University of Cyprus
PV Technology

15/12/2016

PV Activities at the University of Cyprus (UCY)

George Makrides
University of Cyprus, PV Technology Laboratory

Outline

- Introduction
- PV Technology Laboratory
  - Education and Training
  - Testing and Services
  - Ongoing and future Research activities
- Conclusions

Acknowledgement

Stimulating scientific excellence through twinning in the quest for sustainable energy (TwinPV).

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AIT AUSTRIAN INSTITUTE OF TECHNOLOGY
TOMORROW TODAY

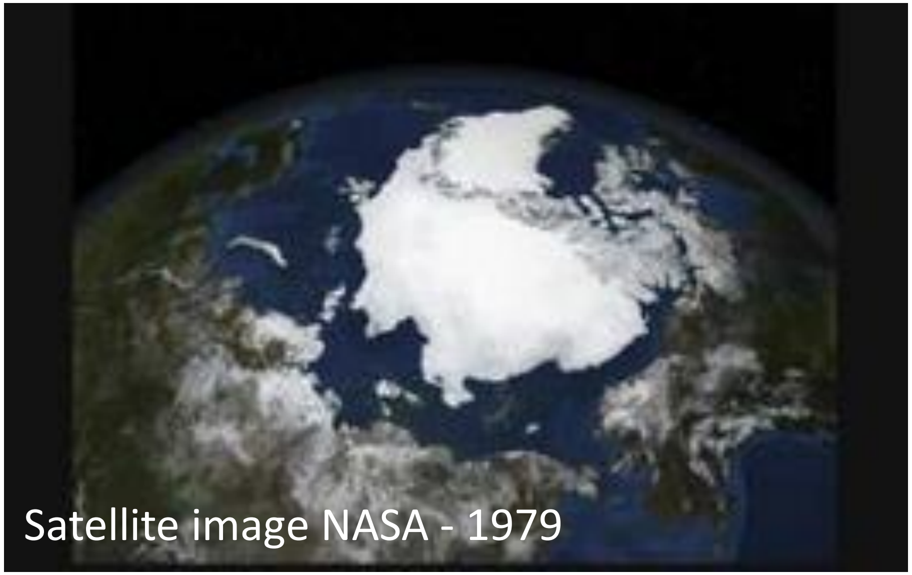
DTU

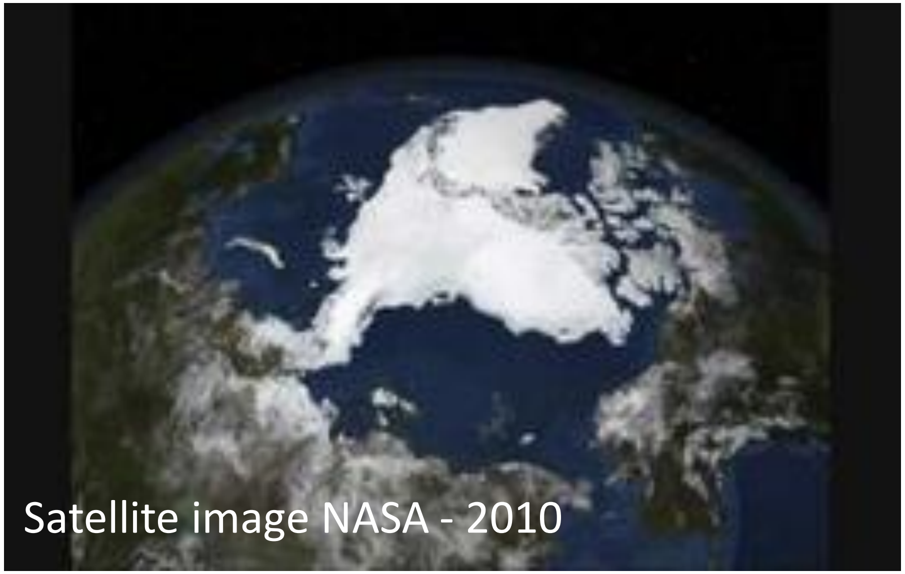
TWinPV

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the agreement No. 692031

Introduction

- Energy crisis:
  - Limited supply of fossil fuels
  - Environmental impact of conventional fuel usage

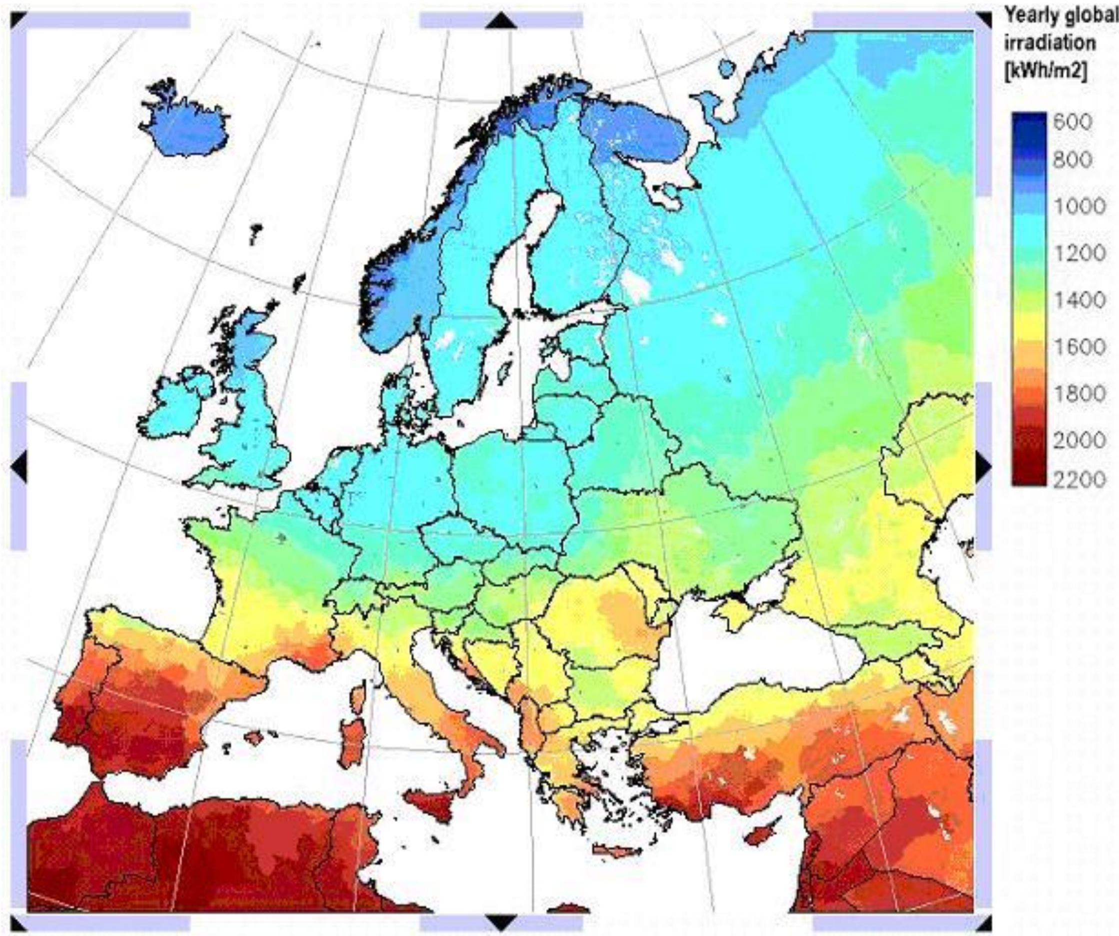

Satellite image NASA - 1979


Satellite image NASA - 2010

PV potential in Cyprus

- Enormous prospects and potential especially in countries of high solar irradiance.
- Solar Irradiation in Cyprus is one of the highest in Europe.

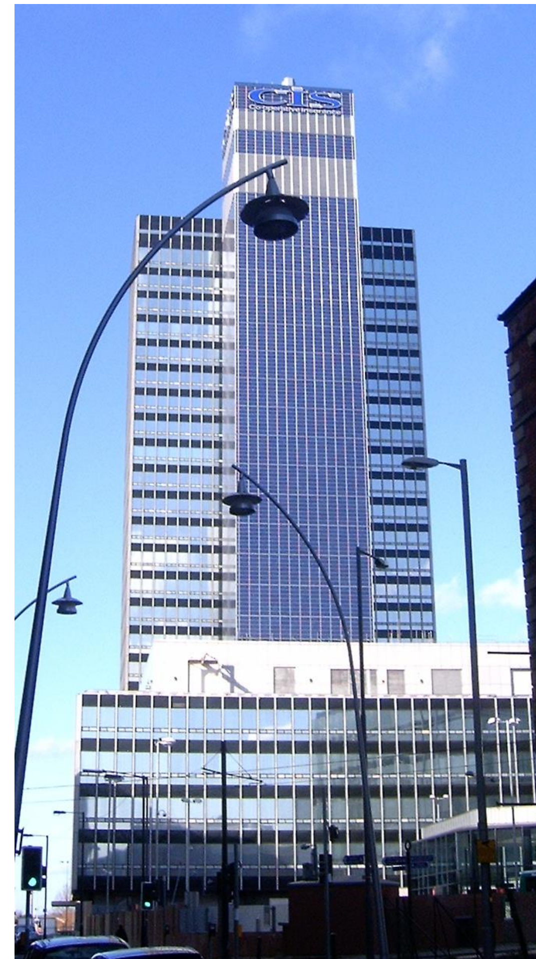
Based on the IRENA analysis, renewable energy could provide 25% to 40% of Cyprus' total electricity supply in 2030 and 11,000-22,000 jobs.



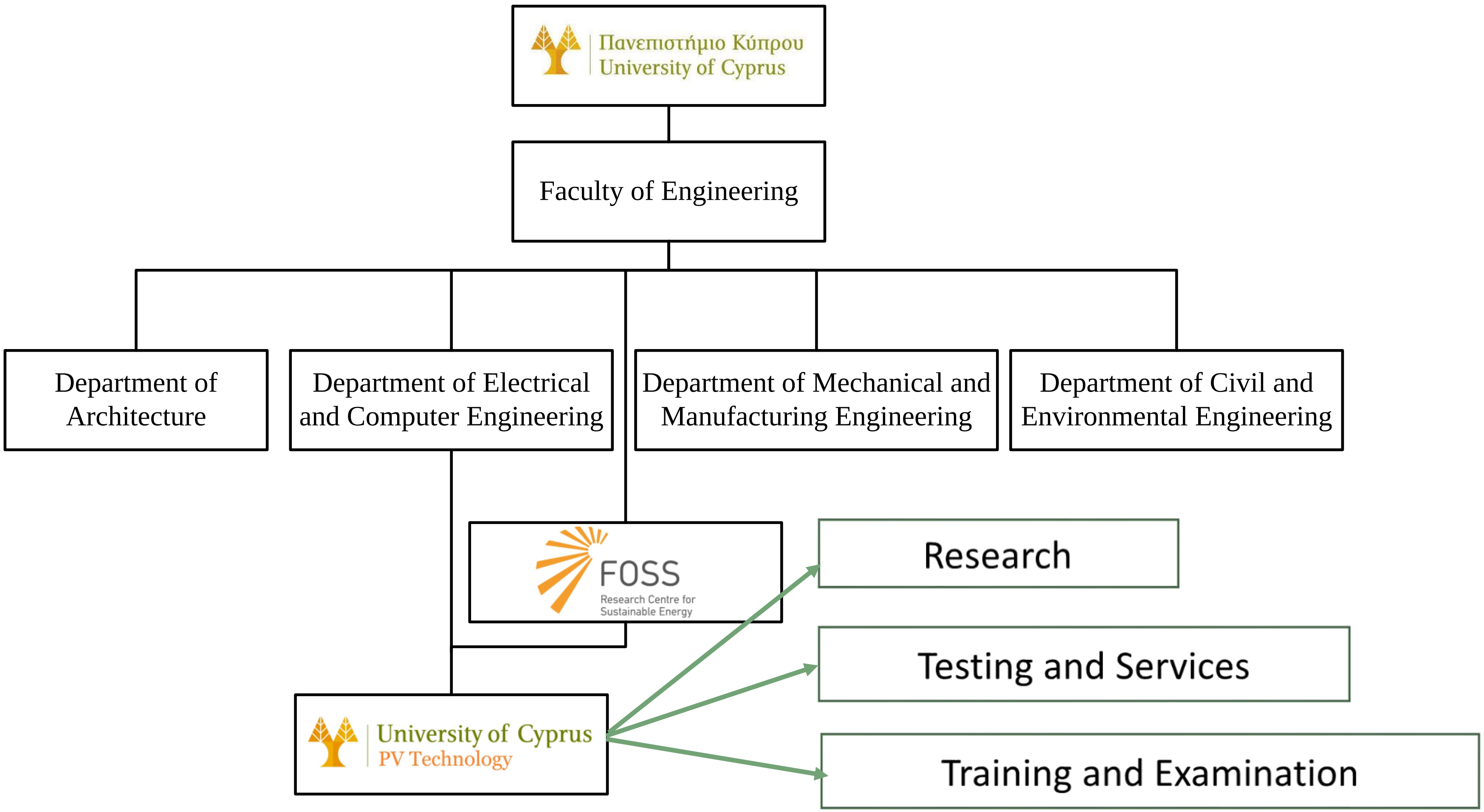
Source: JRC PVGIS

Challenges of PV technology

- Cost / Efficiency
- Improve Performance / Energy yield
- Reliability
- Grid/Market integration



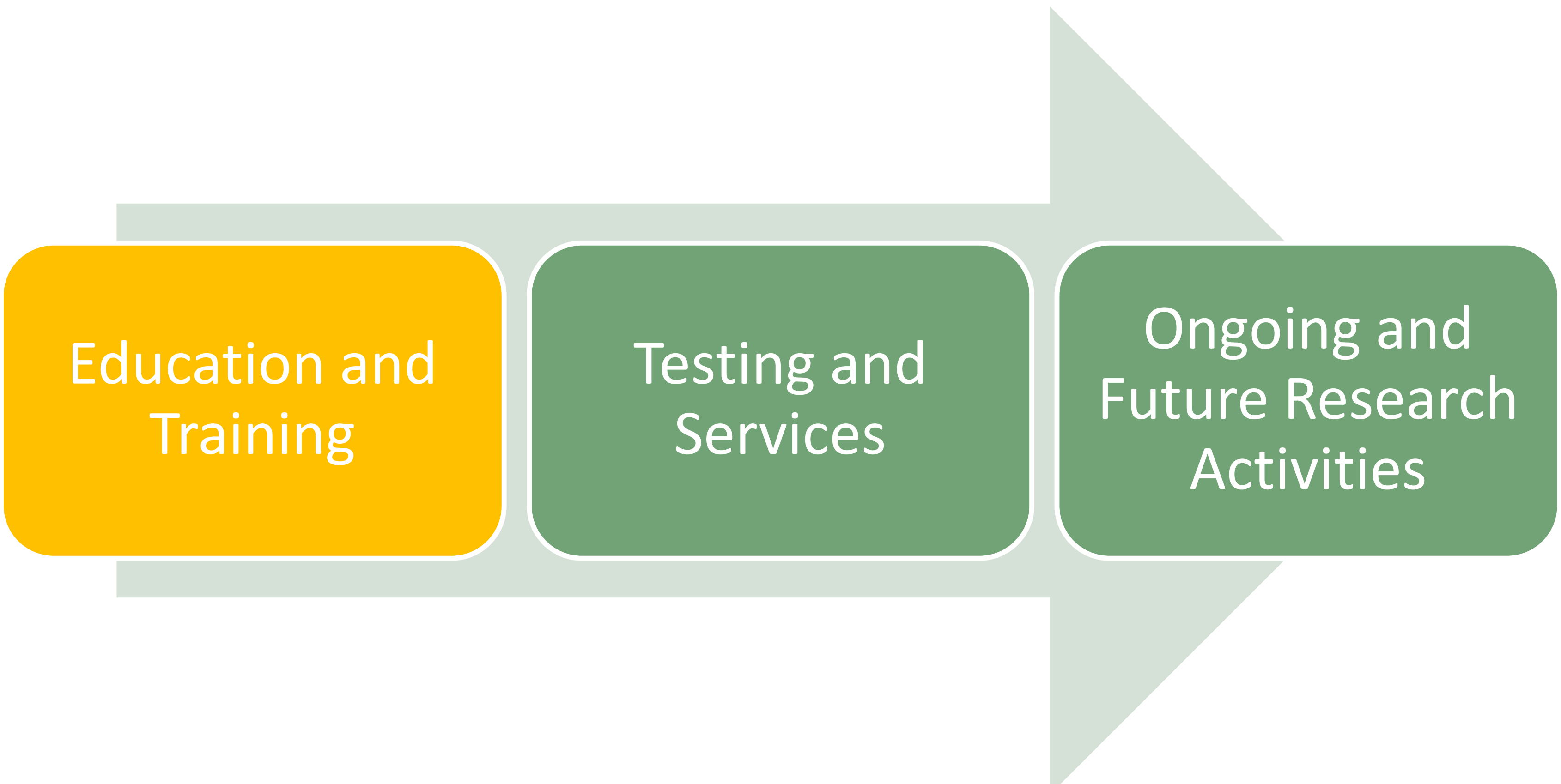
Organizational Chart
PV Technology Laboratory



Highlights of PV Technology Laboratory

- Participation/coordination of over 60 national/international research projects
- Research funding of 10 Million over the past 6 years
- Comprises of 30 researchers
- Over 250 research publications
- Research quality/awards at international conferences

PV Technology Laboratory UCY



Academic courses

ECE447: Renewable Energy Sources: Photovoltaics
This course covers theoretical and practical aspects of photovoltaic technology and in particular introduces students to aspects of solar generation, technology characteristics, design principles and system types.

