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pv magazine webinars

Weather parameters and their effects on PV performance

28 June 2023
11:00 am – 12:00 pm | EDT, New York City
4:00 pm – 5:00 pm | BST, London
5:00 pm – 6:00 pm | CEST, Berlin, Madrid

Ryan Kennedy
Editor
pv magazine

Sajad Badalkhani
Manager, Technical Support and Services
OTT HydroMet

Welcome!

Do you have any questions? ❓

Send them in via the Q&A tab. 👉 We aim to answer as many as we can today!

You can also let us know of any tech problems there.

We are recording this webinar today. 📹

We‘ll let you know by email where to find it and the slide deck, so you can re-watch it at your convenience. 👀 💡

Weather parameters and their effects on PV performance

Sajad Badalkhani

June 2023

The Emergence of Solar Energy and the necessity for Optimization

Key Determinants in Solar Power Optimization

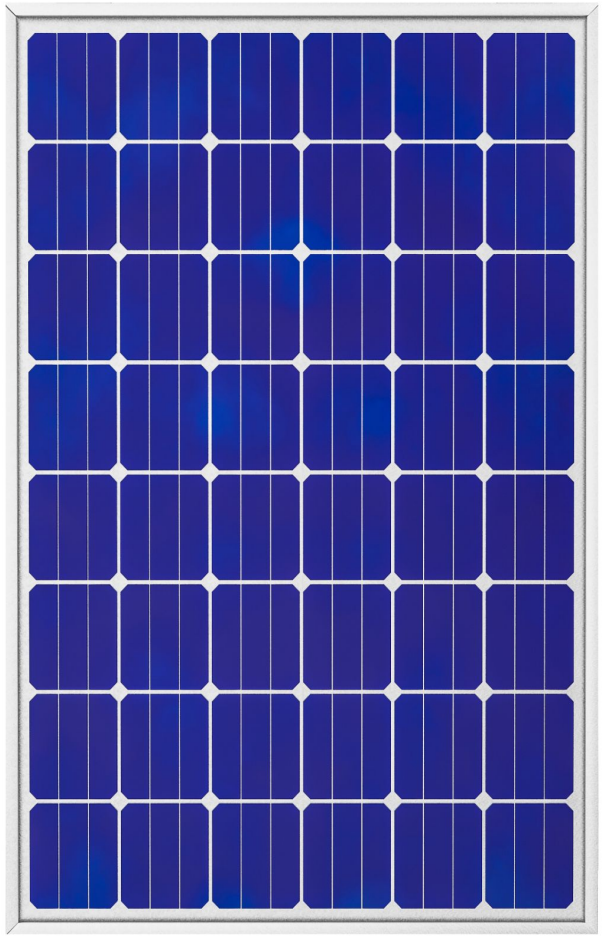
System Design Factors

Operational Factors

Weather and Environmental Factors

Additional Factors

PV system



Energy Yield

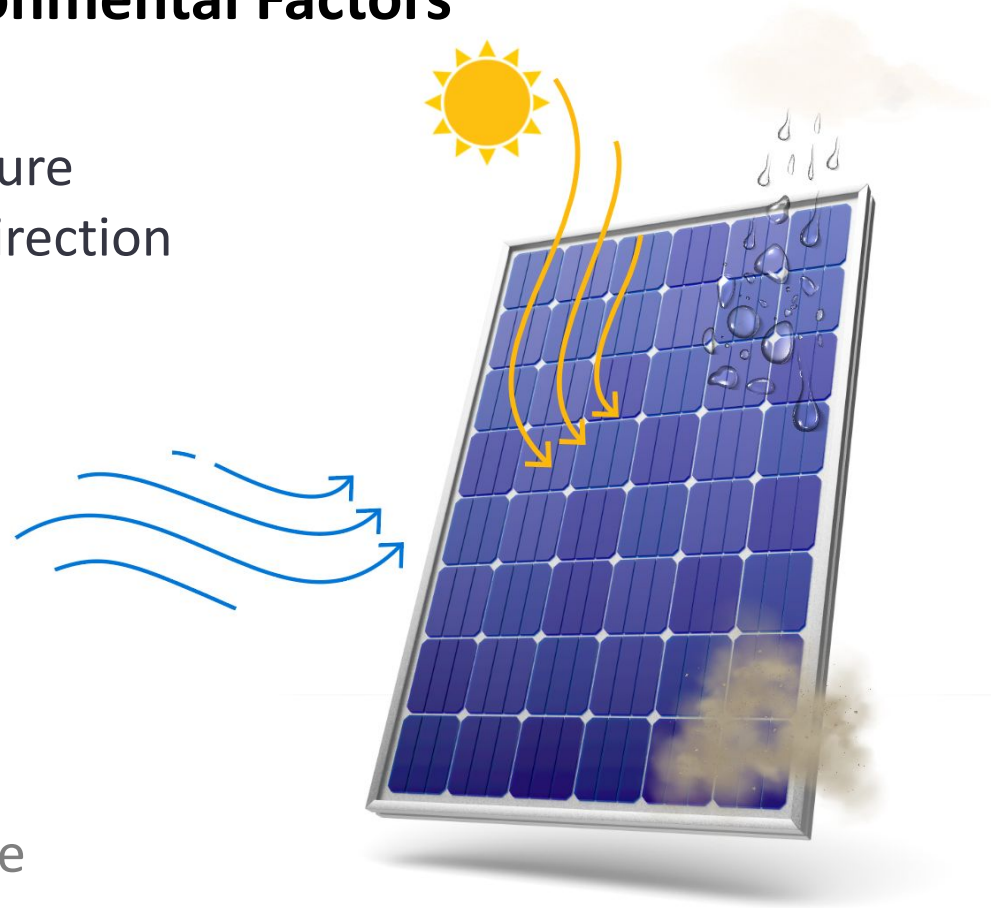
Key Determinants in Solar Power Optimization

System Design Factors

- System Size
- Array Configuration
- PV panel Efficiency
- Inverter Efficiency
- tilt Angle
- Albedo
- Shading
- Location

Weather and Environmental Factors

- Solar Irradiance
- Ambient Temperature
- Wind Speed and Direction
- Precipitation
- Soiling



Operational Factors

- Line Losses
- Maintenance
- Age and Degradation

Additional Factors

- Mounting Structure
- Tracking Systems
- Local Policies and Grid Connection

The Concept of Performance Ratio

Performance Ratio:

Is the ratio of measured energy to expected energy

Or

Comparing actual energy produced to the potential energy from the sunlight it received.

$$PR = \frac{Y_f}{Y_r}$$

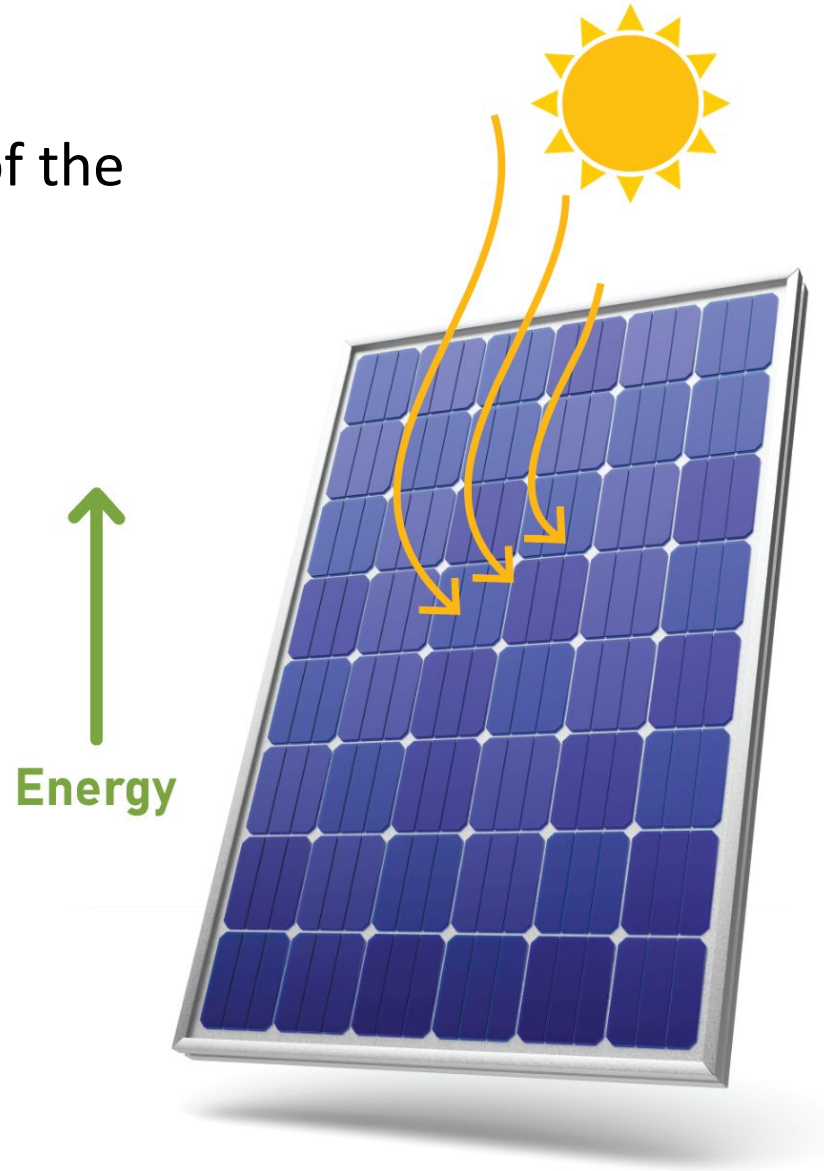
The Concept of Performance Ratio

$$PR = \frac{Y_f}{Y_r} = \frac{\left(\frac{E_{out}}{P_0}\right)}{\left(\frac{H_i}{G_{i,ref}}\right)}$$

Impact of Environmental and Weather Parameters

Solar Irradiance:

