The Terawatt challenge: Why do we need PV monitoring?

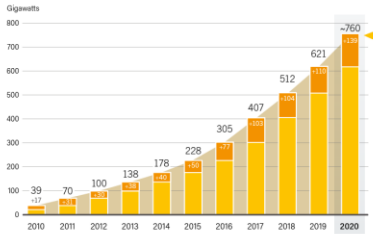
PEARL-PV Conference, Enschede

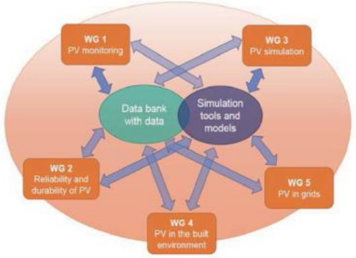
14 March 2022

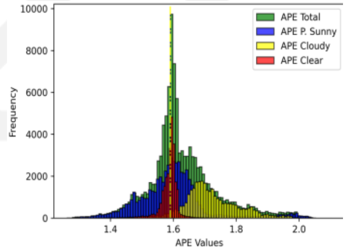
Anne Gerd Imenes, University of Agder, Norway

Overview

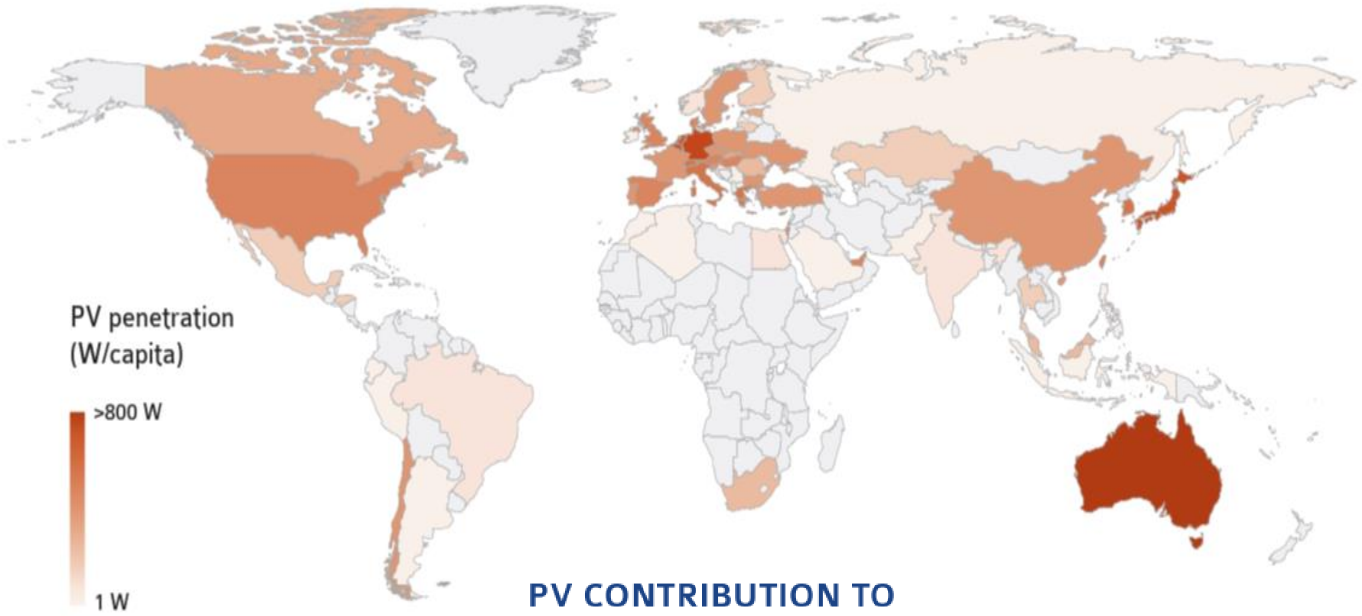
- Setting the scene – why do we need PV monitoring?
- A brief look at history & status of PV monitoring
- Important international databases/work on monitoring
- Work in PEARL WP1: ST1.1 guidelines & PV database
- Use of the database (example spectral)
- Monitoring challenges, trends and future needs







The Terawatt transition: Where are we today….

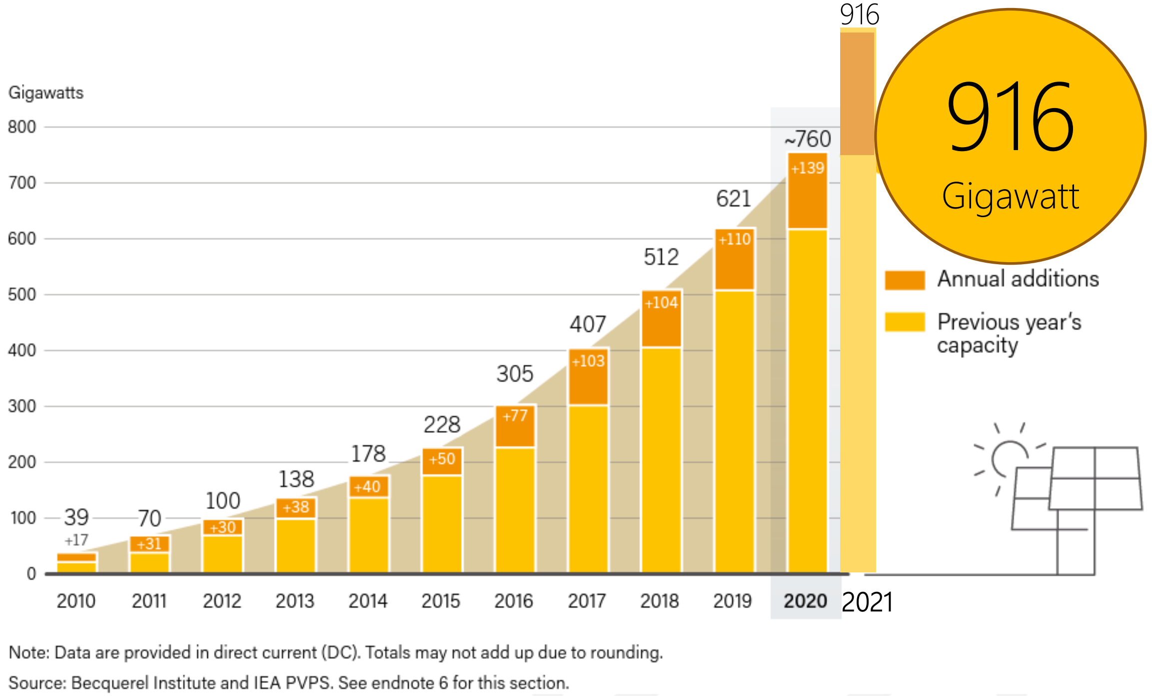


PV CONTRIBUTION TO ELECTRICITY DEMAND

4%

Share of PV in the global electricitiy demand in 2020

Source: Snapshot of Global PV Markets 2021, Report IEA PVPS T1-39:2021.

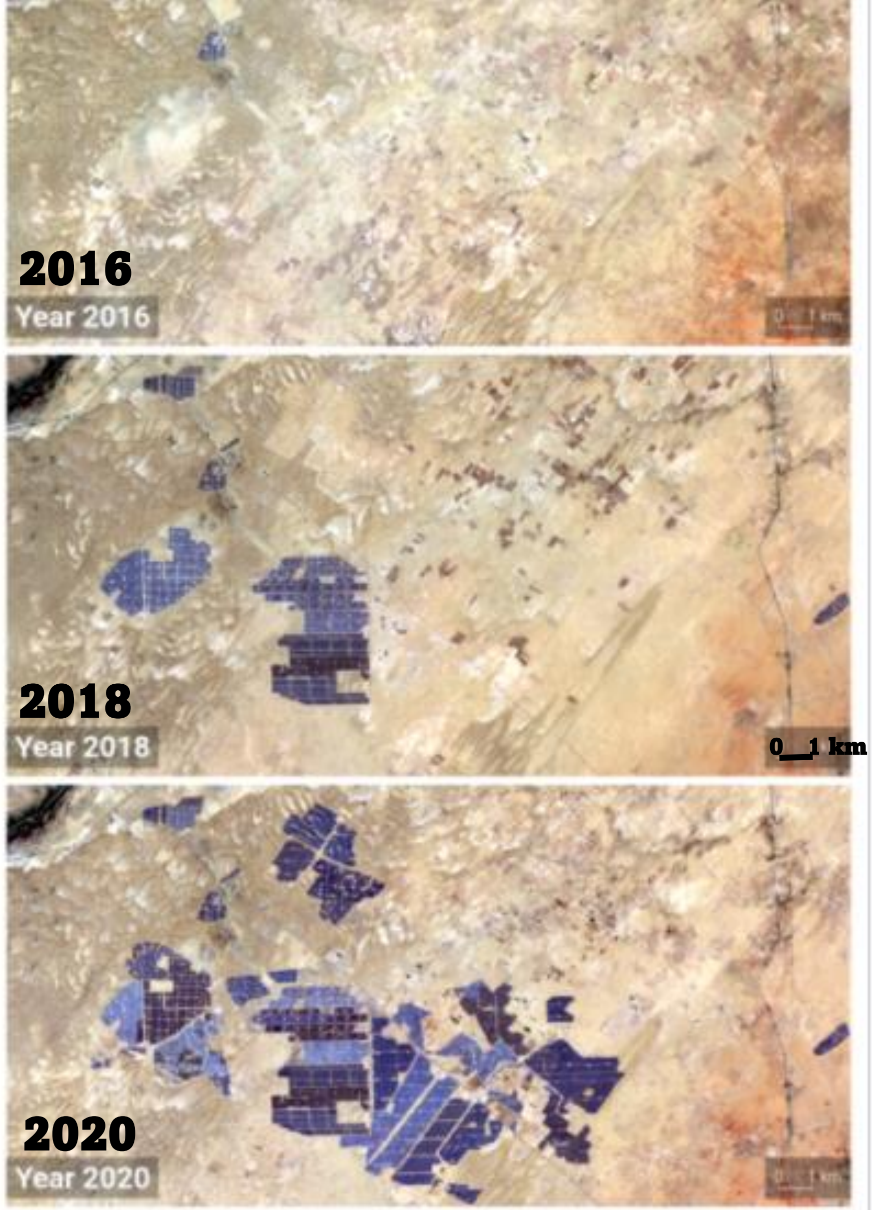


Installed PV capacity

Source: IEA PVPS / REN21 Renewables 2021 Global Status Report & IEA estimate end 2021

Largest PV plant today - Bhadla Solar Park, India (2.245 GW_p)

Dry and sandy region
14 000 acres (ca 7.5 km x 7.5 km)
>10 million modules



Photovoltaic power plants cluster development near Bhadla, Rajasthan, India.
Satellite imagery source: Copernicus Sentinel Hub, Sentinel-2, True color
a) 2016-05-21, L1C product, b) 2018-07-10, L2A product, e) 2020-05-10, L2A product
Composed by Solargis, Rendered in QGIS.

2016–2020 development of Bhadla Solar Park (India) documented by satellite imagery Source: Wikipedia

...and where are we heading?

