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Research Centre for Sustainable Energy

DIEGO
Development of quality system through EnerGy Efficiency cOurses

Co-funded by the Erasmus+ Programme of the European Union

University of Cyprus
PV Technology

PV production Forecasting: State-of-the-Art

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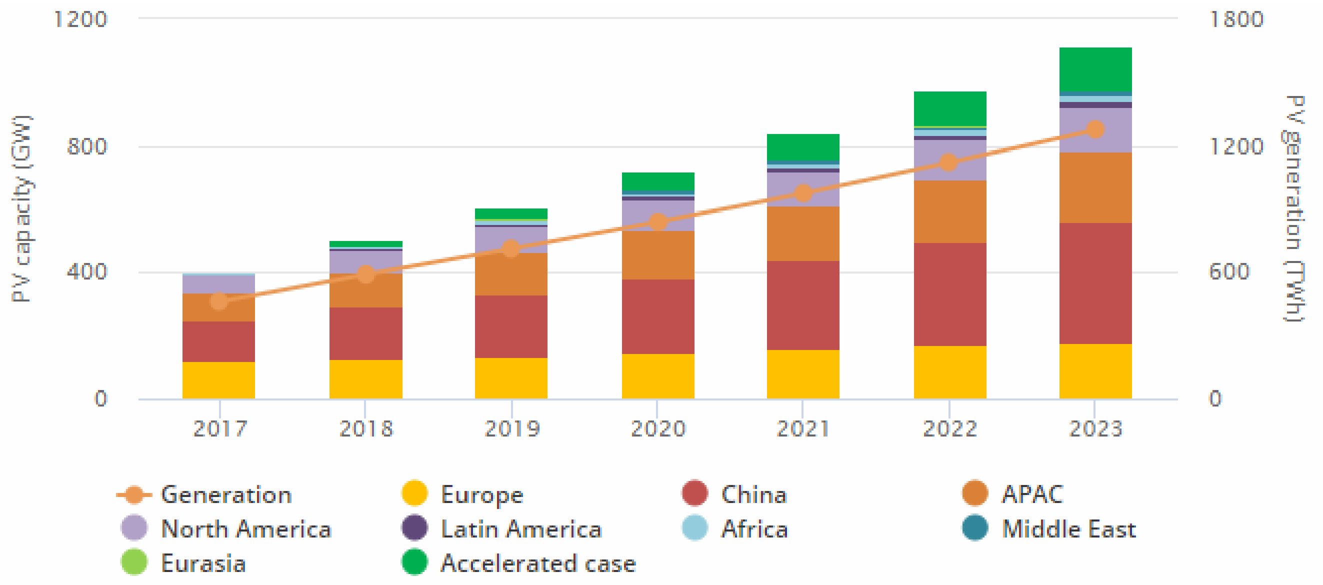
Outline

- Introduction
- Uncertainties in PV System Yield Predictions and Assessments
- Forecasting
- New Research Areas
- Conclusions

Introduction

- The field of solar and photovoltaic (PV) forecasting is rapidly evolving and in order to facilitate further integration, accurate PV production forecasting is necessary especially at the distribution system.
- Diverse resources are used to generate PV production forecasts, ranging from measured weather and PV system data to satellite and sky imagery observations of clouds, to numerical weather prediction (NWP) models which form the basis of modern weather forecasting.
- The usefulness of these resources varies depending on the forecast horizon considered: very short-term forecasts (0 to 6 hours ahead) perform best when they make use of measured data, while numerical weather prediction models become essential for forecast horizons beyond approximately six hours.

Introduction

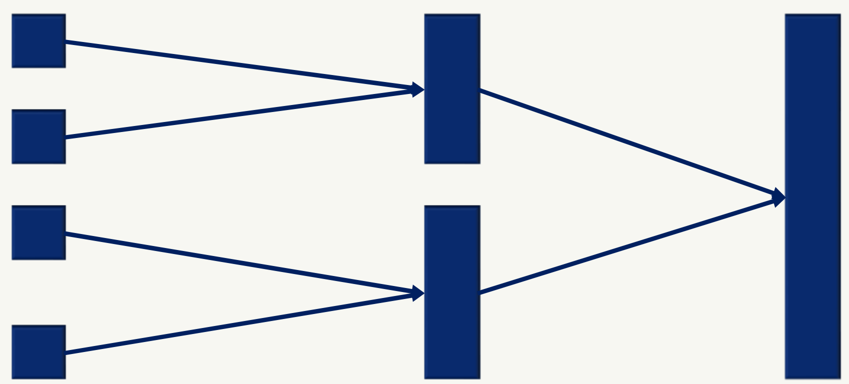


Introduction

- The best approaches make use of both **historical data** and **NWP models**.
- Examples of this strategy include the use of NWP model outputs in machine learning models, or the use of measured data for post-processing NWP models to correct systematic deviations between NWP model outputs and measured data.
- Benchmarking is also necessary to compare the accuracy of various PV forecast models against common datasets. Such benchmarking is critical to assessing forecast accuracy, since this accuracy depends on numerous factors, such as local climate, forecast horizon and whether forecasts apply to a single point or cover a wide geographic area.

