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University of Cyprus
PV Technology

Machine Learning Model Selection for PV Forecasting

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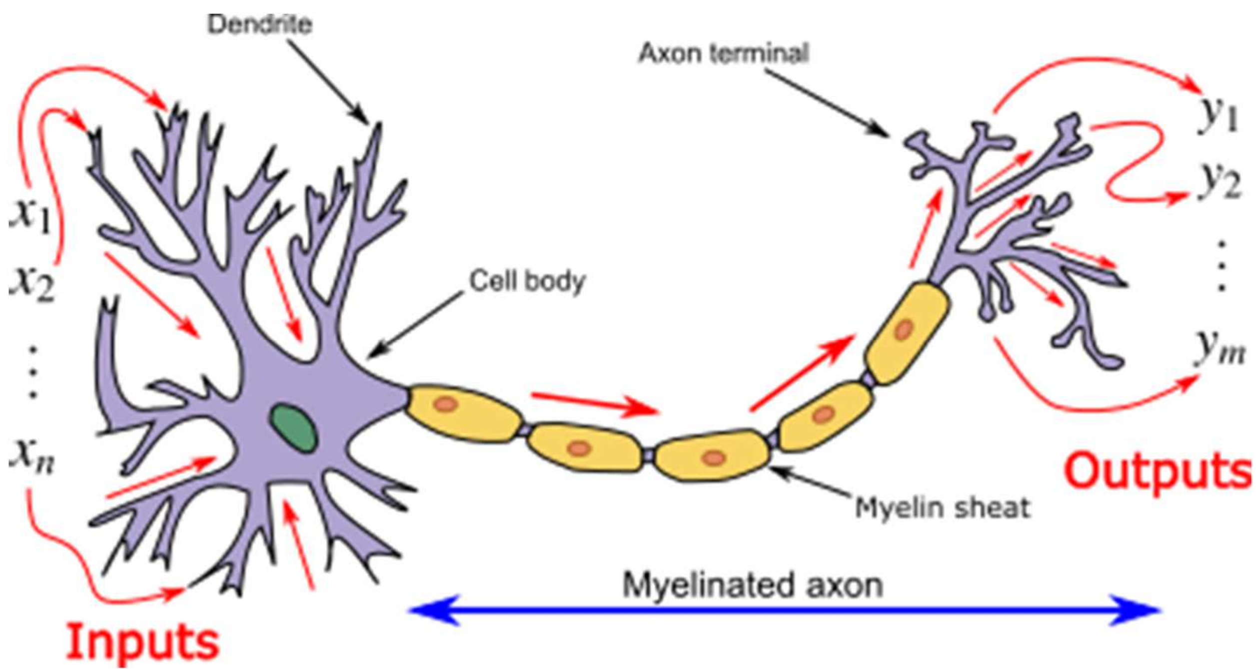
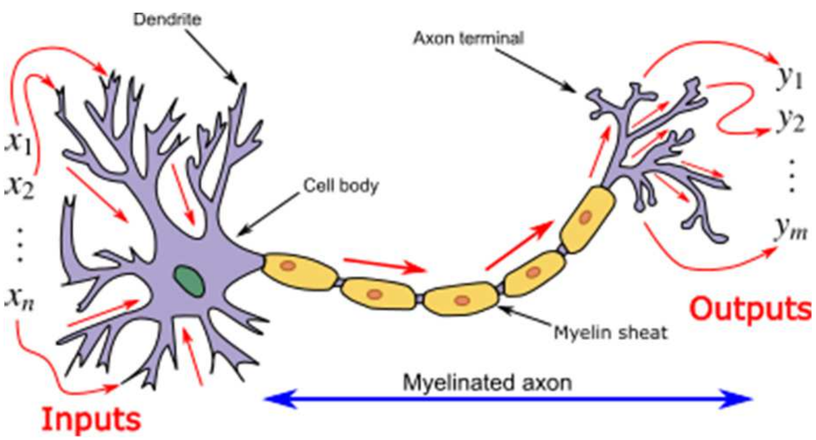
Outline