APRIL 2019

Funded by DBU Deutsche Bundesstiftung Umwelt STIFTUNG MERCATOR

GLOBAL ENERGY SYSTEM BASED ON 100% RENEWABLE ENERGY

Power, Heat, Transport and Desalination Sectors

Study by

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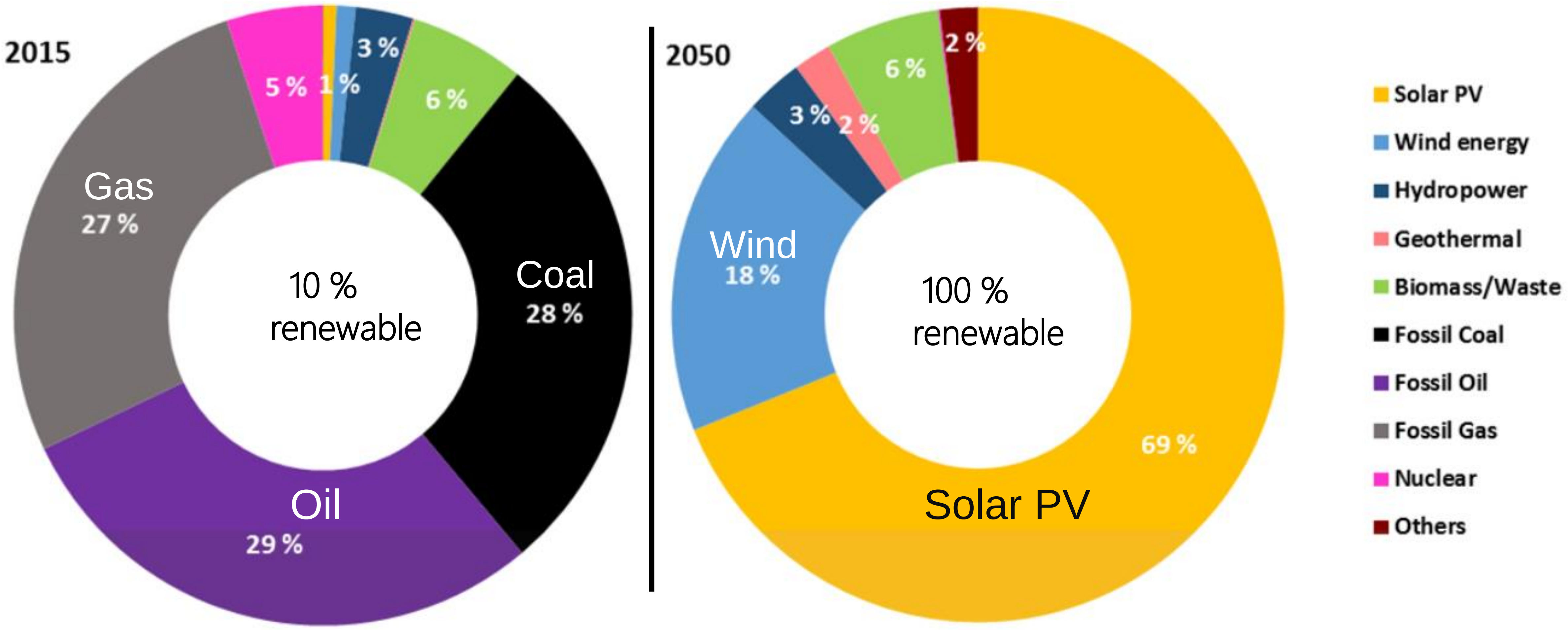
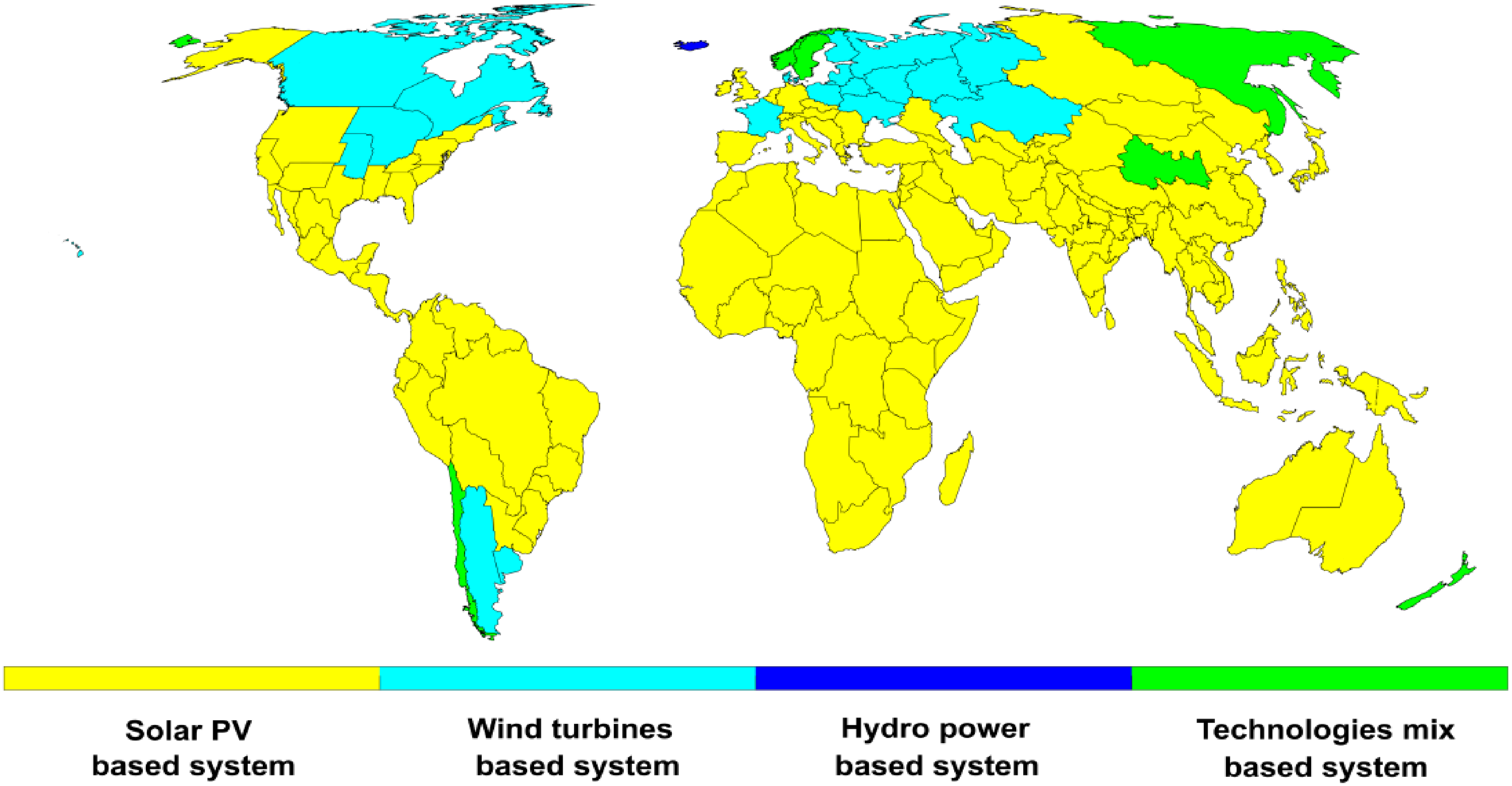


Global primary energy

UiA

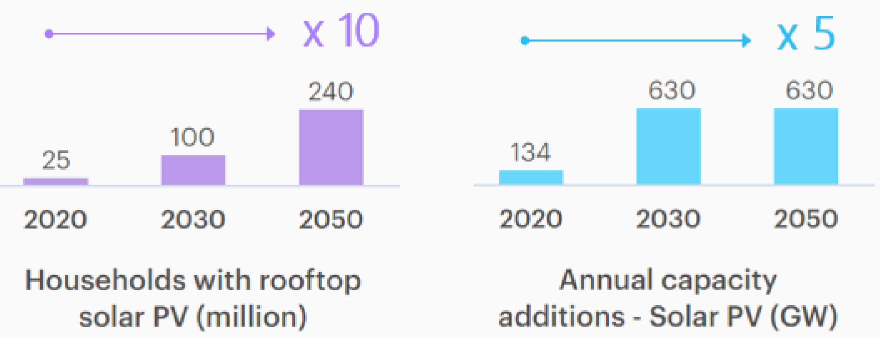
Source: Ram M., Bogdanov D., Aghahosseini A., Gulagi A., Oyewo A.S., Child M., Caldera U., Sadovskaia K., Farfan J., Barbosa LSNS., Fasihi M., Khalili S., Dalheimer B., Gruber G., Traber T., De Caluwe F., Fell H.-J., Breyer C. Global Energy System based on 100% Renewable Energy – Energy Transition Across Power, Heat, Transport and Desalination Sectors. Study by LUT University and Energy Watch Group, Lappeenranta, Berlin, March 2019. ISBN: 978-952-335-339-8.

Main types of 100 % renewable electricity systems in 2050:



Source: Ram M., Bogdanov D., Aghahosseini A., Gulagi A., Oyewo A.S., Child M., Caldera U., Sadovskaia K., Farfan J., Barbosa LSNS., Fasihi M., Khalili S., Dalheimer B., Gruber G., Traber T., De Caluwe F., Fell H.-J., Breyer C. Global Energy System based on 100% Renewable Energy – Energy Transition Across Power, Heat, Transport and Desalination Sectors. Study by LUT University and Energy Watch Group, Lappeenranta, Berlin, March 2019. ISBN: 978-952-335-339-8.

Additional 13 000 GW (2030-2050) and 240 million rooftop systems



Source: IEA Reports Net Zero by 2050 https://www.iea.org/reports/net-zero-by-2050 (accessed 04.03.2022)

- of the order 10^{10} PV modules
  - of the order 10^8 - 10^9 string inverters or combiner boxes
    - millions to billions of various electrical components
      - exposed to a warmer, wilder, wetter climate…

What could possibly go wrong?

PEARL PV

The real challenge is not amount of installed capacity – but amount of delivered energy!

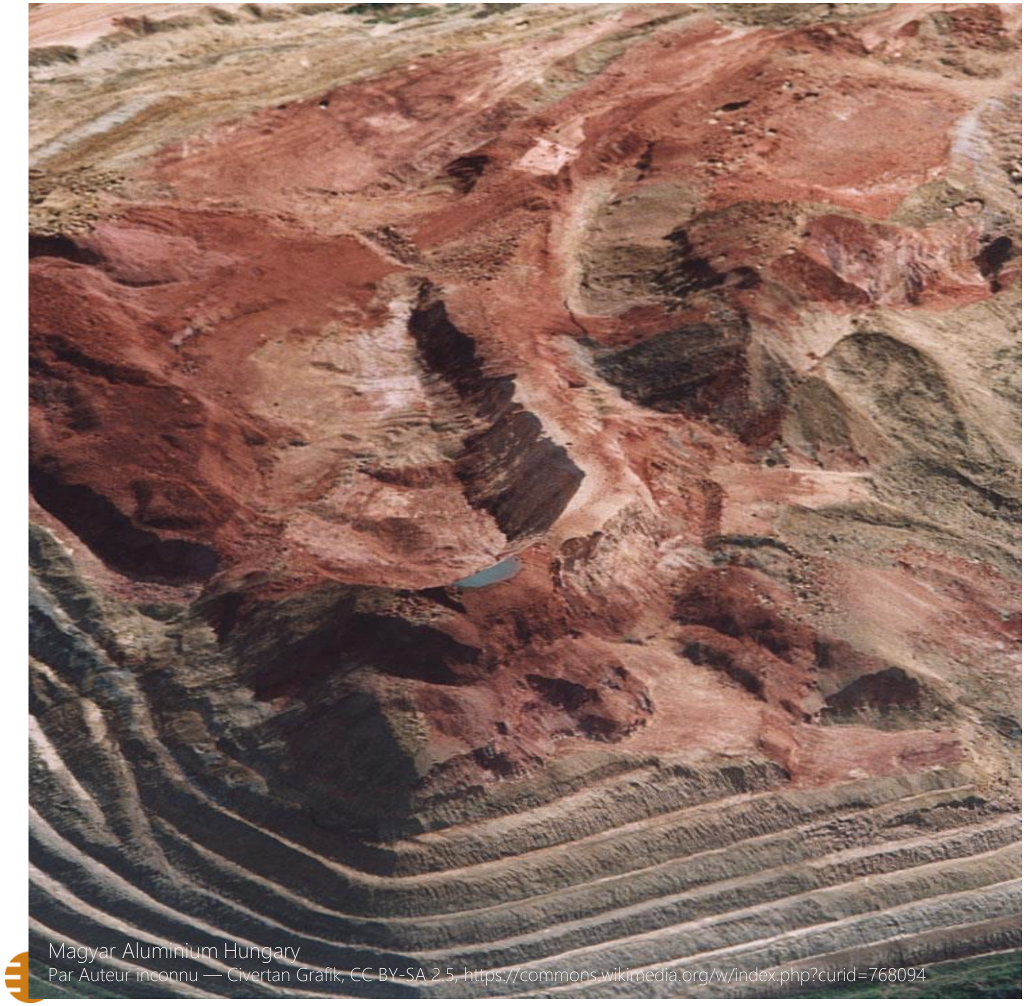

Image: Michael Bloch, https://www.solarquotes.com.au/blog/abb-solar-egypt-mb0337/


Image: Own photo


Image. Vikram Raj Singh; https://rvsolarsolution.com/effect-of-shading-on-solar-system-and-best-way-to-handle-them/

→ PV monitoring!

…actually the real challenge is delivered energy and sustainable circular economy!

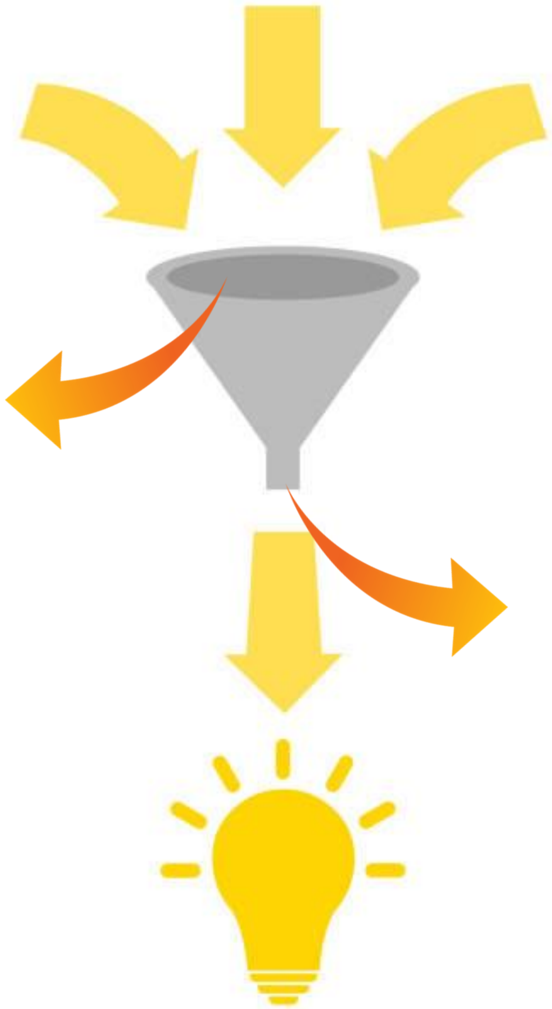


Magyar Aluminium Hungary
Par Auteur inconnu — Civertan Grafik, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=768094

SOURCE JESSICA RINALDI/THE BOSTON GLOBE VIA GETTY

So why do we need PV monitoring?

