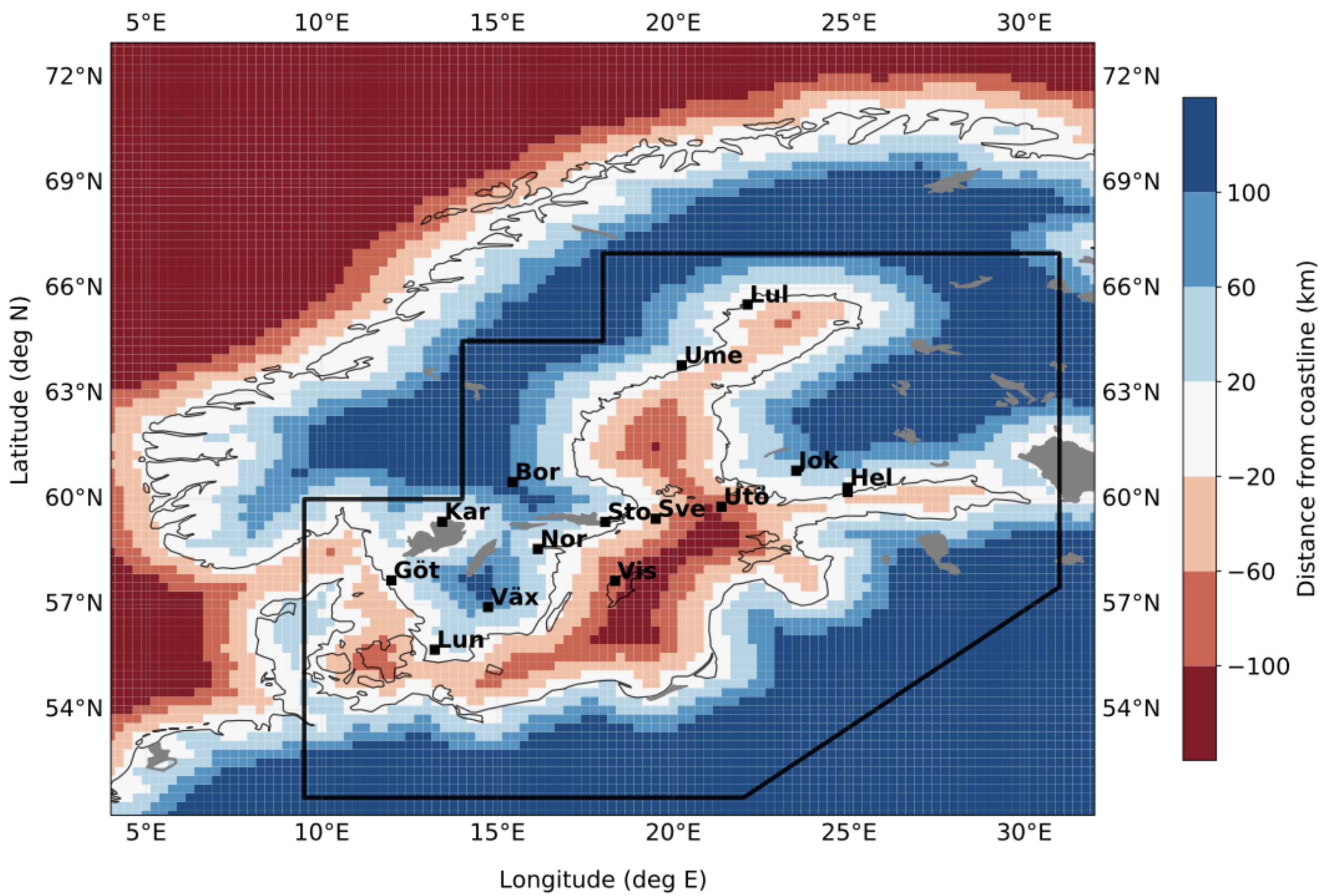

MODIS 2018/06/30
Lindfors et al. (2020)
http://dx.doi.org/10.3390/rs12213509

# Solar radiation climate vs. distance to coastline in the Baltic

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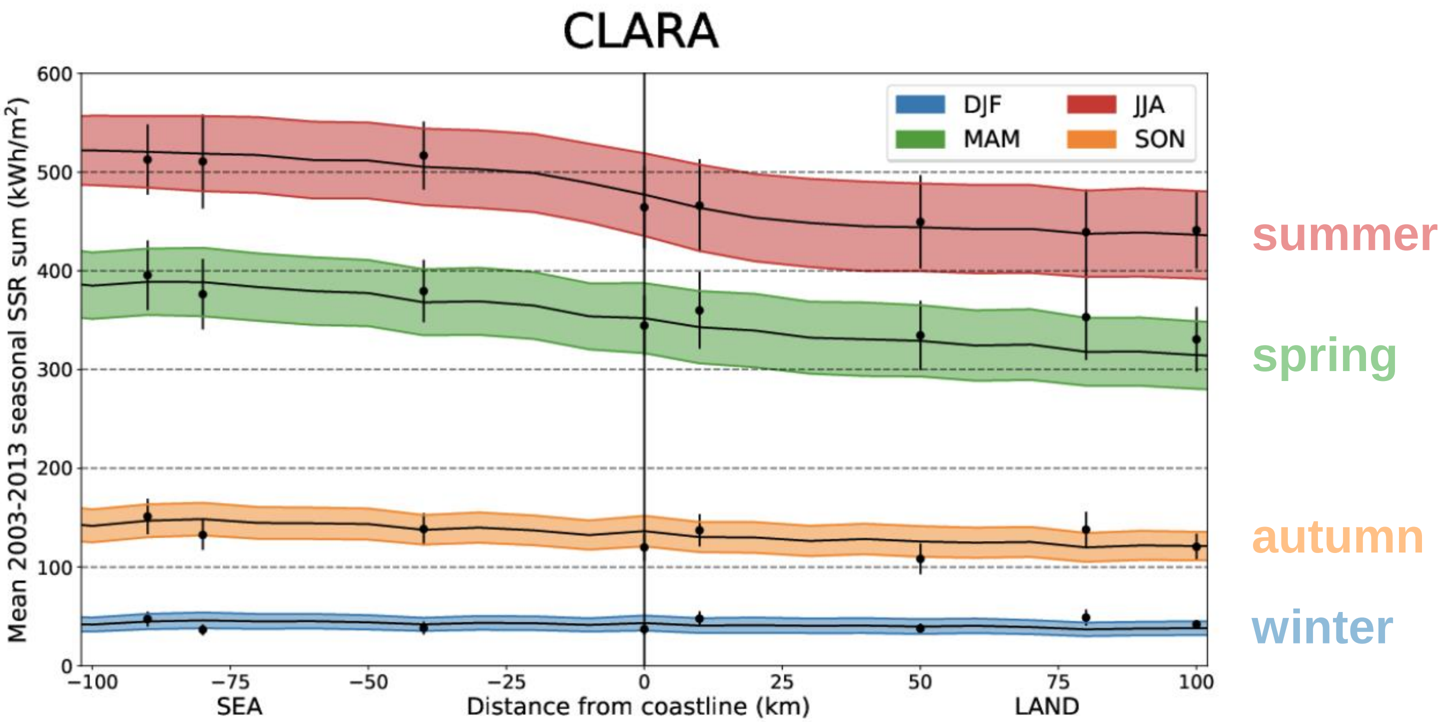
From Lindfors et al. (2020). http://dx.doi.org/10.3390/rs12213509

# Land-sea contrast in solar radiation: CMSAF CLARA and station data




**Example, coastline vs. 50 km inland:**

✧ difference ca 0,5 kwh/m2

✧ accumulated MJJ difference = 45 kWh/m2
5—6 sunny days more during these 3 months

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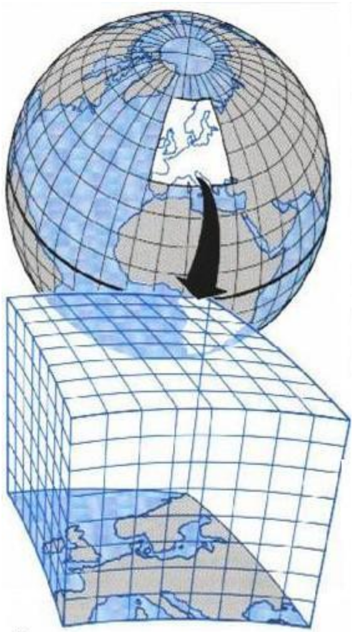
From Lindfors et al. (2020). http://dx.doi.org/10.3390/rs12213509