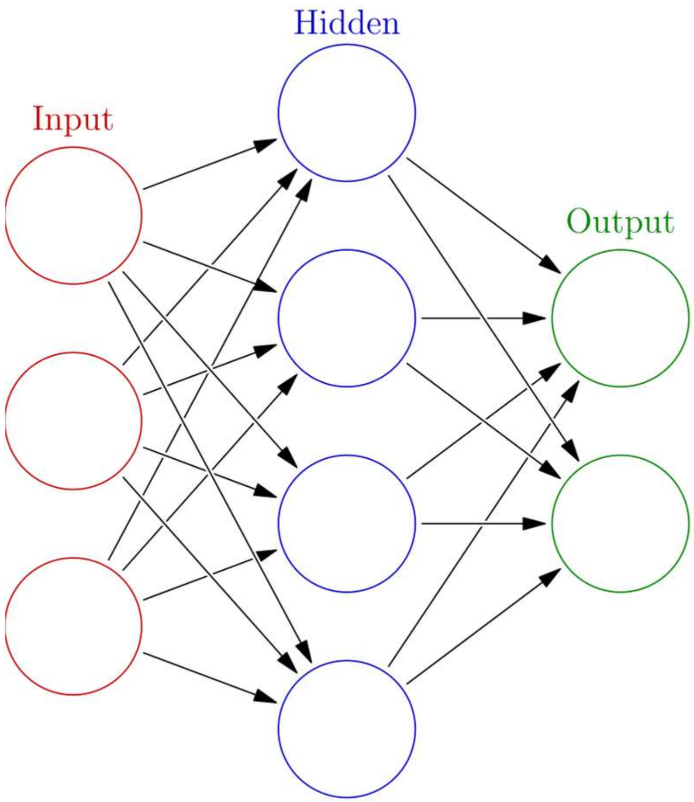
- Artificial Neural Networks
- Support Vector Machines
- Trees
- Model Selection
- Methodology
- Results

Artificial Neural Networks



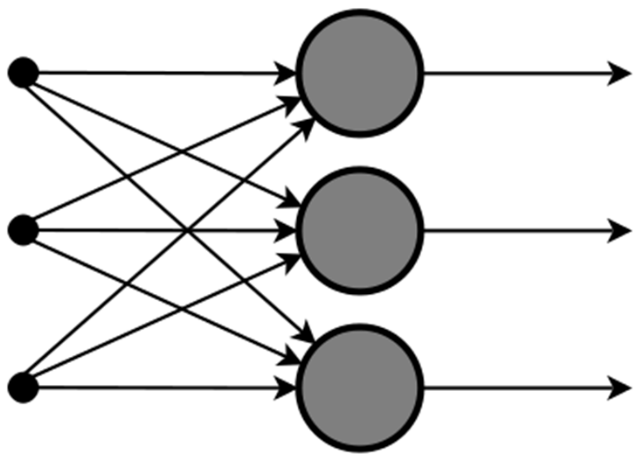
Artificial Neural Networks





Artificial Neural Networks

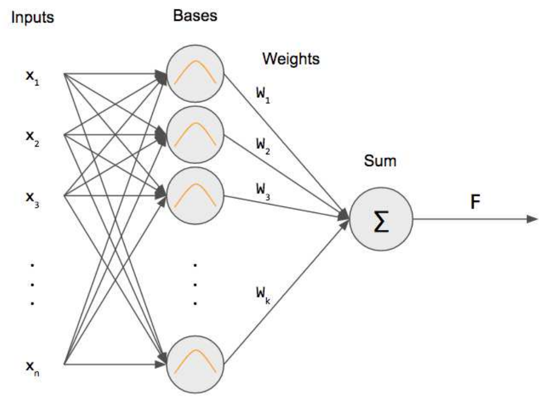
- Types of ANN:
  - Feedforward Neural Network

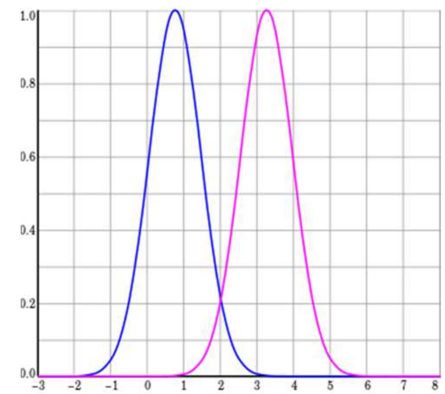


- Applications:
  - Computer Vision (Sky and Satellite Images for intra-day forecasts)
  - Speech Recognition