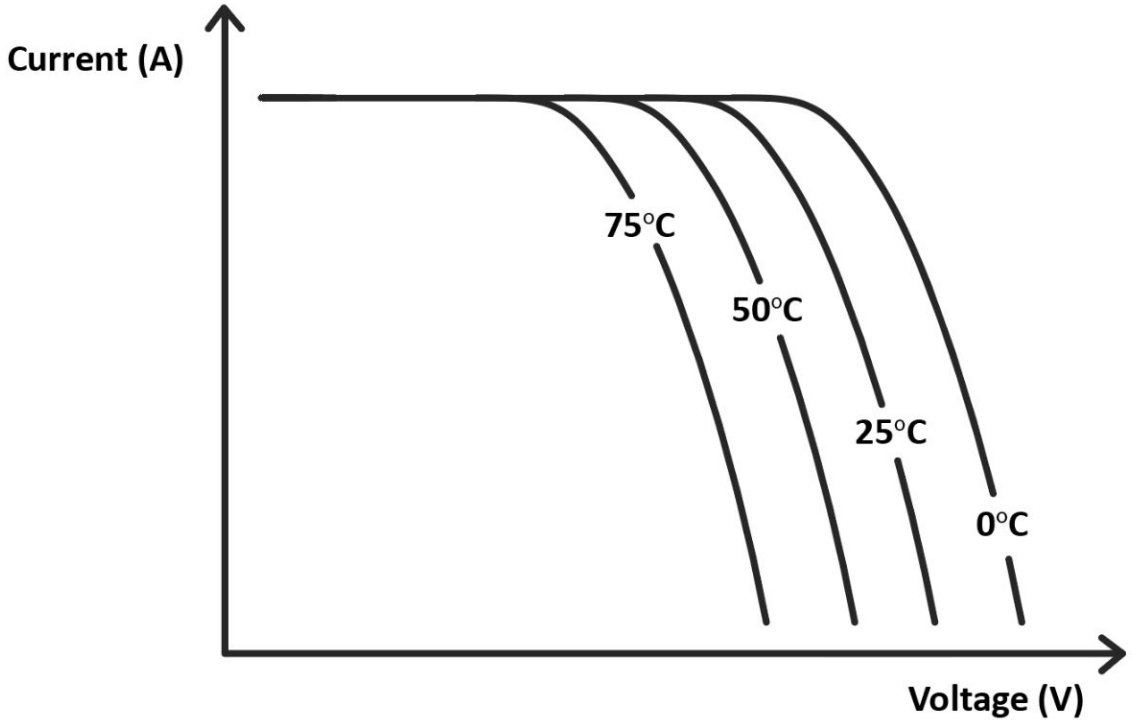
PR is designed to be ideally independent of the irradiance level.

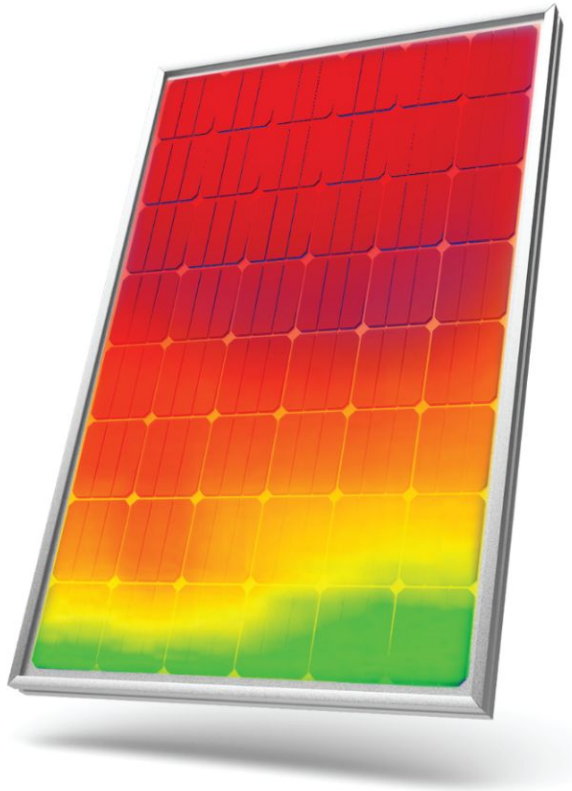


Impact of Environmental and Weather Parameters

Ambient Temperature:

PV cell efficiency drops as temperature rises due to the negative temperature coefficient of solar cells.

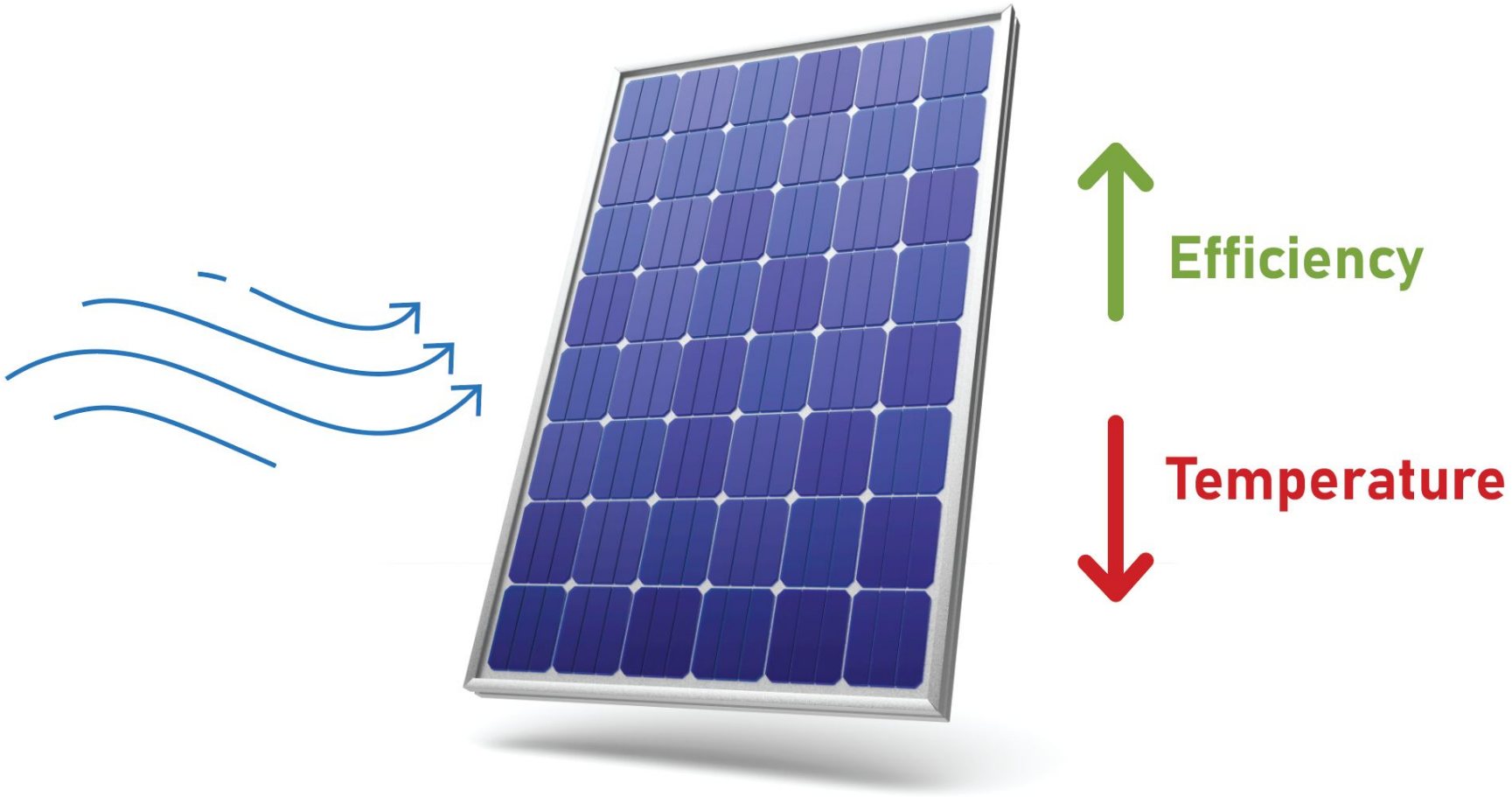




Impact of Environmental and Weather Parameters

Wind Speed:

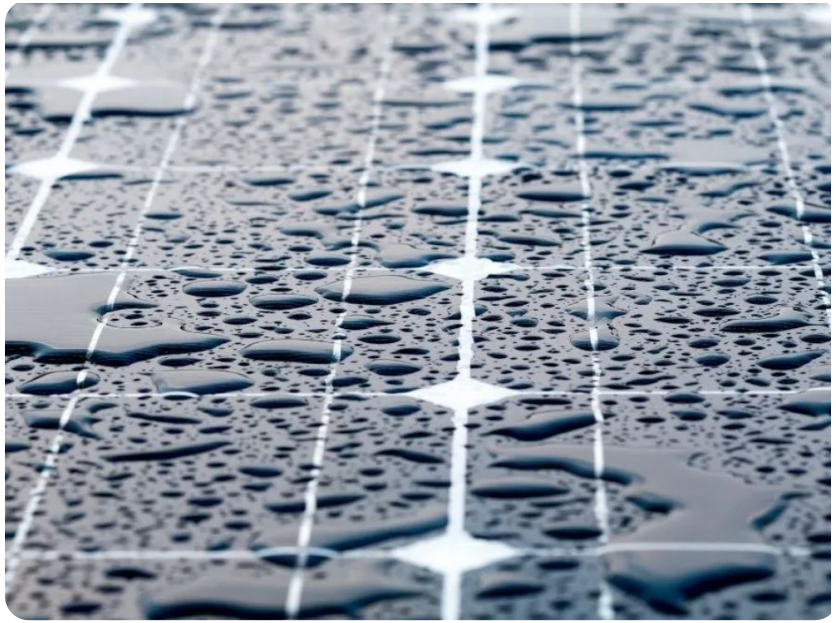
Nature's cooling system, it lowers the operating temperature of our panels, enhancing efficiency.