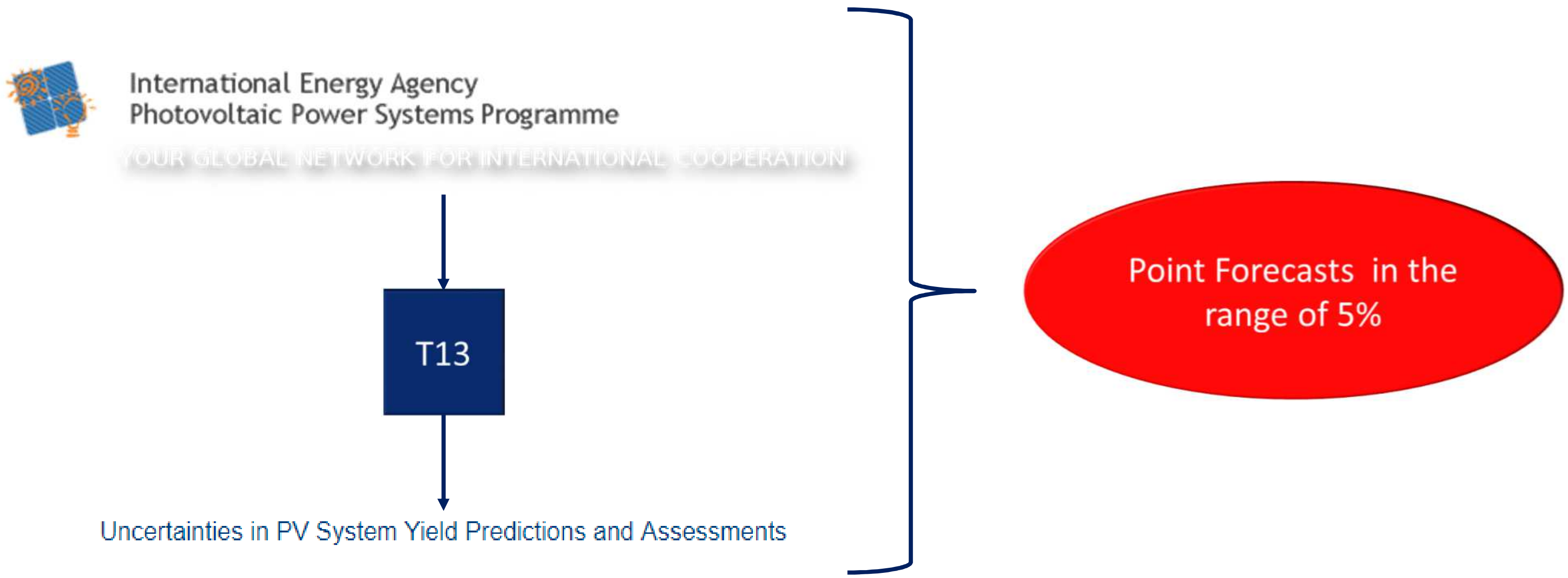
Introduction

- Forecasts may apply to a single PV system (**point forecasts**), or refer to the aggregation of large numbers of systems spread over an extended geographic area (aggregated forecasts).



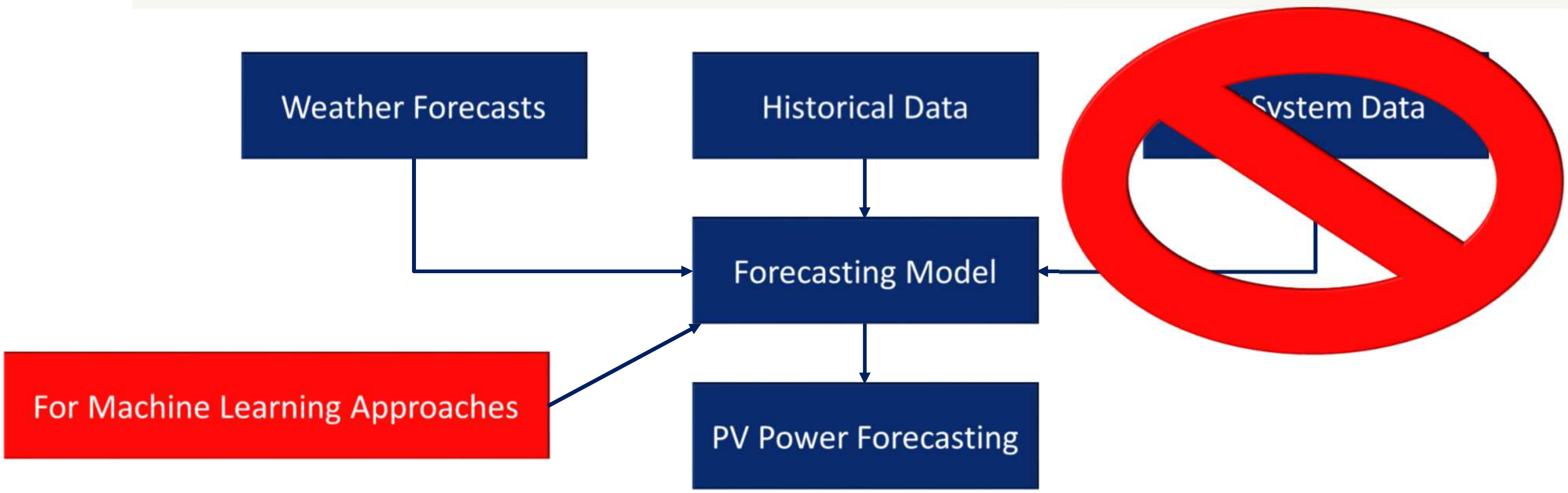
- Forecasts may focus on the **output power** of systems or on its **rate of change** (also known as the ramp rate).