# Solar forecasts

# Solar electricity production forecasts



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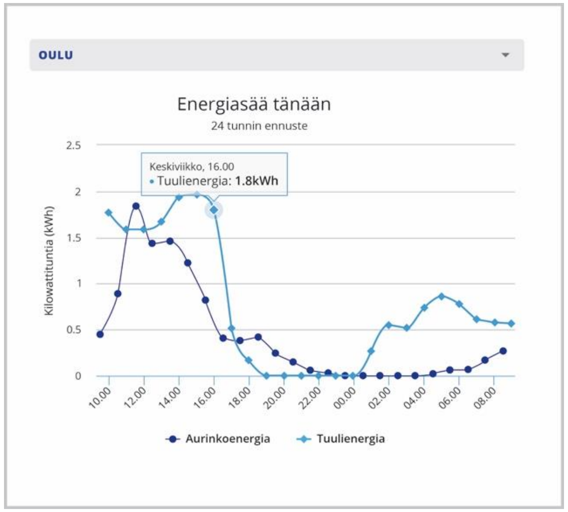
http://www.bcdcenergia.fi/energiasaa/




**Numerical Weather Prediction** *contains information relevant to renewable energy production*

**Conversion algorithm** *translates meteorological information into energy production*

**Energy Weather Forecast** *gives predicted energy production hour by hour*

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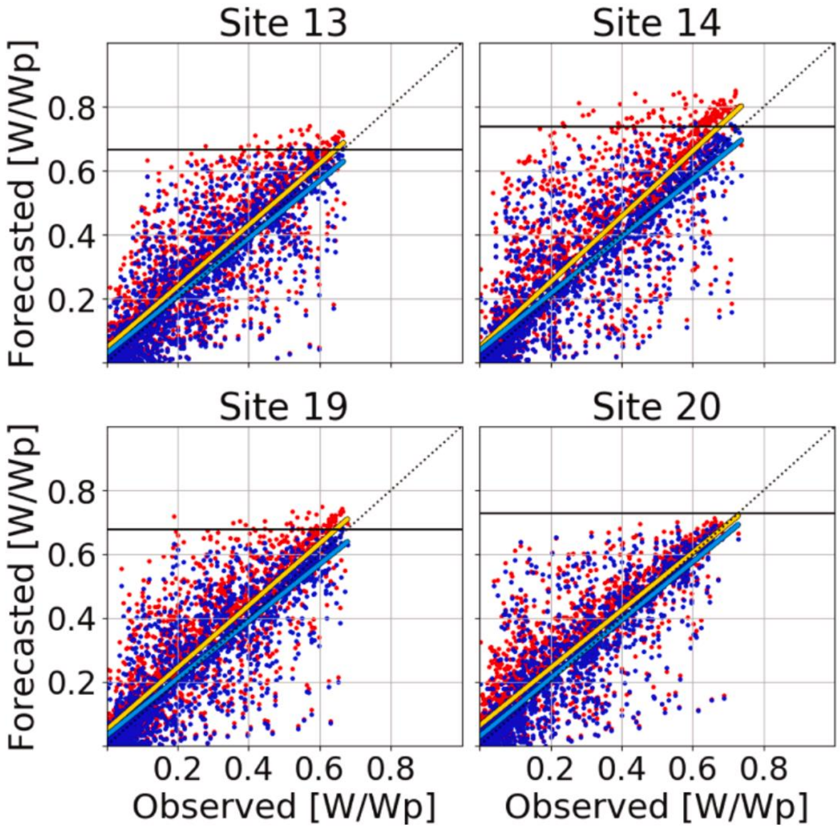
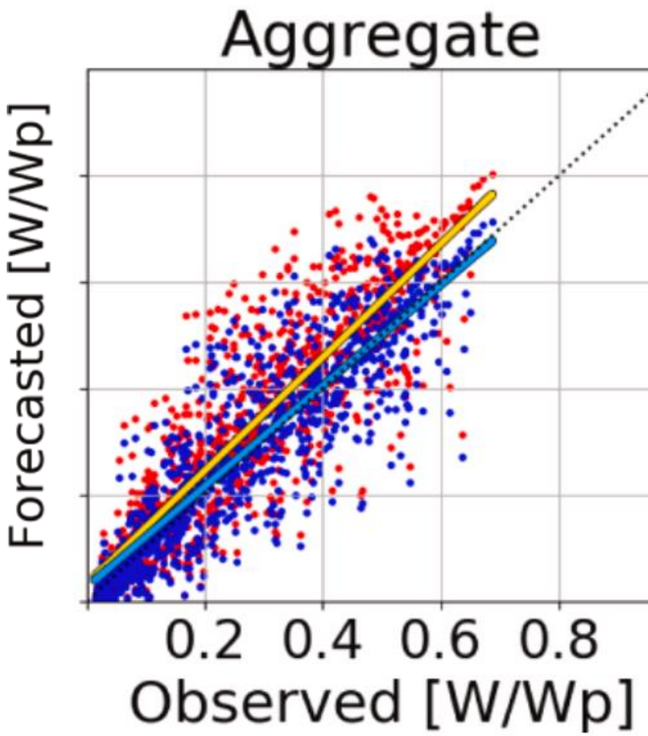
BCDC ENERGY