Artificial Neural Networks

- Types of ANN:
  - Radial basis function Neural Network



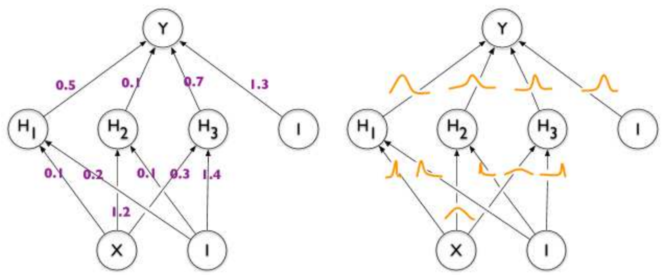


- Applications:
  - Power Restoration Systems

Artificial Neural Networks

- Types of ANN:
  - Bayesian Neural Networks

$$p(w|y) = \frac{p(y|w)p(w)}{p(y)} \qquad p(w) = N(w|0, \sigma_P^2 I_D)$$



- Applications:
  - Variety of areas

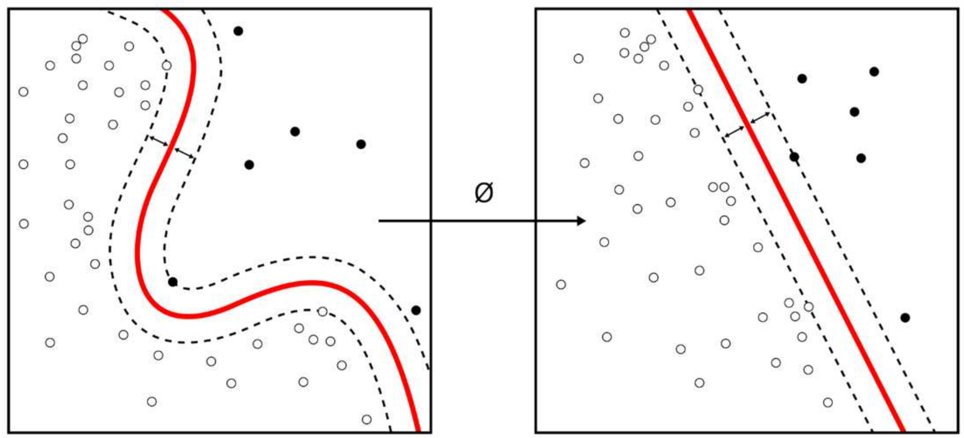
Artificial Neural Networks

- Types of ANN:
  - Feedforward Neural Network
  - Radial Basis Function Neural Network
  - Bayesian Neural Network

1. Weight optimization
2. Programmable
3. Fast

Support Vector Machines

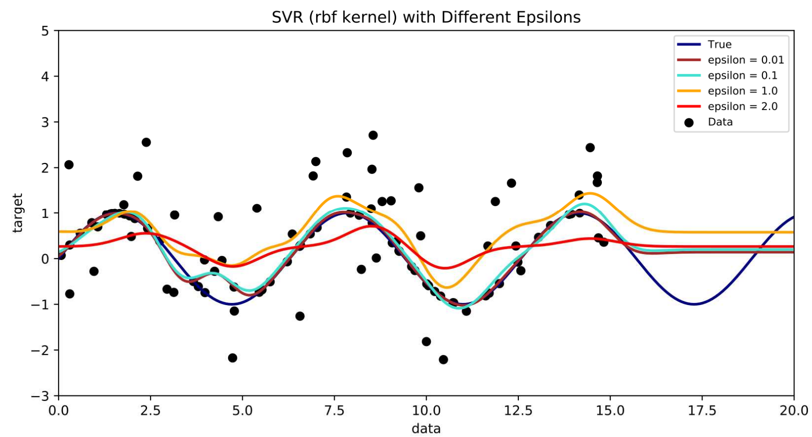
- Support Vector Machines for Classification



- Applications:
  - 2 class classification
  - Multiclass SVM: Not accurate

Support Vector Machines

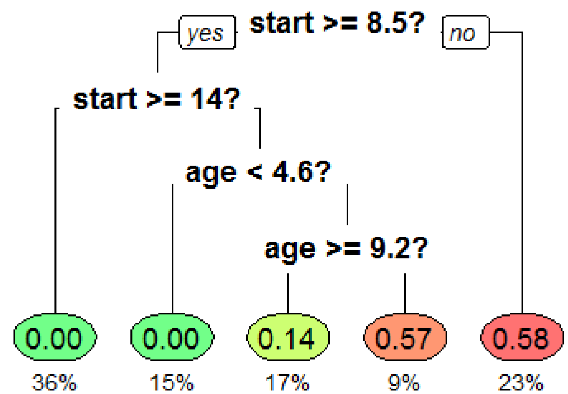
- Support Vector Machines for Regression



- Applications:
  - Simple Regression Problems (e.g. intra-day forecasting)