ECE687: BIPV - Towards nearly zero energy buildings (NZEB)
This course covers theoretical and practical aspects of building integrated photovoltaics (BIPV) in the domain of nearly zero energy buildings (NZEB).

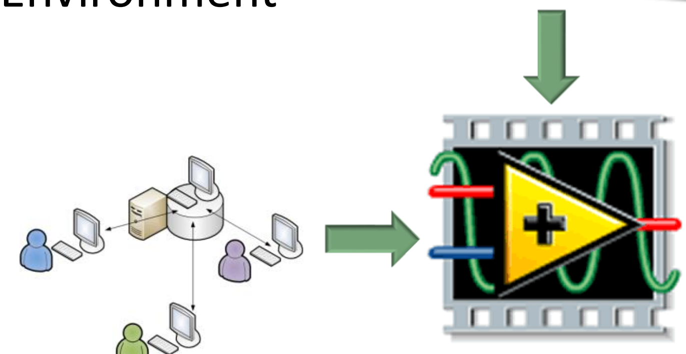
Academic courses

New courses

- Building integrated Photovoltaics
- Socio-economics of renewables
- Grid integration of renewables
- Smart grids
- Energy Efficiency

New laboratories Virtual Laboratory Environment

- Building integrated PV (BIPV)
- Microgrid



Integration to VLE

Erasmus+

Vocational Training - Photovoltaics

1. PV System Designer and Installer

2. PV System Inspection and Performance Testing according to EN 62446

3. Fundamentals of building integrated PV (BIPV)

4. Fundamentals of nearly zero energy buildings (NZEB)

Human Resource Development Authority of Cyprus
HRDA

MINISTRY OF ENERGY COMMERCE INDUSTRY AND TOURISM

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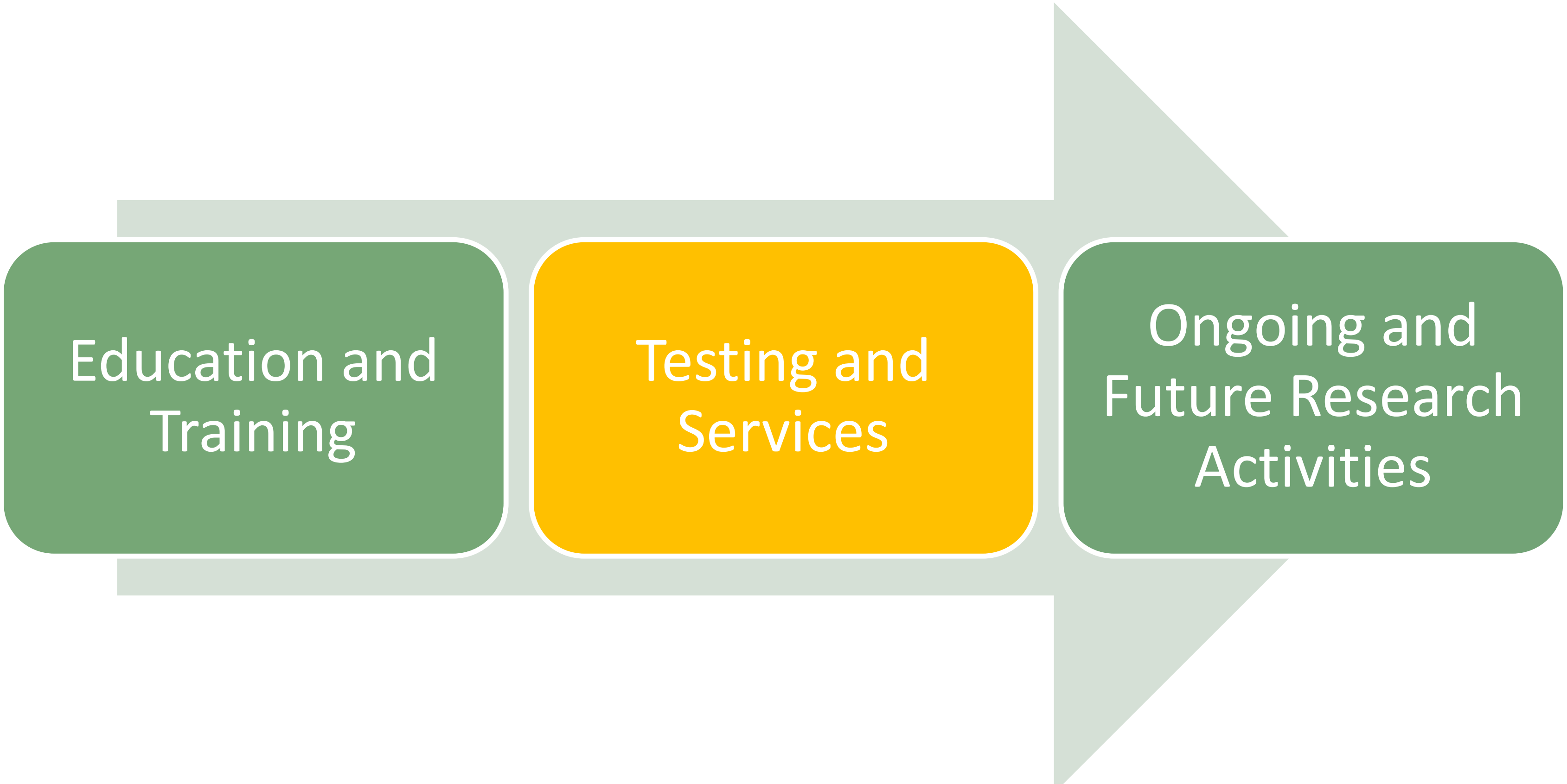


Testing and Services

UCY0 (2006)
Outdoor Facility

UCY1 (2010)
Outdoor Facility

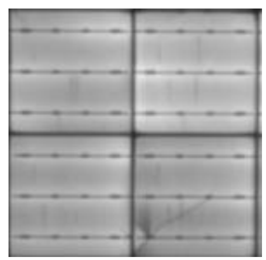
PV Lab1 (2011)
Indoor Facility

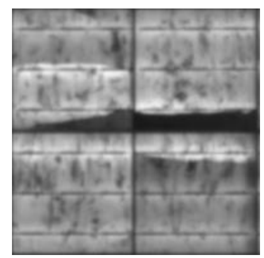
UCY2 (2014)
Outdoor Facility

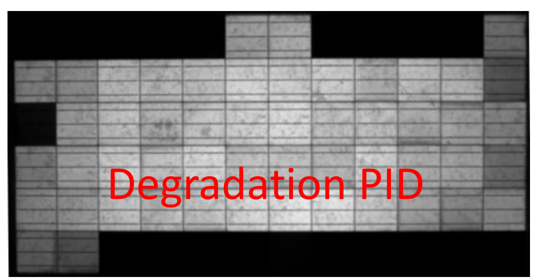
Indoor / Outdoor testing

Indoor Testing

Electroluminescence Imaging







Outdoor Testing

UCY1 - CPV cell/module testing

- Accurate two-axis trackers (CPV testing).
- Solar irradiance assessment (DNI, GHI, DHI, spectrum).
- I-V curve acquisition (cell / module characterization).

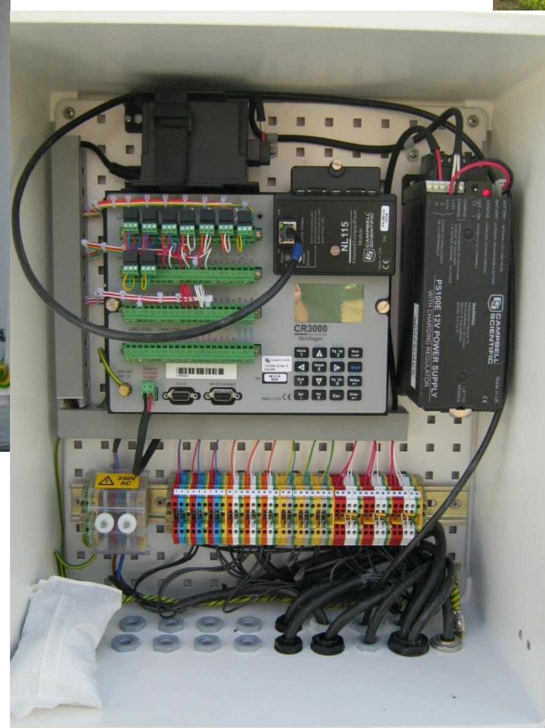
UCY1 - Outdoor testing infrastructure

Sensors for outdoor performance assessments

UCY1 - Outdoor CPV infrastructure

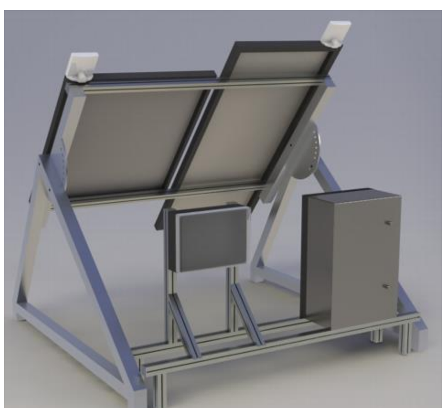
- Complete I-V curve measurement of CPV modules.
- Measurements of parameters at maximum power point (V_{MPP}, I_{MPP} and P_{MPP}).
- Tracker accuracy (Black Photon sensor).

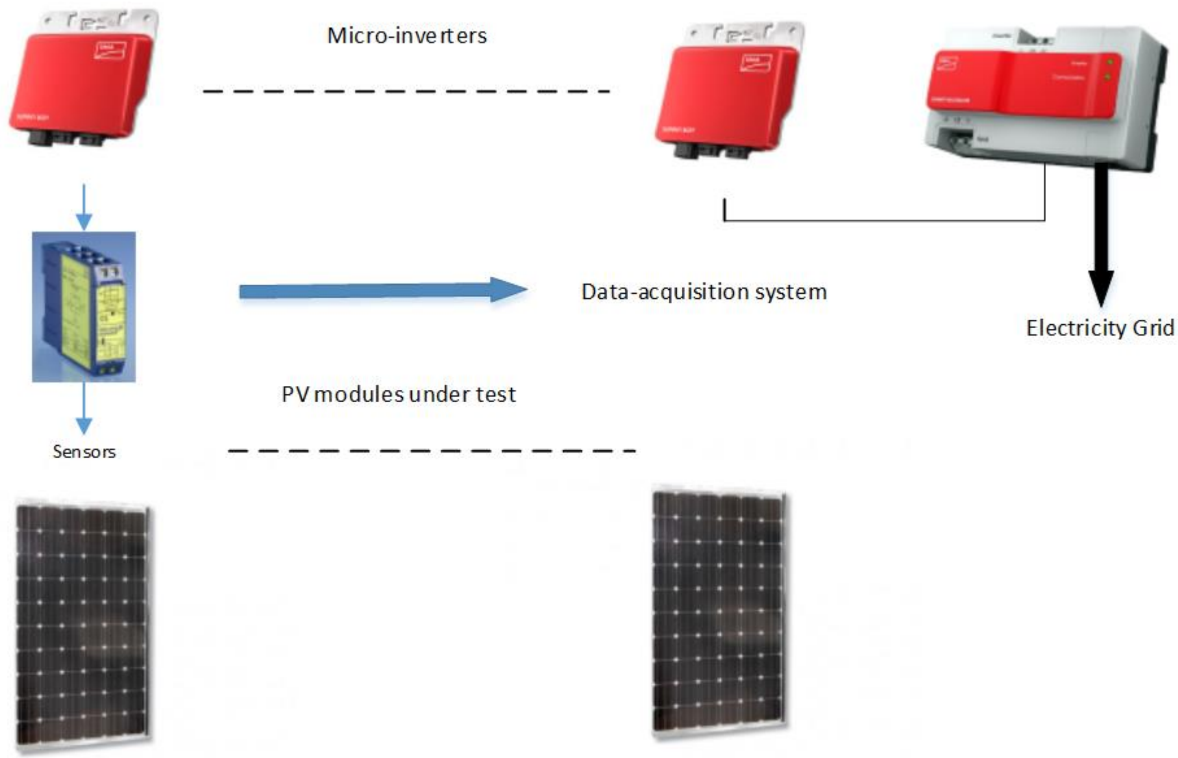
UCY2 - Outdoor testing infrastructure



UCY2 - Outdoor testing infrastructure

- Measurements of parameters at maximum power point (V_{MPP}, I_{MPP} and P_{MPP}).
- Programmable inverter for grid integration research.