Impact of Environmental and Weather Parameters

Precipitation:

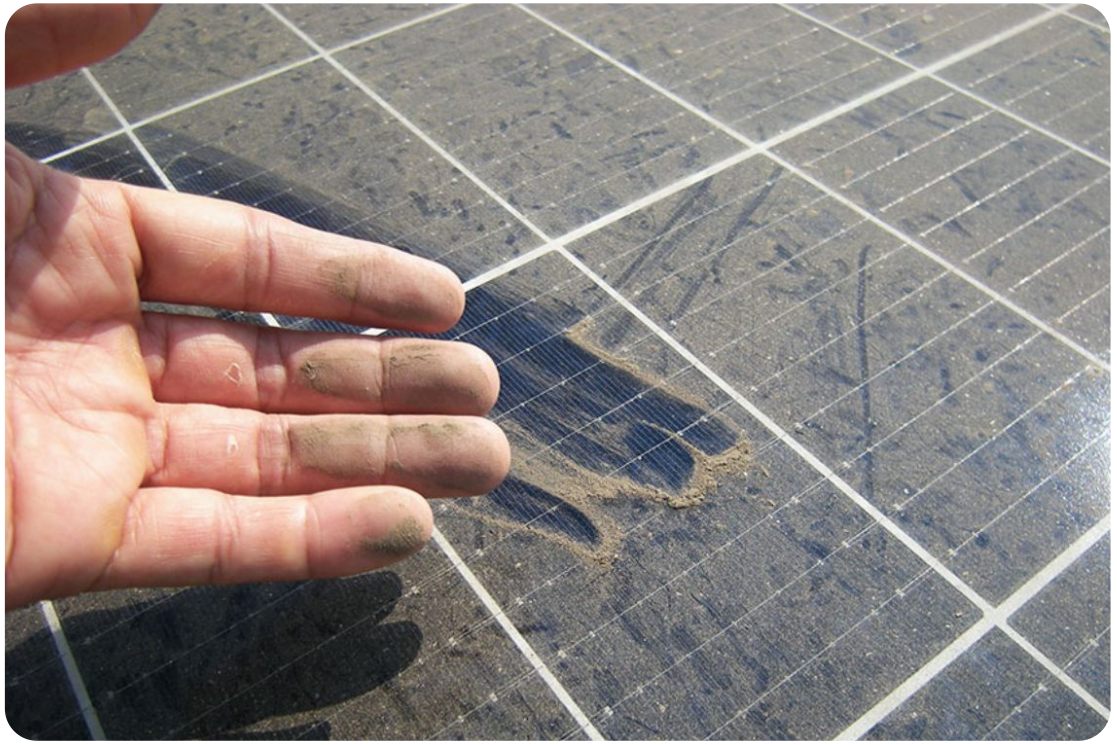
Nature's cleaning mechanism can help remove soiling from panels, boosting their performance. However, it's possible to encounter negative effects as well, since the absorption and scattering of solar energy can potentially reduce irradiance.



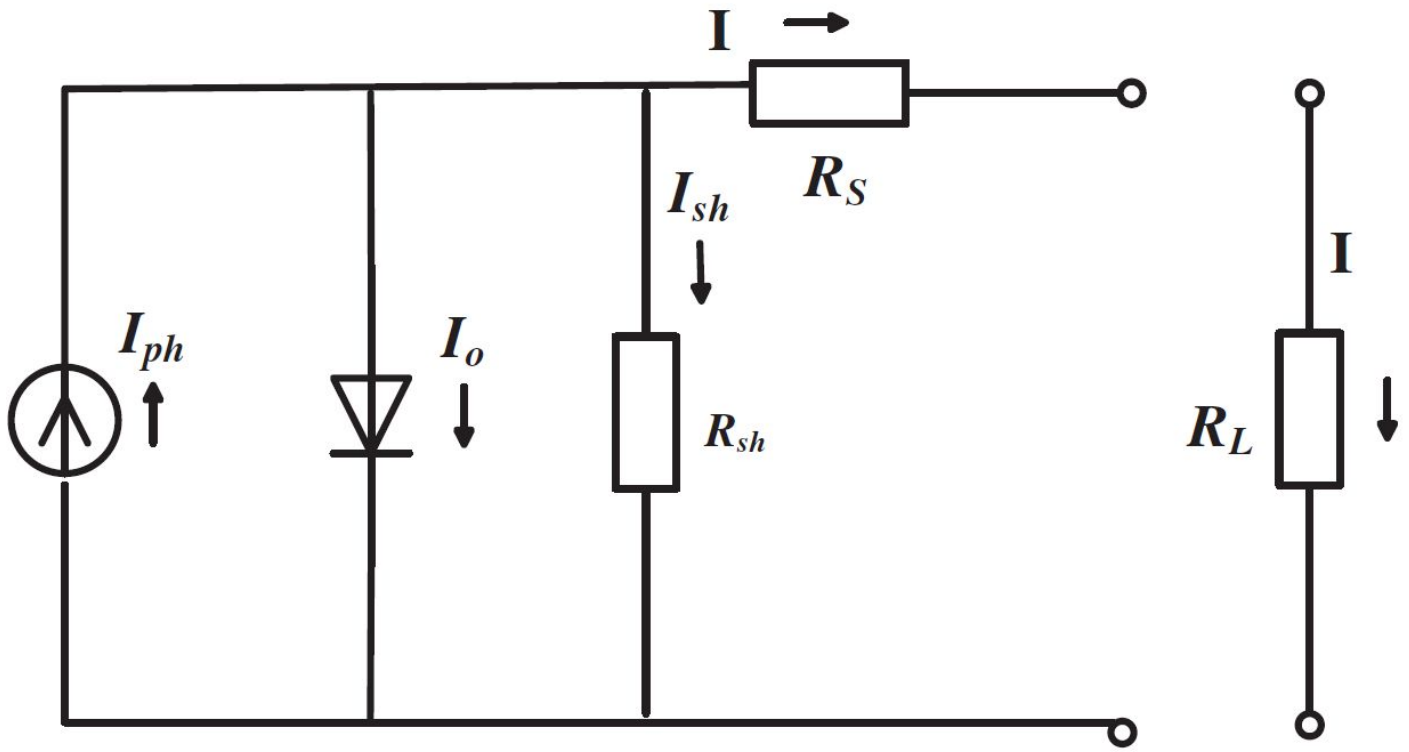
Impact of Environmental and Weather Parameters

Soiling:

Reducing the energy output, by absorbing and scattering the light and negatively impacting the efficiency.