# Solar electricity production forecasts

Hourly day-ahead forecast, MEPS deterministic, 23 sites somewhat concentrating around Helsinki

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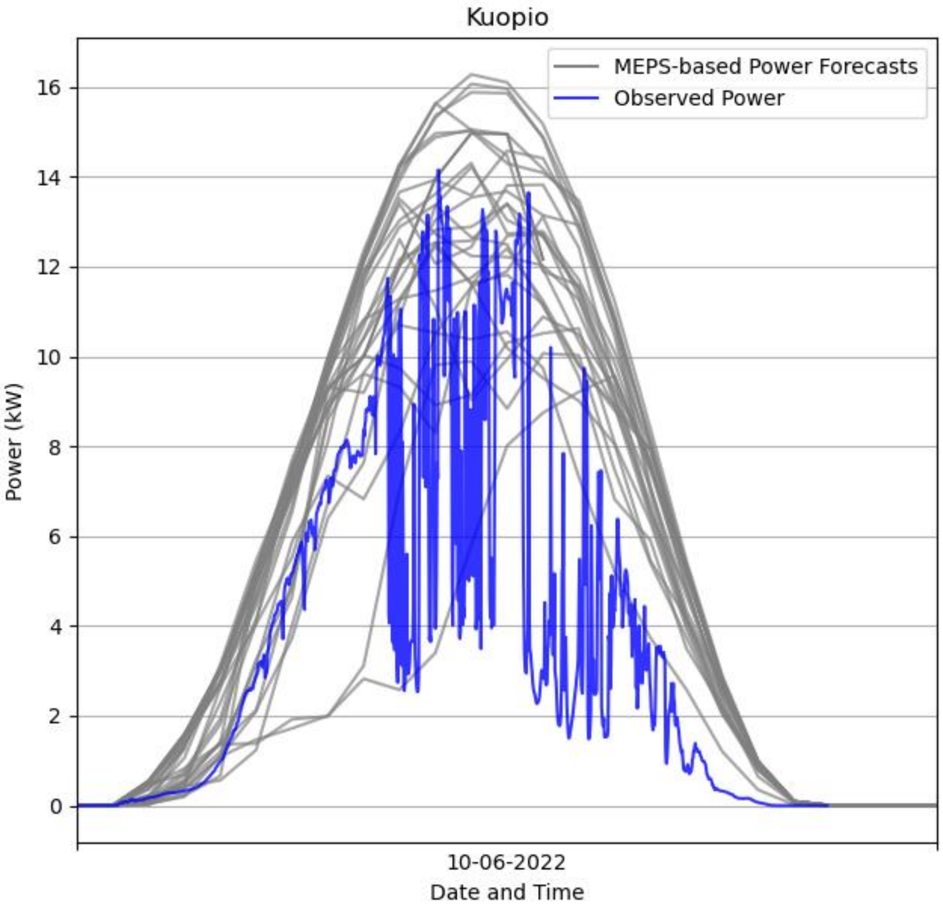
From Böök & Lindfors (2020). https://doi.org/10.1016/j.solener.2020.10.024