Testing site

Official testing site for over 40 different manufacturers:

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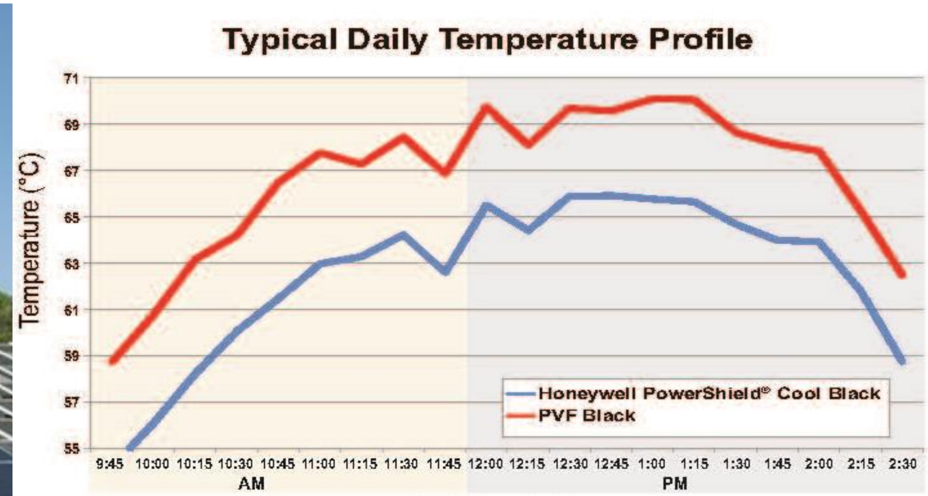
Honeywell

15/12/2016

Innovative packaging material for improved energy yield

- Up to 10 ^{o}C temperature difference
- Reduced thermal losses
- Improved reliability expected



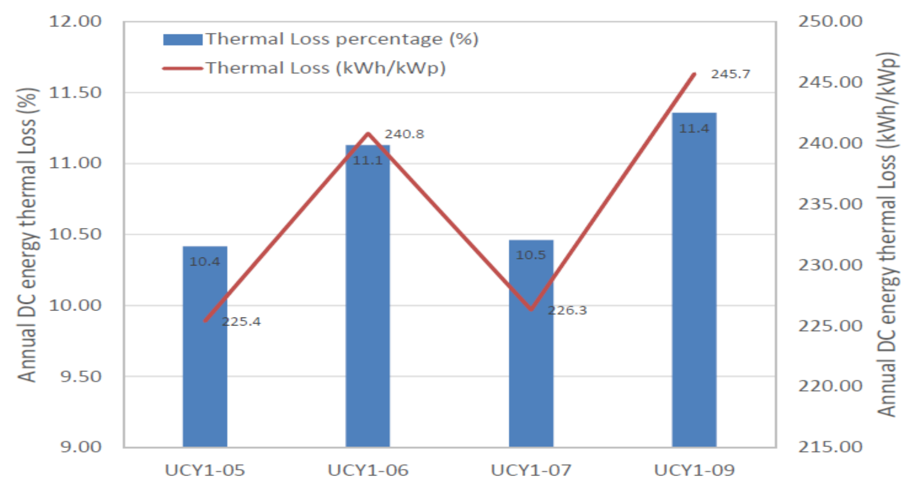
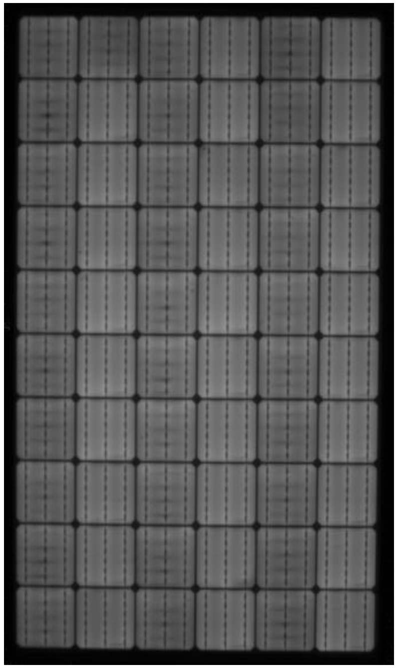


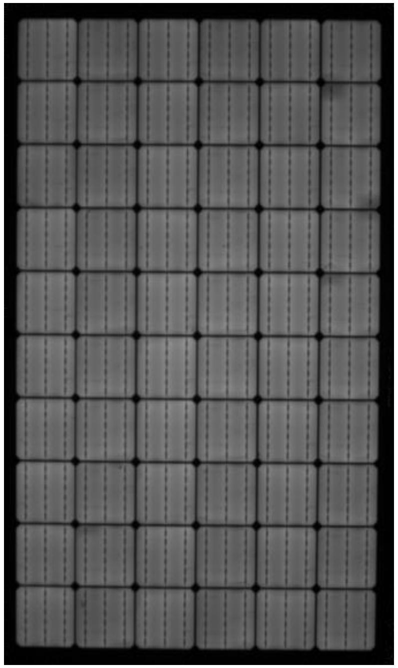
Figure 37. Annual thermal loss of installed systems.

Results
Reliability – EL imaging after two years

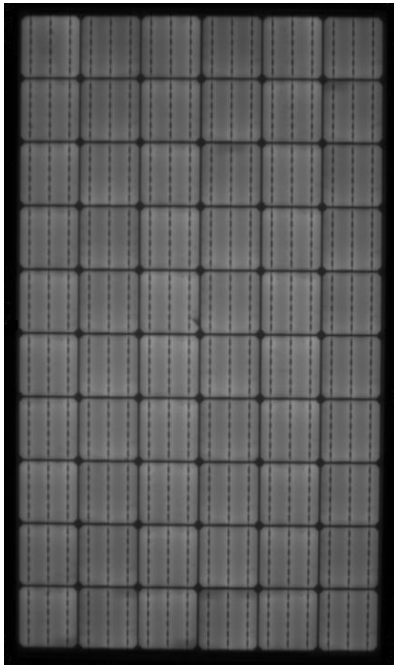
EL images after two years



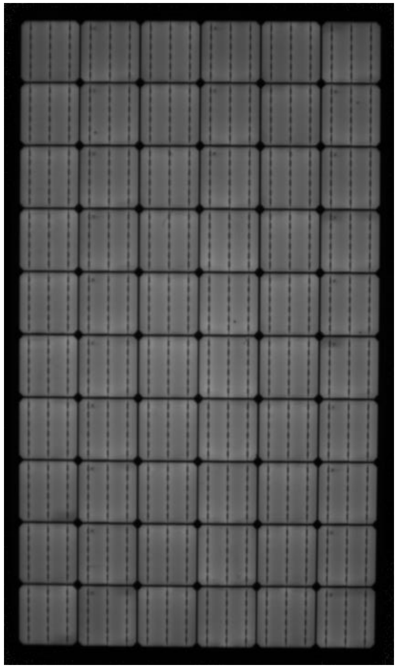
ucy1-05
Black thermal management backsheet



ucy1-06
FPE black control backsheet



ucy1-07
FPE white control backsheet



ucy1-09
FPF black control backsheet

Comparative energy yield and failure endurance study

- Comparative energy yield studies of latest technologies.
- Failure endurance of backsheet materials.

NOCT and PV module exposure testing

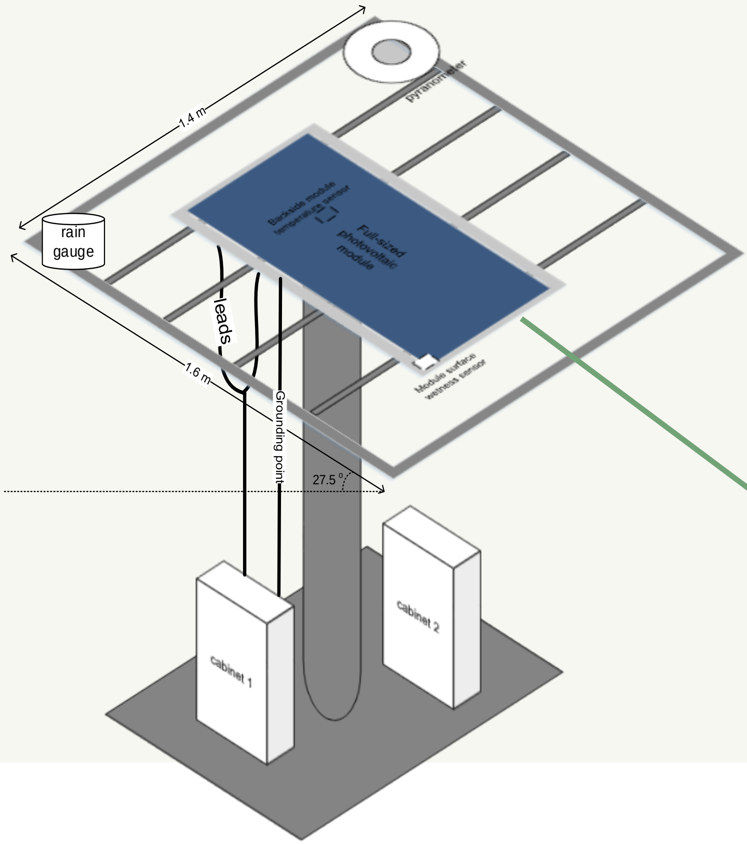
- NOCT measurements
  (IEC 61215 Clause 10.5).

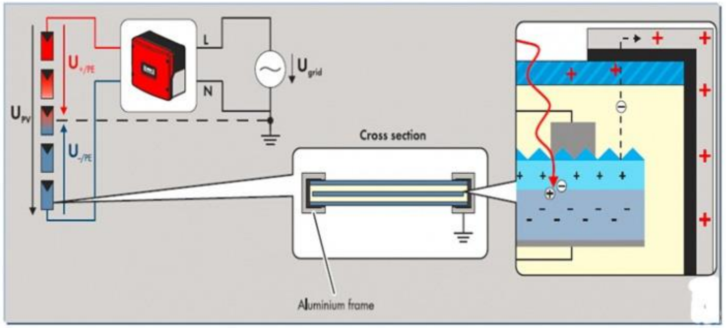
- PV module exposure testing.

Photovoltaik Institut Berlin

PID testing infrastructure

- Model PID progression and occurrence.

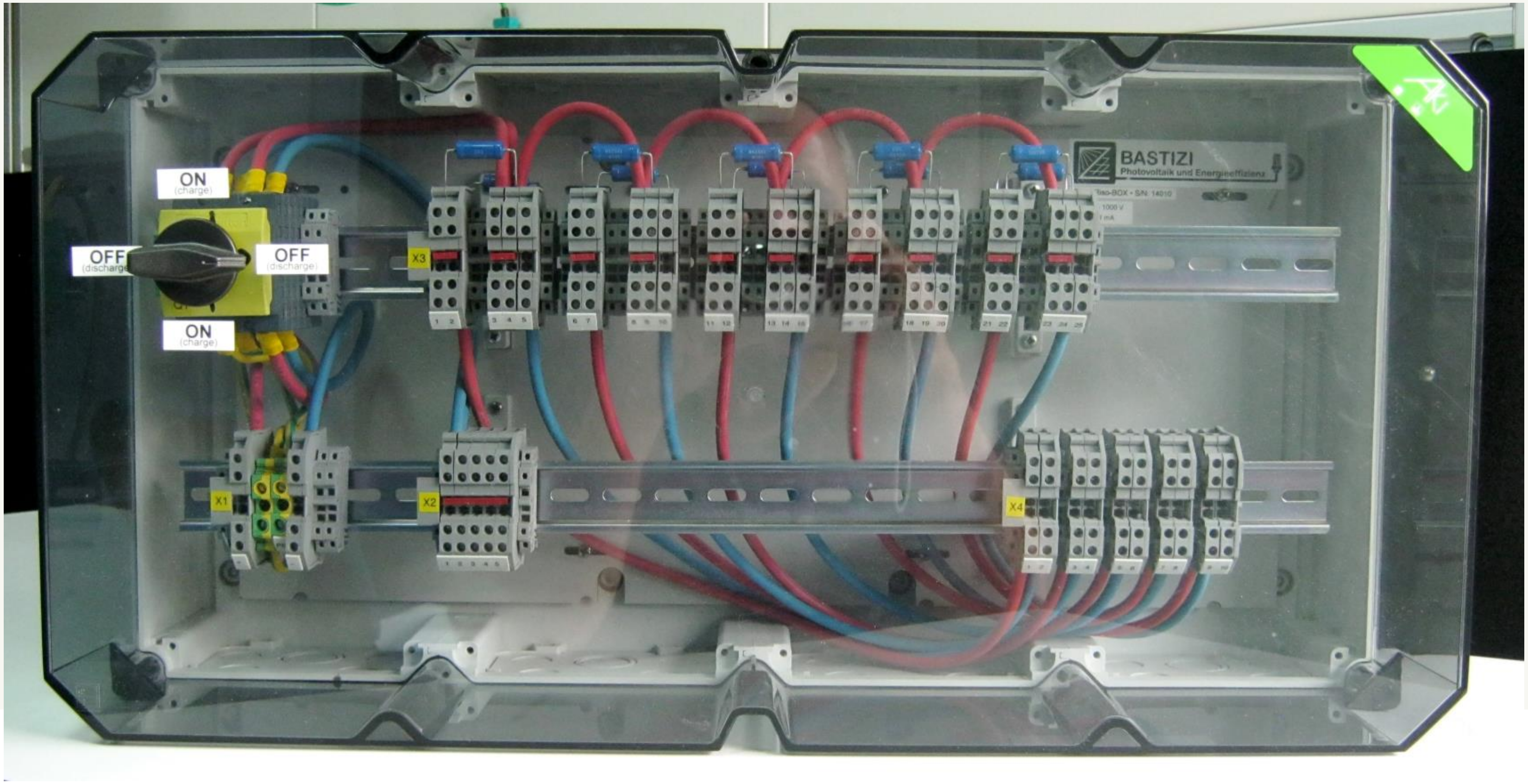




Source: SMA

PID testing infrastructure

- Acquisition of leakage current and shunt resistance for PID.



Indoor testing infrastructure

UV Simulator

Climatic Chamber

Solar Simulator

Infrastructure suitable for IEC 61215, 61646 and 62108 testing

Indoor testing infrastructure

Test Report

University of Cyprus - PV Technology

PVT_ITR_STCEL – 07/12/2015

Test Report:

- Performance under standard test conditions (IEC 61215 Ed. 2 Procedure 10.2)
- Electroluminescence imaging inspection

Test dates:	07 December 2015
Manufacturer:	--
Description:	Poly-crystalline Silicon
Performed by:	G. Makrides
Reviewed by:	G. E. Georghiou
Report produced for:	--
Report date:	--

The results of tests contained within this report apply only to the specimens tested. This report shall not be reproduced except in full, without the written approval of the Photovoltaic Technology Laboratory, University of Cyprus.

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Cyprus

Record Rev.: 1.0	Issue Date: 07/12/2015
Status: Current	Page #: 1 of 8

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PVT_ITR_STCEL – 07/12/2015

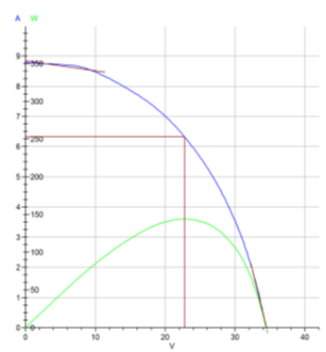
Test Results

Performance under Standard test Conditions (IEC 61215 Ed. 2 - 10.2)

Manufacturer	--
Type	--
Serial Number	21306690011
Date	07 December 2015

Measurement	P_{MPP} [W]	I_{SC} [A]	I_{MPP} [A]	V_{OC} [V]	V_{MPP} [V]	FF [%]
Measurement 1	143.939	8.34	6.32	34.507	22.760	47.2
Nameplate	245	8.5	7.9	37.5	31.0	-
Manufacturer	249	8.82	8.27	37.7	30.1	-

Current – Voltage (I-V) Curve



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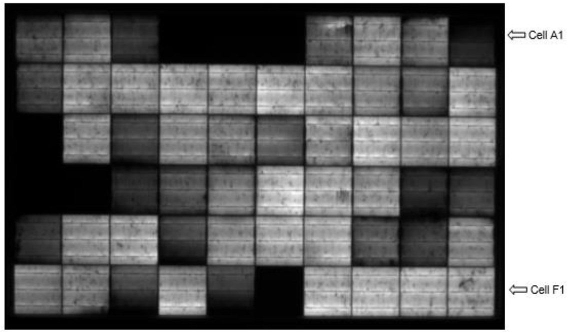
PVT_ITR_STCEL – 07/12/2015

Test Results

Electroluminescence Imaging Inspection

Manufacturer	--
Type	--
Serial Number	21306690011
Date	07 December 2015



Voltage bias at I_{SC}

Record Rev.: 1.0	Issue Date: 07/12/2015
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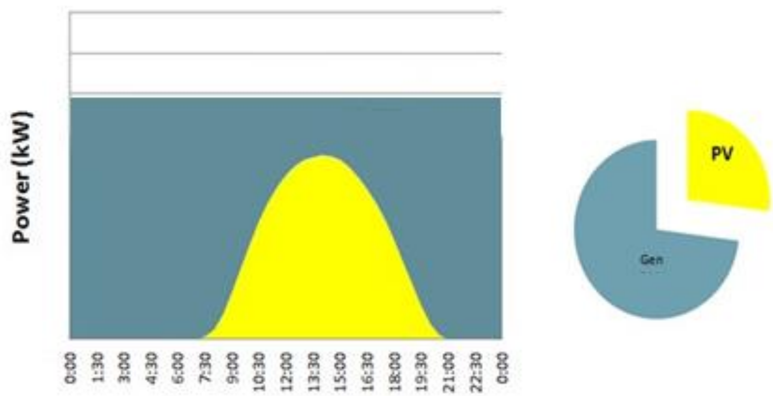
PV system consulting

- Advanced site survey and shading analysis studies.
- PV system Techno-economic analysis.