- *It all looks nice on the paper…*
- *…but we know the reality of results!*



- Predictability
- Bankability
- Sustainability

Example: Case PV plant optimization

Monitoring for the detection of inefficiencies and experts to recognise causes

Result

+20 %

PERFORMANCE RATIO - € 96,500 IN 12 MONTHS WITH 2-MONTH PAY BACK TIME

Plant type: **Ground, biaxial tracking**
Nominal power: **996,84 kWp**
Site: **Padua, Italy**
Year of connection: **2009**

Intervention: **2017**
Tools: **Due Diligence + Energy Intelligence IoT Platform + Continuous Monitoring**

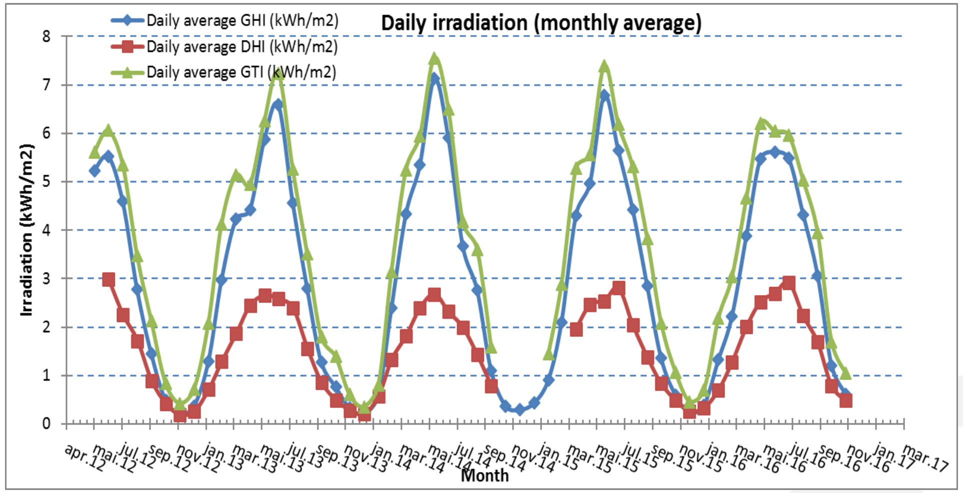
Comparing 2016 & 2017 data:
Efficiency: **+20% PR**
PBT: **2 months**
Savings: **€96,500 in 12 months**

https://www.energyintelligence.it/en/solutions/photovoltaic-investors/case-history-photovoltaic-plant-optimisation-performance-monitoring/

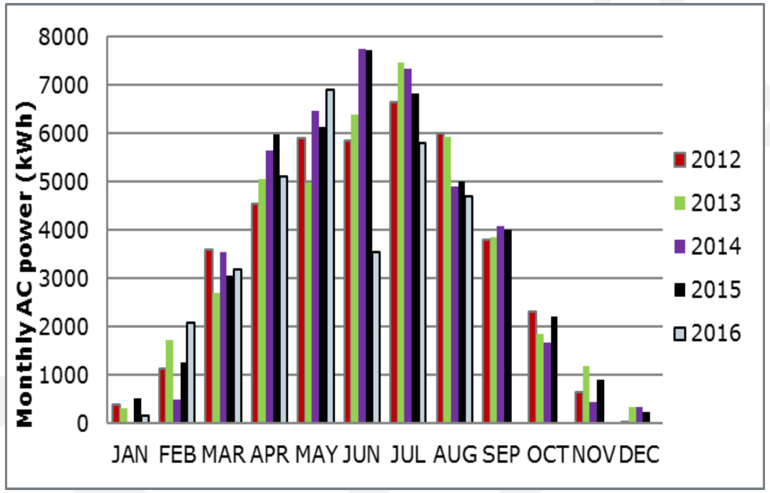
UNIVERSITETET I AGDER

Long term performance data is critical!

Solar variability
Technology
Shading
Component performances
Downtime and maintenance
Snow
Degradation
Power outages
Sensor calibration and uncertainties



Global horizontal irradiation (moving avg) GHI= 1054 kWh/m²
Diffuse horizontal irradiation (moving avg) DHI= 527 kWh/m²
Tilted (20°) global irradiation (moving avg) GTI= 1279 kWh/m²



Annual production: ~42 000 kWh
Annual yield: 900-950 kWh/kW$_p$
System efficiency: ~10 %

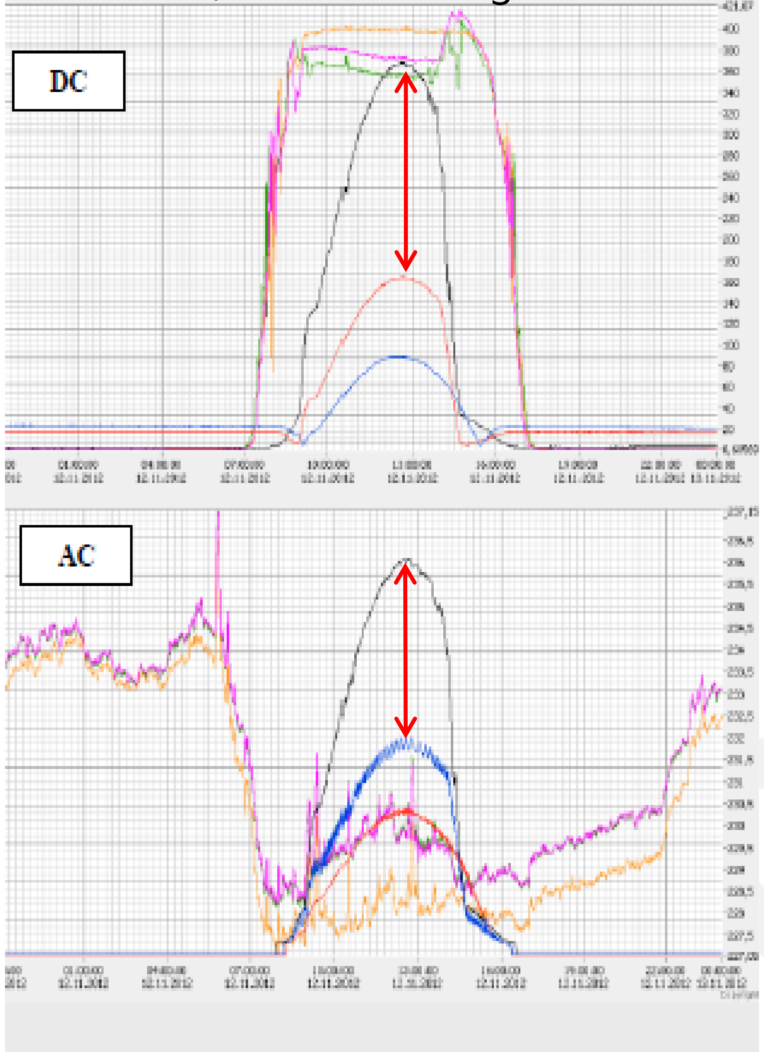
Agder Energi, Kjøita KRISTIANSAND, NORWAY

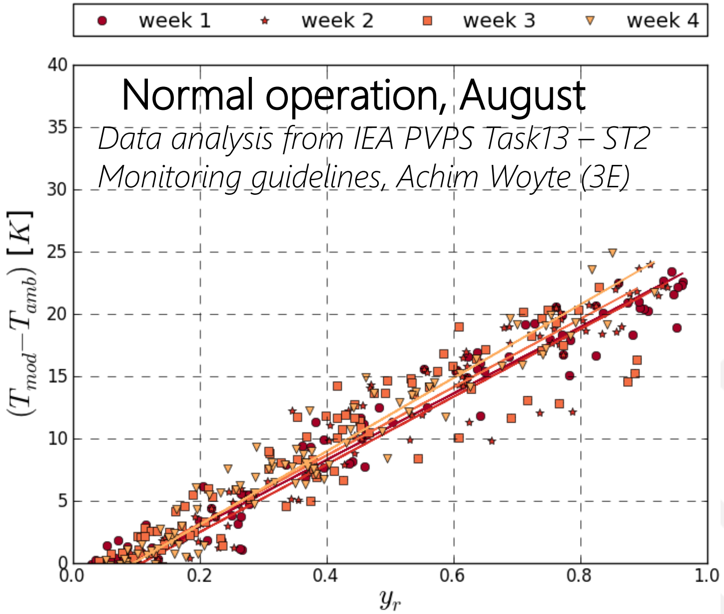
Dealing with ‘real data’ and uncertainties can be a lot of work… ☺

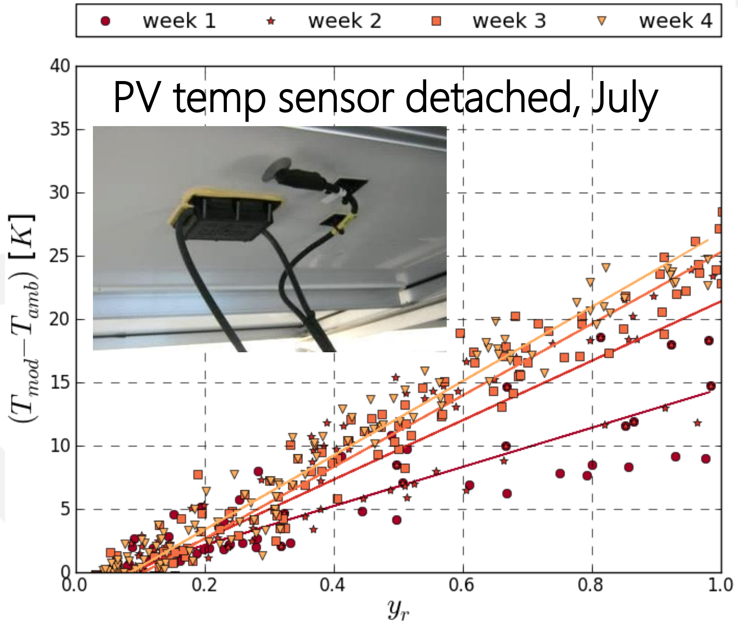
Some of our own examples:

- Pyranometer offsets
- AC/DC transducer offsets
- Power meter accuracy
- Clock drift
- Power outage (lightening)
- Inverter downtime
- Detached sensors
- Loose contacts
- Shading from cranes
- Nesting seagulls
- …

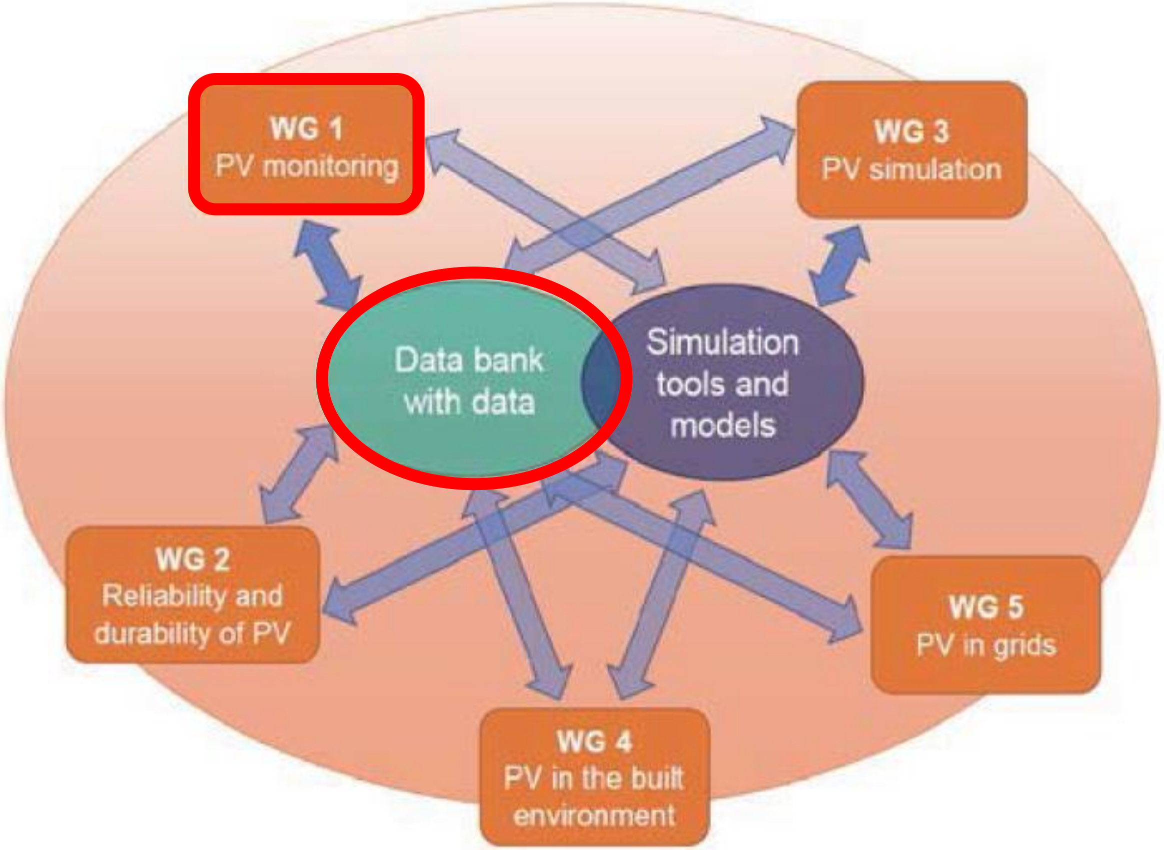
Current dropped to half for one inverter, detached string contact







Data must be linked with models & simulation: Big data & long time series



COST Action PEARL-PV aims:

i) improve the energy performance and reliability of PV systems in Europe leading to lower **cost** of PV electricity and higher **energy yield**

ii) longer lifetime eventually beyond the guaranteed 20 years as specified by manufacturers

iii) a reduction in the perceived **risk** in investments in PV projects.

- Angele Reinders, David Moser, Wilfried Van Sark, Gernot Oreski, Nicola Pearsall, Alessandra Scognamiglio, Jonathan Leloux. Introducing 'PEARL-PV': Performance and Reliability of Photovoltaic Systems: Evaluations of Large-Scale Monitoring Data. In: Conf. Proc. Of the IEEE PVSC 2018.