Uncertainties in PV System Yield Predictions and Assessments

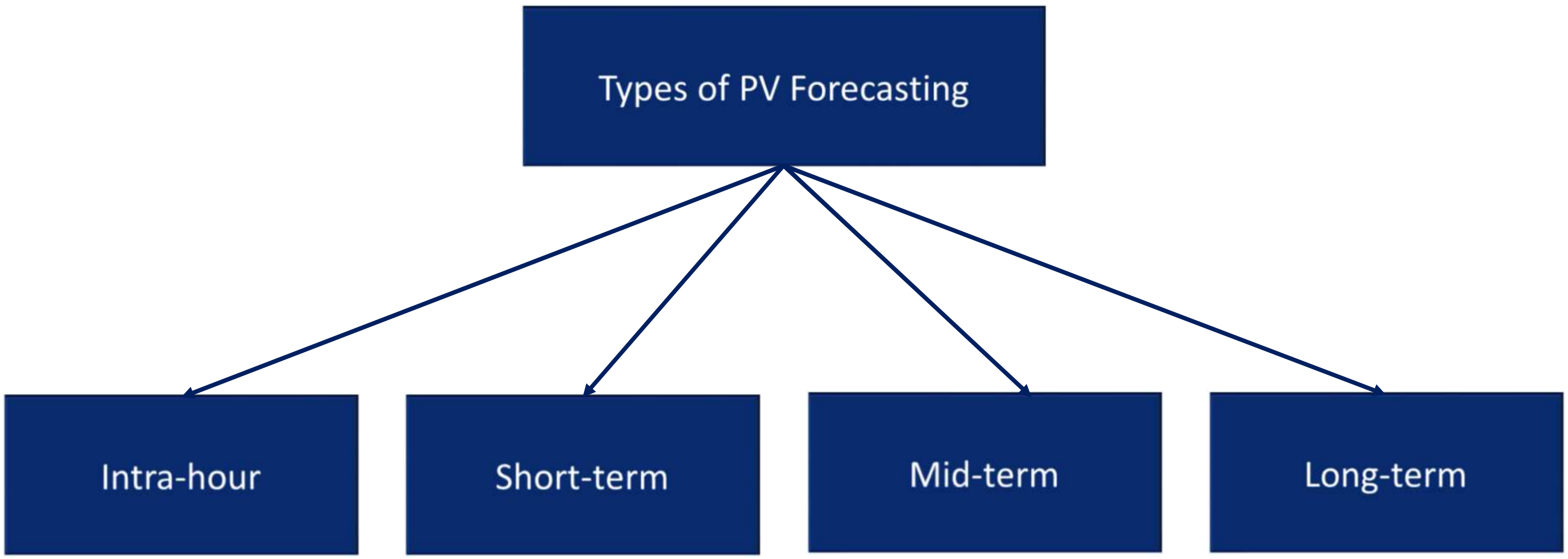


PV Production Forecasting

- Forecasting methods also depend on the tools and information available to forecasters, such as data from weather stations and satellites, PV system data and outputs from numerical weather prediction (NWP) models.