Shading analysis for MW plant in Tamasos.

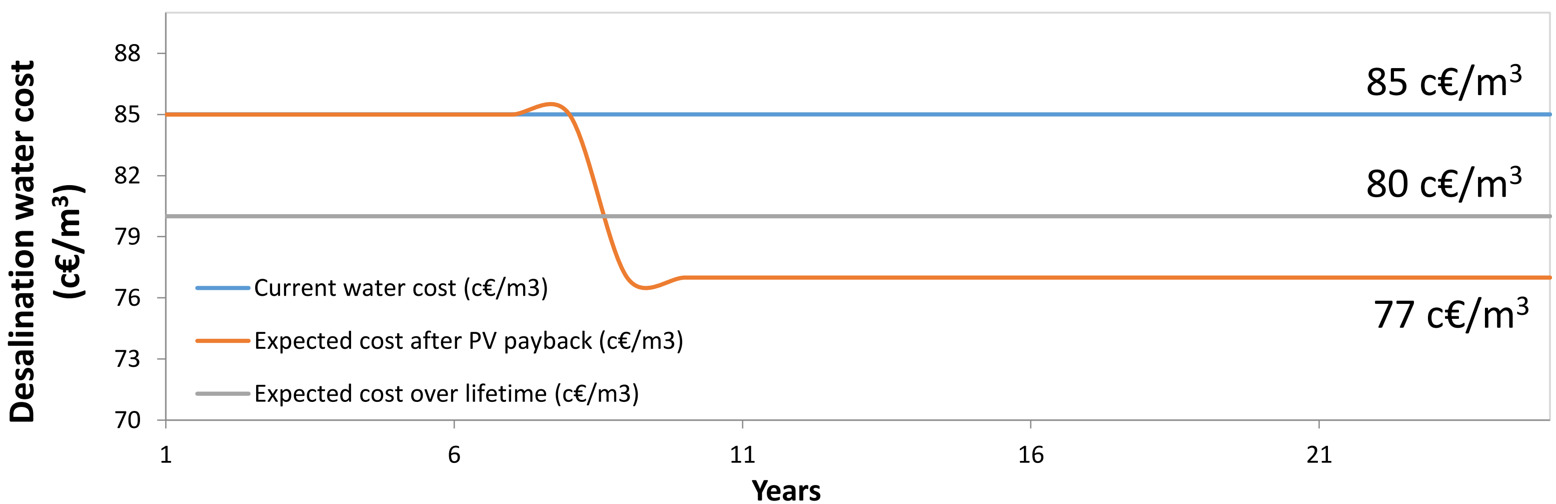
Solar Desalination Plant

Desalination plant PV potential in Larnaca to Lower Water Cost:

- Current water cost from Larnaca Desalination Plant: **85 c€/m^3**
- Electricity cost accounts for 50% – 58% of water cost **42 – 49 c€/m^3**

Less Conservative Scenario

- After 8 years - Decrease of current water cost by ~7 - 9 % = **77 c€/m^3**
- Over 25 years lifetime – Decrease of current water cost by ~6 % = **80 c€/m^3**



PV Technology Laboratory UCY

Education and Training

Testing and Services

Ongoing and Future Research Activities

Main Research Areas

PV performance and modelling: reliability, degradation, and performance of PV technologies, system issues as well as building integration.

Grid integration issues: power quality, control techniques for distributed generation, market tools and storage.

Energy management systems: smart grids, demand side management and energy forecasting.

PV research at the UCY

In order to evaluate the PV performance outdoors in Cyprus the PV testing infrastructure, was installed in 2006 in collaboration with the Institute of Physical Electronics, University of Stuttgart.

Before and after…
First PV research infrastructure in Cyprus

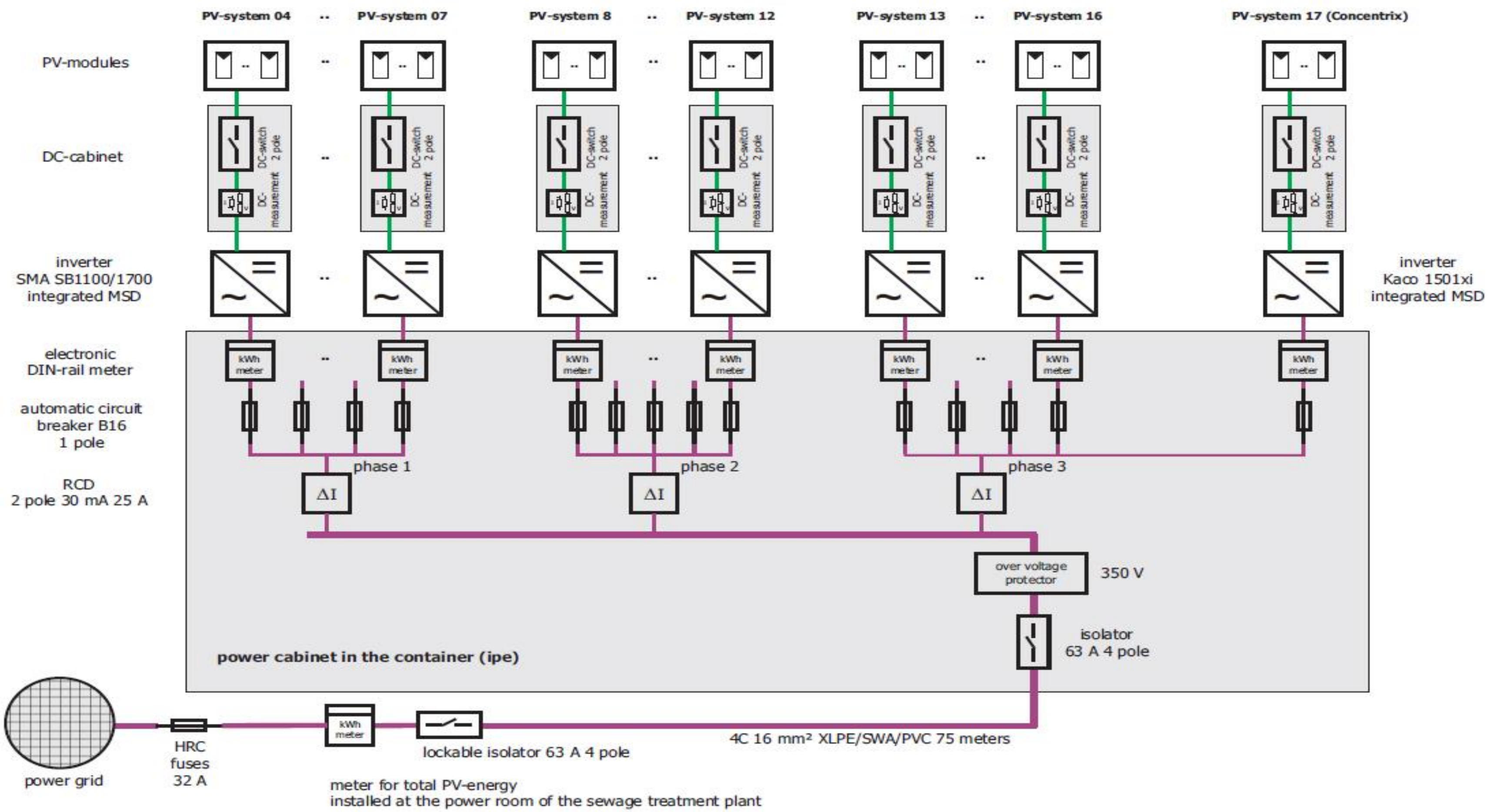
PV system installation

- Nominal power 1 kWp
- Same inverters
- Fixed-plane plane of array 27.5°
- Two-axis tracker

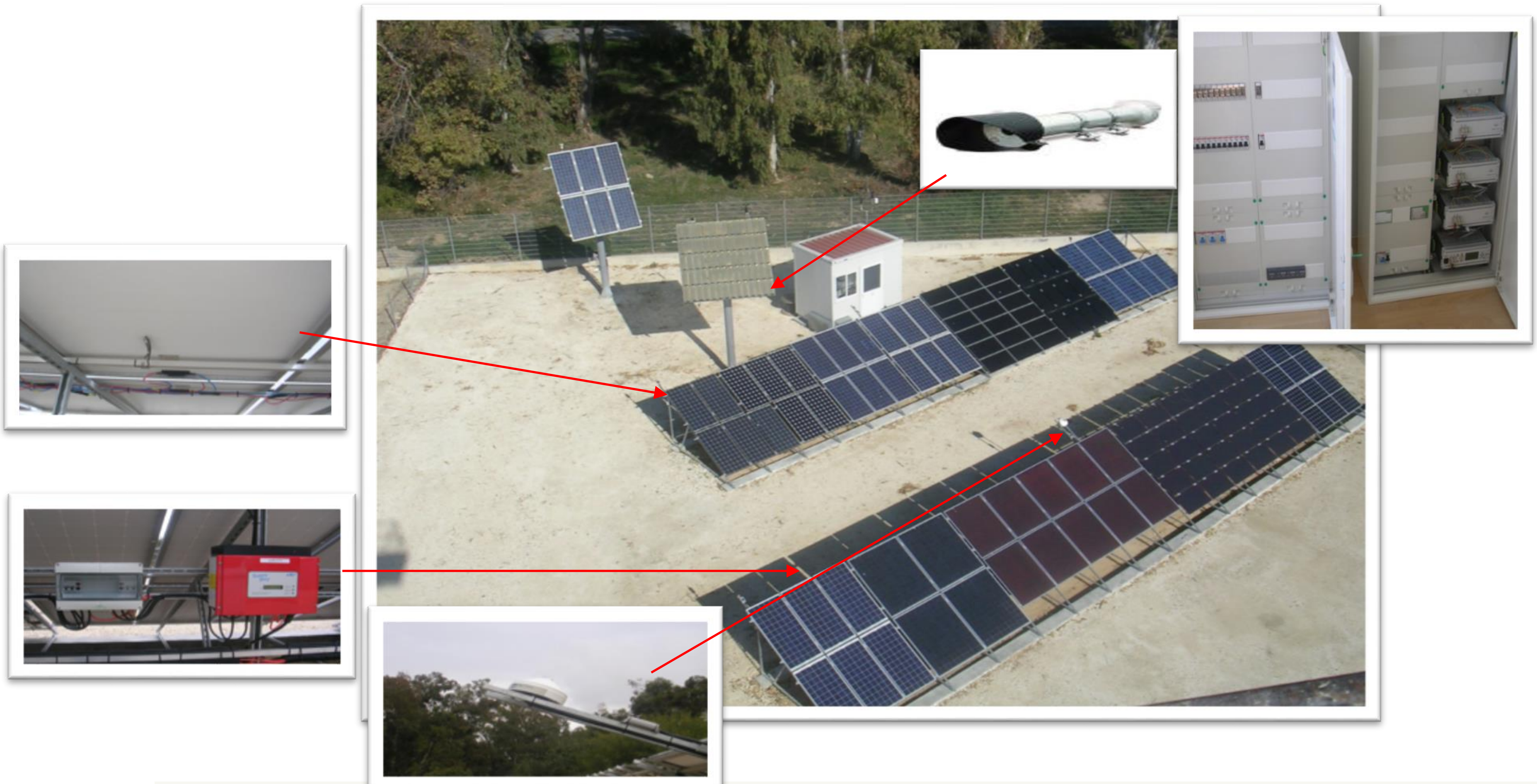
PV system installation

- Mono-crystalline Silicon (Atersa)
- Multi-crystalline Silicon (SolarWorld, Solon)
- Amorphous Silicon (Schott Solar, MHI)
- EFG and Main (Schott Solar)
- Mono-crystalline Silicon Saturn (BP Solar)
- Mono-crystalline Silicon Back Contact Cell (Sunpower)
- Mono-crystalline Silicon HIT (Sanyo)
- Cadmium Telluride (First Solar)
- Copper Indium Gallium Diselenide, CIGS (Wurth Solar)
- Concentrator System (Concentrix Solar)