# MEPS-based probabilistic forecast of solar electricity production

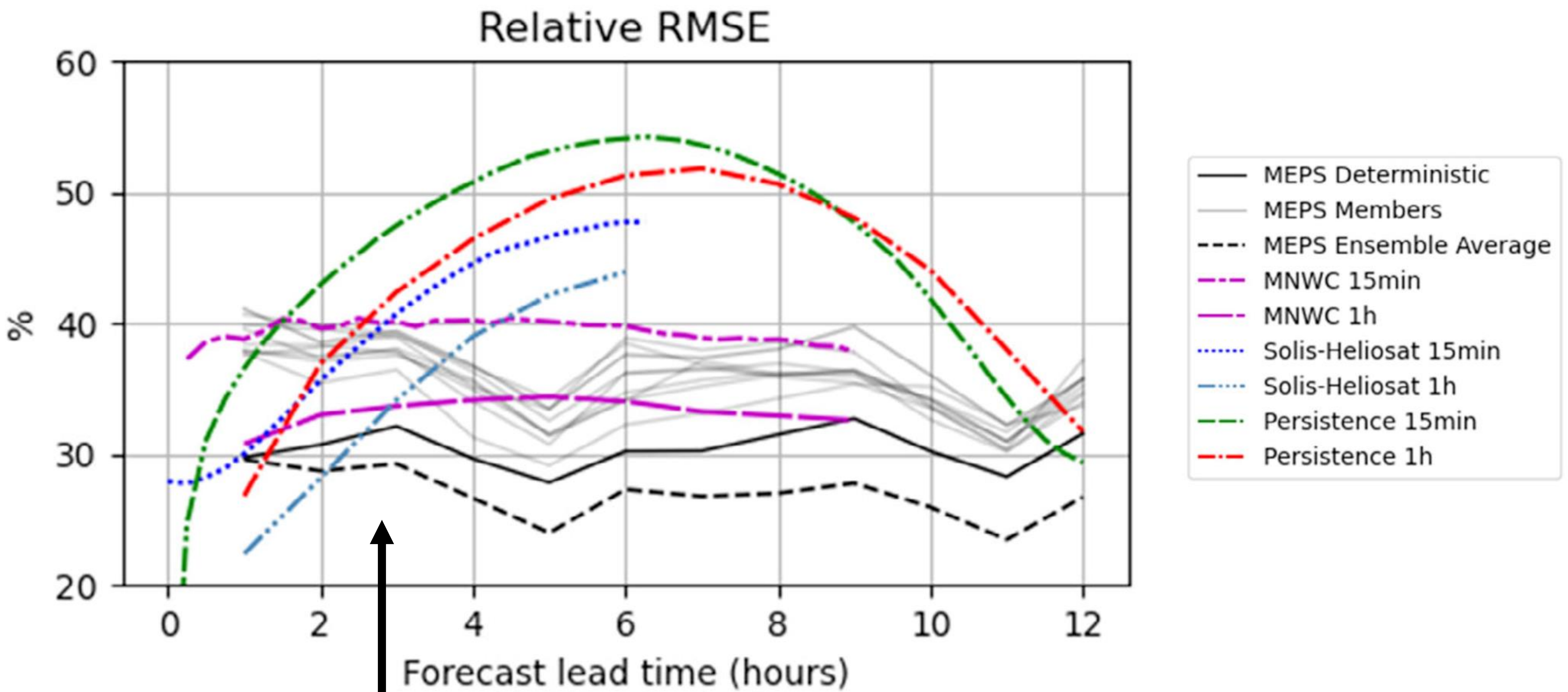
- Example day: 10 June 2022
- FMI's Kuopio solar PV plant
- **30 MEPS members (grey)**
- origin time: 2022-06-09 12:00
- **Observed PV output (blue)**
- varying convective cloudiness over region of interest


Figure: NASA Worldview




*Work in progress*. Figure by Viivi Kallio-Myers.

# MEPS and MetCoOp Nowcasting solar radiation forecasts




Ca +2-3h is where MEPS/deterministic & MNWC becomes better than satellite-based solar radiation forecast (Solis-Heliosat 1h)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From Kallio-Myers et al. (2022). https://doi.org/10.1002/met.2051

# To conclude

- weather forecasts are needed to facilitate the energy transition
  - Domestic hot water control utilizing solar PV forecasts demonstrated ~40% monetary savings compared to baseline (Knuutinen et al., 2021; https://doi.org/10.1016/j.renene.2021.05.139)
- accurate modelling of solar electricity production can help monitor performance of solar power plants
  - Kuopio winter/spring 2018 suffered losses because of snow cover equivalent to 1.5 months of summer time production (Böök et al., 2020; https://doi.org/10.1016/j.solener.2020.04.068)
  - Also maximum power tracking algorithm fault was detected
- MEPS-based probabilistic solar electricity production forecasts are work in progress
- MEPS solar radiation forecasts behave well throughout the forecast (Kallio-Myers et al., 2022; https://doi.org/10.1002/met.2051)