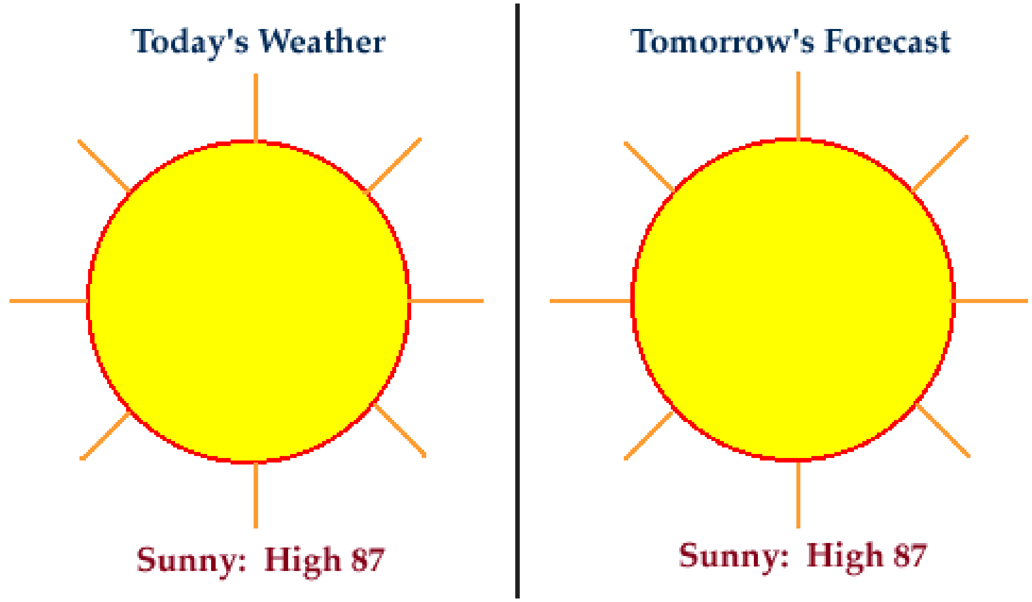


Types of PV Forecasting



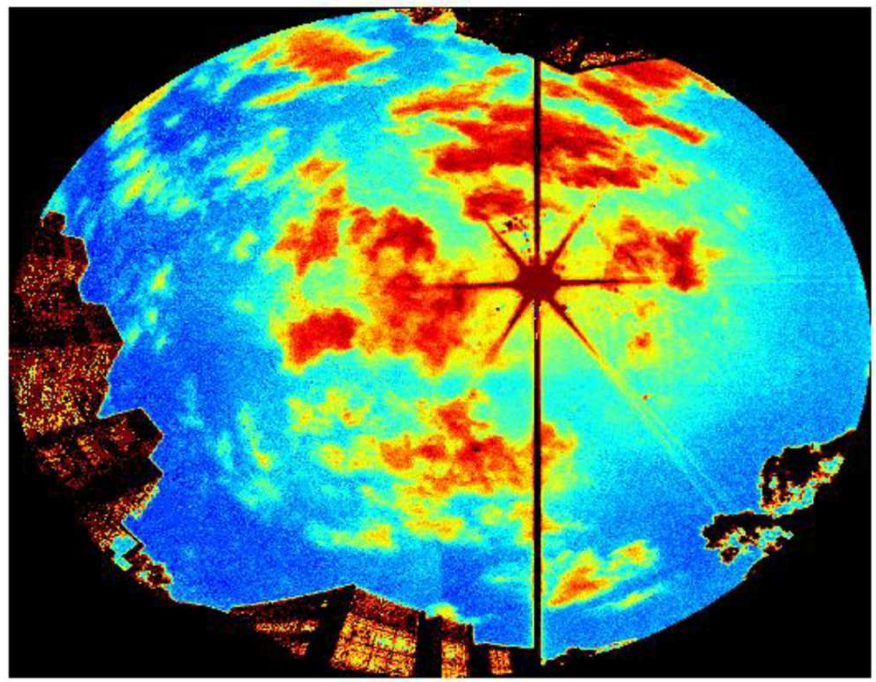
Forecasting Methods For Different Horizons: Intra-hour Forecasting.

- Persistence Modelling



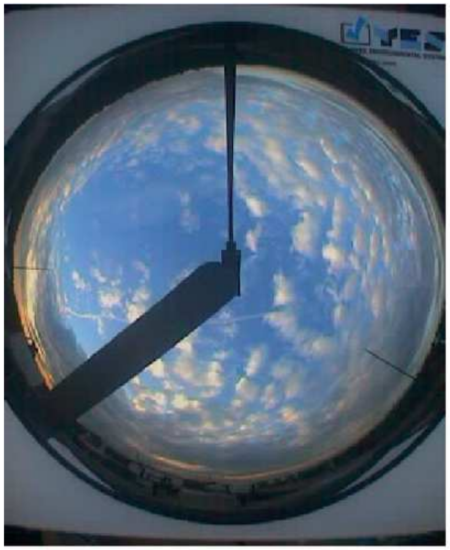
Suitable only few minutes ahead forecasts

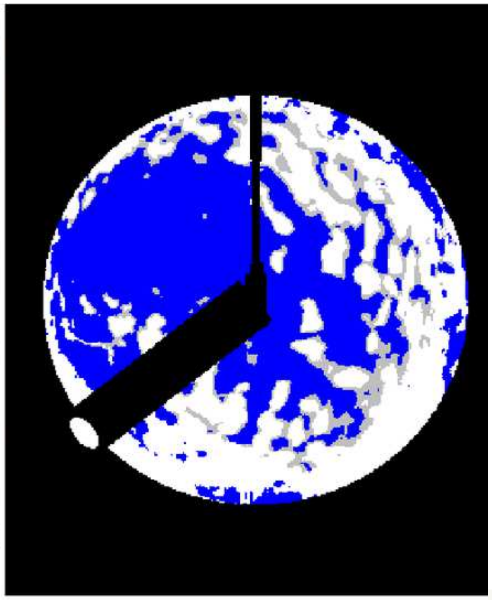
Forecasting Methods For Different Horizons: PV forecasting 0 to 6 hours ahead (Intra-day forecasts)



Forecasting Methods For Different Horizons: PV forecasting 0 to 6 hours ahead (Intra-day forecasts).