Small-scale vs large-scale monitoring:

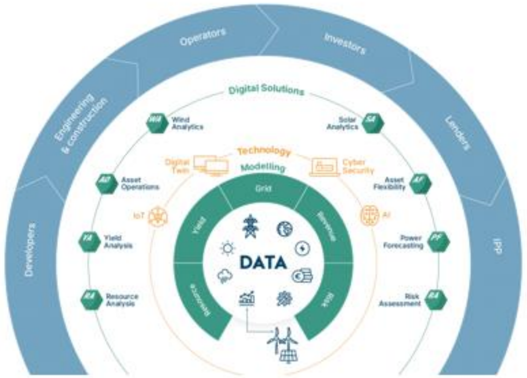
Very different level of data monitoring and supervision – public vs professional

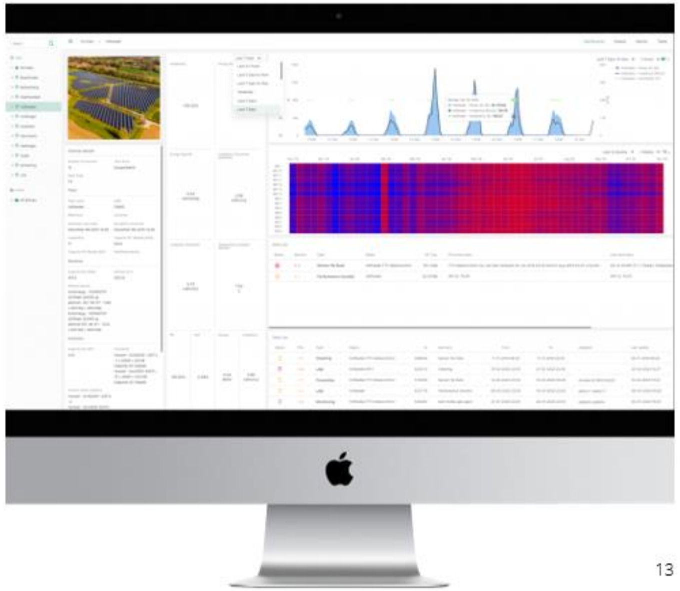
Residential monitoring (example: SMA)

Inverter with display

Inverter with app

SCADA (example: 3E, Synaptic)



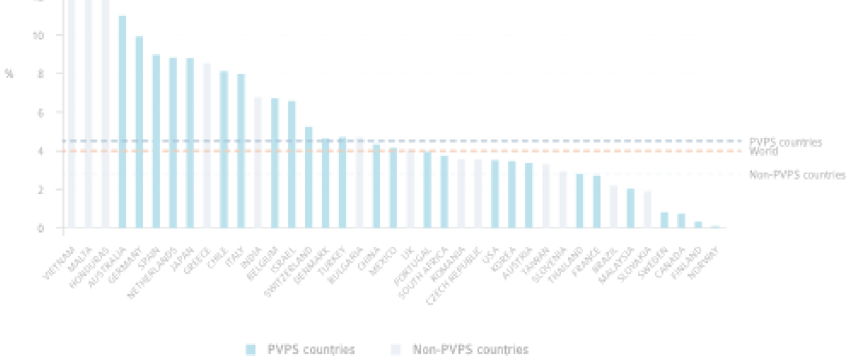


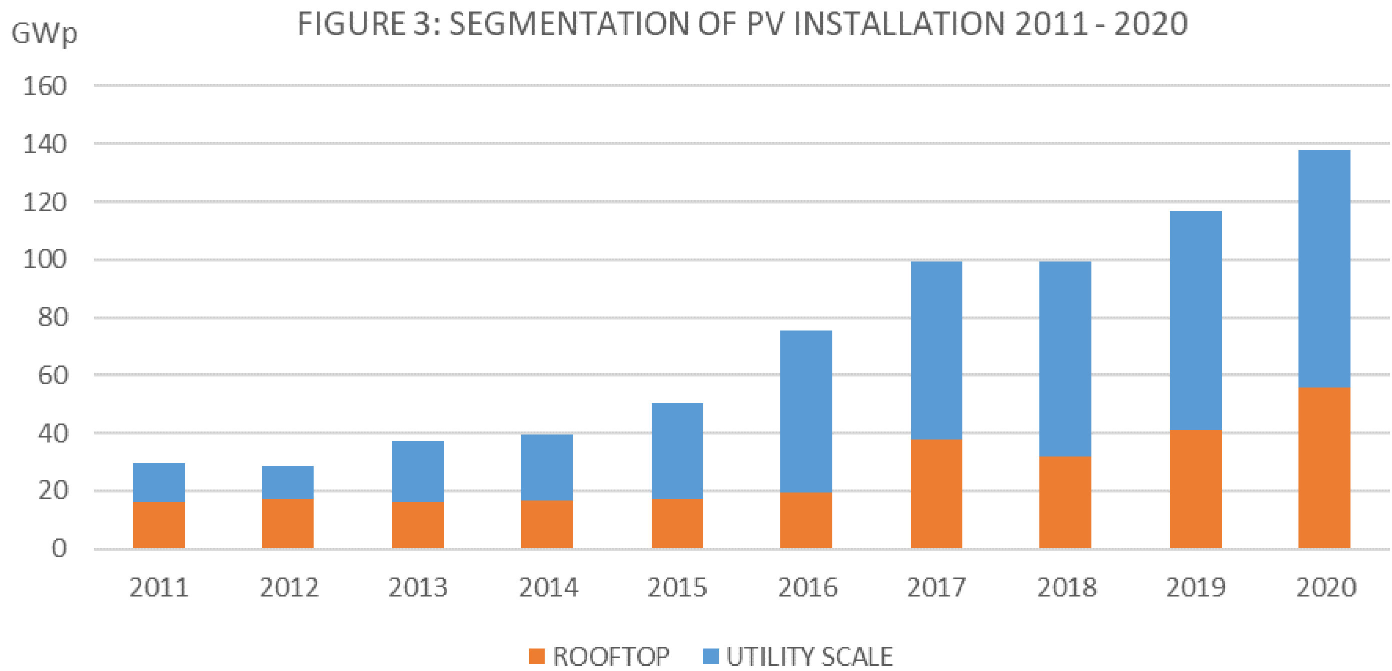
Data access is difficult for around half of PV capacity monitoring data:

Source: Wilfried van Sark, PEARL-PV Training School presentation 09.03.2022

- Different inverters, web-portals, log-in solutions
- Various company and governmental repositories data remain confidential

= Large uncertainty for estimating PV contributions to electricity demand!





IEA-PVPS, Trends in Photovoltaic Applications 2021

Global capacity: 40% residential, 60% utility

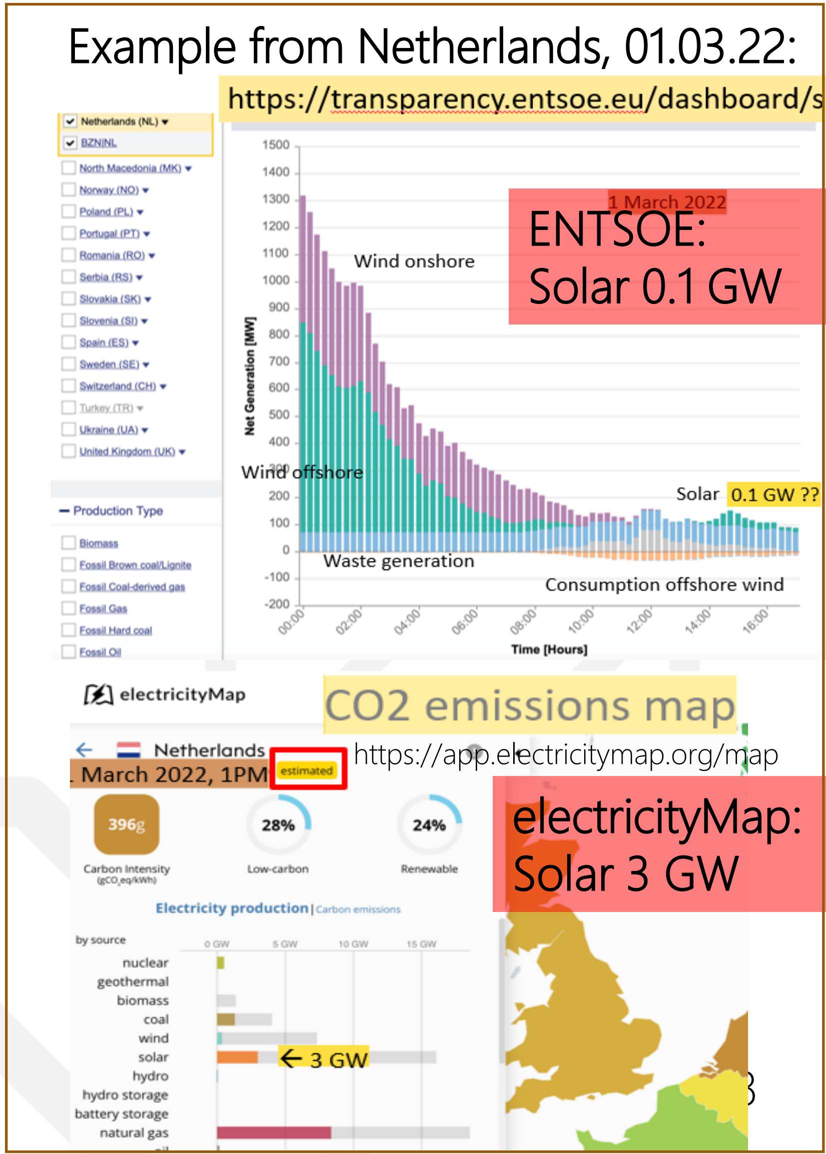
European capacity: 50% residential, 50% utility

Monitoring is imperative for grid planning and control:

Source: Wilfried van Sark, PEARL-PV Training School presentation 09.03.2022

- Inventory of all PV installations in all the regions of the world
  → installed capacity
- Database of annual (monthly/daily/hourly) energy yield
  → contribution to electricity demand
- For grid management (HV/MV/LV, TSO/DSO)
  → realtime power production

With PV as major contributor in a 100% renewable society, data unavailability is unacceptable (security of supply, loss of load probability, grid management)



A brief look at the history of PV performance monitoring

A brief look at history:

1963

- Sharp mass-produces solar cells, bringing solar practicality down from space shuttles/satellites to the general public.

Sharp's early solar cell. Source: Sharp

1973

- Dr. Elliot Berman funded by Exxon designs a cheaper solar panel, bringing price down from $100 per W to $20 per W.

Elliot Berman tests solar arrays. Source: Solar Power Corp. /John Perlin.

Elliot Berman (center) and his team at Solar Power Corp. pose outside their office and manufacturing facility in Braintree, Mass., in 1973.

Source: Robert Willis/Solar Power Corp. via John Perlin.

John Perlin, author of Let It Shine: The 6,000-Year Story of Solar Energy, credits Berman, Solar Power Corp. and Exxon with "planting the flag of photovoltaics throughout the world.".

The game changer: Oil crisis 1973-74

Image source: npr.org / AP

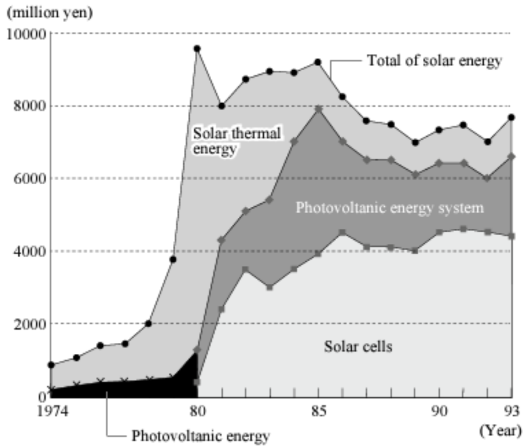
A brief look at history:

1974

- The Solar Energy Industries Association (SEIA) first forms, promoting solar in US.
- The International Energy Agency (IEA) forms to secure energy supplies.

1974

- The Japanese Sunshine Project is launched, a national R&D program aiming for mass production of PV cells/ modules and efficient solar power systems.



Shimamoto M. (2020) What is the Sunshine Project: Overview of the Project. In: National Project Management. Advances in Japanese Business and Economics, vol 25. Springer, Singapore. https://doi.org/10.1007/978-981-15-3180-4_2

1977

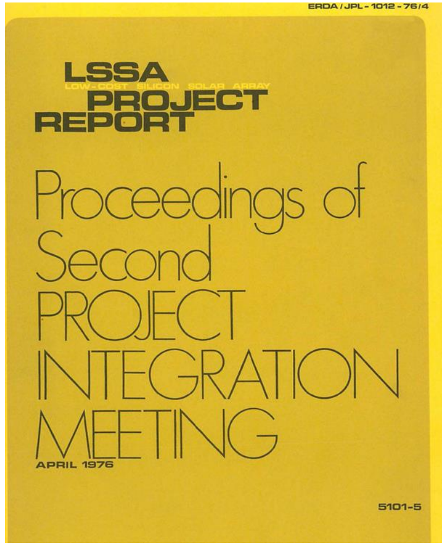
- The Solar Energy Research Institute (SERI), later known as the National Renewable Energy Laboratory (NREL), is launched by the US Department of Energy (DoE).

1977

- Germany introduces an Energy Research and Technology program to facilitate R&D in PV.
- In **1981**, Prof Goetzberger founded the Fraunhofer Institute for Solar Energy Systems ISE in Germany.

A brief look at history:

- **1976**
- Sandia tested the performance and reliability of the first field terrestrial systems in a joint program of DOE, NASA and the Jet Propulsion Lab.