Modeling approach: 1 diode and 2 resistors

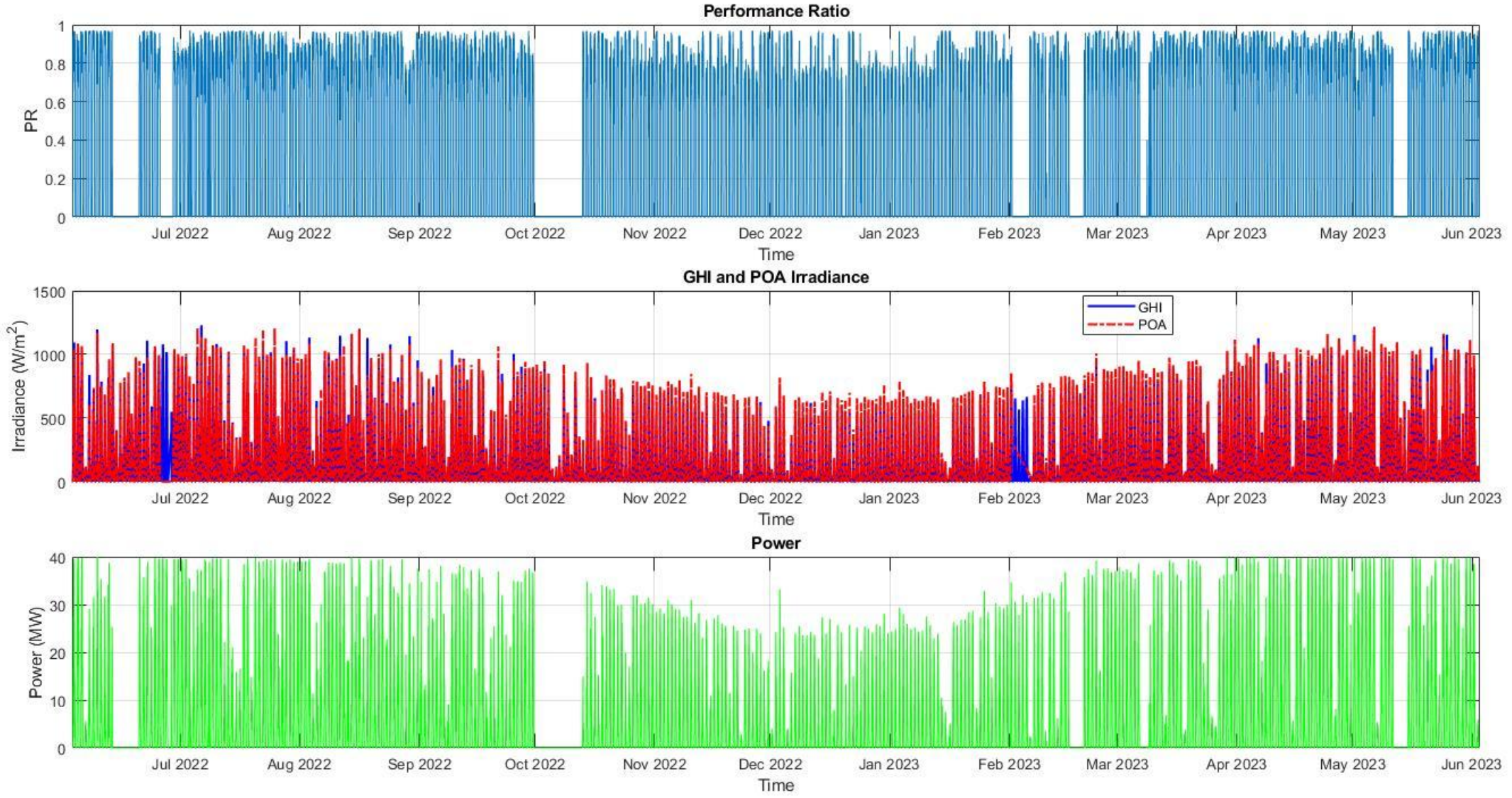


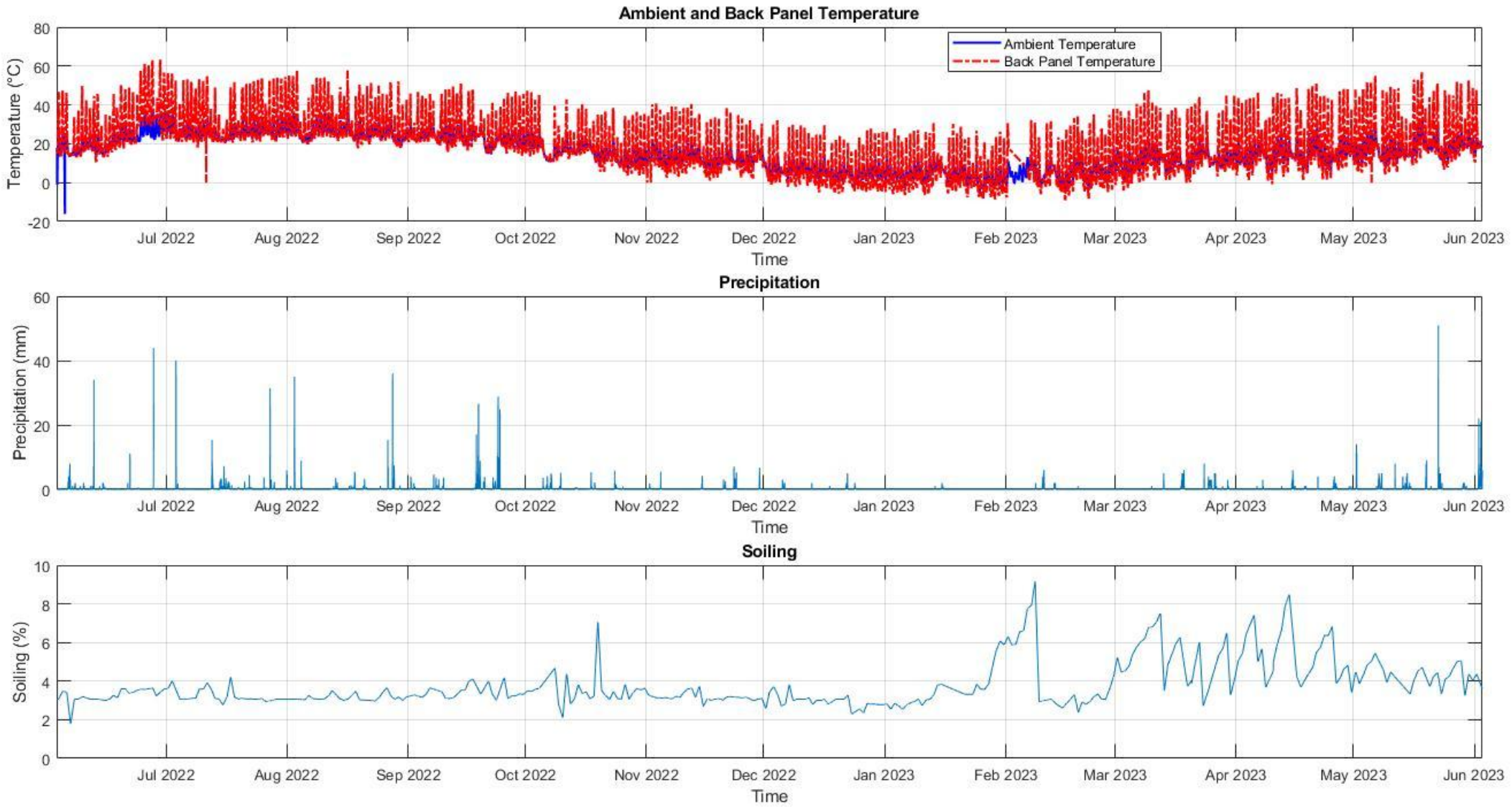
$$a = \frac{nkT}{q}$$

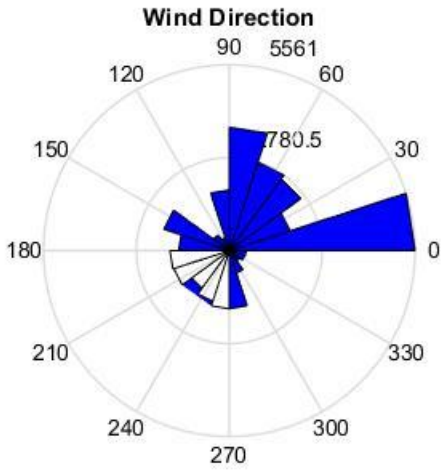
$$I = I_{ph} - I_o - I_{sh} = I_{ph} - I_o\left\{\exp\left(\frac{V + IR_s}{a}\right) - 1\right\} - \frac{V + IR_s}{R_{sh}}$$

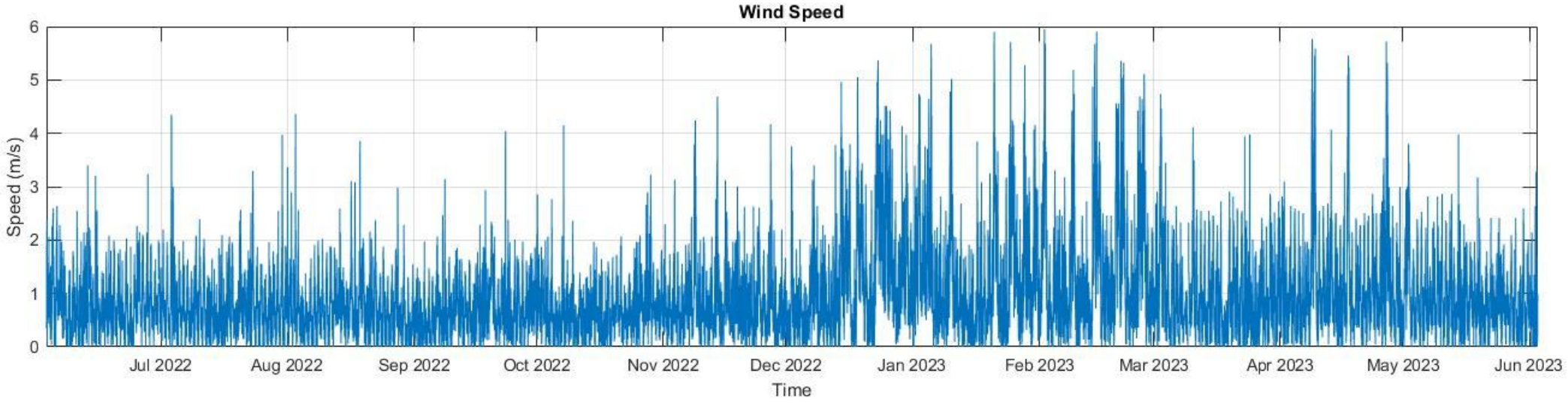
Case study

- Site Location: Japan
- Size: 40 MWp
- Fixed panels
- Monofacial


Performance Ratio
PR
1
0.8
0.6
0.4
0.2
0
Jul 2022
Aug 2022
Sep 2022
Oct 2022
Nov 2022
Dec 2022
Jan 2023
Feb 2023
Mar 2023
Apr 2023
May 2023
Jun 2023
Time
GHI and POA Irradiance
Irradiance (W/m2)
1500
1000
500
0
GHI
POA
Time
Power
Power (MW)
40
30
20
10
0
Time

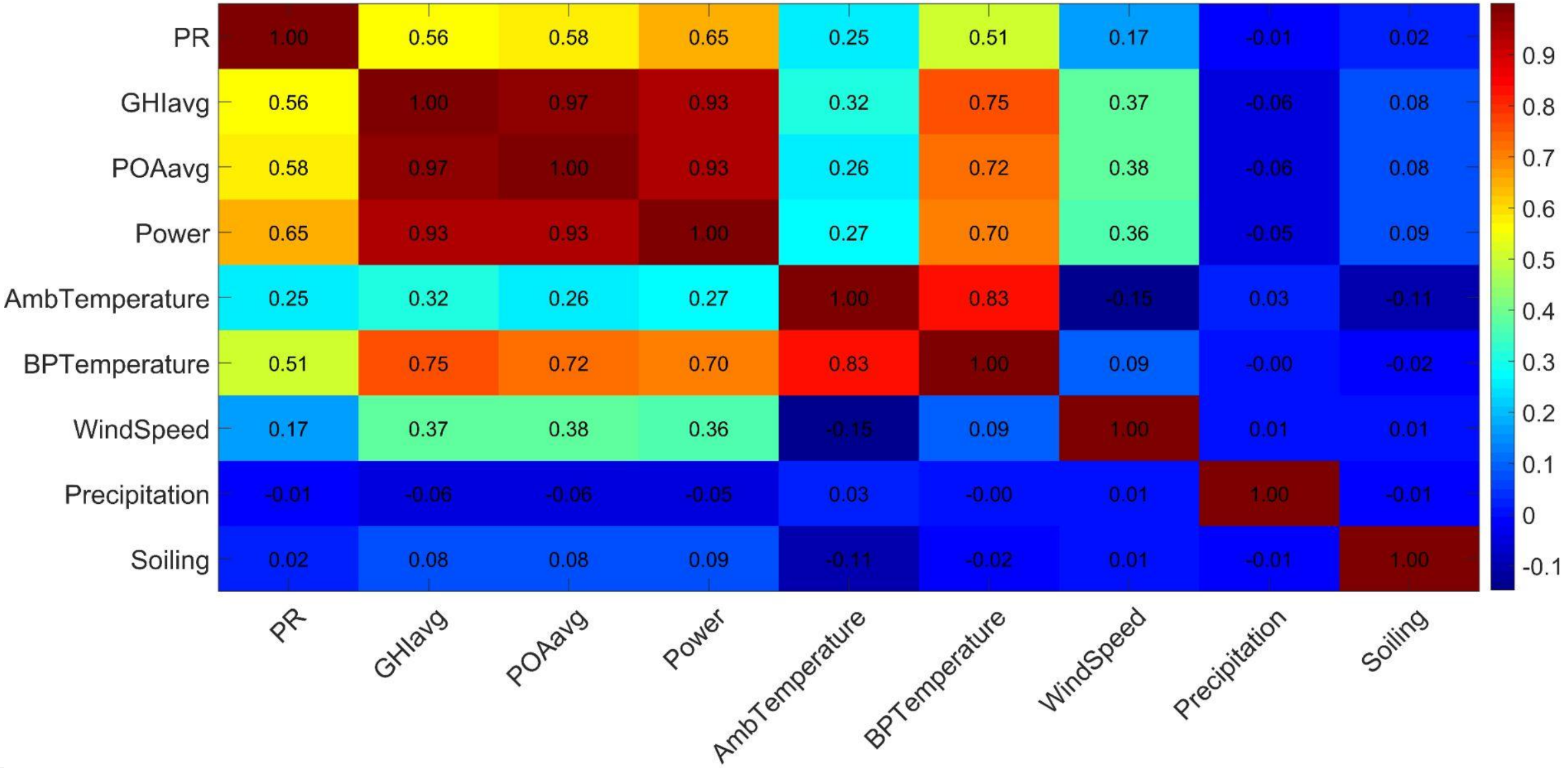

Ambient and Back Panel Temperature
Ambient Temperature
Back Panel Temperature
Temperature (°C)
80
60
40
20
0
-20
Jul 2022
Aug 2022
Sep 2022
Oct 2022
Nov 2022
Dec 2022
Jan 2023
Feb 2023
Mar 2023
Apr 2023
May 2023
Jun 2023
Time
Precipitation
Precipitation (mm)
60
40
20
0
Jul 2022
Aug 2022
Sep 2022
Oct 2022
Nov 2022
Dec 2022
Jan 2023
Feb 2023
Mar 2023
Apr 2023
May 2023
Jun 2023
Time
Soiling
Soiling (%)
10
8
6
4
2
0
Jul 2022
Aug 2022
Sep 2022
Oct 2022
Nov 2022
Dec 2022
Jan 2023
Feb 2023
Mar 2023
Apr 2023
May 2023
Jun 2023
Time