Electrical single line diagram

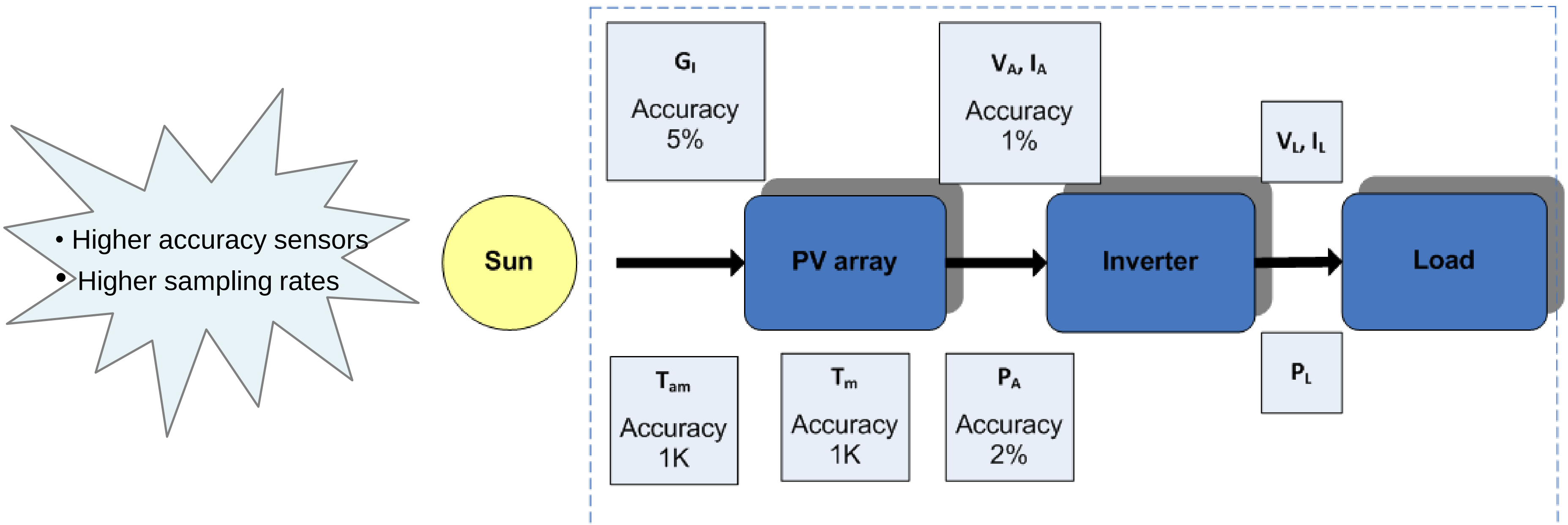


Performance data-acquisition system

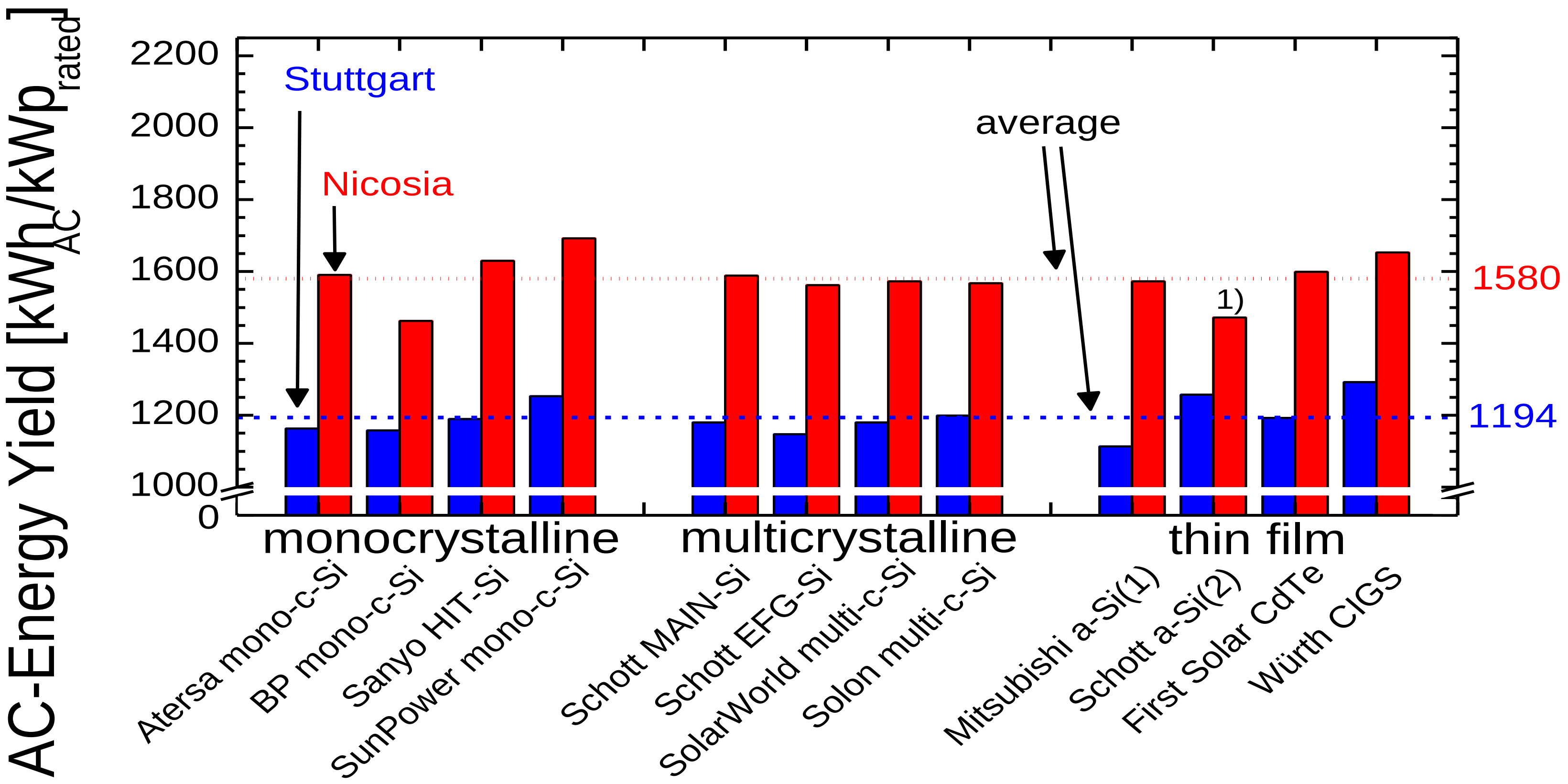


Data Analysis

- Requirement for good quality data.
- IEC 61724 “Photovoltaic system performance monitoring Guidelines for measurement, data exchange and analysis”.



Performance vs climatic conditions (Cyprus and Germany)



G. Makrides, B. Zinsser, M. Norton, G. Georghiou, M. Schubert, J. Werner, "Potential of Photovoltaic Systems in Countries with High Solar Irradiation", Renewable & Sustainable Energy Reviews.

Energy yield modeling

- The energy yield prediction of 4 models was investigated.

Single-point Efficiency model (mathematical model)

$$P_{DC} = \eta_{STC} \cdot A \cdot G_{POA}$$

Single-point Efficiency model with temperature correction (mathematical model)

$$P_{DC} = \eta_{T} \cdot \eta_{STC} \cdot A \cdot G_{POA}$$

$$\eta_{T} = 1 + \gamma_{MPP} \cdot \left(T_{Module} - T_{STC}\right)$$

Photovoltaics for Utility Scale Applications (PVUSA) model (empirical model)

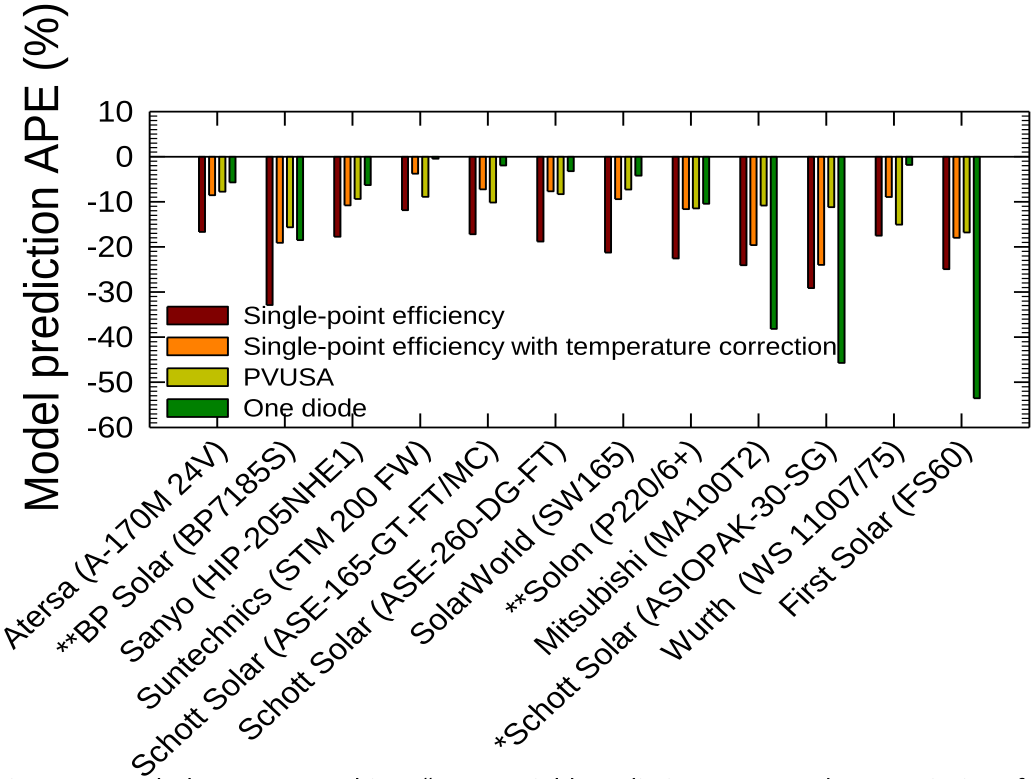
$$P_{DC} = G_{POA} \cdot \left(aG_{POA} + bT_{Amb} + cWS\right)$$

One-diode model (electrical model)

$$I = I_{Ph} - I_{0}\left(e^{\frac{q(V+IR_{series})}{nkT}} - 1\right) - \frac{V + IR_{series}}{R_{shunt}}$$

Energy yield model prediction benchmark

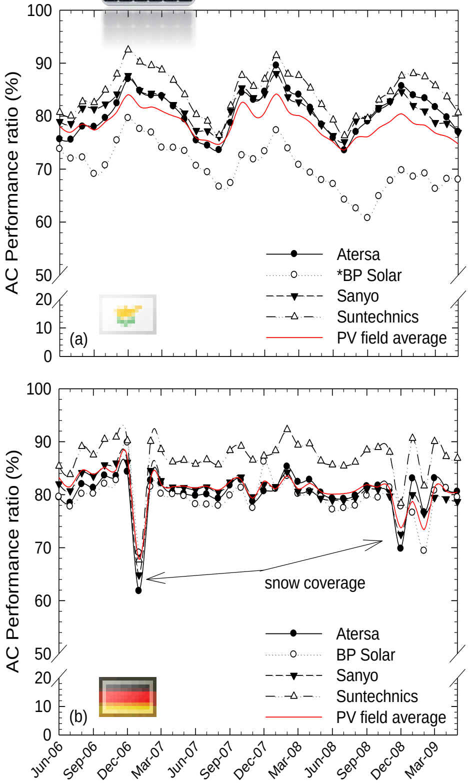
- The models exhibited different prediction performance for the different technologies.



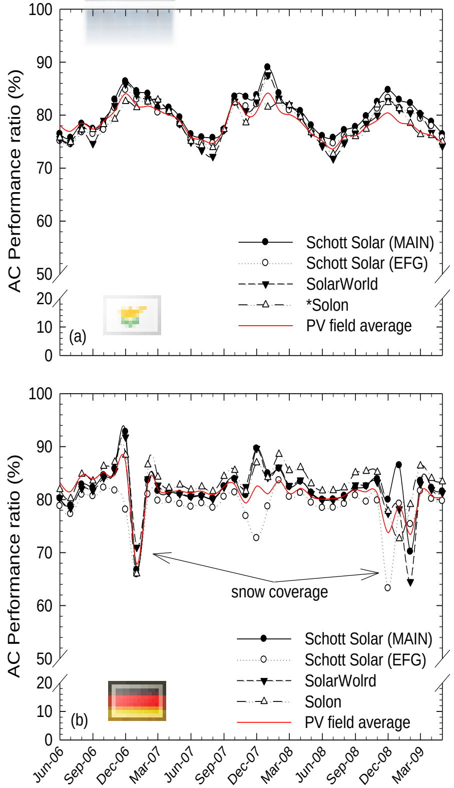
G. Makrides, B. Zinsser, M. Schubert, G. Georghiou, "Energy yield prediction errors and uncertainties of different photovoltaic models", Progress in Photovoltaics: Research and Applications, 2011.

Performance comparison Nicosia-Stuttgart

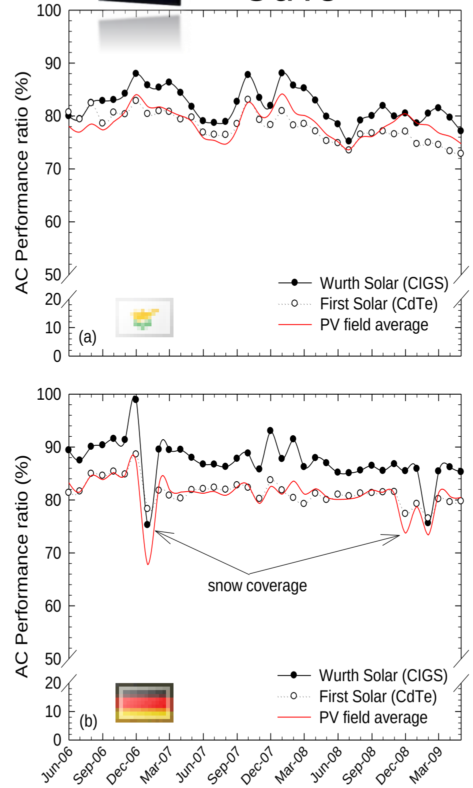
Mono-c-Si



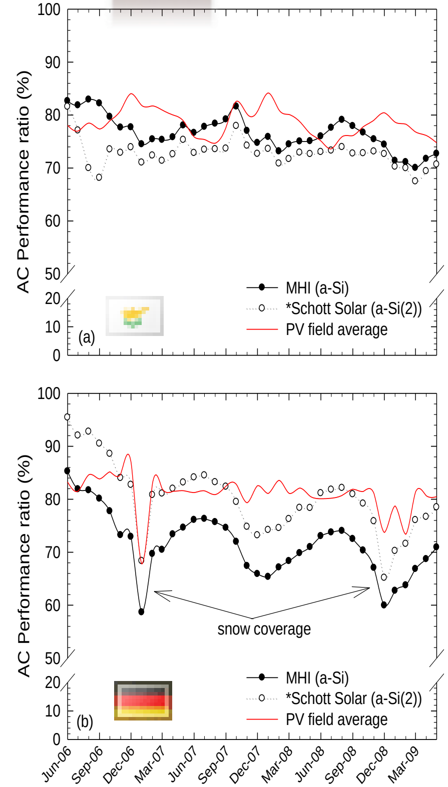
Multi-c-Si



Thin-film
CIGS
CdTe



Thin-film
a-Si



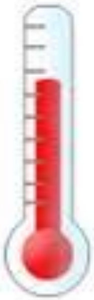
Performance comparison in Cyprus

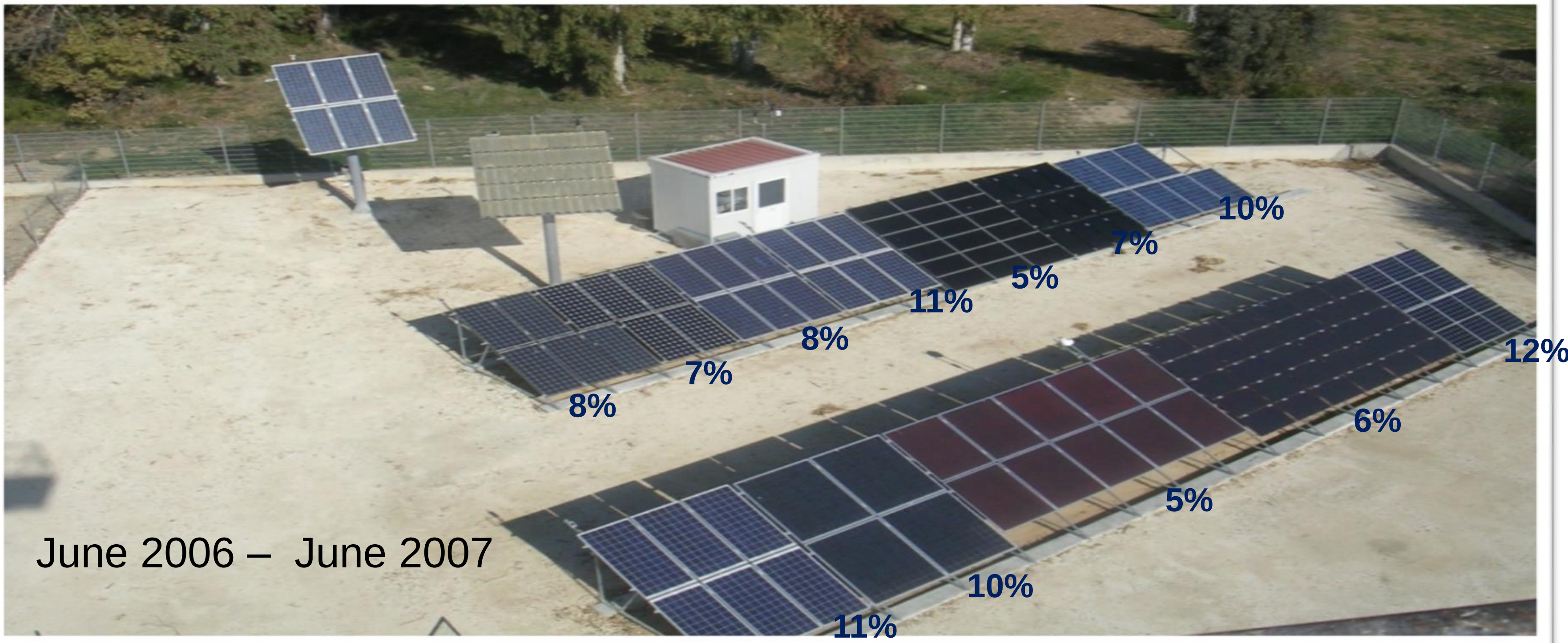
Year	First	Second	Third	Fourth
		Nicosia		
2006-2007	Suntechnics mono-c-Si	Würth Solar CIGS	Sanyo HIT mono-c-Si	First Solar CdTe
2007-2008	Suntechnics mono-c-Si	Würth Solar CIGS	Sanyo HIT mono-c-Si	Atersa mono-c-Si
2010-2011	Suntechnics mono-c-Si	Schott Solar multi-c-Si	Atersa mono-c-Si	Sanyo HIT mono-c-Si

15th Year
c-Si and Thin Film

Thermal loss on yearly energy yield

- Using the manufacturers’ MPP power temperature coefficients

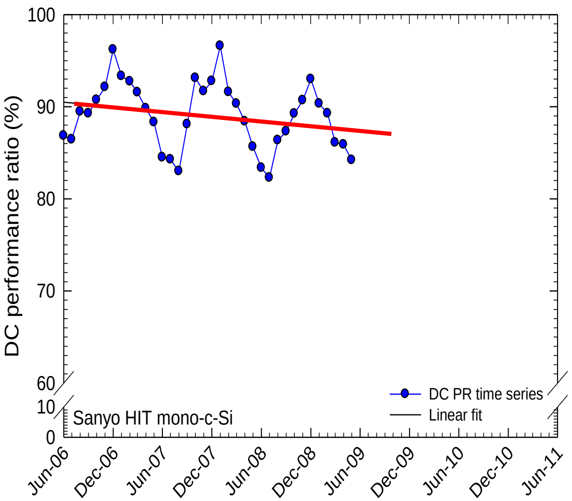




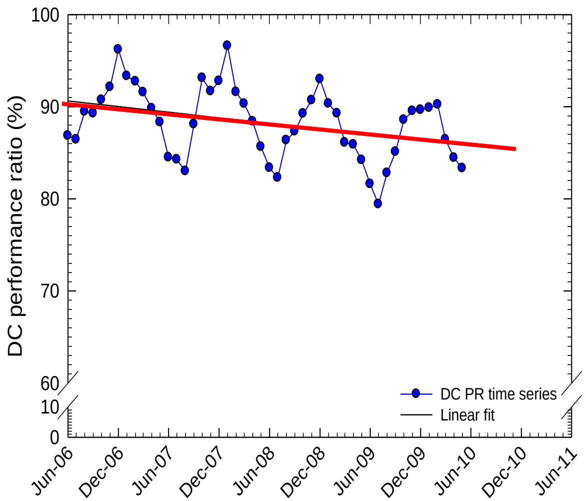
G. Makrides, B. Zinsser, A. Phinikarides, M. Schubert, G. Georghiou, “Temperature and thermal annealing effects on different photovoltaic technologies”, Renewable Energy, 2011.