- Total Sky Imager (TSI): Full-color sky image system that offers live processing and display of daytime sky conditions. At many sites, the accurate determination of sky conditions is a highly desirable yet rarely attainable goal.





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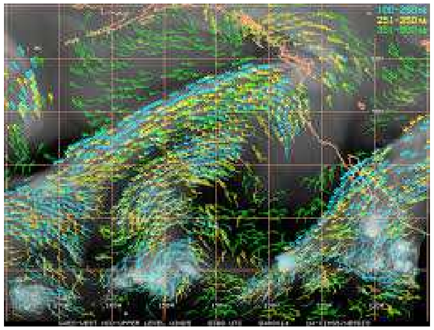
Forecasting Methods For Different Horizons: PV forecasting 0 to 6 hours ahead (Intra-day forecasts)

- **Satellite Cloud Motion Vector Approach:** The satellite-cloud motion vector approach is conceptually similar to the sky image method; cloud patterns are detected through the use of visible and/or infrared images from satellite-based sensors flying overhead. The advantage compared to the WSI is that a much larger spatial scale of cloud patterns can be detected and that high quality satellite imagery is continuously available for the entire world.

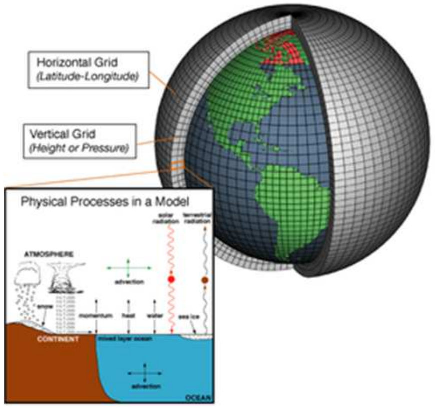


Forecasting Methods For Different Horizons: PV forecasting 0 to 6 hours ahead (Intra-day forecasts)

- **Stochastic Learning Techniques:** For very short-term (intra-hour, and up to 2 or 3 hours ahead depending on the time averaging interval) forecasts, stochastic learning techniques without exogenous input (i.e. only the power plant output is used) can be highly competitive in accuracy and relatively easy to setup, especially when advanced forecasting engines are used. However, inclusion of relevant exogenous data from sky imagery, satellite, and NWP (in order of increasing forecast horizon), as well as data from other meteorological databases (NWS, NDFD, etc.) can significantly increase accuracy and forecasting skills.

Forecasting Methods For Different Horizons: PV Forecasting from Hours to Days

- The best approaches utilized at present for accurate day-ahead forecasts include:
- **Numerical weather prediction models:** Numerical weather prediction models are based on dynamical equations that predict the evolution of the atmosphere up to several days ahead from initial conditions.



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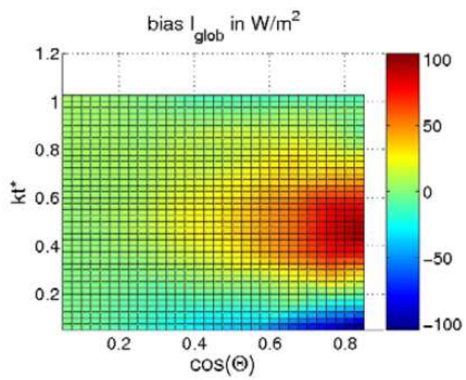
Forecasting Methods For Different Horizons: PV Forecasting from Hours to Days

- **Improving forecasts through post-processing of NWP models:** Forecast improvements are often performed by comparing to measured data during a training period which is used to develop corrected forecasts. This type of approach is often referred to as Model Output Statistics, or MOS.

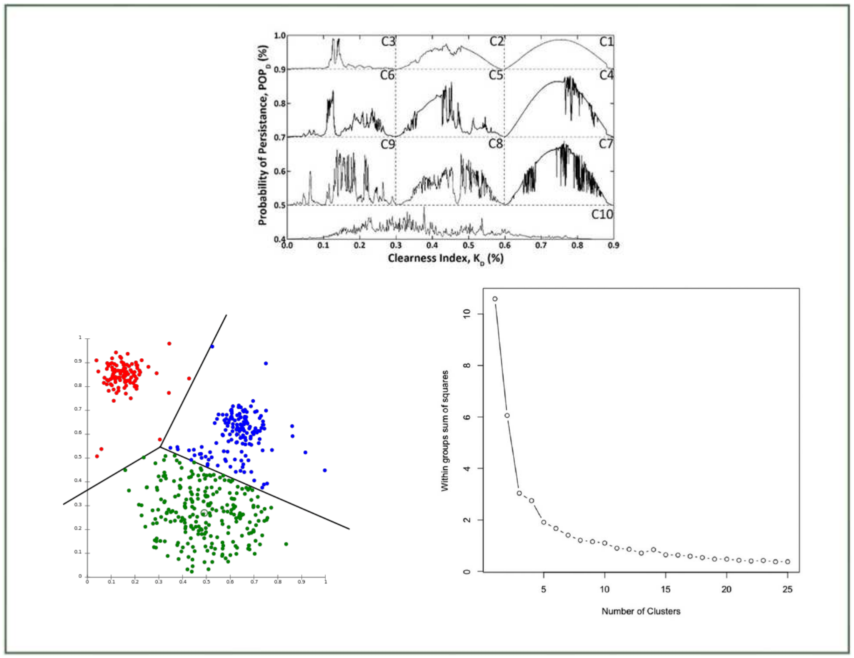


Forecasting Methods For Different Horizons: PV Forecasting from Hours to Days

- **Improving forecasts through precautious actions or post-processing:** Training of various models based on weather classification.