Wind Direction
90
5561
60
120
780.5
30
150
180
0
210
330
240
300
270


Wind Speed
Speed (m/s)
0
1
2
3
4
5
6
Jul 2022
Aug 2022
Sep 2022
Oct 2022
Nov 2022
Dec 2022
Jan 2023
Feb 2023
Mar 2023
Apr 2023
May 2023
Jun 2023
Time

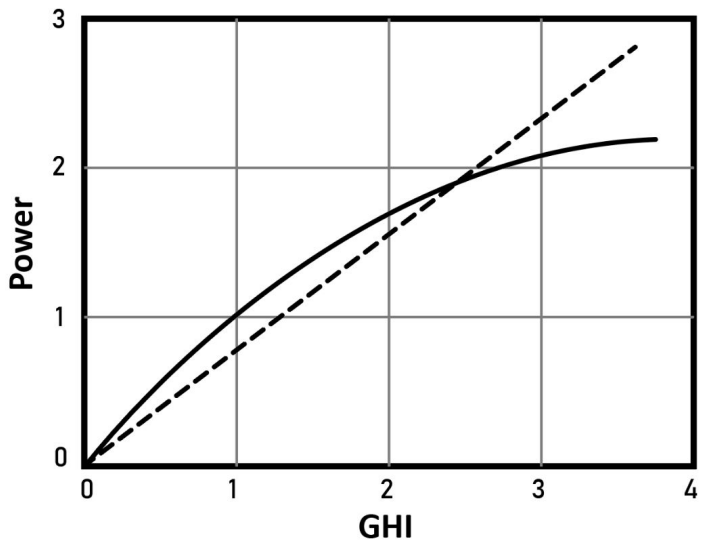
Uncovering Correlations:
How Do Parameters Interplay?

Correlation Matrix Heat Map



Correlation Matrix Heat Map

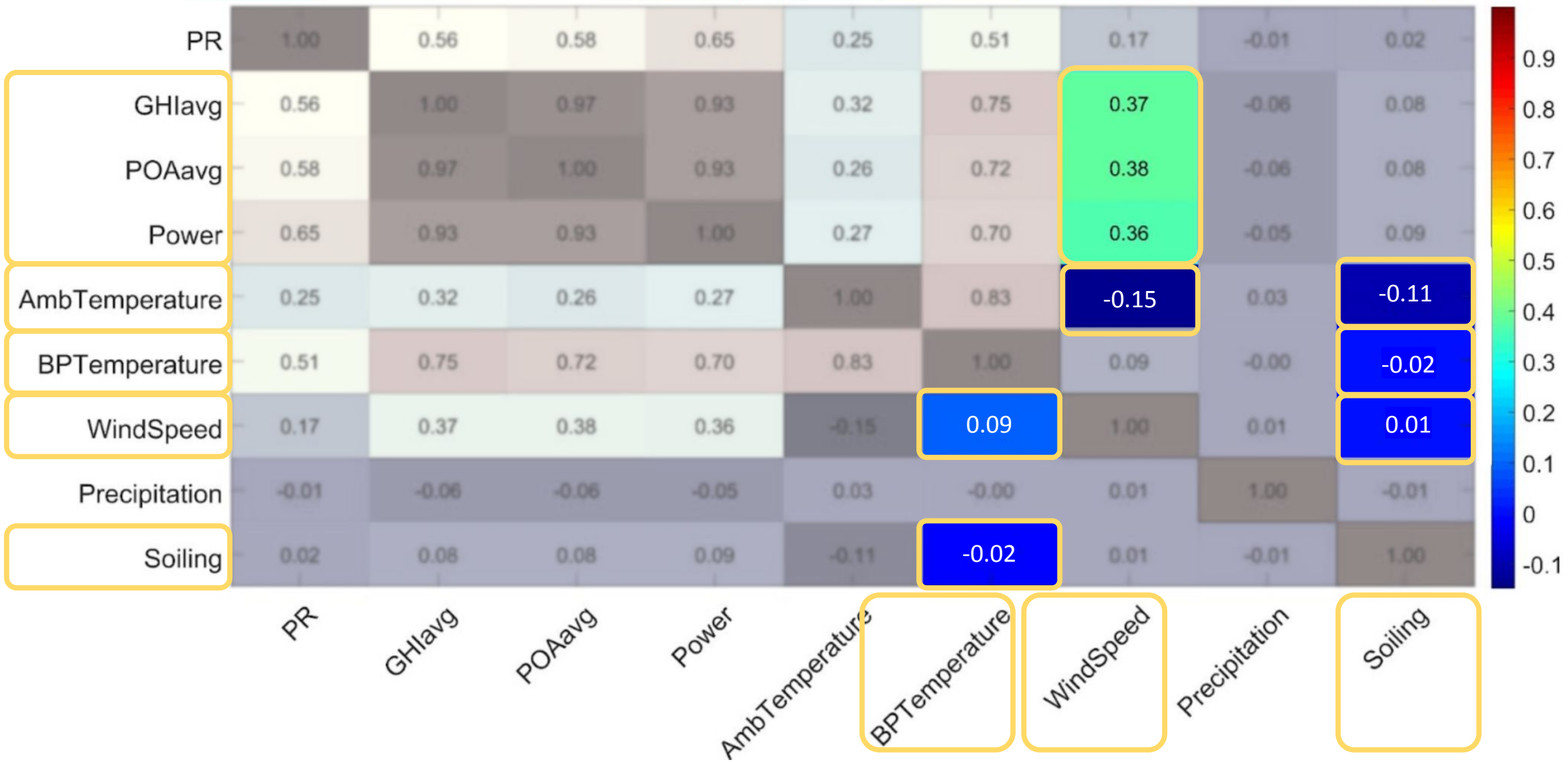
	PR	GHIavg	POAavg	Power	AmbTemperature	BPTemperature	WindSpeed	Precipitation	Soiling
PR	1.00	0.56	0.58	0.65	0.25	0.51	0.17	-0.01	0.02
GHIavg	0.56	1.00							0.08
POAavg	0.58	0.97							0.08
Power	0.65	0.93							0.09
AmbTemperature	0.25	0.32							-0.11
BPTemperature	0.51	0.75							-0.02
WindSpeed	0.17	0.37							0.01
Precipitation	-0.01	-0.06							-0.01
Soiling	0.02	0.08	0.08	0.09	-0.11	-0.02	0.01	-0.01	1.00



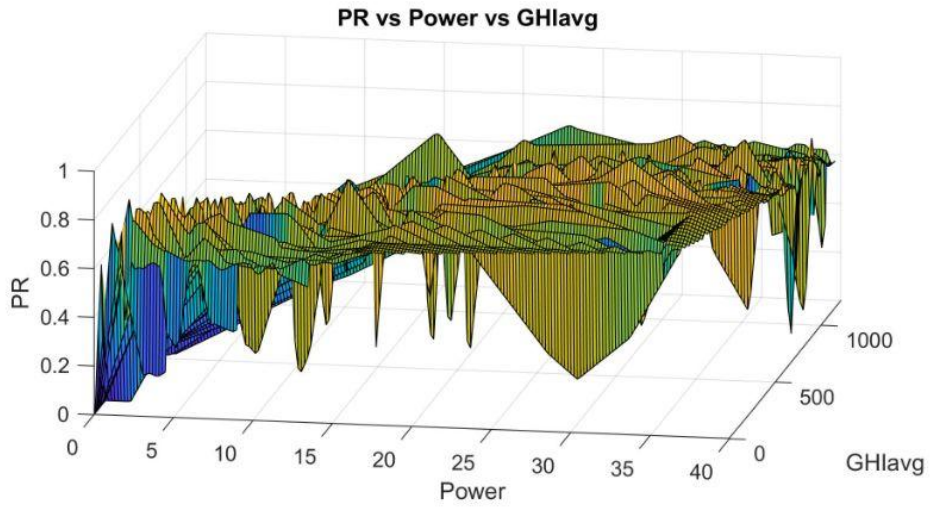
$$PR = \frac{Y_f}{Y_r} = \frac{(\frac{E_{out}}{P_0})}{(\frac{H_i}{G_{i,ref}})}$$

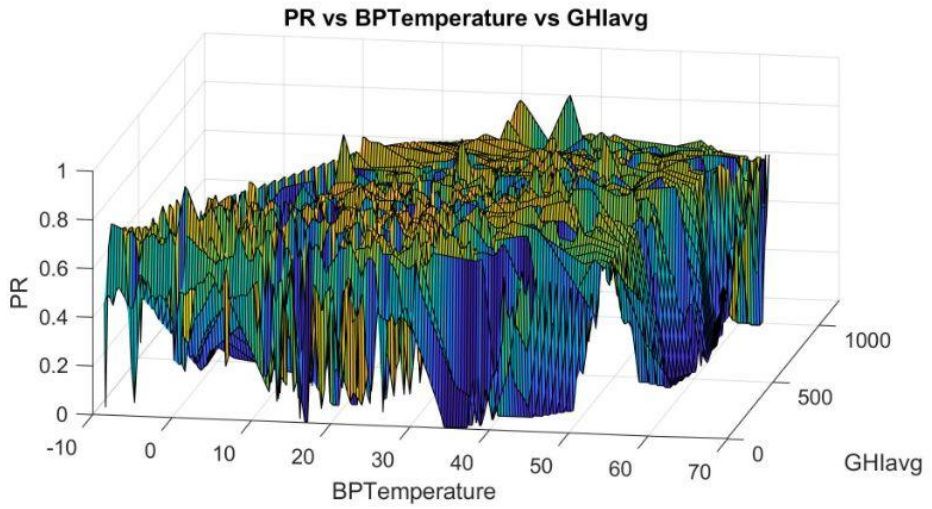
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1