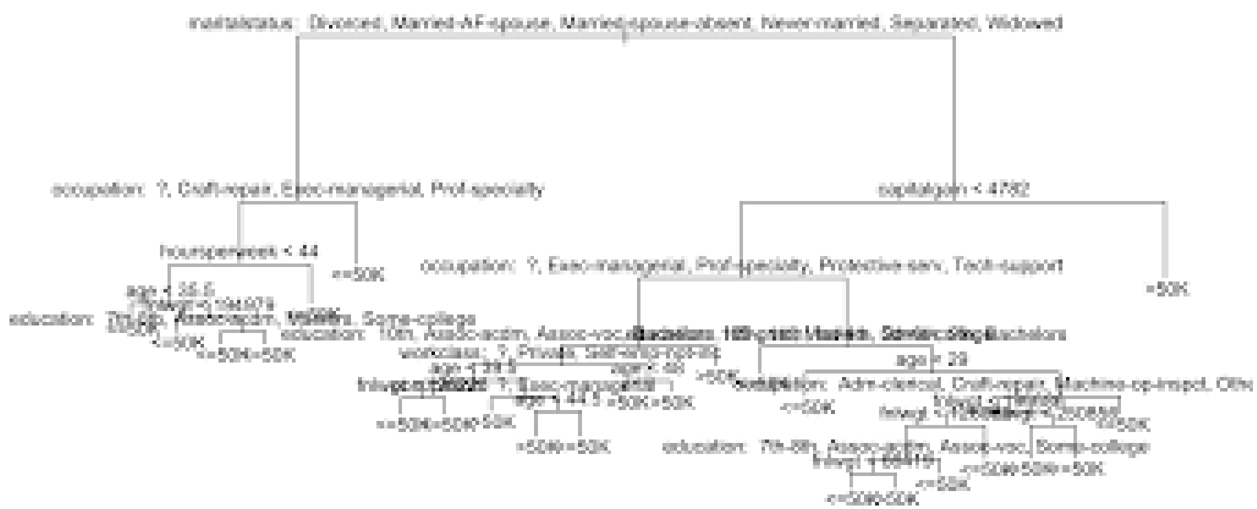
Trees

- Decision Trees



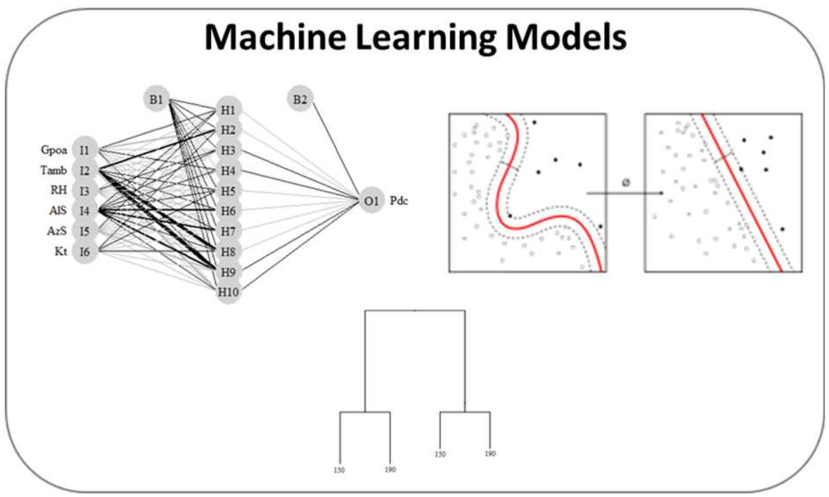
Trees

- Classification and Regression Trees (CART)



Model Selection

- Bayesian Neural Network
- Support Vector Machine for Regression
- Regression Trees



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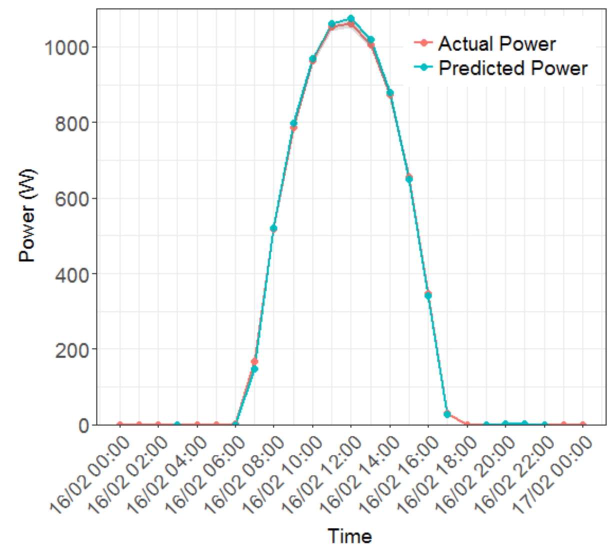
Model Selection

Weather Measurements

PV Power Forecast
- Machine Learning models



Estimation
Forecasting

Methodology – Experimental Apparatus

- Grid-connected Poly-c-Si PV (1.3 kWp).
- Monitoring system to acquire PV operational and meteorological measurements.
- Data acquired since June 2015 and accumulated as 60-minute averages.