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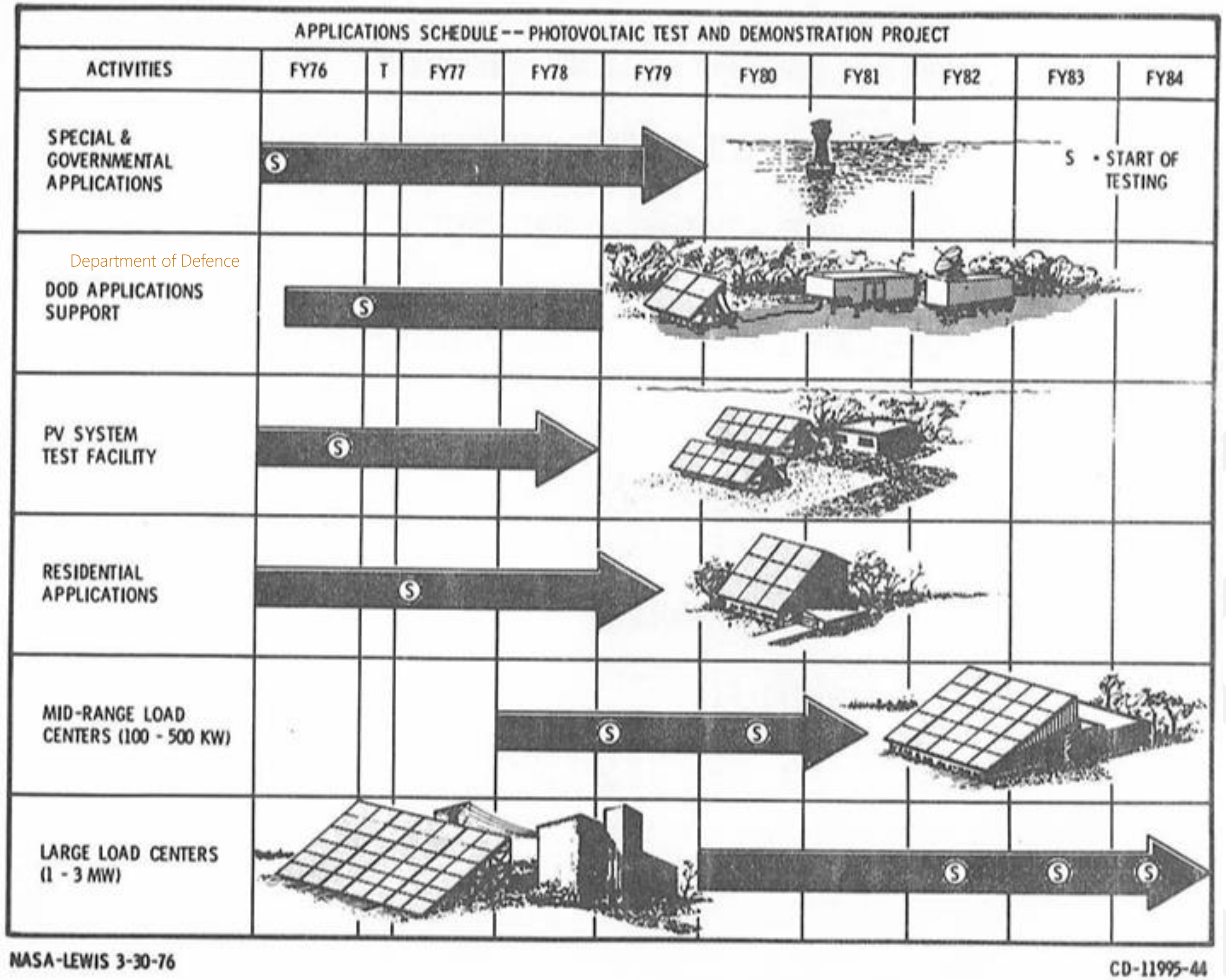


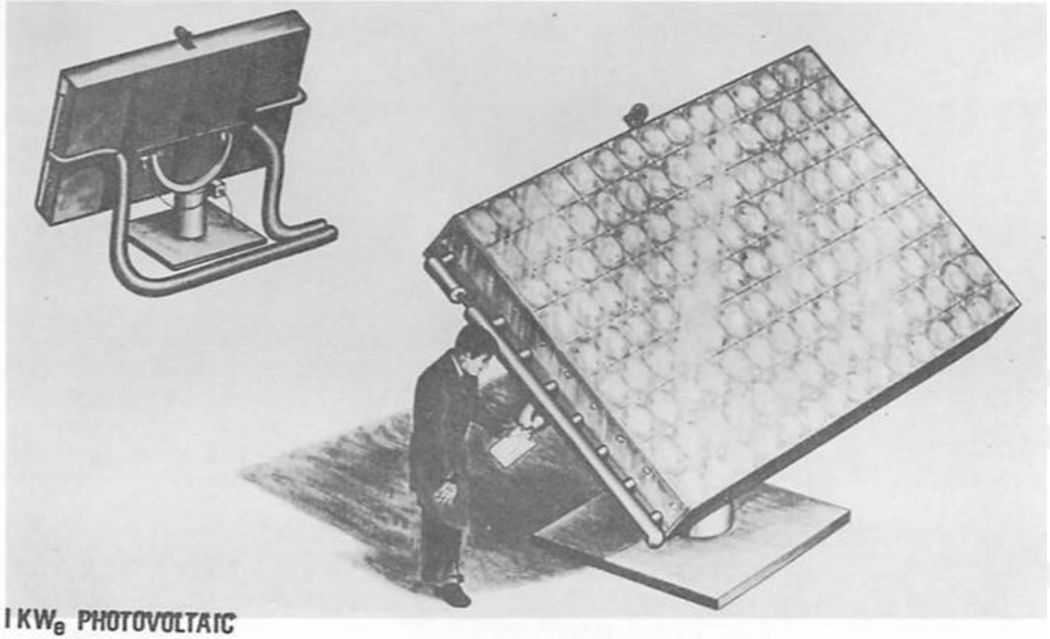
1976-1984 test and demo project LSSA (Low-Cost Silicon Solar Array)

Sandia LSSA project 1976:

https://www2.jpl.nasa.gov/adv_tech/photovol/2016PROJ/Proc%202nd%20PIM%204-1976_5101-5.pdf

- Establish standard (terrestrial) conditions and procedures for measurement of solar cells and arrays
- Facility for measuring performance of solar modules and system (up to 100 kW) and diagnosis of solar cell problems
- Acquire insolation data using solar cells as detectors
- Endurance testing in a variety of geographic and climatological conditions

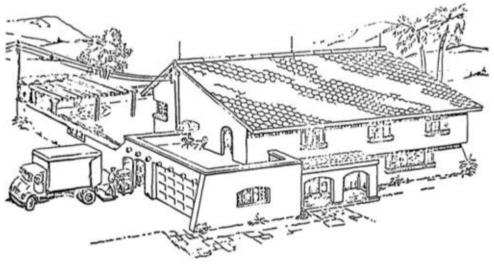
1 kW_E concentrator system



CONCEPT OF 1-kW_E CONCENTRATOR SYSTEM USING FRESNEL LENS

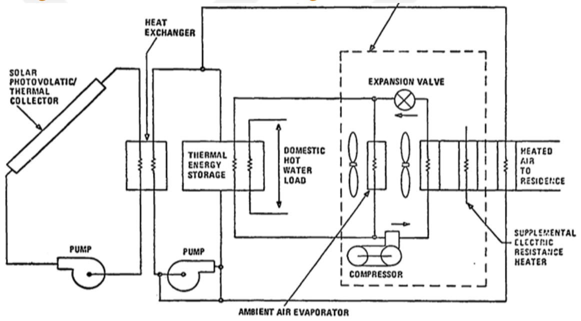
SLA 328

Residential rooftop



GENERAL ELECTRIC PHOTOVOLTAIC RESIDENTIAL CONCEPT

Hybrid PV/T system



Hybrid Photovoltaic/Solar Thermal System

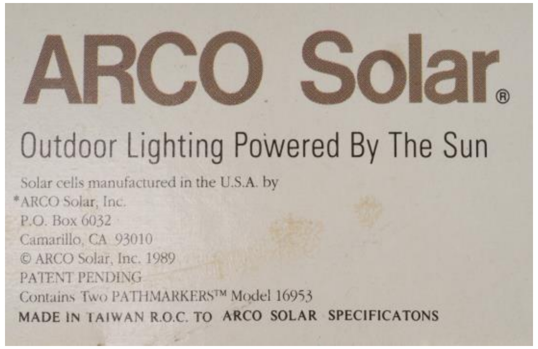
SLA 328

P A R L P V

A brief look at the history:

1980

- ARCO Solar is the first panel manufacturer to hit **1 MW** yearly production.



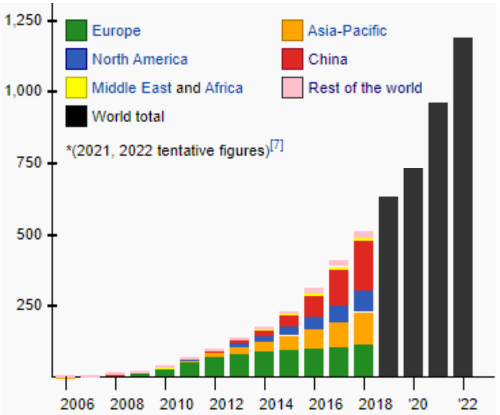
1990

- German government started a 1000 Rooftops Program to promote the PV market.

- In 1999, the program was expanded to the 100,000 Rooftops Program.

2000

- Worldwide solar PV installations surpass **1 GW**.



Cumulative PV capacity (GW$_p$), IEA estimates. Fig: Wikipedia

https://en.wikipedia.org/wiki/Growth_of_photovoltaics

2022

- Worldwide solar PV installations expected to surpass **1 TW**.

Panda Green Energy 50 MW, China. Image: UNDP

- China became the world's leading installer of PV in 2013, today accounting for 1/3 of total installed capacity.

P A R L P V

PV performance monitoring: Historical results (1998)

IEA PVPS Task 2: Performance, reliability and Analysis of PV Systems

15th European Photovoltaic Solar Energy Conference, Vienna, Austria, July 1998

INTERNATIONAL ENERGY AGENCY TASK II DATABASE ON PHOTOVOLTAIC POWER SYSTEMS: STATISTICAL AND ANALYTICAL EVALUATION OF PV OPERATIONAL DATA

U. Jahn[1], M. Niemann[1], G. Blaesser[2], R. Dahl[3], S. Castello[4], L. Clavadetscher[5], D. Faiman[6], D. Mayer[7], K. van Otterdijk[8], J. Sachau[2], K. Sakuta[9], M.Yamaguchi[10], M. Zoglauer[11]

Conclusions: (260 PV plants)

- Stand-alone PV systems without backup PR=0.1-0.4
- Stand-alone PV systems with backup PR=0.2-0.6
- Grid-connected PV systems PR=0.6-0.8
- Large grid-PV plants & excellent inverters ~PR>0.8