Degradation / Performance Loss Rates

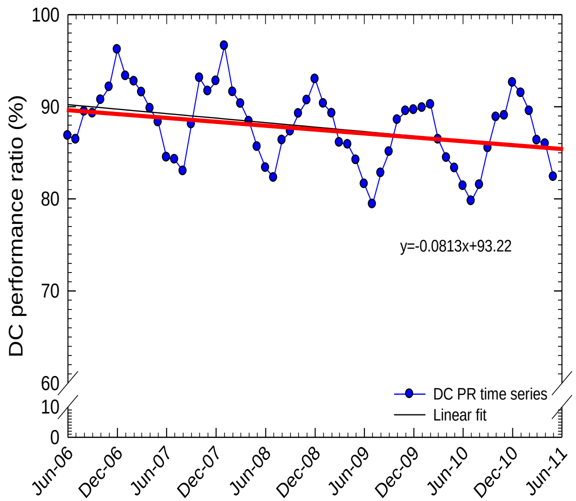
- Yearly performance loss rate of c-Si was on average -0.6 %/year (over the 5-year period)
- Yearly performance loss rate of thin-film was -1.78 %/year



3-year

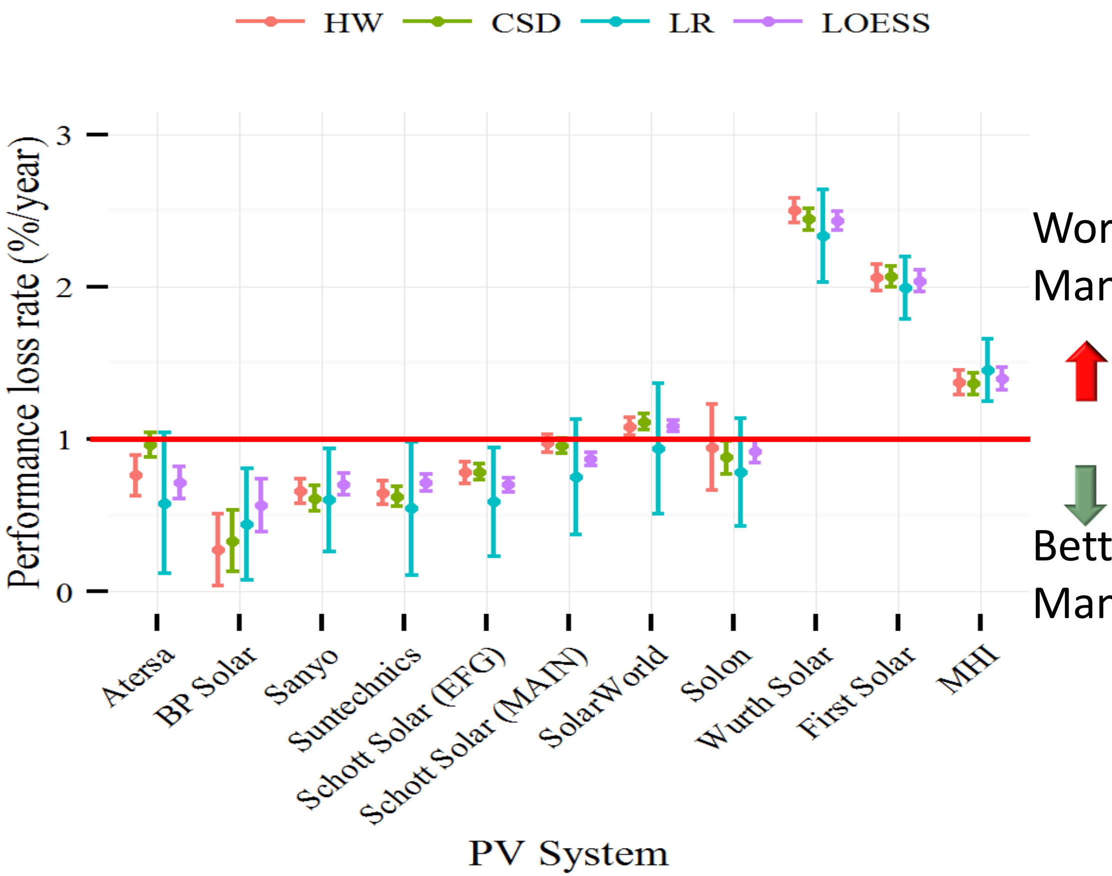


4-year



5-year

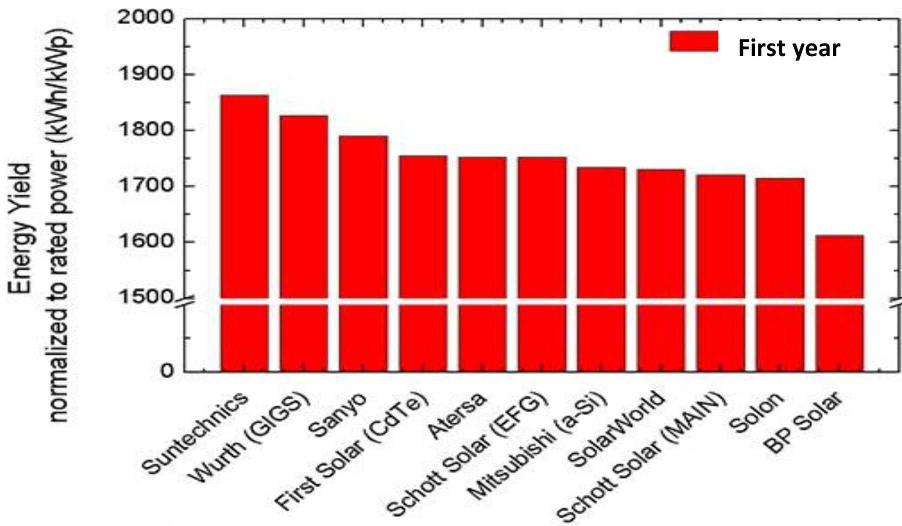
Protocol for Establishment of Degradation