Sensors

PV system

Solar Position Algorithm for Solar Radiation Applications

NREL

Elevation Angle of the Sun (*AlS*)
Azimuth of the Sun (*AzS*)

Methodology-Machine Learning Approach

Data set (1 year of hourly data)

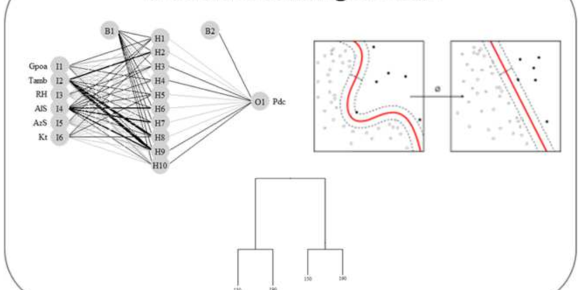
Train Set (70 %) 255 Days	Test Set (30 %) 111 Days

G_{poa}	T_{amb}	RH	WS	W_{alpha}	AzS	AlS	P_{DC}

Measured

Calculated

Machine Learning Models



Training (Train Set)
Validation (Test Set (15 %))
Testing (Test Set (15 %))

1. Data preparation

- Data split (Representative)
- Feature extraction
- Outlier correction

2. Models Design

- Optimization
- Architectural Design
- Validation

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Methodology-Assessment Metrics - Validation

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

$$MAPE = \frac{100}{n} \times \sum_{i=1}^{n} \left| \frac{y_{\text{actual,i}} - y_{\text{predicted,i}}}{y_{\text{actual,i}}} \right|$$

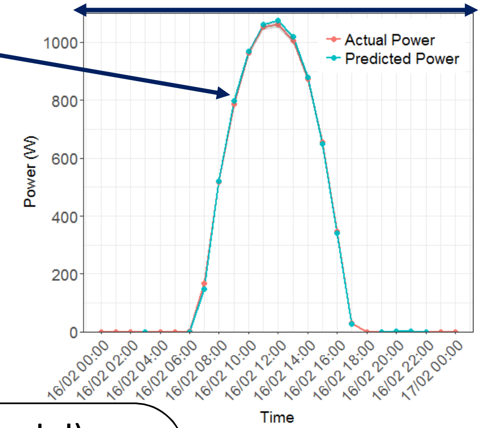
$$RMSE = \sqrt{\frac{1}{n} \times \sum_{i=1}^{n} (y_{\text{actual,i}} - y_{\text{predicted,i}})}$$

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

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

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

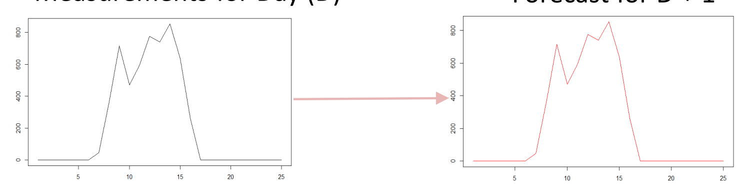
Error / APE for each point



Persistence Model (Reference Model)

Measurements for Day (D)

Forecast for D + 1

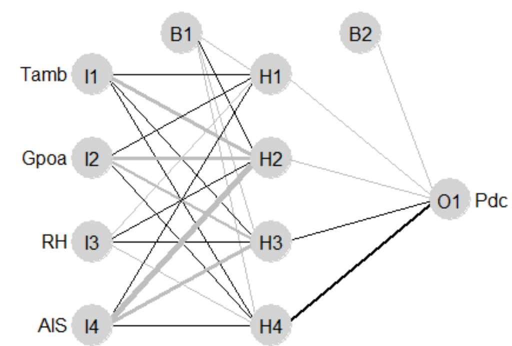


Results-Input parameters

Input Correlation Analysis (Pearson)

Cutoff <|0.5|

	P_{DC}
G_{poa}	0.9
AIS	0.8
RH	-0.7
T_{amb}	-0.5
W_{alpha}	-0.3
WS	0.2
AzS	-0.01
Rain	0. 0005