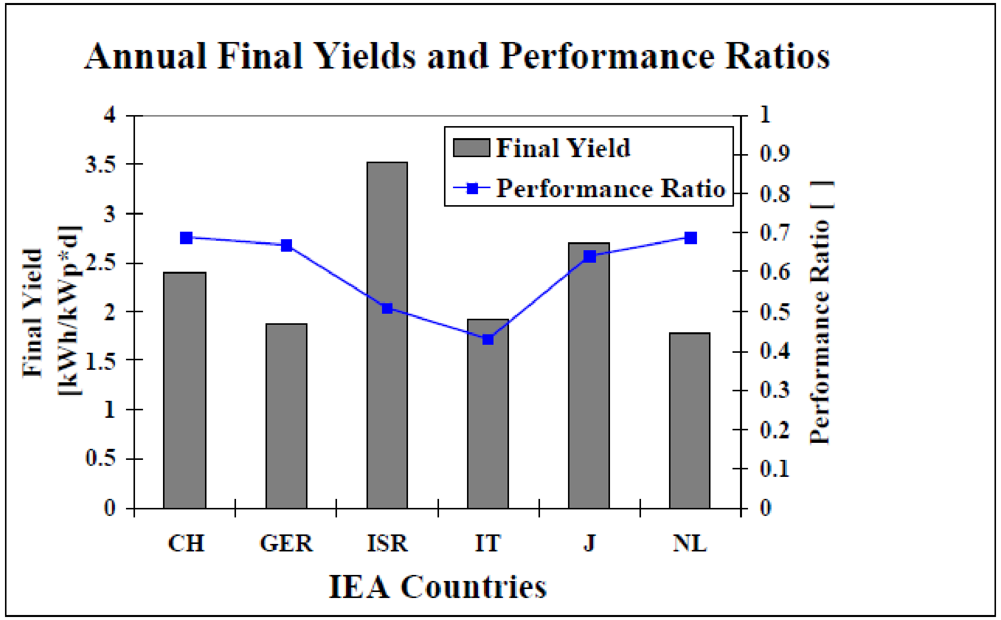
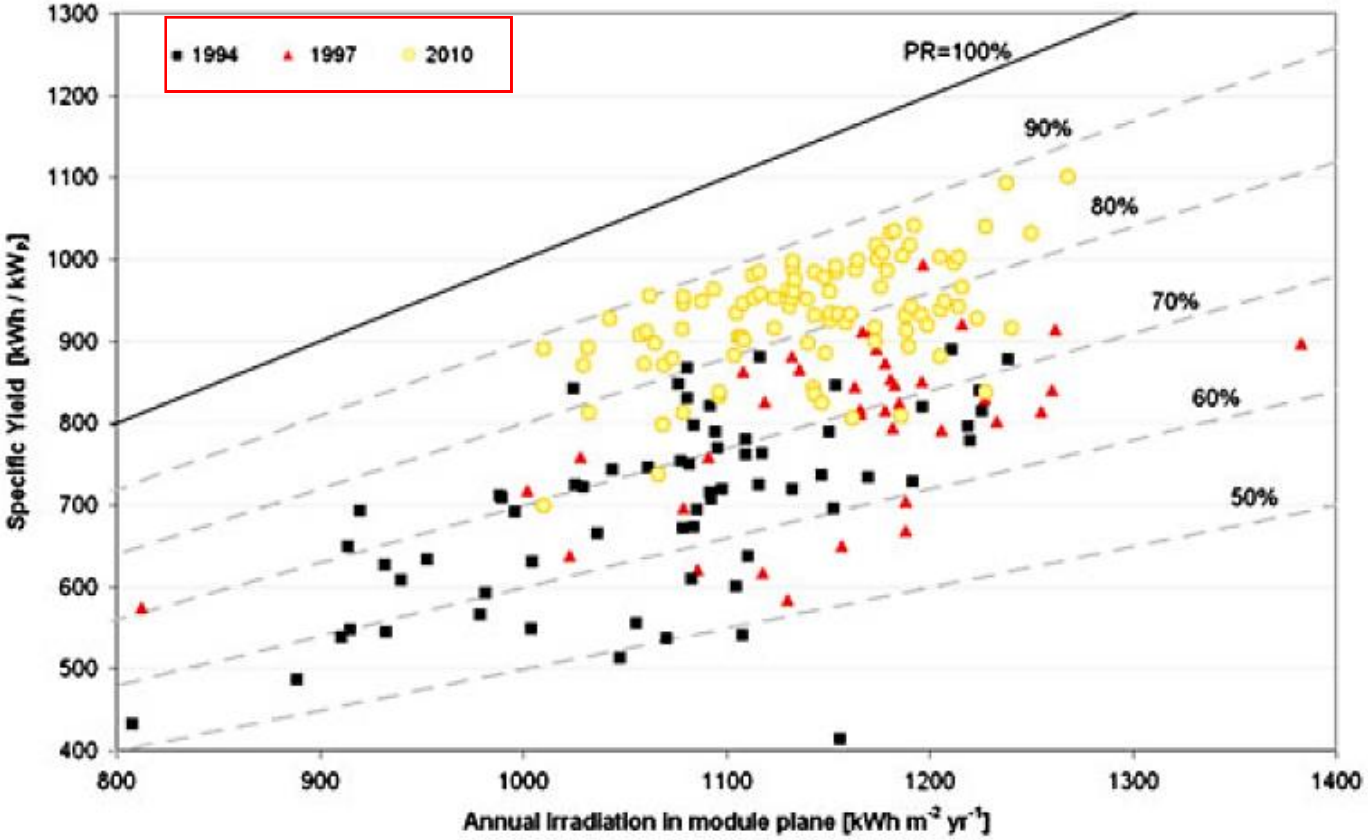


Figure 2: Presentation of operational results from 140 grid connected PV systems in six IEA countries - system yields and performance ratios Source: Jahn et al, EU PVSEC 1998.

PV performance monitoring: Historical results (2010)

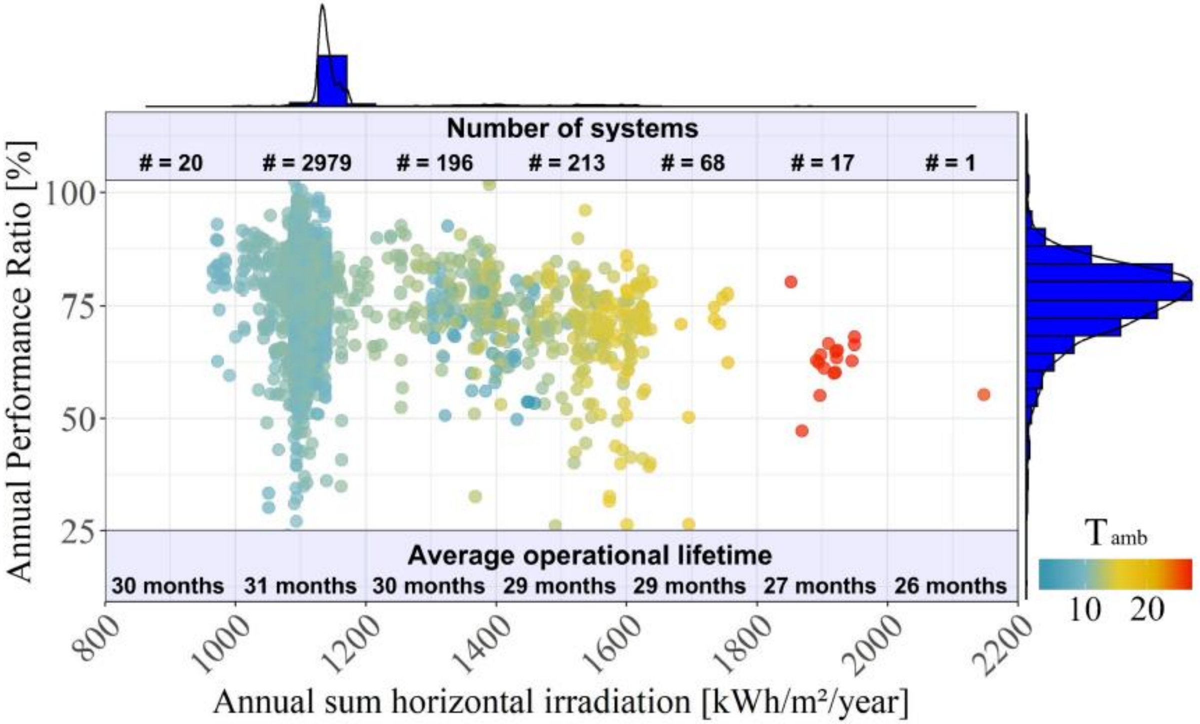
Data from 1000-Roofs Programme 1994/1997 and in 2010 by Fraunhofer ISE



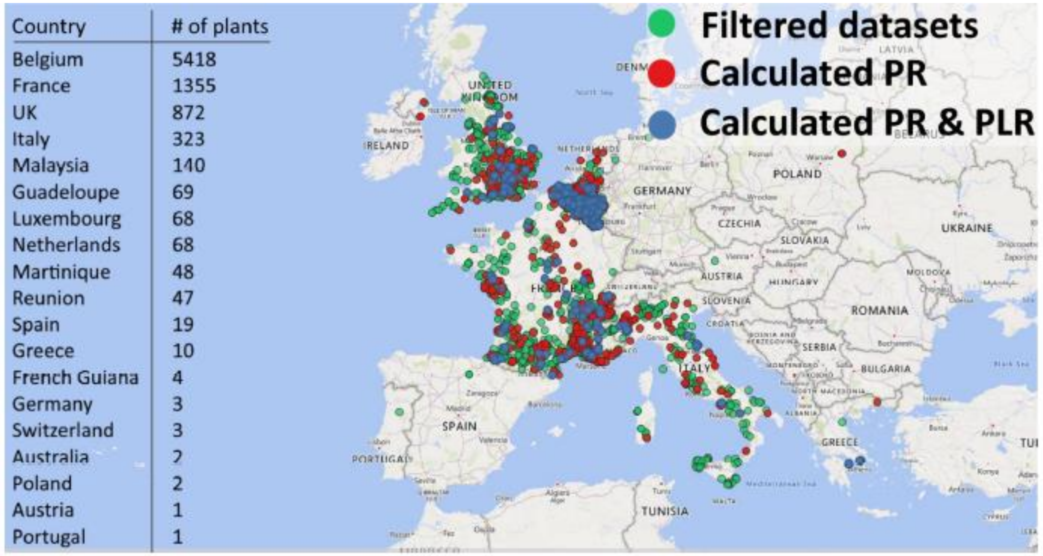
- Monitored specific yield as a function of total plane-of-array irradiation of photovoltaic systems installed in years 1994, 1997, and 2010 with corresponding performance ratio contour lines. Source: N.H. Reich, B. Mueller, A. Armbruster, W. van Sark, K. Kiefer, C. Reise, Performance ratio revisited: is PR >90% realistic? Progress in Photovoltaics: Research and Applications, 2012, 20:717.

PV performance monitoring: New results (2021)

S. Lindig, J. Ascencio-Vàsquez, J. Leloux, D. Moser, A. Reinders, Performance Analysis and Degradation of a Large Fleet of PV Systems, IEEE JPV vol 11 (5), sep 2021.



- Annual sum of horizontal irradiation [kWh/m^2/year] versus annual PR [%] categorized by ambient temperature [°C] together with respective histograms.



Country	# of plants
Belgium	5418
France	1355
UK	872
Italy	323
Malaysia	140
Guadeloupe	69
Luxembourg	68
Netherlands	68
Martinique	48
Reunion	47
Spain	19
Greece	10
French Guiana	4
Germany	3
Switzerland	3
Australia	2
Poland	2
Austria	1
Portugal	1

Fig. 1. Distribution of PV systems of Pearl PV database in Europe together with number of systems; green—filtered datasets, red—Calculated PR, blue—Calculated PLR & PR.

Data quality grading criteria

Letter Grade	Outlier [%]	Missing percentage [%]	Longest Gap [days]	Pass-Fail criterion
A	Below 10	Below 10	Below 15	*P*:
B	10 to 20	10 to 25	15 to 30	x $\geq$ 24 months
C	20 to 30	25 to 40	30 to 90	*F*:
D	Above 30	Above 40	Above 90	x $<$ 24 months

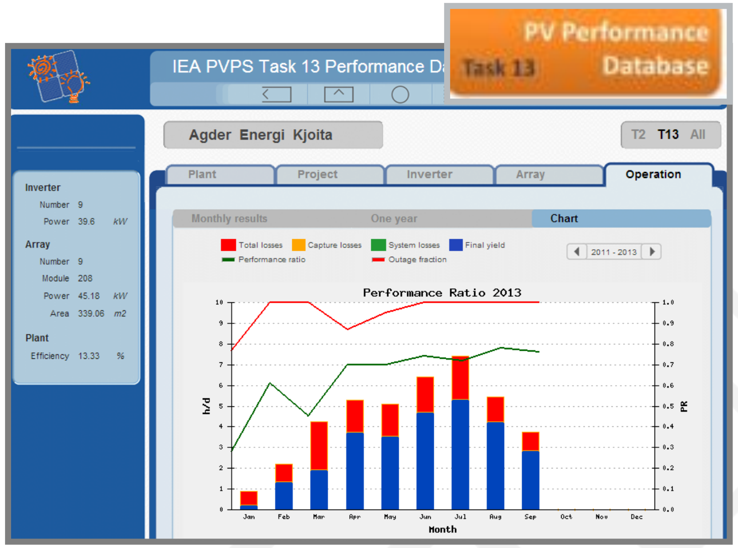
P A R L P V

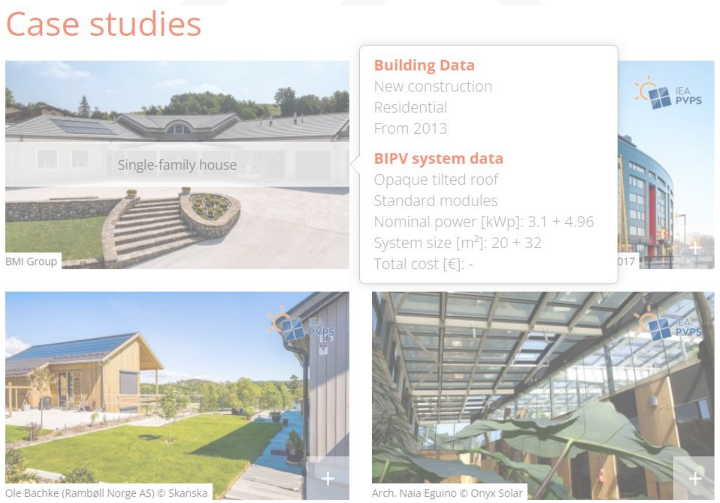
What ACCESS TO DATA do we have?