Forecasting Methods For Different Horizons: PV Forecasting from Hours to Days

Weather Classification



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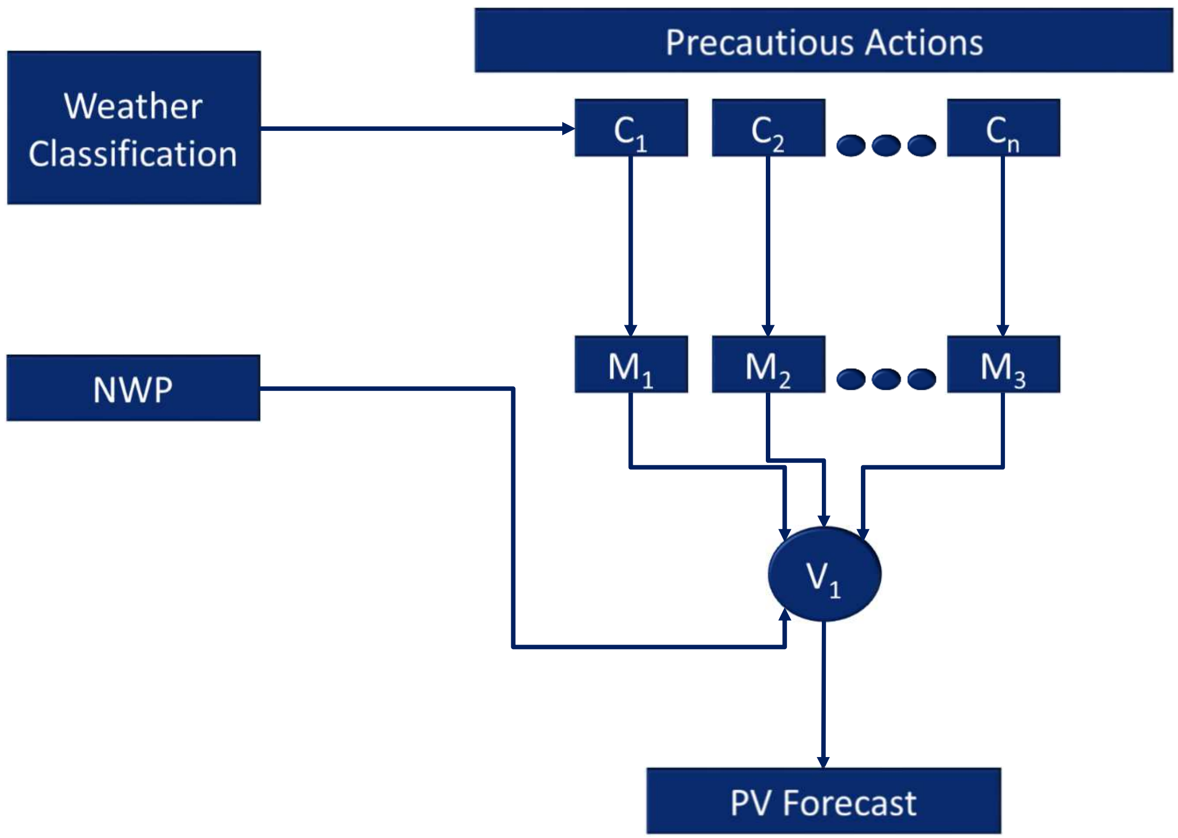
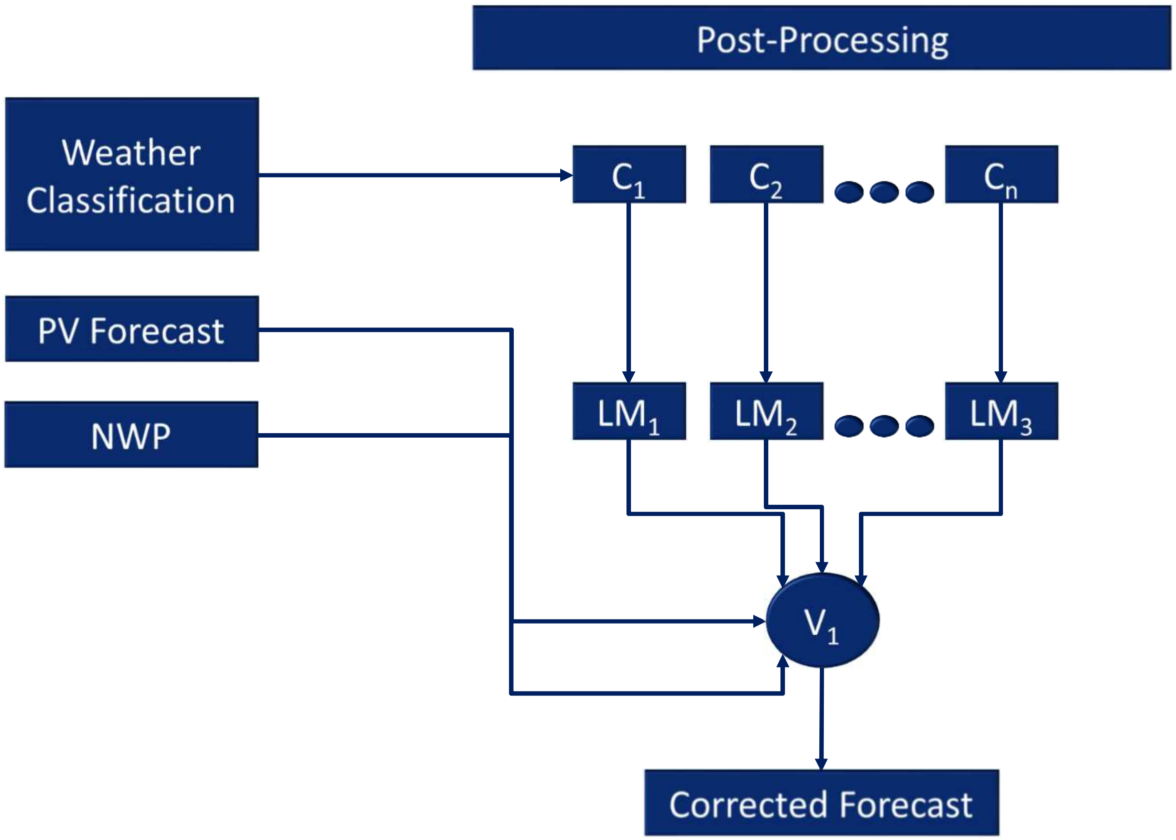
Forecasting Methods For Different Horizons: PV Forecasting from Hours to Days