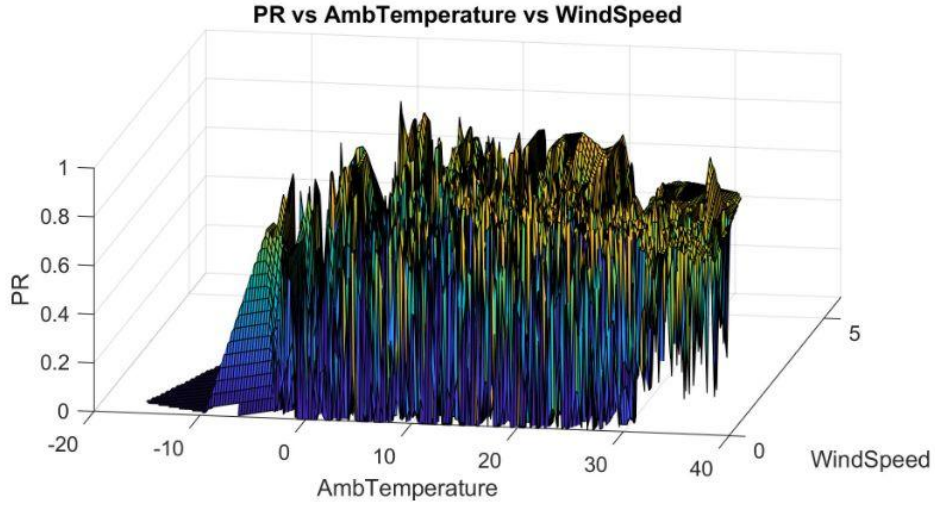
Correlation Matrix Heat Map

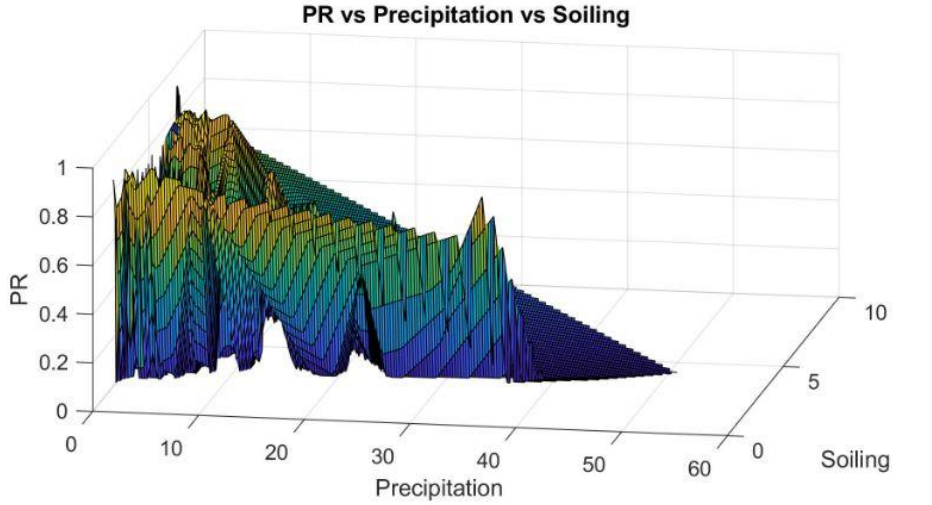


Closer look into interplays

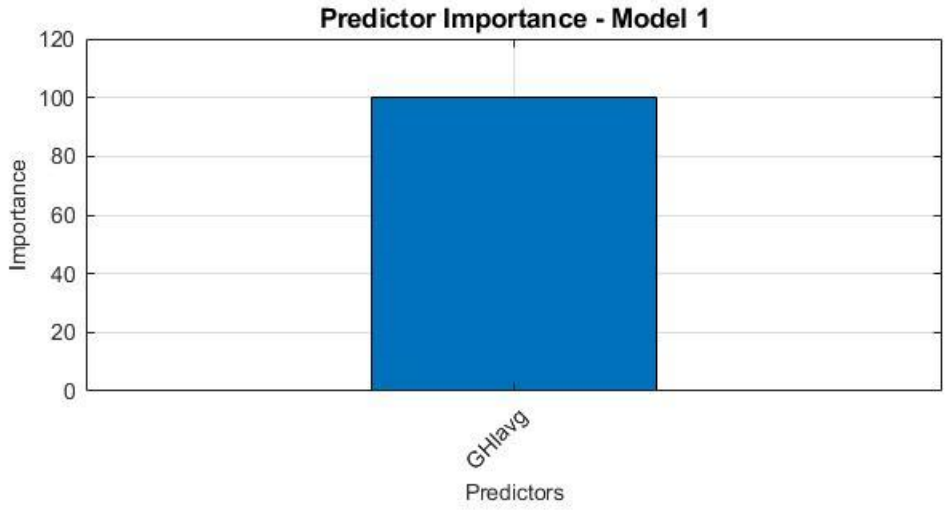


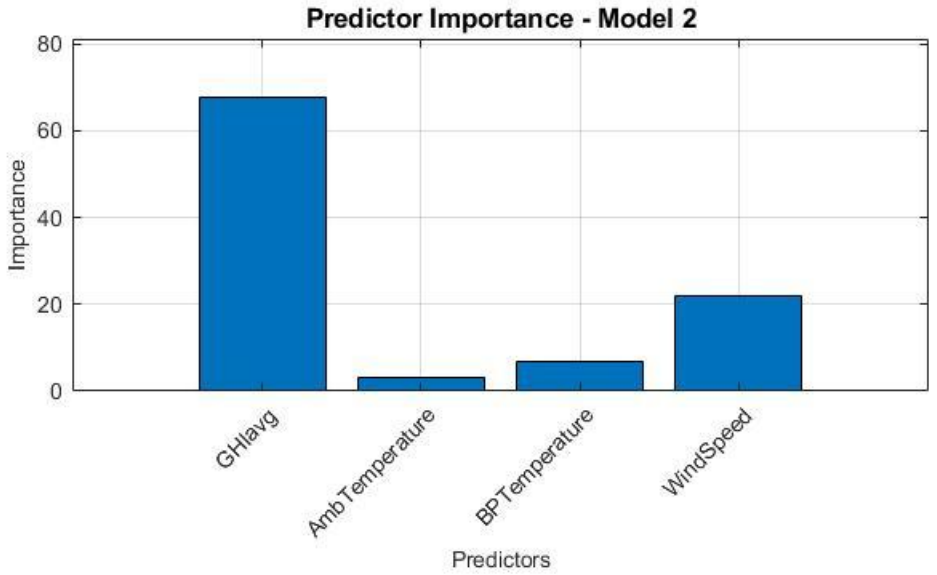


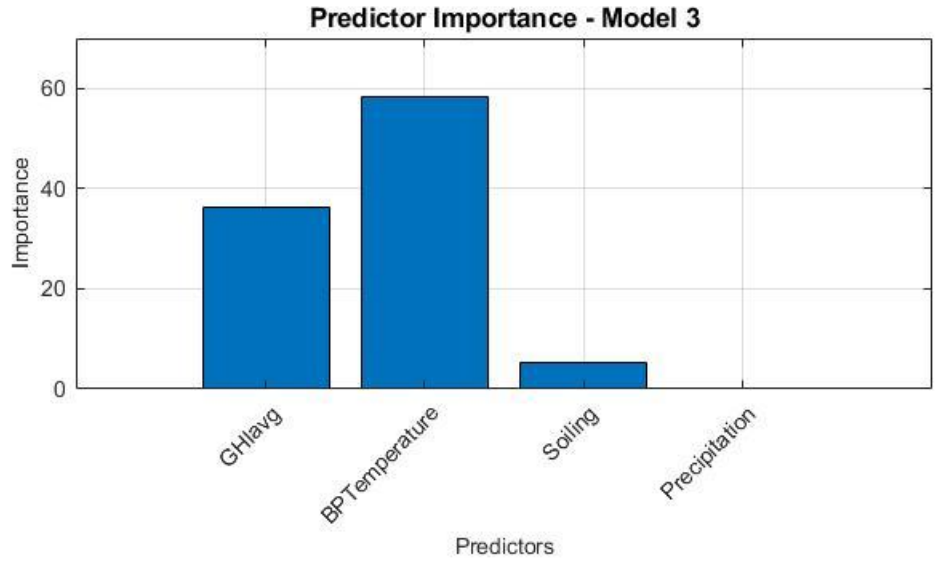


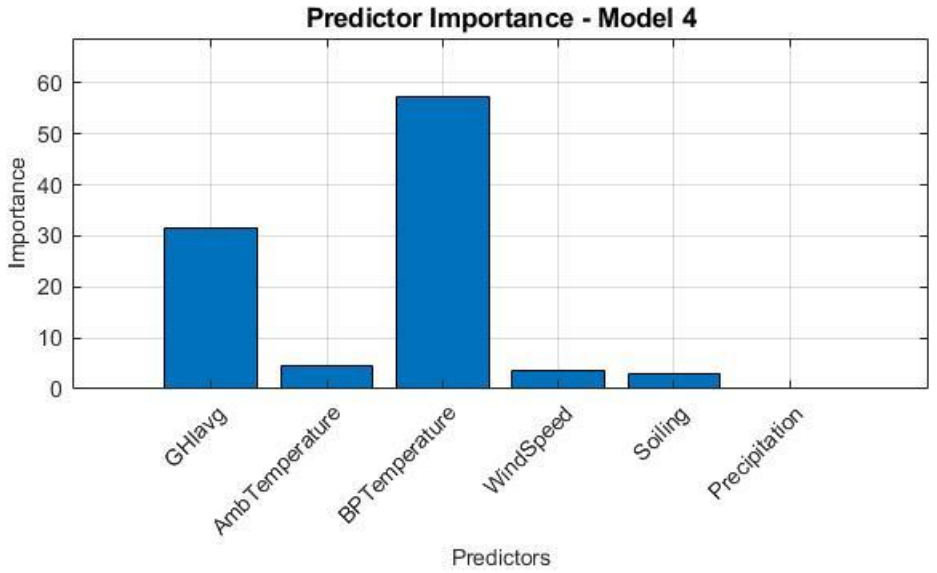


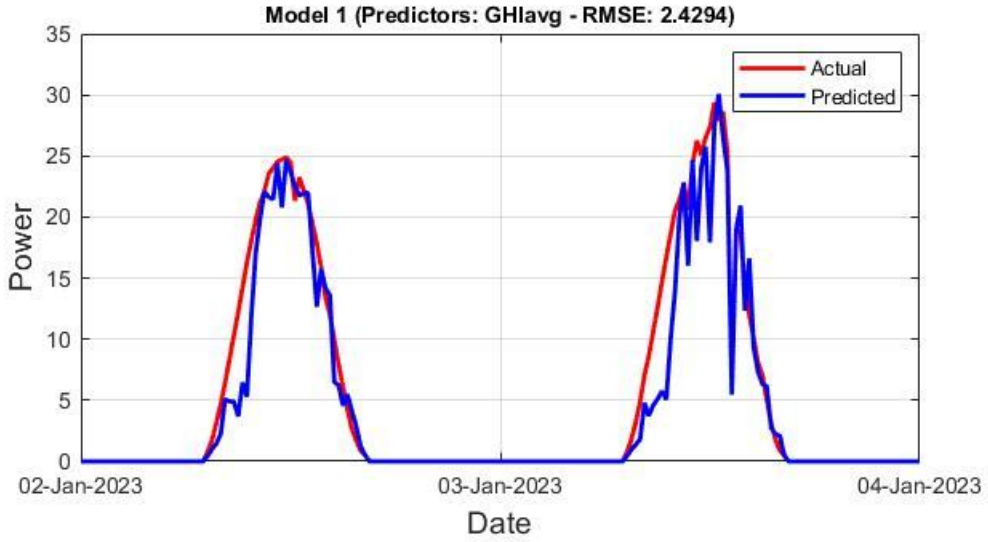
Determining Importance:
Which Parameters Matter Most?

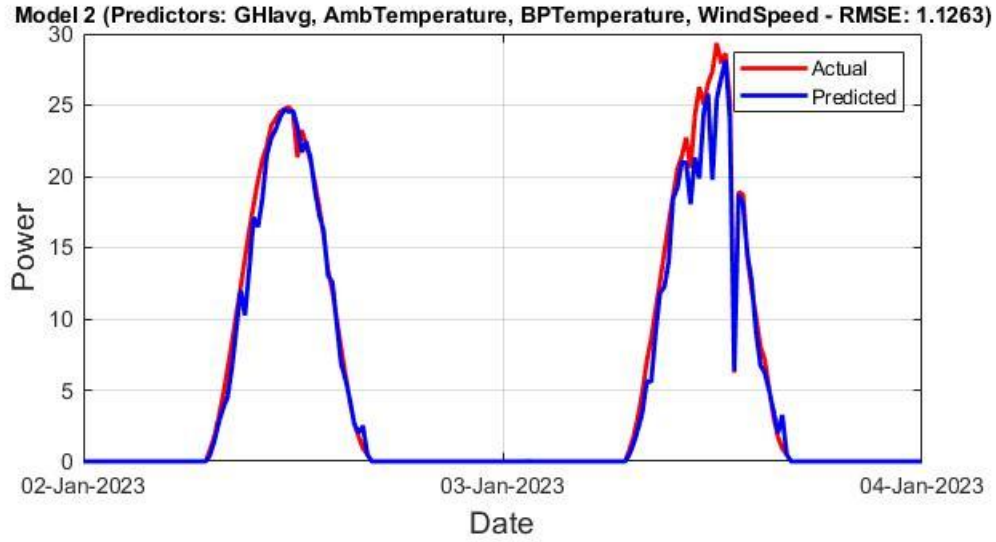

Predictor Importance - Model 1
Importance