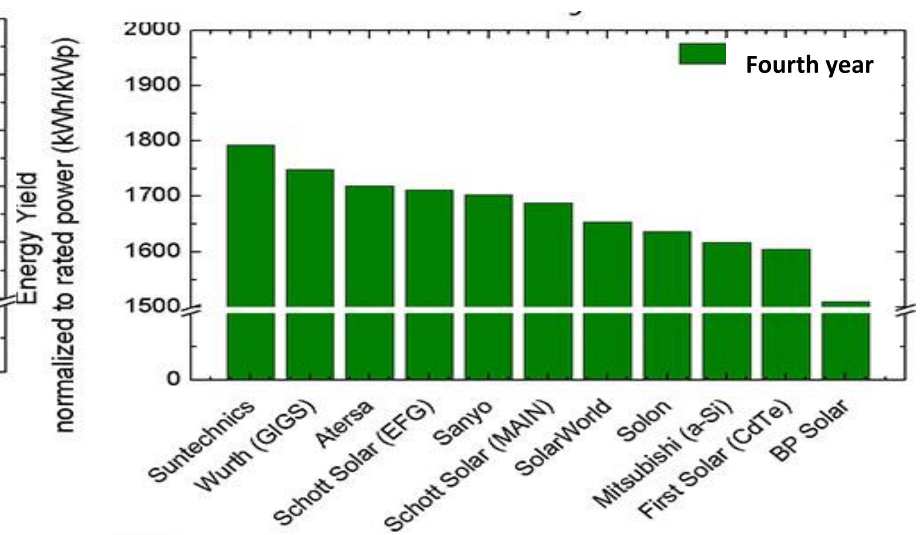


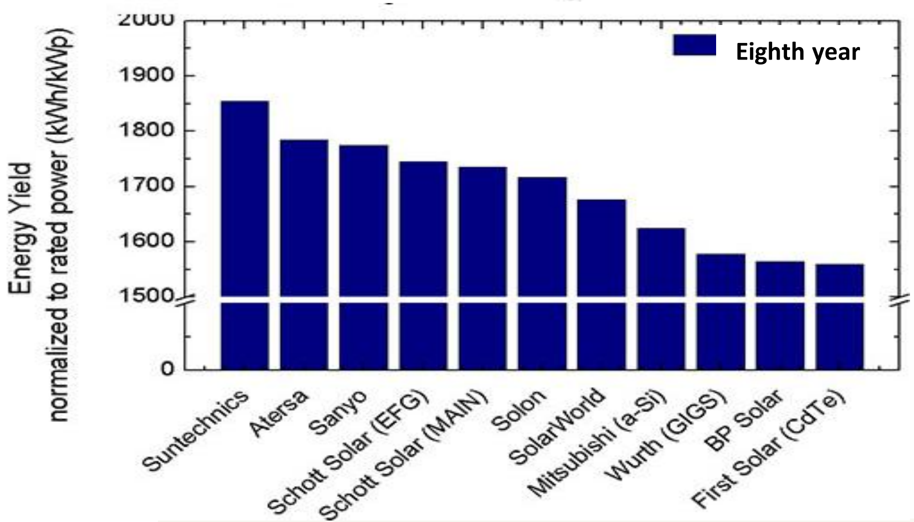
Worse than Manufacturers Warranty

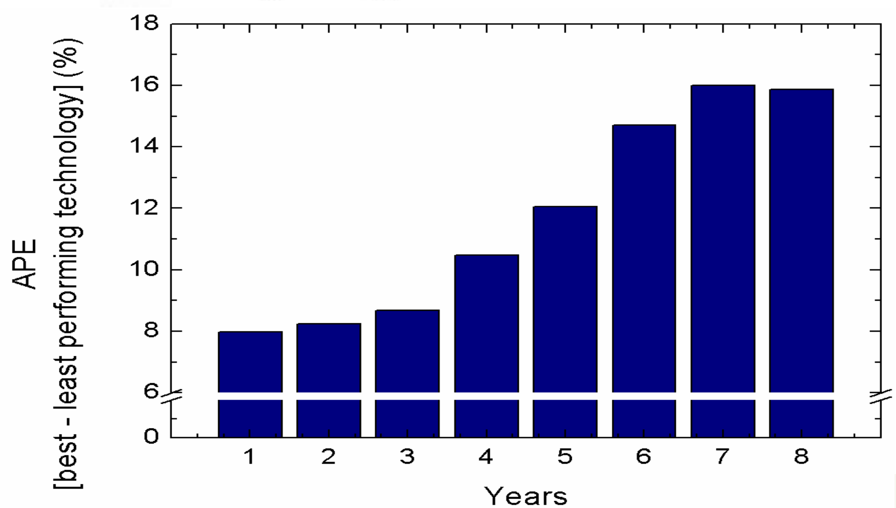
Better than Manufacturers Warranty

Long term Energy Yield



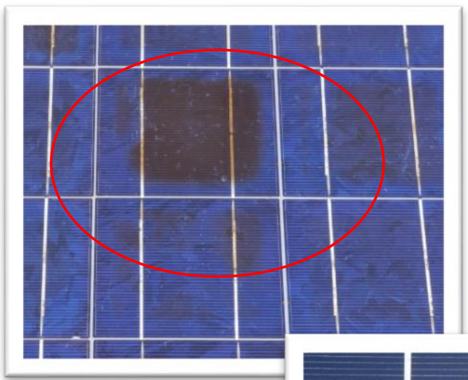


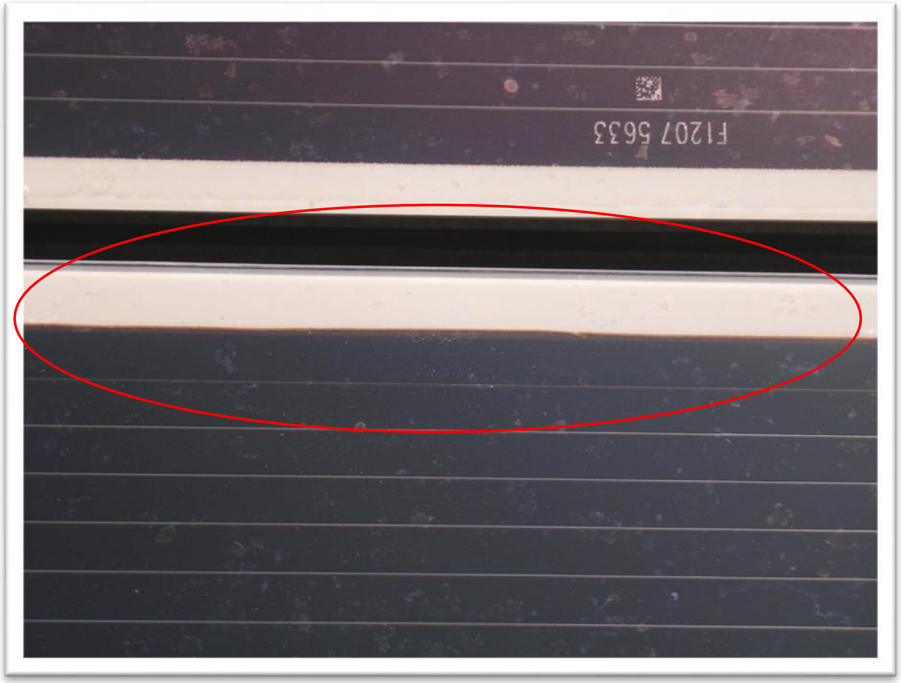




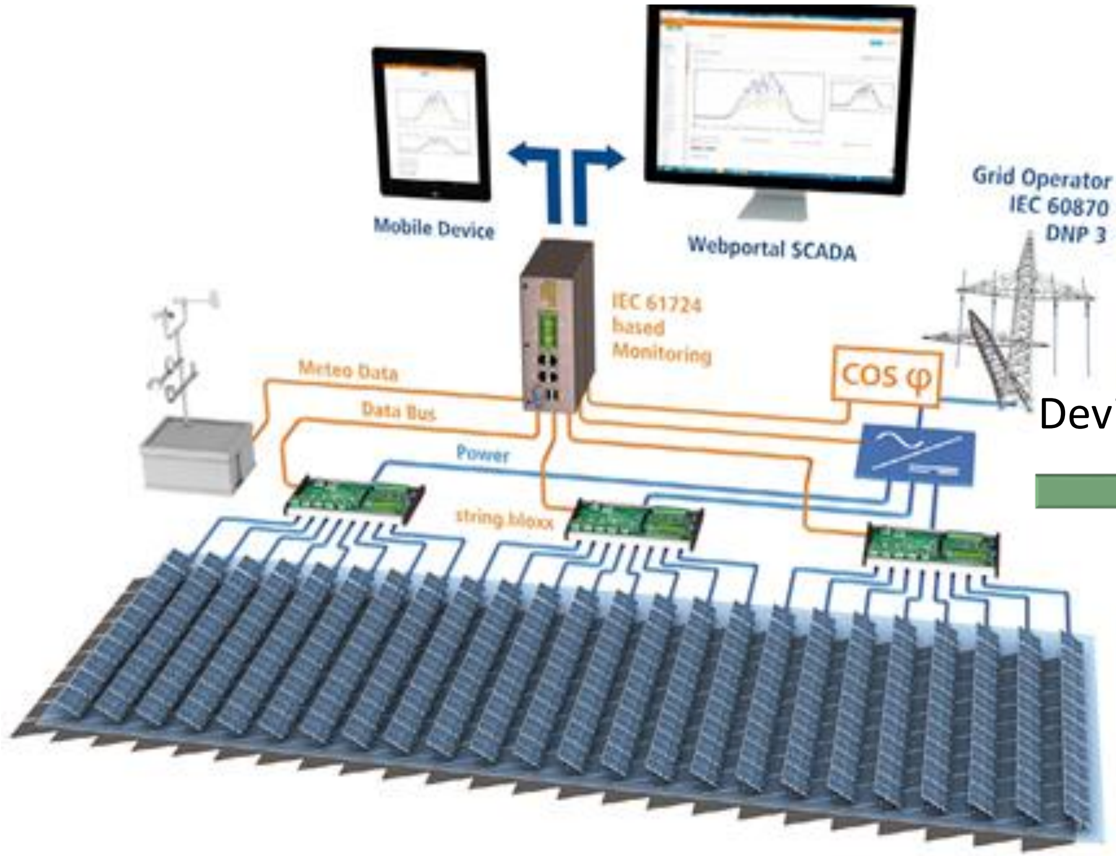
Failure modes

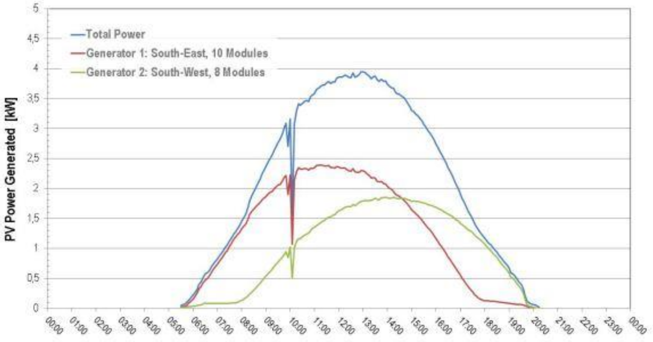
- Ethylene Vinyl Acetate (EVA) yellowing, corrosion and hot-spots.





Failure detection routines and algorithms





Devices to detect faults and failures

SOLAR-era.net

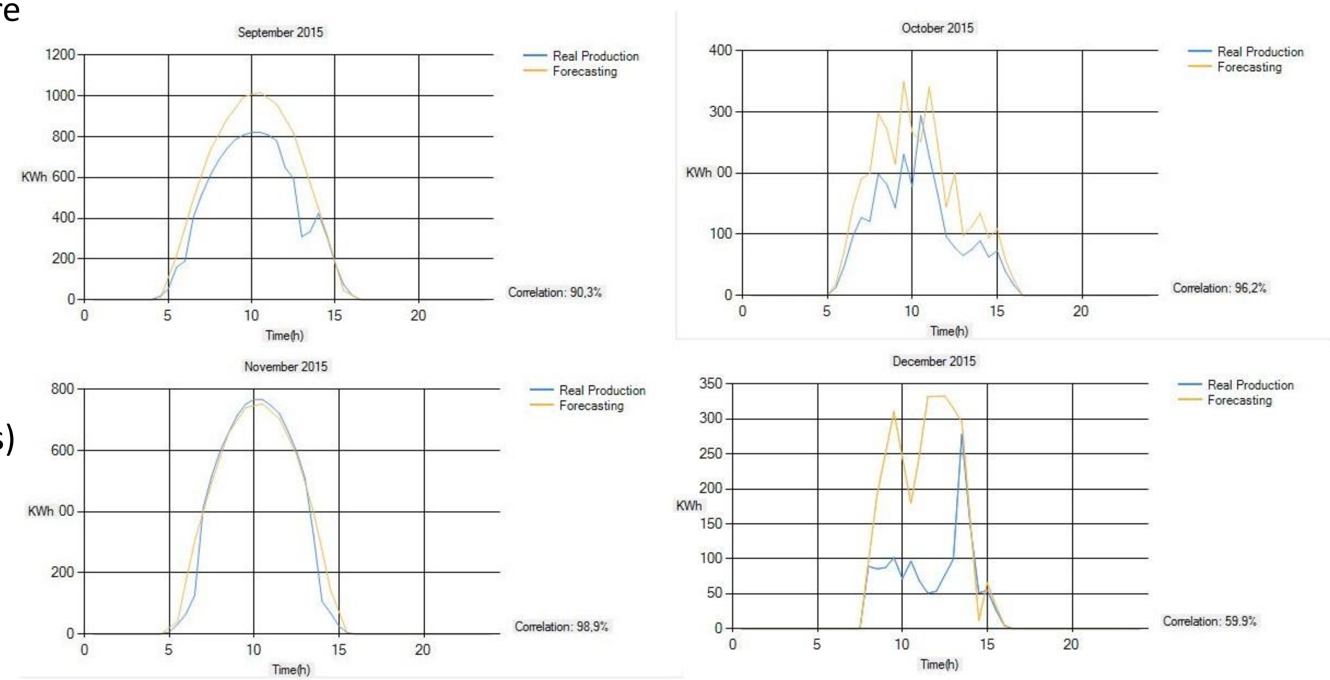
Forecasting PV production

- Forecasting next day PV generation.

NWP of irradiance and temperature

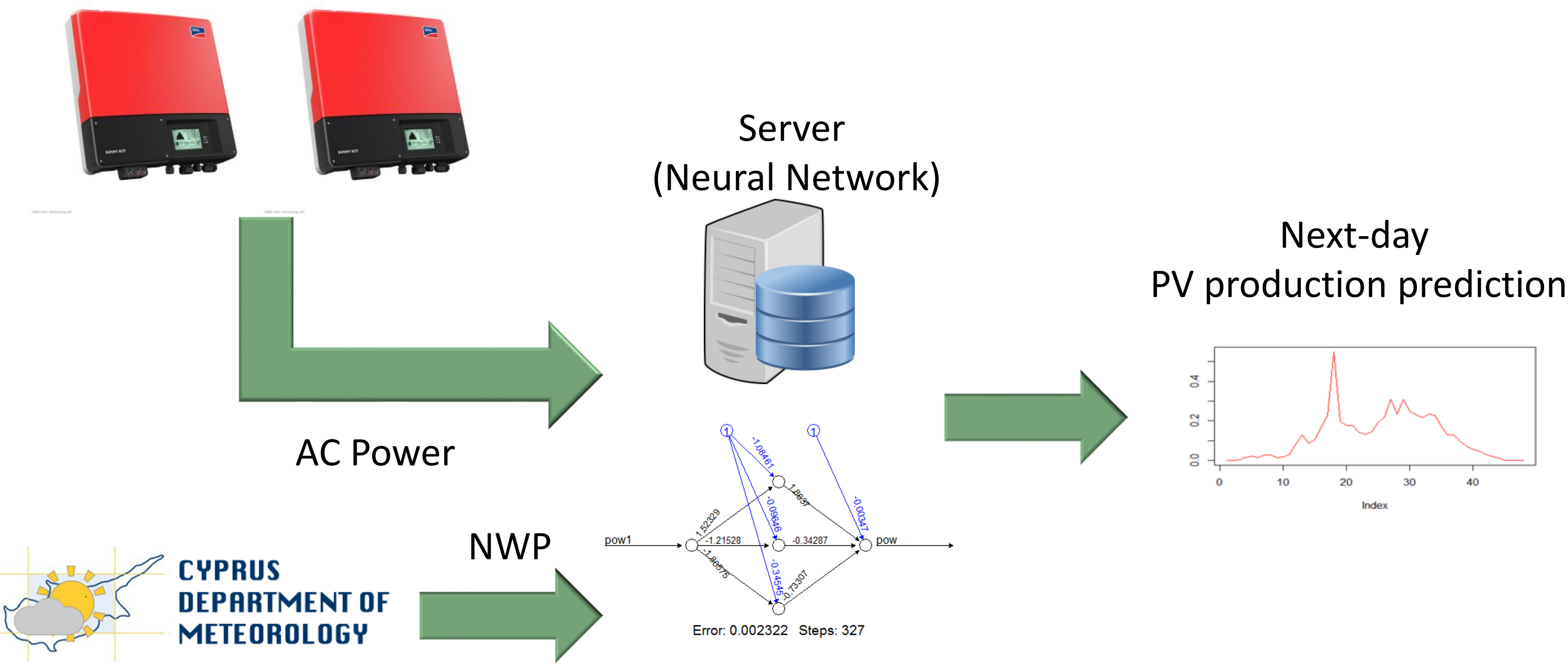
CYPRUS DEPARTMENT OF METEOROLOGY

Parametric models to forecast Power generation of PV (based on PV system specifications)



Forecasting PV production

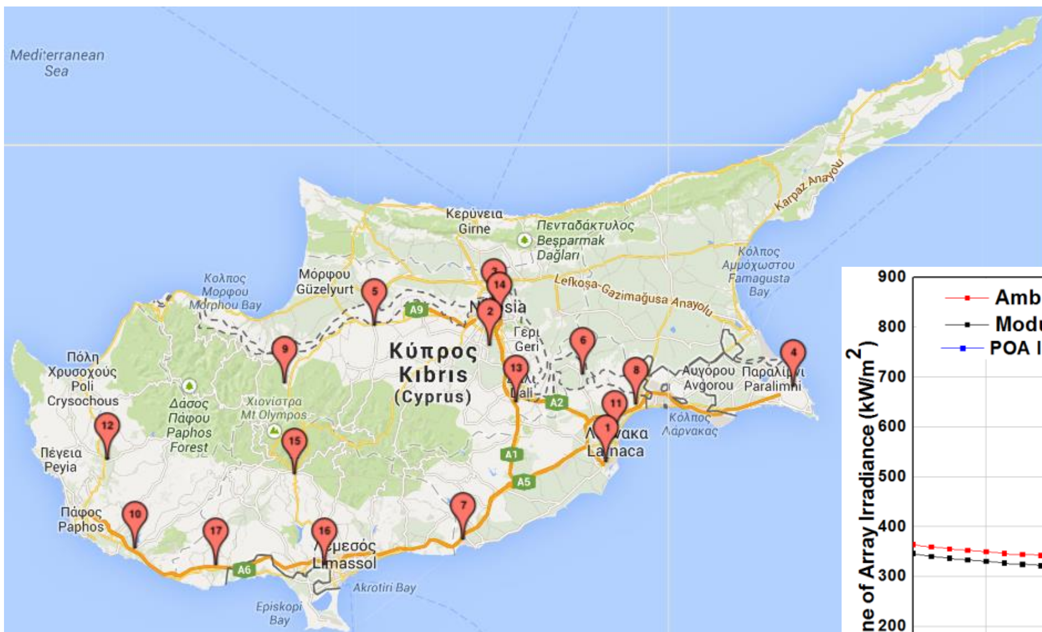
- Forecasting next day PV generation (less than 5 % RMSE).

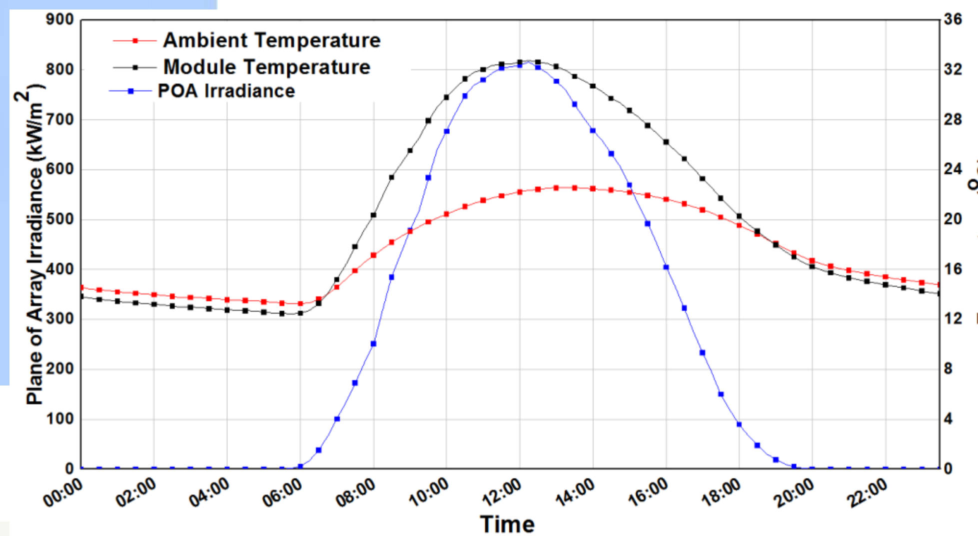


Weather Stations

17 Weather stations

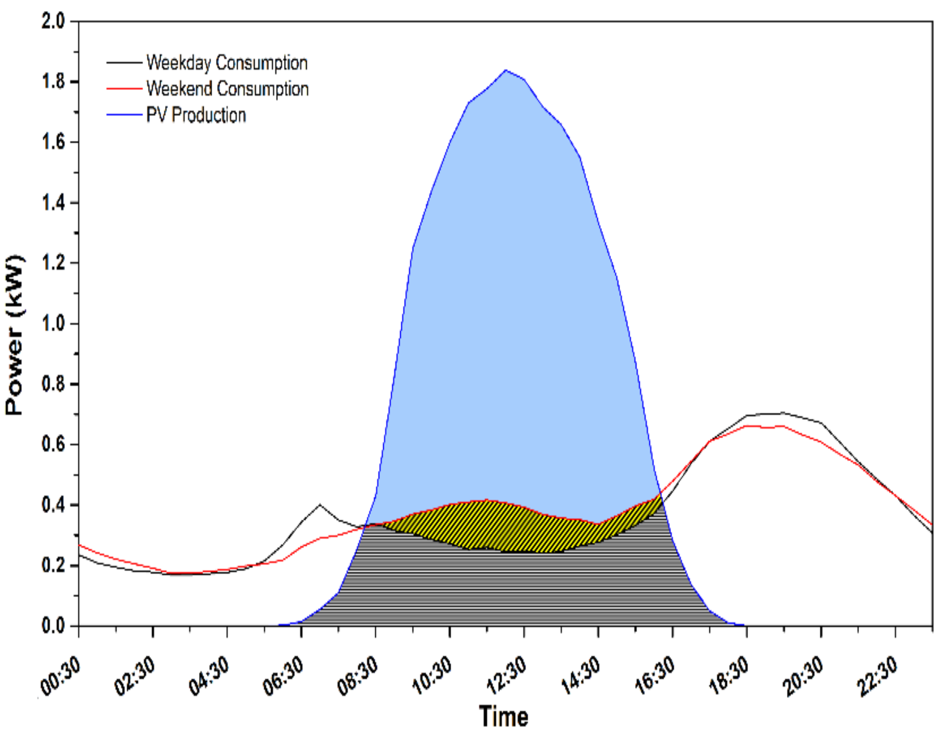
POA Irradiance $(^{W}/_{m^2})$	Ambient temperature (°C)	Module Temperature (°C)