EXAMPLES OF MAJOR INTERNATIONAL PV MONITORING INITIATIVES & DATABASES

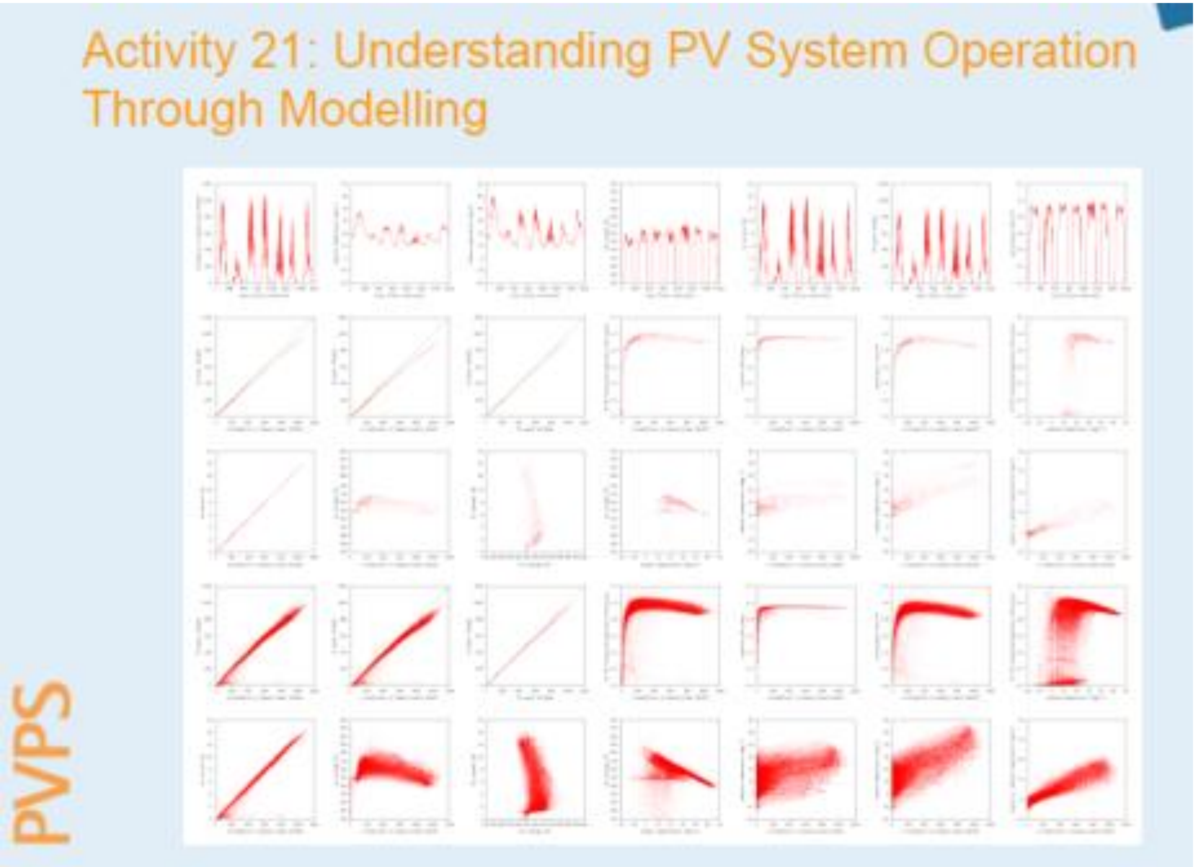
IEA Photovoltaic Systems Programme (PVPS):

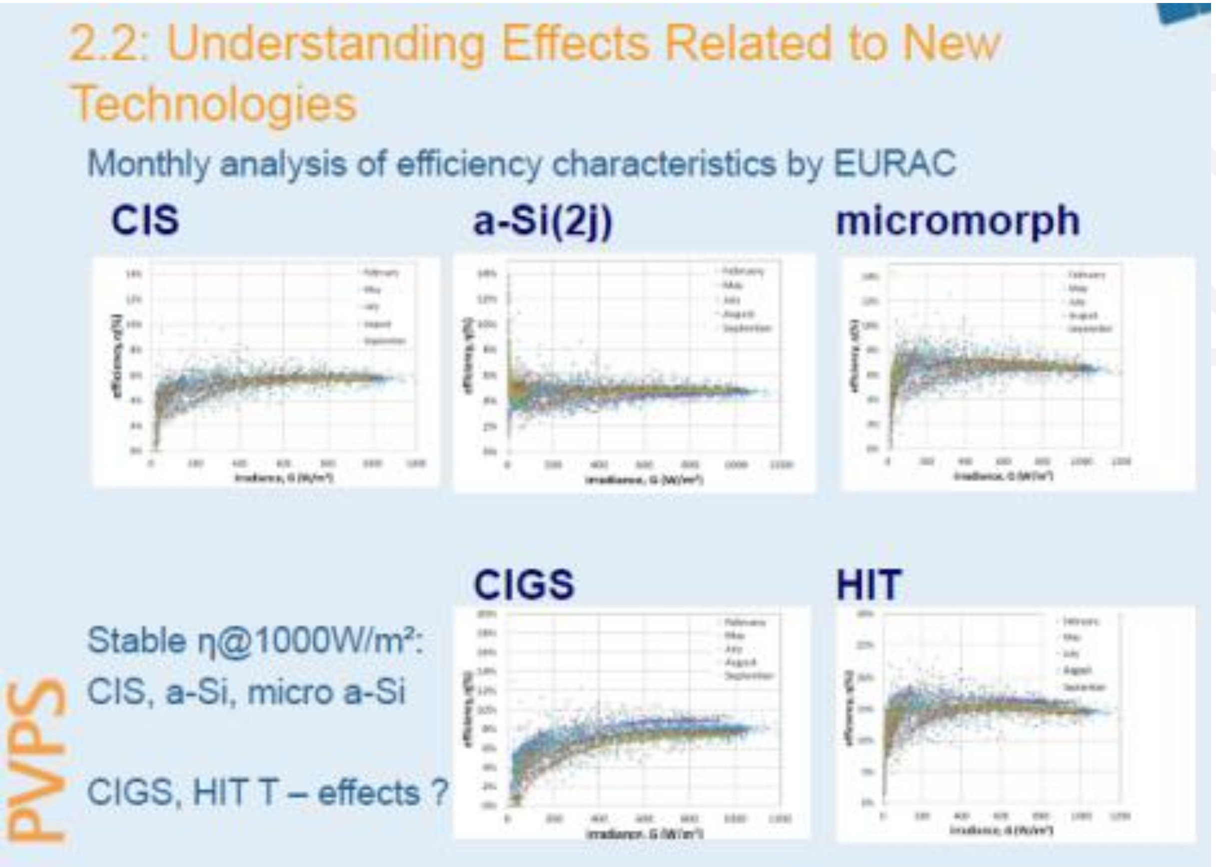
- Task 2: (1999-2004)
  - *Task 2: Performance, reliability and analysis of photovoltaic systems*
  - *Performance Database "PVbase" (http://www.iea-pvps-task2.org/database/)*
  - *Performance analysis of PV modules and systems (hybrid, stand-alone, grid), data from 1987-1997.*
- Task 13: (2010-2014), extended (2014-2017), (2018-2021)
  - *Task 13: Performance, (operation) and reliability of photovoltaic systems*
  - *(Phase 1) Performance database: continuation of work in Task 2 (member)*
  - *Performance analysis of PV systems and modules based on outdoor field measurements*
- Task 10: (2007-2011)
  - *Task 10: Urban-scale grid-connected PV applications*
  - *Database "PVDATABASE" (http://www.pvdatabase.org/)*
  - *Project database of community and BIPV applications; educational tool.*
- Task 15: (2015-2019); (2020-2023)
  - *Task 15: Enabling framework for the development of BIPV*
  - *Eurac database (https://bipv.eurac.edu/en)*
  - *BIPV products & Case studies ("submit your projects/products")*





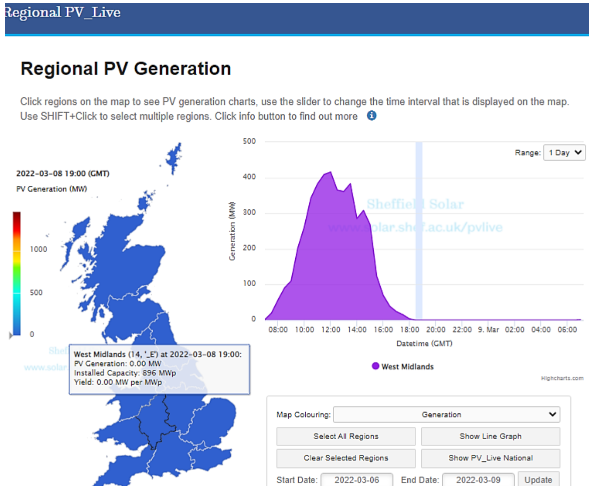
IEA PVPS Task 13: Performance database «Stamp collection» (research data)

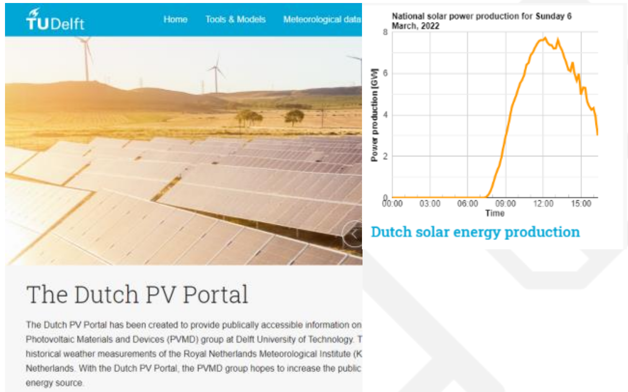


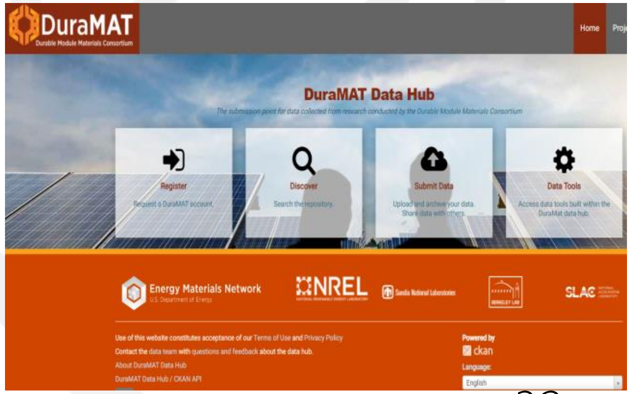


Other various databases (examples):

- UK:
  - Early 2000s: Large Scale BIPV Field Trial Programme (LSBIPV), data on CD.
  - 2011-2021: Sheffield Solar research group operated the MicrogenDB database
    Closed down, but websites remain: PV_Forecast and PV_Live (live generation)
    https://www.solar.sheffield.ac.uk/pvlive/
- France:
  - BPDV Base de Données PhotoVoltaïque (non profit organization) https://www.bdpv.fr/en/
- Austria:
  - Sonnenertrag (non profit organization) http://www.solar-yield.eu/
- Netherlands:
  - TU Delft operates the Dutch PV portal – Meteorological & PV power data
    https://www.tudelft.nl/en/ewi/over-de-faculteit/afdelingen/electrical-sustainable-energy/photovoltaic-materials-and-devices/dutch-pv-portal
- Germany;
  - Emerging PV reports initiative: EPVRI database https://emerging-pv.org/
- USA:
  - PV reliability data: DuraMAT Data Hub (DoE, NREL, Sandia, Berkeley)
    https://datahub.duramat.org/
  - PV fleet data initiative (long-term PV system performance benchmark)



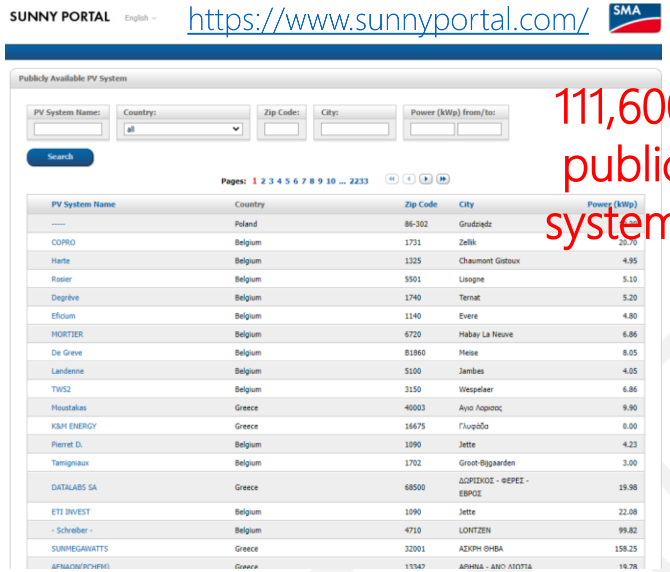




Data from distributed residential PV systems:

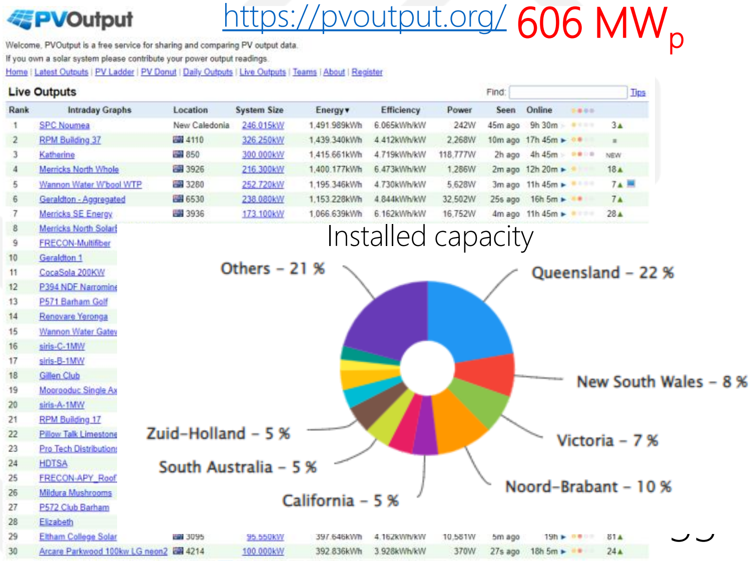
- Examples of publicly available data:
  - Inverter producers and residential monitoring providers: SMA Sunny Portal, Solar-Log, etc (cloud access, inverter data)
  - PVOutput.org (free sharing service, inverter data)
- Challenges:
  - (i) Data quality
  - (ii) Available parameters for analysis
  - (ii) Extracting large datasets efficiently
- Different inverters, web-portals, log-in solutions, file formats = Very time consuming to analyze! => Web Scraping
  - “What you see, is what you can extract” Python scripts developed to mimic human navigation.

https://www.sunnyportal.com/



111,600 public systems

https://pvoutput.org/ 606 MW_p



Big data analysis: “Stamp collection” (public data)