120
100
80
60
40
20
0
GHIavg
Predictors

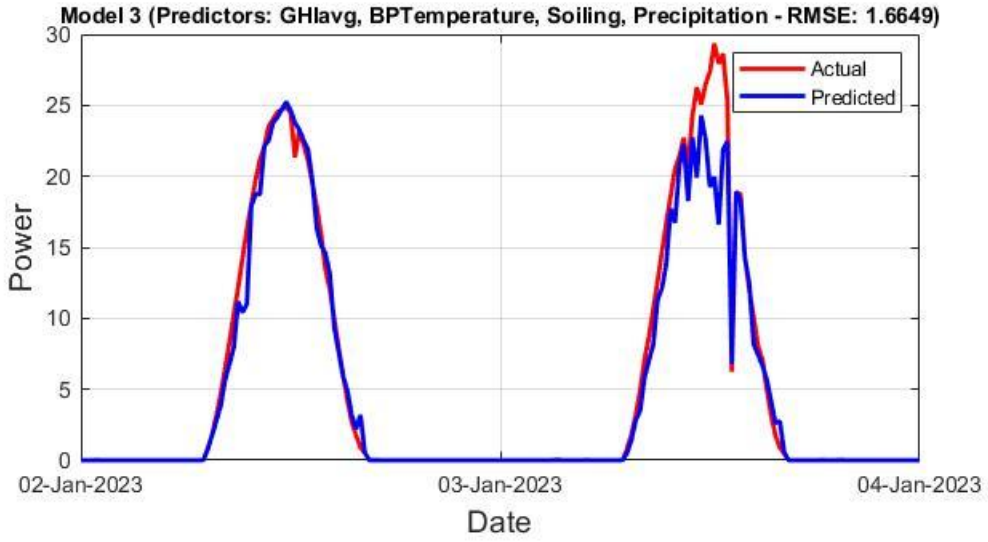

Predictor Importance - Model 2
Importance
80
60
40
20
0
GHIavg
AmbTemperature
BPTemperature
WindSpeed
Predictors

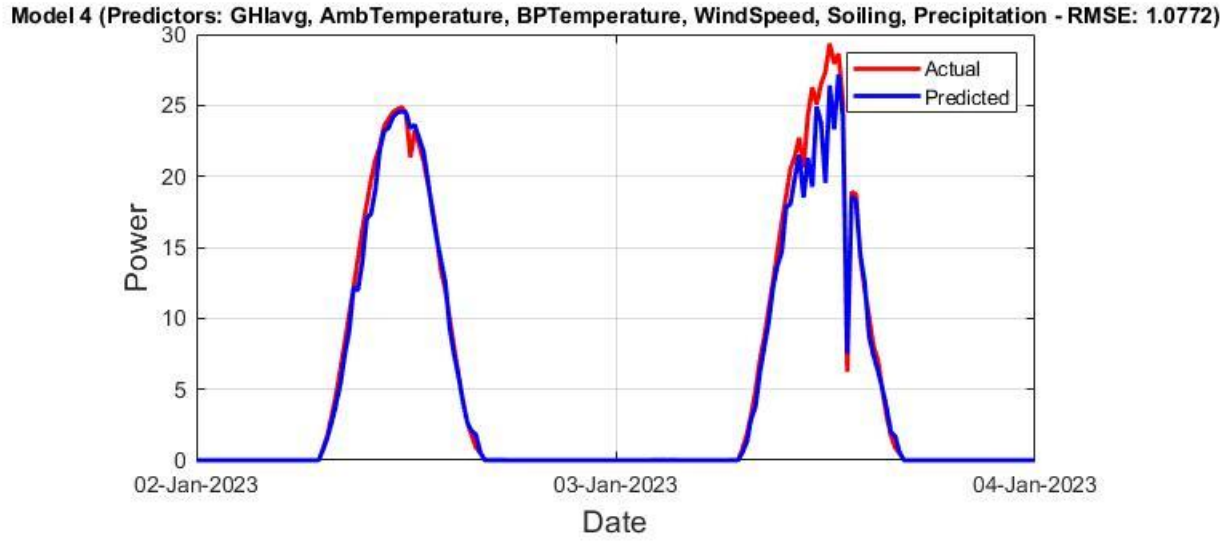

Predictor Importance - Model 3
Importance
60
40
20
0
GHIavg
BPTemperature
Soiling
Precipitation
Predictors


Predictor Importance - Model 4
Importance
60
50
40
30
20
10
0
GHIavg
AmbTemperature
BPTemperature
WindSpeed
Soiling
Precipitation
Predictors