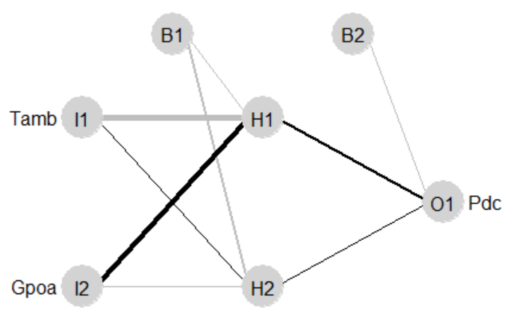


Reference Model

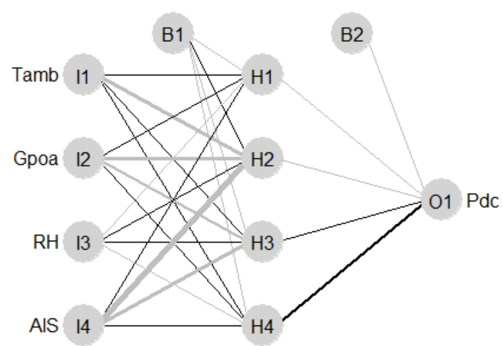
Results-Input parameters

Continuous Samples

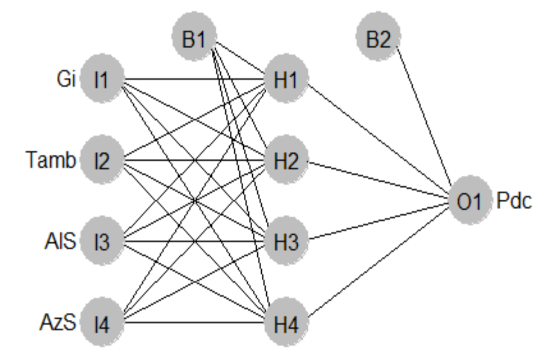
nRMSE(%) 1.15 %



nRMSE(%) 1.08 %



nRMSE(%) 0.90 %



Random Samples

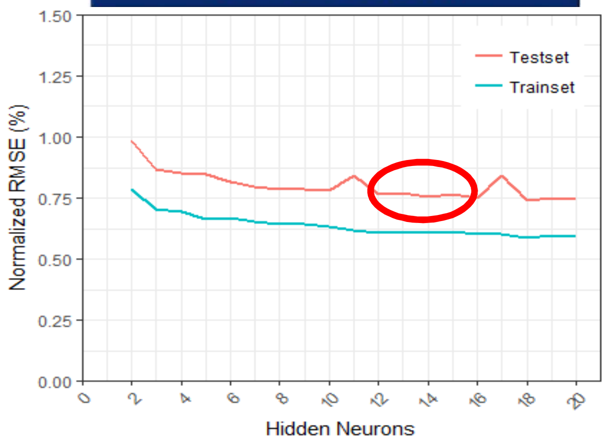
nRMSE(%) 1.11 %

nRMSE(%) 1.01 %

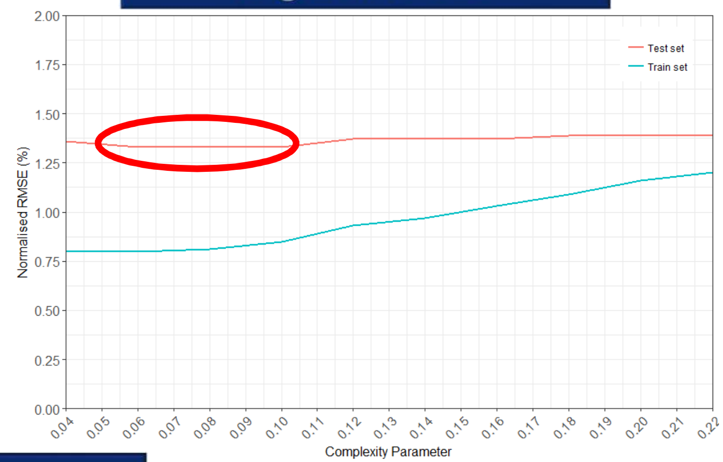
nRMSE(%) 0.80 %

Results-Architectural parameters

Neural Network



Regression Tree

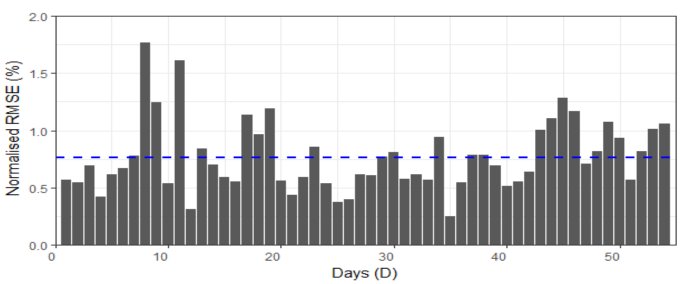


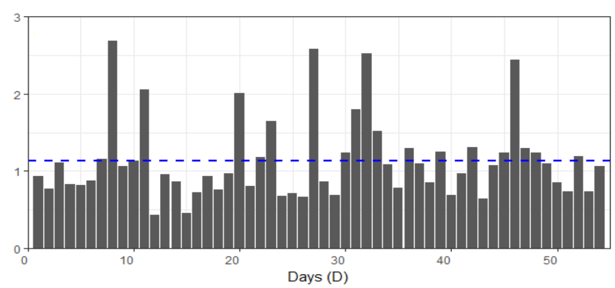