$C_1 \ldots C_n$: Weather classes
$M_1 \ldots M_n$: Forecasting Models
V_1 : Voter

Forecasting Methods For Different Horizons: PV Forecasting from Hours to Days



$C_1 \ldots C_n$: Weather classes
$LM_1 \ldots LM_n$: Linear Model
V_1 : Voter

Forecasting Assessment Metrics

$$MAE = \frac{1}{n} \times \sum_{i=1}^{n} \left| y_{\text{actual,i}} - y_{\text{predicted,i}} \right|$$

$$MBE = \frac{1}{n} \times \sum_{i=1}^{n} \frac{y_{\text{actual,i}} - y_{\text{predicted,i}}}{y_{\text{actual,i}}}$$

$$RMSE = \sqrt{\frac{1}{n} \times \sum_{i=1}^{n} (y_{\text{actual,i}} - y_{\text{predicted,i}})^2}$$

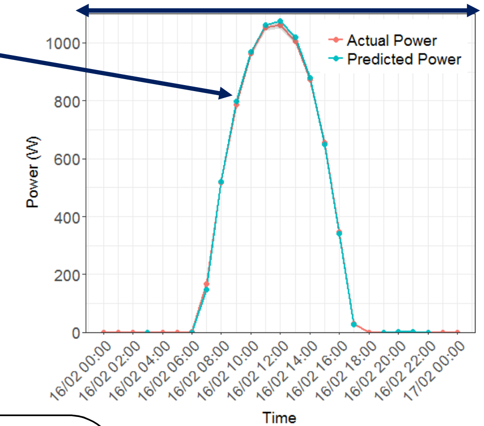
$$nRMSE = \frac{100}{P_{\text{nominal}}} \times \sqrt{\frac{1}{n} \times \sum_{i=1}^{n} (y_{\text{actual,i}} - y_{\text{predicted,i}})^2}$$

Operations & Maintenance Best Practices

A Guide to Achieving *Operational Efficiency*

MBE / RMSE / nRMSE(%) over a day period

Error / APE for each point

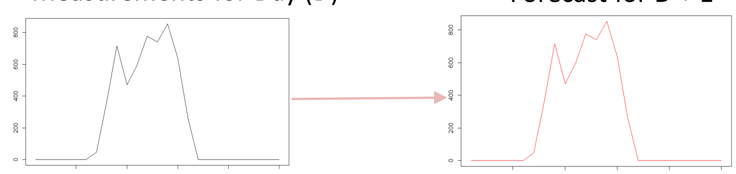


$$SS = 100 \times \left(1 - \frac{RMSE_{\text{predicted}}}{RMSE_{\text{reference}}} \right)$$

Persistence Model (Reference Model)

Measurements for Day (D)