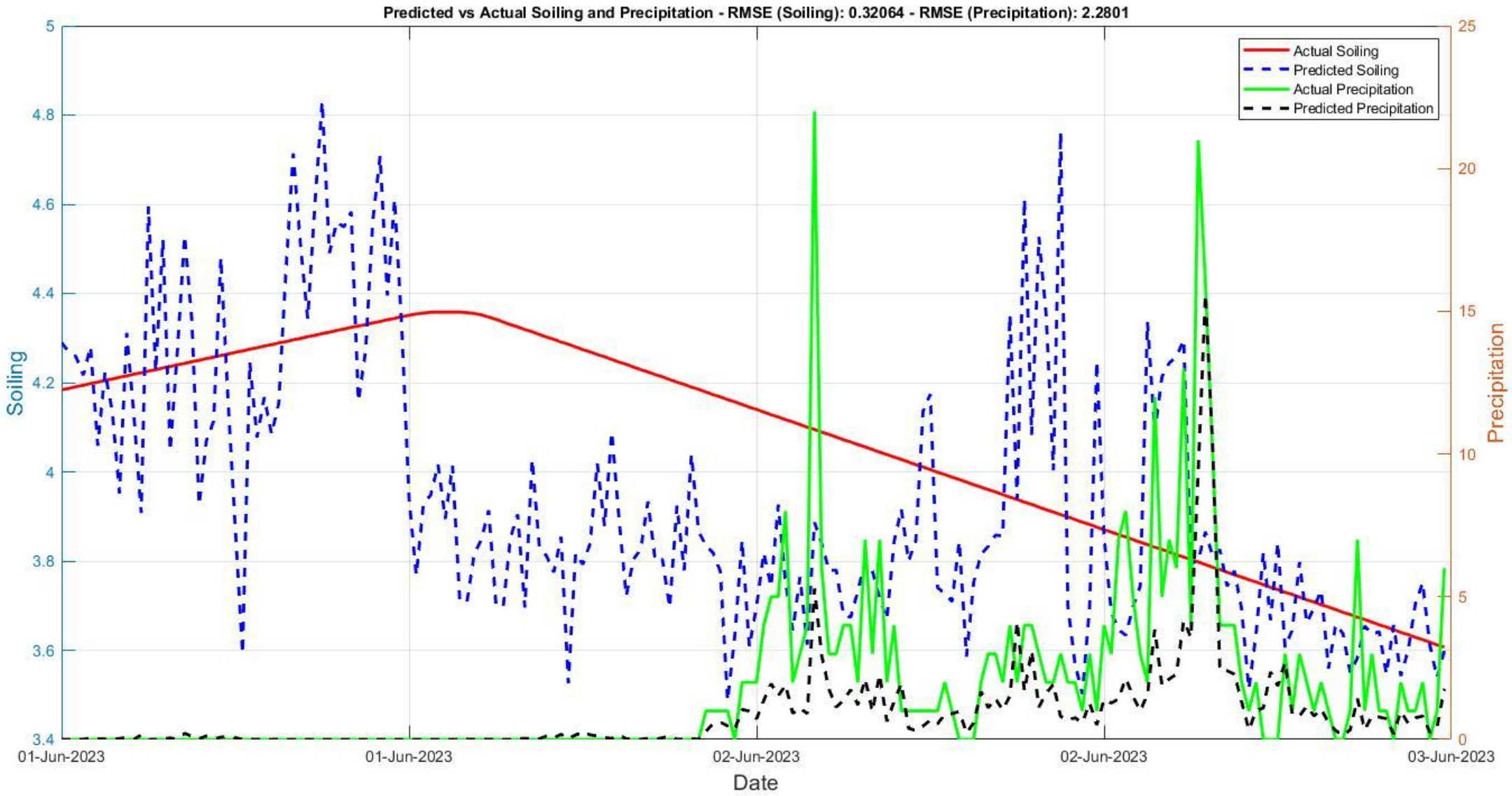

Model 1 (Predictors: GHIavg - RMSE: 2.4294)
Actual
Predicted
Power
Date
02-Jan-2023
03-Jan-2023
04-Jan-2023
0
5
10
15
20
25
30
35


Model 2 (Predictors: GHIavg, AmbTemperature, BPTemperature, WindSpeed - RMSE: 1.1263)
Actual
Predicted
Power
Date
02-Jan-2023
03-Jan-2023
04-Jan-2023
0
5
10
15
20
25
30


Model 3 (Predictors: GHIavg, BPTemperature, Soiling, Precipitation - RMSE: 1.6649)
Actual
Predicted
Power
Date
02-Jan-2023
03-Jan-2023
04-Jan-2023
0
5
10
15
20
25
30


Model 4 (Predictors: GHIavg, AmbTemperature, BPTemperature, WindSpeed, Soiling, Precipitation - RMSE: 1.0772)
Actual
Predicted
Power
Date
02-Jan-2023
03-Jan-2023
04-Jan-2023
0
5
10
15
20
25
30

Predicting Soiling and Precipitation: Driving Decision-Making



Key Insights

What's worth measuring?

Who stands to gain from this data?

- Manufacturers
- Designers
- Site Owners
- Maintenance Firms
- Others

Alternatives to ground measurements?

Utilizing Satellite Data

Space-Based Potential:

- Global Coverage
- Continuous Monitoring
- Multiple Data Points

Limitations:

- Resolution Limitations:

  Difficulty Measuring Localized Phenomena
- Need for Ground-Truth Validation
- Atmospheric Interference
- Temporal Resolution

Spotlight on NREL Data: A Case Study

- BEST bifacial PV field test [1]
- 75 kWp
- Single-axis tracker
- Bifacial and monofacial modules
- Ground data
- Lat.: 39.742 Long.: -105.179

Satellite- ground comparison

GHI	Yearly	Monthly	Daily	5 minutes
Difference	5.7%	5.1%	9.3%	28%

POA	Yearly	Monthly	Daily	5 minutes
Difference	20.5%	31.6%	73.9%	114%

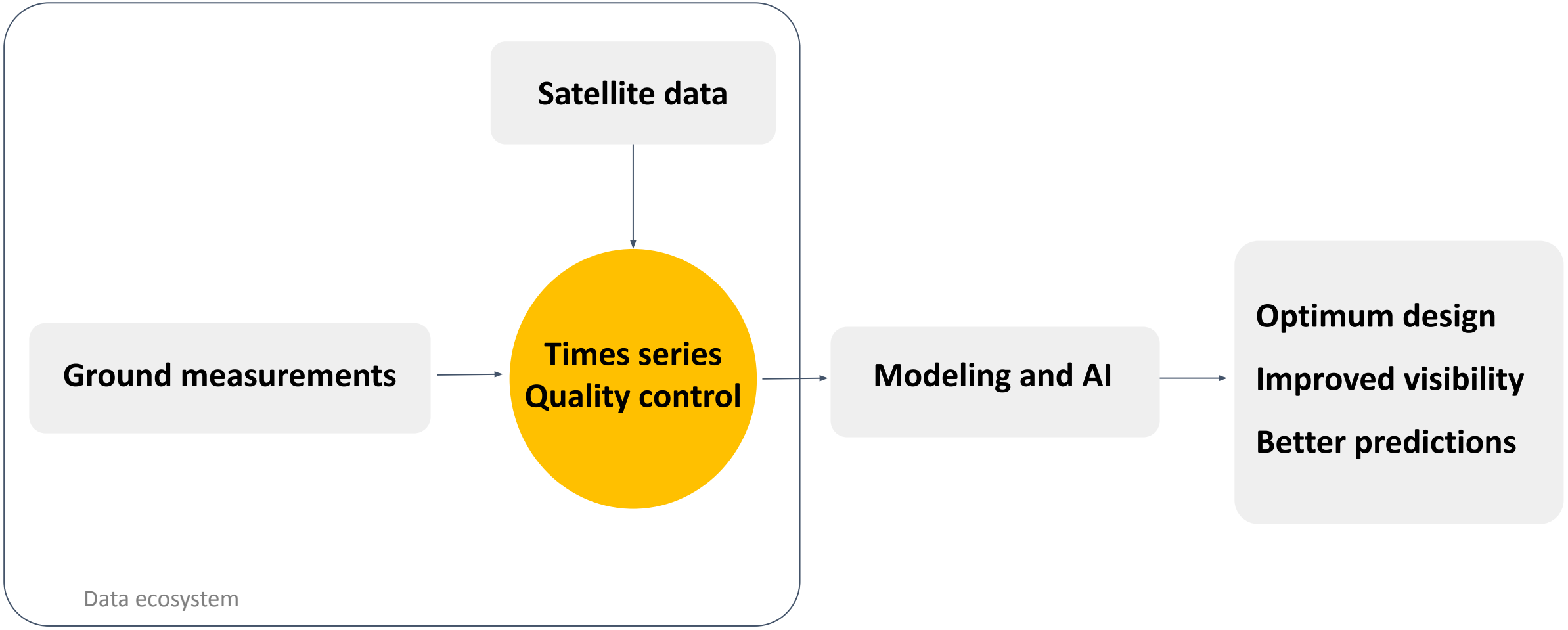
Wind	Yearly	Monthly	Daily	5 minutes
Difference	0.57 m/s	–	–	1.28 m/s

Temperature	Yearly	Monthly	Daily	5 minutes
Difference (Celsius)	0.7°	–	–	2.9°

Module Temperature	Yearly	Monthly	Daily	5 minutes
Difference (Celsius)	1.8°	1.8°	2.4°	4.1°

PR	Yearly	Monthly	Daily	5 minutes
Difference	0.8%	14.3%	33%	57%

Conclusions Drawn



OTT HydroMet:
Solutions for Effective Parameter Measurement

POA and GHI







	SP Lite2	SMP3	SMP6	SMP10	SMP10:CVF4	SMP12	SMP22
Classification Guide							
IEC Class A					✓	✓	✓
ISO Class A				✓	✓	✓	✓
ISO Class B			✓				
ISO Class C-Flat		✓					
ISO Class C-Fast	✓						
Typical Market Relevance							
Commercial & Industrial	✓	✓	✓	✓	✓	✓	✓
Utility GHI				✓	✓	✓	✓
Utility GHI_{refl}		✓	✓	✓	✓	✓	✓
Utility POA				✓	✓	✓	✓
Utility POA_{rear}		✓	✓	✓	✓	✓	✓

OTT HydroMet:
Solutions for Effective Parameter Measurement

POA and GHI: SMP12

- **Fast Response & Class A Accuracy**
- **Integrated Sensors**
- **heated**
- **Enhanced Surge Protection**
- **Smart**

→ **Precision in PR Measurement**

OTT HydroMet:
Solutions for Effective Parameter Measurement

Soiling: DustIQ

- Optical soiling measurement technology
- Know exactly when and where to clean
- Optimize yield
- Maintenance free
- Integrated into leading plant management software

OTT HydroMet: Solutions for Effective Parameter Measurement

Weather stations

	WS200	WS300	WS400	WS500	WS501	WS510	WS600	WS601	WS700	WS800
Air Temperature		✓	✓	✓	✓	✓	✓	✓	✓	✓
Air Pressure		✓	✓	✓	✓	✓	✓	✓	✓	✓
Relative Humidity		✓	✓	✓	✓	✓	✓	✓	✓	✓
Wind Speed	✓			✓	✓	✓	✓	✓	✓	✓
Wind Direction	✓			✓	✓	✓	✓	✓	✓	✓
Precipitation			✓				✓	✓	✓	✓
Irradiance (GHI)					✓	✓			✓	✓
Lightning Counts										✓
External Rain	✓	✓		✓	✓	✓				
WT1 BOM_{Temp}	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Q & A

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Q&A

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by Bella Peacock

Panasonic introduces new home battery

by Ryan Kennedy

pv magazine webinars

Coming up next...

Wednesday, 5 July 2023
3:00 pm – 4:00 pm CEST, Berlin, Paris, Madrid
9:00 am – 10:00 am EDT, New York City

Right on Smart Track: Bankability criteria for single-axis trackers

Monday, 10 July 2023
4:00 pm – 5:00 pm CEST, Berlin, Paris, Madrid
10:00 am – 11:00 am EDT, New York City

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Ryan Kennedy
Editor
pv magazine

Thank you for joining today!