Support Vector Regression

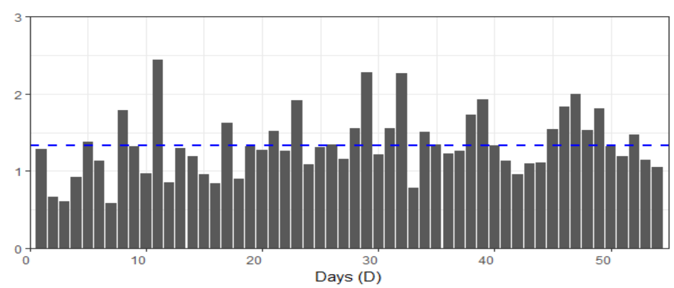
Gamma Parameter, γ (γ)	Cost of Constraints Parameter, C (C)			
	1	100	1000	10000
0.0001	1.1395	1.1453	1.1411	1.1388
0.001	1.1405	1.1512	1.1427	1.1762
0.01	1.1387	1.1485	1.1659	1.1793
0.1	1.1321	1.499	1.1439	1.1873

Results-Optimized Models

Neural Network 12 Neurons	Support Vector Regression 0.1 Gamma 1 Cost of Constraints	Regression Trees 0.06 Complexity Parameter







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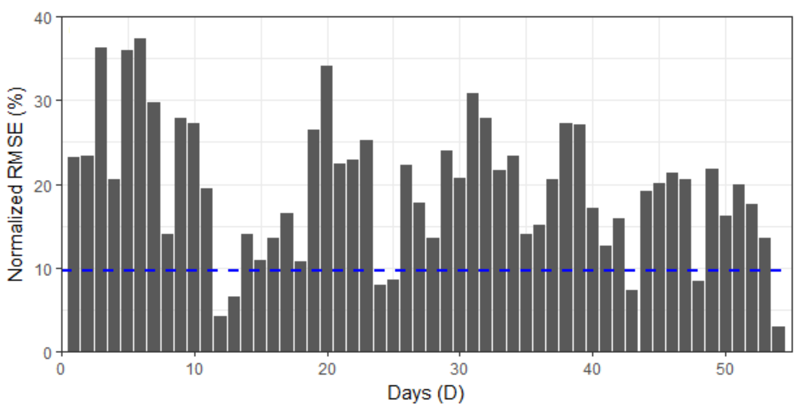
Results-Models Assessment

