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- > Digital Twin for Weather induced and geophysical extremes consists of two main components:
 - Global continuous digital twin component (ECMWF)
 - On-demand extremes digital twin (DE_330_MF project consortium led by Météo-France)

ECMWF

Impact: PV production

- > Photovoltaic (PV) production is given in kWh
- > NWP models produce SW \downarrow (at the surface)







Image from iea.pvps.org

CECMWF

Data

- PV production data from
 Energinet.dk the Danish TSO
- ➤ ... from 2017 onwards
- > 15 minute resolution
- ➢ 98 Danish municipalities (GDPR)
- Corresponding we have hourly SW↓ (or GHI) observations from 26 stations, and from the operational model





DESTINATION EARTH PV performance ratio

- > PV production is given in kWh
- > NWP models produce SW \downarrow (at the surface)
- For solar energy SW↓ is referred to as Global Horizontal Irradiance – or *GHI*
- ➤ Global tilted irradiance: GTI
- ➤ Direct and diffuse tilted irradiance: DrTI and DfTI
- > Produced DC power: P_a
- > Nominal PV production at 1000 W/m² (*GHI*_{ref}), 25°C (T_{ref})
- > DC performance ratio: PR_{DC}

$$PR_{DC} = \frac{P_a \ GHI_{ref}}{(DrTI \ k_{shadow} \ (\theta_0, \varphi_0) \ k_{inc} \ (\Theta) + DfTI) \ P_{nomG} \ (1 - \beta \ (T - T_{ref}))}$$







DESTINATION EARTH Evolution of nominal PV production 12000 2018 2019 10000 Solar yield [kwh/h] 8000 6000 4000 From Vejen 2000 municipality 800 900 300 400 500 600 700 0 100 200Global irradiation [Wh/h/m²] P_a GHI_{ref} $PR_{DC} = \frac{1}{(DrTI \, k_{shadow} \, (\theta_0, \varphi_0) \, k_{inc} \, (\Theta) + DfTI) \, P_{nomG} \, (1 - \beta \, (T - T_{ref}))}$ **C**ECMWF 6

CECMWF







From Vejen municipality

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Evolution of nominal PV production





From Lolland municipality

Solar irradiance components

- $DrTI = DNI \cos(\Theta)$
- DNI: Direct Normal Irradiance
- Θ: The angle between the solar direction and the tilted
 PV surface normal





$$PR_{DC} = \frac{P_a \ GHI_{ref}}{(DrTI \ k_{shadow} \ (\theta_0, \varphi_0) \ k_{inc} \ (\Theta) + DfTI) \ P_{nomG} \ (1 - \beta \ (T - T_{ref}))}$$

Solar irradiance components



- $DrTI = DNI \cos(\Theta)$
- DNI: Direct Normal Irradiance
- Θ: The angle between the solar direction and the tilted
 PV surface normal
- DNI implemented in HARMONIE-AROME as an output variable by Rontu et al.



$$PR_{DC} = \frac{P_a \ GHI_{ref}}{(DrTI \ k_{shadow} \ (\theta_0, \varphi_0) \ k_{inc} \ (\Theta) + DfTI) \ P_{nomG} \ (1 - \beta \ (T - T_{ref}))}$$

Solar irradiance components

Key issue: The direct solar irradiance measured is not the same as that modelled in an NWP model, nor the direct solar irradiance received by a PV module!



$$P_{a} GHI_{ref}$$

$$PR_{DC} = \frac{P_{a} GHI_{ref}}{(DrTI k_{shadow} (\theta_{0}, \varphi_{0}) k_{inc} (\Theta) + DfTI) P_{nomG} (1 - \beta (T - T_{ref}))}$$
ECMWF







Specular reflectance







From Allerød municipality

Thank you for your attention!

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