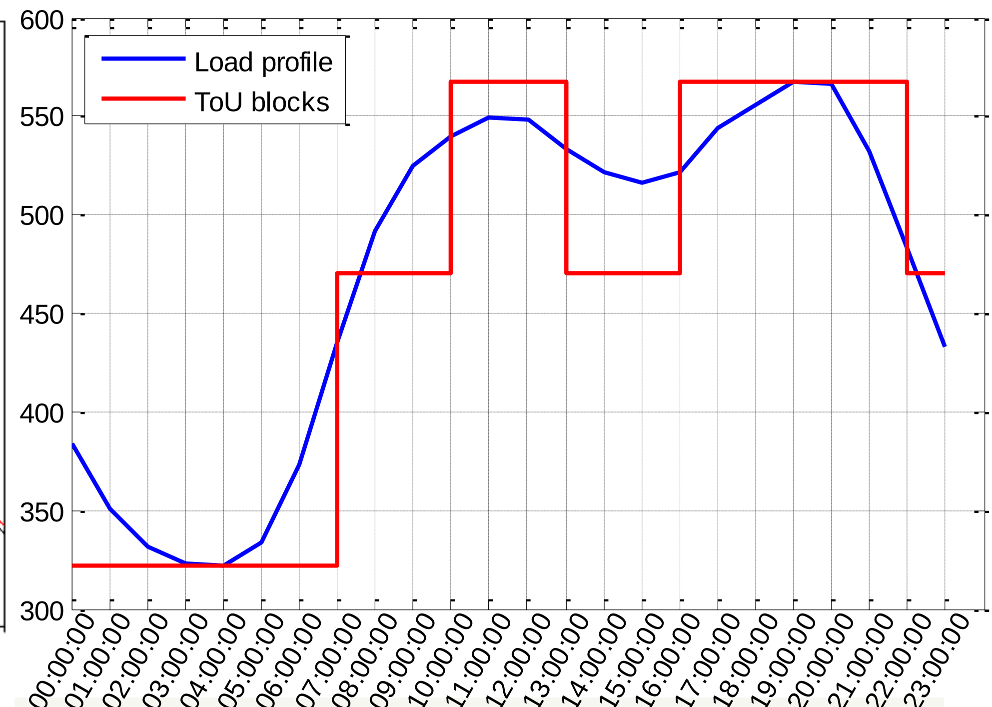




Demand-Side Management and Dynamic Tariff Model Development

- Optimize Electricity Consumption and PV Energy production
- Dynamic tariffs + DSM crucial for further PV Penetration
  - 300 Pilot installations with smart meters and PV and DSM (virtual Smart grid)
  - Behavioural change through dynamic tariffs

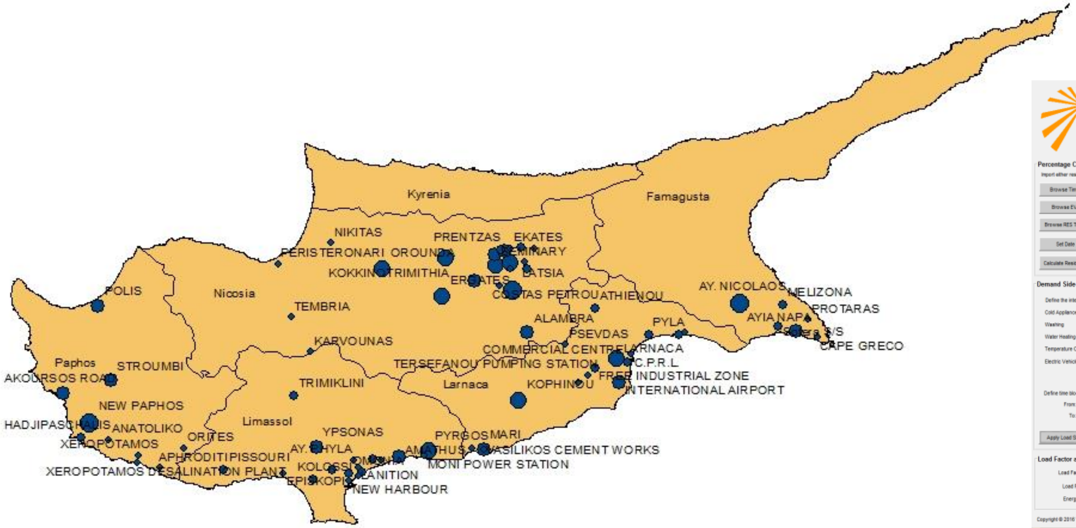


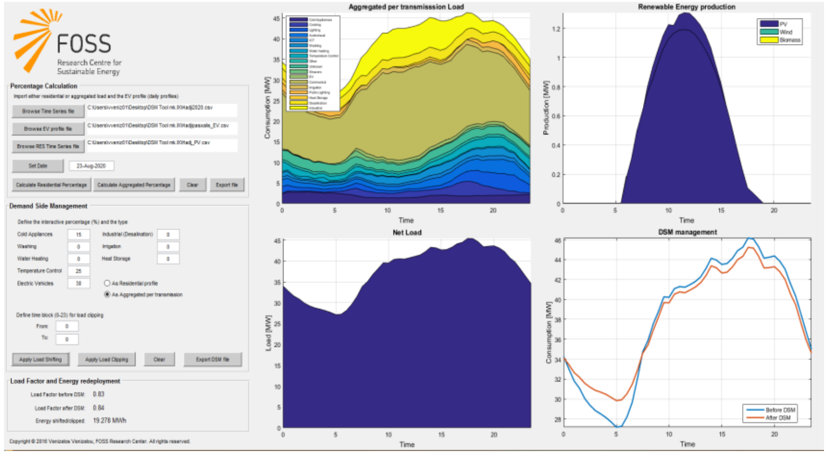


Grid integration of PV

- Investigating distribution grid constraints in the uptake of high levels of renewables:
    - Grid Integration geographical and technical potential of PV
    - Potential of EVs and distribution grid bottlenecks
    - Demand side management

JRC
EUROPEAN COMMISSION





Future Research

Over 10 European and National funded projects in the year 2016.

SEVENTH FRAMEWORK PROGRAMME

Erasmus+

Tempus

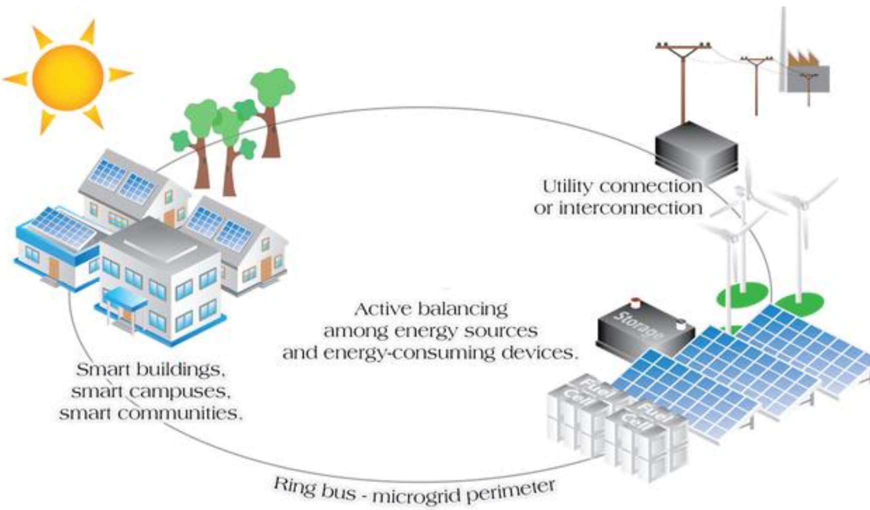
ERANETMED

SOLAR-era.net

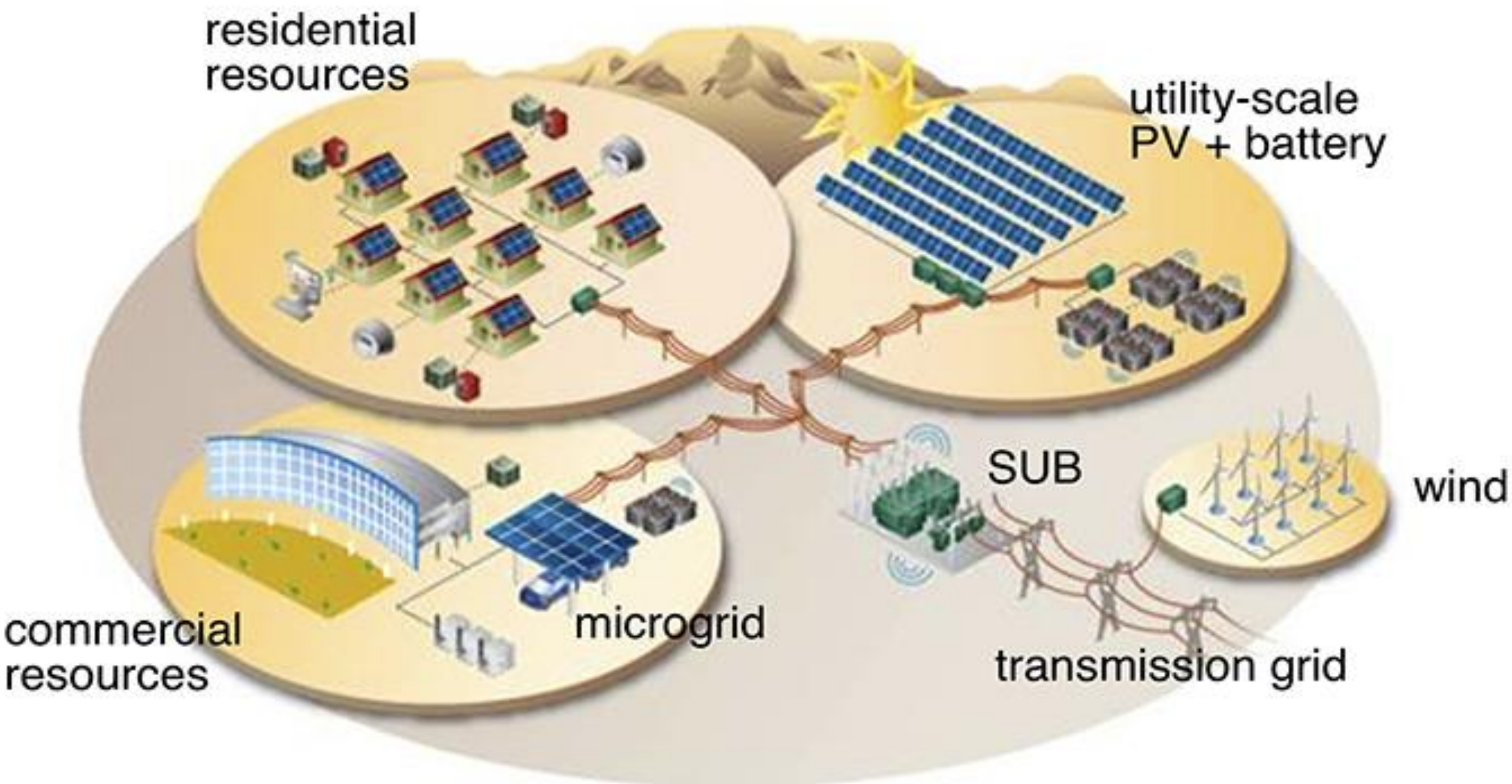
Research Promotion Foundation

Future Research
Microgrid at the University of Cyprus

- Smart meters and sensors for data and local control for effective demand side management policy.
- Local PV generation directly connected to the local grid (400 kWp already connected and operated as self-consumption – 10 MWp planned to be operational by 2017).
- Thermal and electrochemical storage facilities (up to 5 MWh).
- Use of heat pumps for improved efficiencies.
- Charging stations for electric vehicles.
- Full broad band connectivity with the local DSO for improved grid resilience.

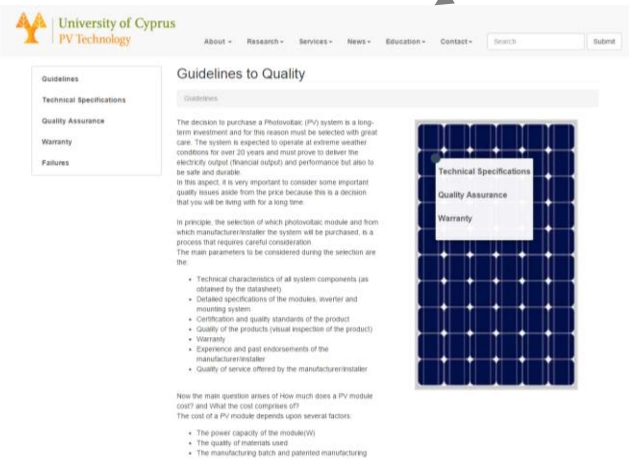


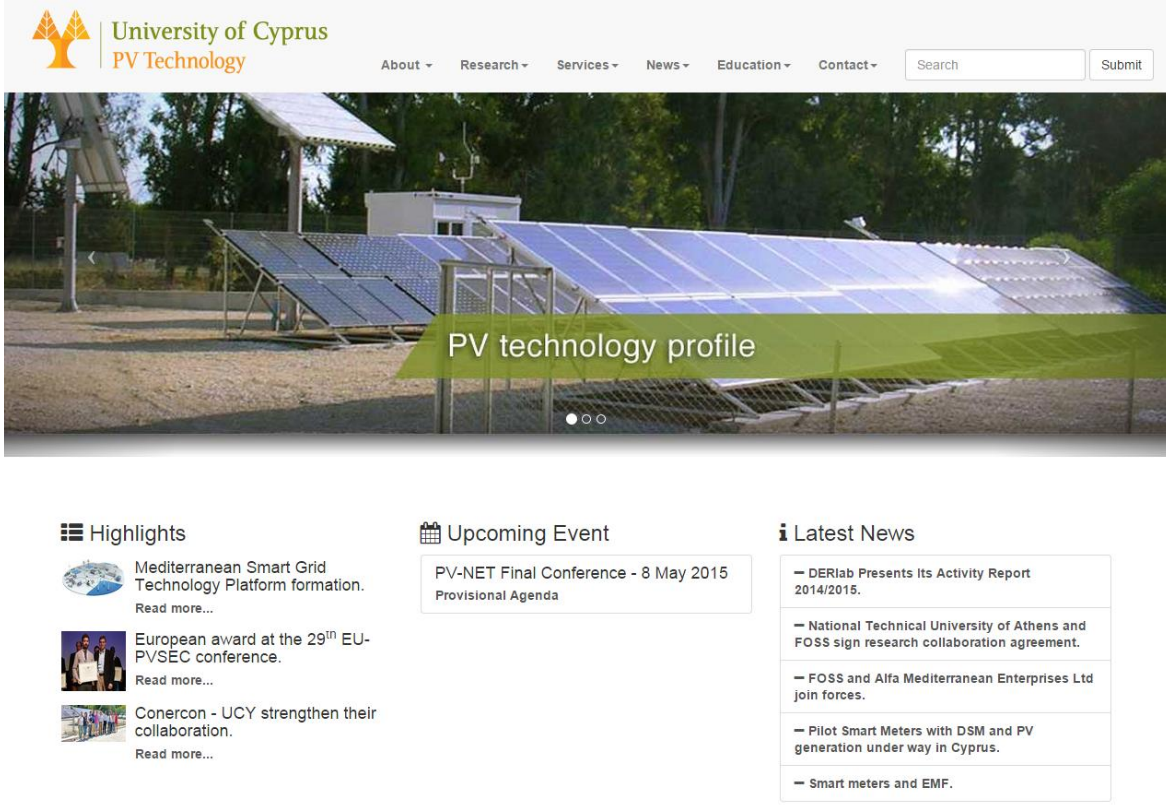
Future Research
Microgrid at the University of Cyprus



More information…

Website
www.pvtechnology.ucy.ac.cy





Conclusion

- The future of PV is BRIGHT and has to be part of our Energy Mix.
- Our group is particularly active in this field of energy both in education and research, in the scope of developing the future “perfect power system”.

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Thank you for your attention

Questions?