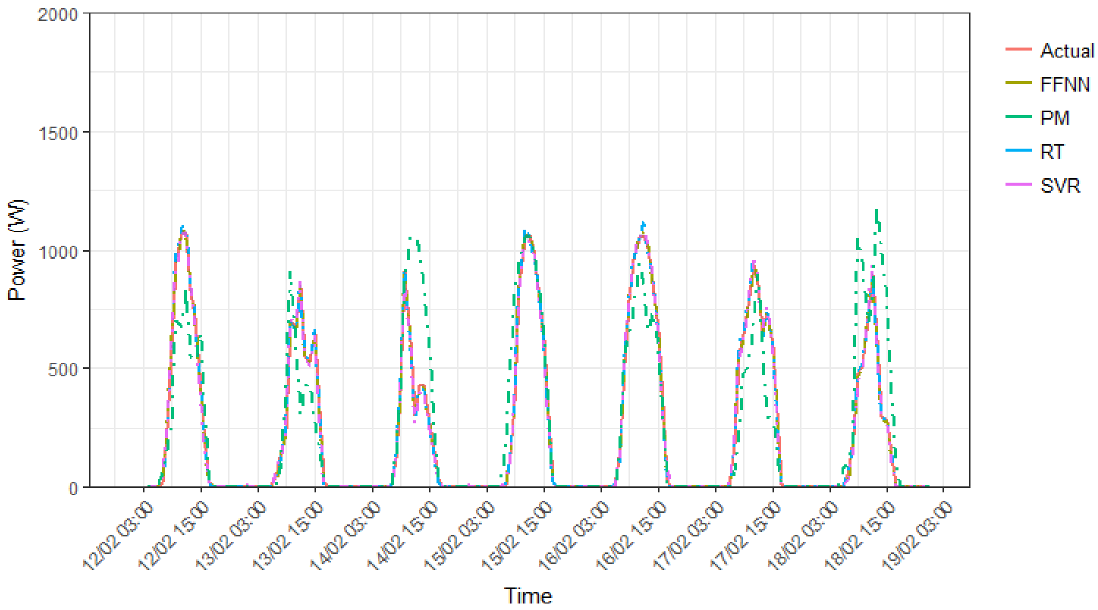
Persistence Model



	Performance Metrics			
Models	MAPE (%)	RMSE (W)	nRMSE (%)	SS (%)
ANN	0.61	10.37	0.76	92.22
SVR	0.75	15.42	1.13	88.34
RT	0.98	18.15	1.33	86.33

Results-Models Assessment

- Plot of a typical week



Conclusions

- Machine learning models could be utilized for the implementation of agile PV power forecasting techniques.
- Results demonstrated that by utilizing simple machine learning techniques (ANNs, RT and SVR), exhibits nRMSEs ~ 1 %.
- The ANN model demonstrated the best-performance over the RT and SVR with nRMSE of 0.76 % while the SVR and RT demonstrated nRMSE of 1.13 % and 1.33 % respectively.
- Finally, all the models achieved higher relative improvement over the reference model, since the SS results ranged from 86 % to 92 %.

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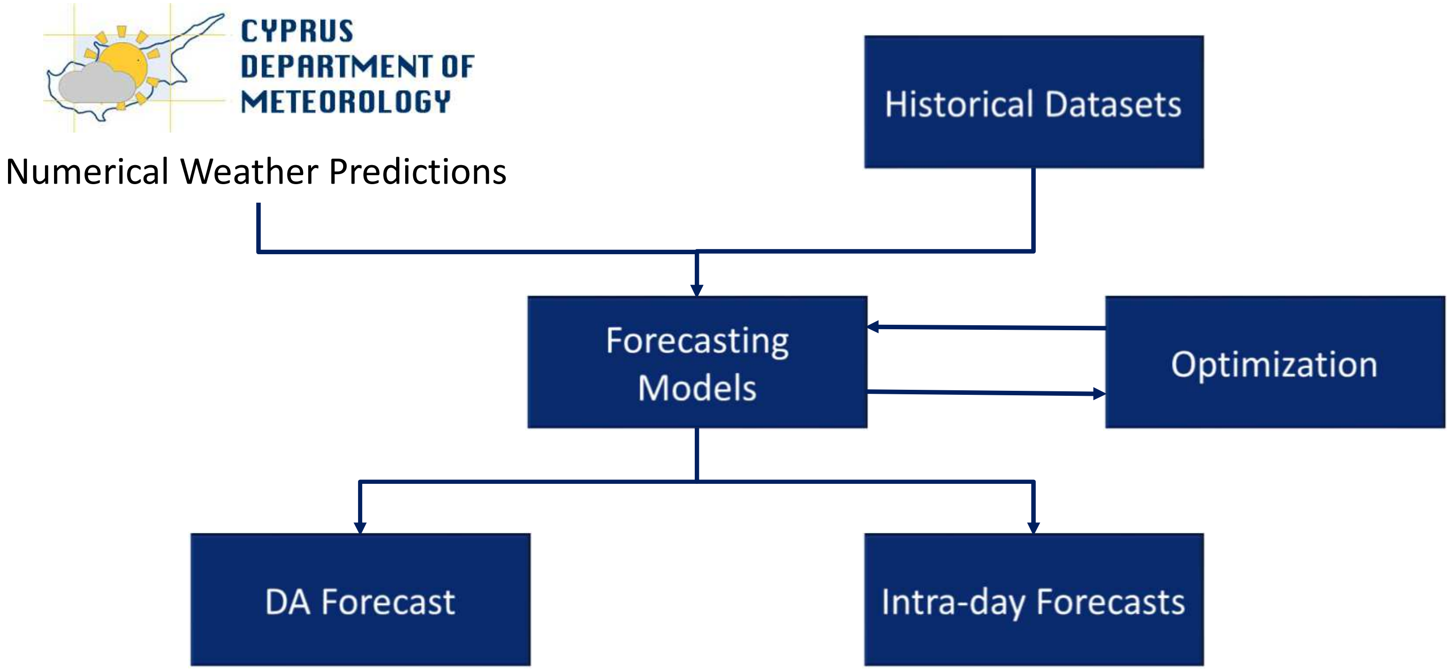
General Methodology



More information...

Website

www.pvtechnology.ucy.ac.cy

Thank you for your attention

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