Forecast for D + 1



Factors affecting forecasting accuracy

- The maximum achievable accuracy is determined mainly by the following factors:
  - Local climate and weather conditions (E.g. Climate of Cyprus: BS - Semi-arid (steppe) desert climate [Köppen climate classification])
  - Single-site or regional forecast
  - Forecast horizon
  - Accuracy metric

***Climate of Uruguay: Cfa*: Humid subtropical climates**

R in PV production forecasting

- R packages for Photovoltaics and PV production forecasting:
  - Solar R: Calculation methods of solar radiation and performance of photovoltaic systems from daily and intradaily irradiation data sources
    Weblink: https://cran.r-project.org/web/packages/solaR/solaR.pdf)
  - Meteoforecast: Access to several Numerical Weather Prediction services both in raster format and as a time series for a location. Currently it works with GFS, MeteoGalicia, NAM, and RAP.
    Weblink: https://cran.r-project.org/web/packages/meteoForecast/meteoForecast.pdf

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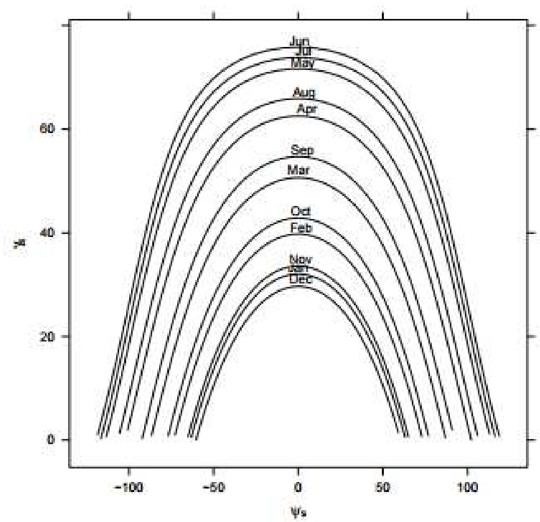
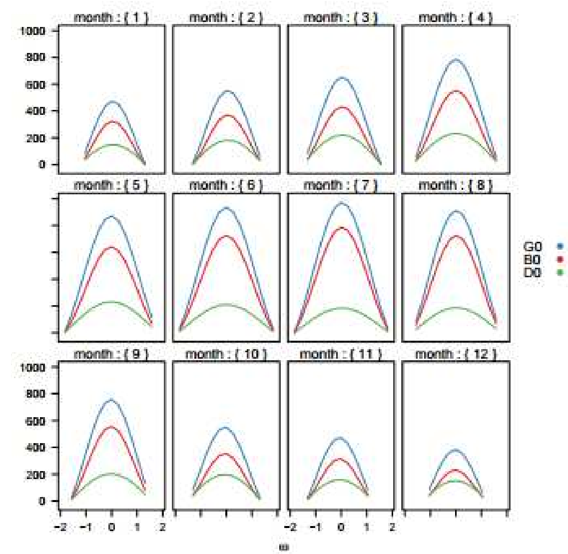
State of the art

Solar package in R

Solar Position Algorithm for Solar Radiation Applications

NREL
National Renewable Energy Laboratory





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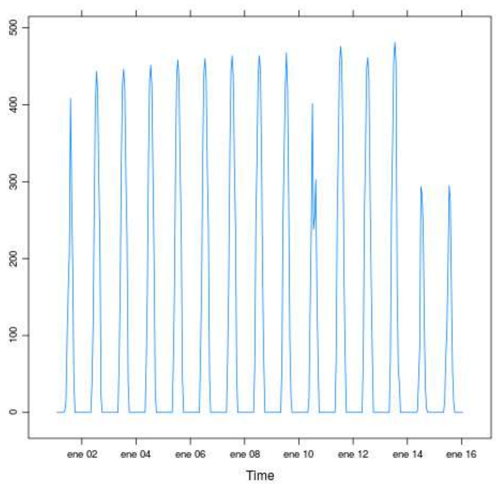
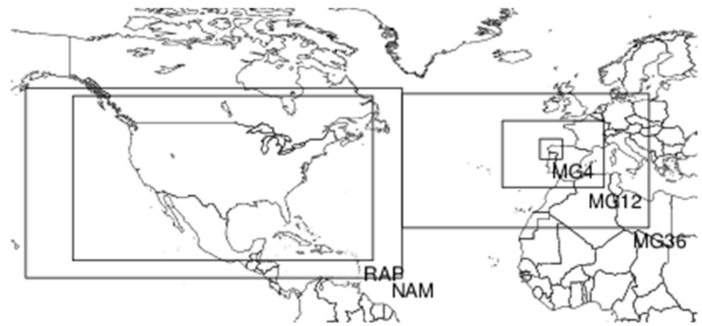
State of the art

Meteoforecast package in R





New Research Areas

Assessment of forecasting point and aggregation techniques

Optimize both WRF and power forecasting algorithms through machine learning algorithms

Conclusions

- Agile forecasting techniques should be introduced for accurate PV Power forecasting.
- Various techniques could be utilised based on the horizon of forecasting.
- Programming and Statistical language R has a variety of packages for PV power forecasting.

Thank you for your attention

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