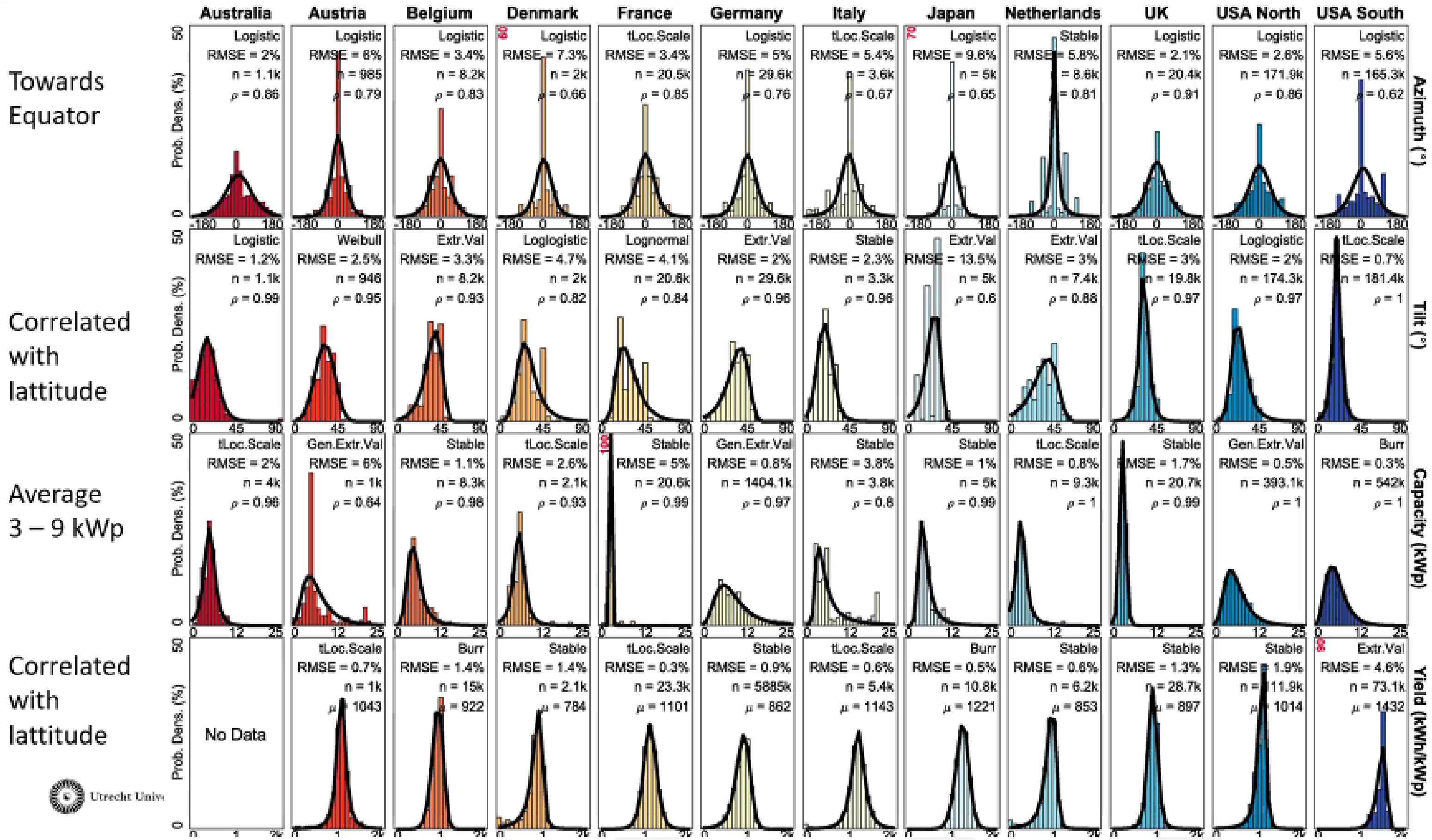
- Global study using 2,802,797 PV systems (Europe, USA, Japan, Australia, total 59 GW_p)

Various data sources:

PVoutput.org, solar-log, sonnenertrag, jyuri.jp, openpv.nrel.gov, bdpv.fr, bundesnetzagentur.de.

Data records:

Installed capacity (100%)
Valid tilt/azimuth (11%)
Location (97%)
Specific annual yield (70%)



Azimuth

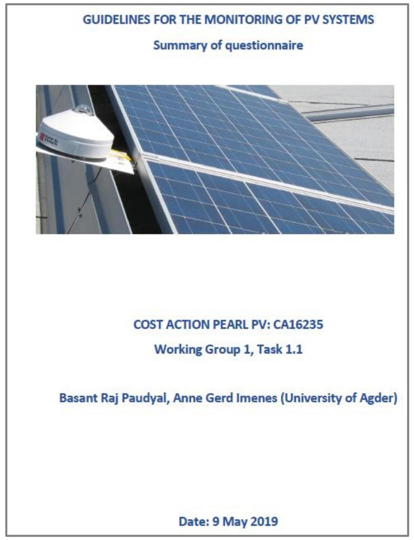
Tilt

Capacity

Yield

Source: Killinger et al., Solar Energy 143 (2017), 120-131.

Source: Wilfried van Sark, PEARL-PV Training School presentation 09.03.2022


GUIDELINES FOR THE MONITORING OF PV SYSTEMS

Summary of questionnaire

COST ACTION PEARL PV: CA16235

Working Group 1, Task 1.1

Basant Raj Paudyal, Anne Gerd Imenes (University of Agder)

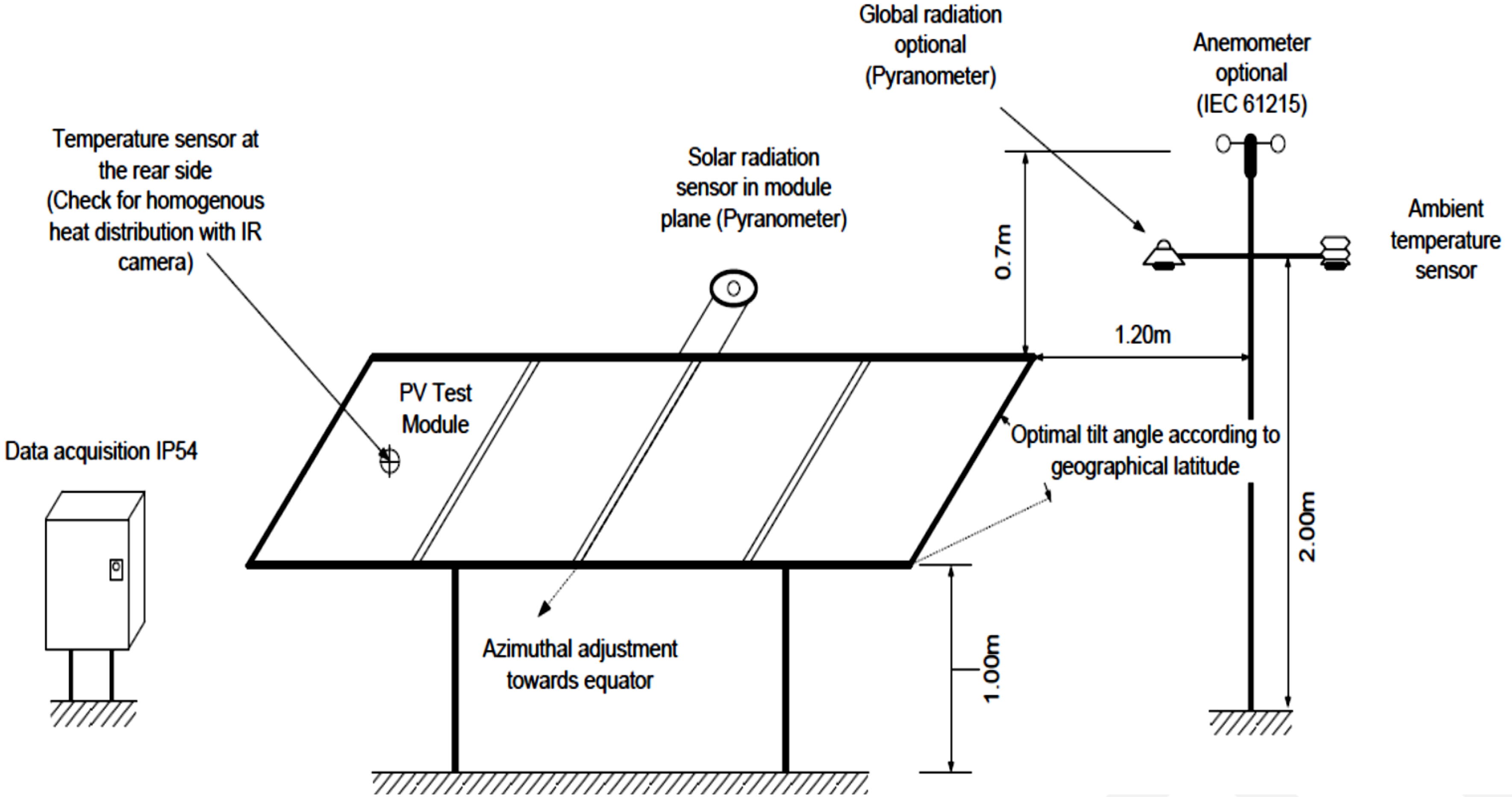
Date: 9 May 2019

PEARL PV WG1 on PV monitoring

ST1.1 Data collection approaches and guidelines

(Objective 1) Development of *generally accepted approaches and guidelines for the **collection of** PV performance monitoring data* (from dataloggers, smart meters, internet scavenging, satellites, visual inspections).

DERlab: Technical guidelines on long-term PV module outdoor tests (2011)



- Examples:
- Time series: *Min 1 year of data, availability 98-99 % , sample rate max 15 sec, record rate 1, 5 or 15 min.*
- Irradiance: *Secondary standard pyranometer in POA (ISO 9060), or ref cell of same PV tech (IEC 60904).*
- IV-curve: *1 x month on clear day with light wind, STC-corrected (IEC 60891), min 3 yrs for degr meas.*

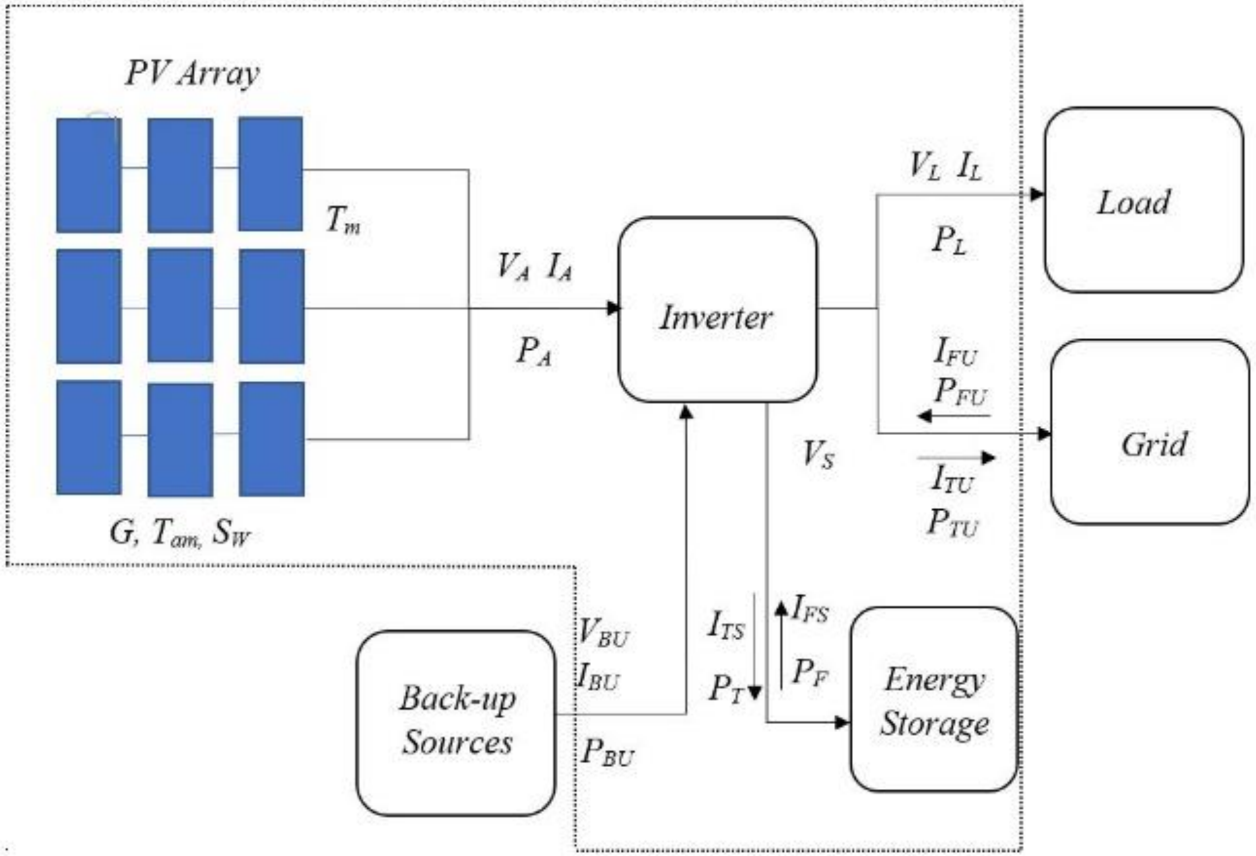
- Source: Vincent Helmbrecht et al, Harmonized procedures for longterm energy yield measurements and performance evaluation of PV modules in outdoor conditions, www.pv-tech.org, pp. 194-201.

P *DERlab = Association of leading labs/research institutes in distributed energy resources (DER). Supports the development of European and international standards by providing technical information and input.*

IEC 61724 PV system performance monitoring (2016)

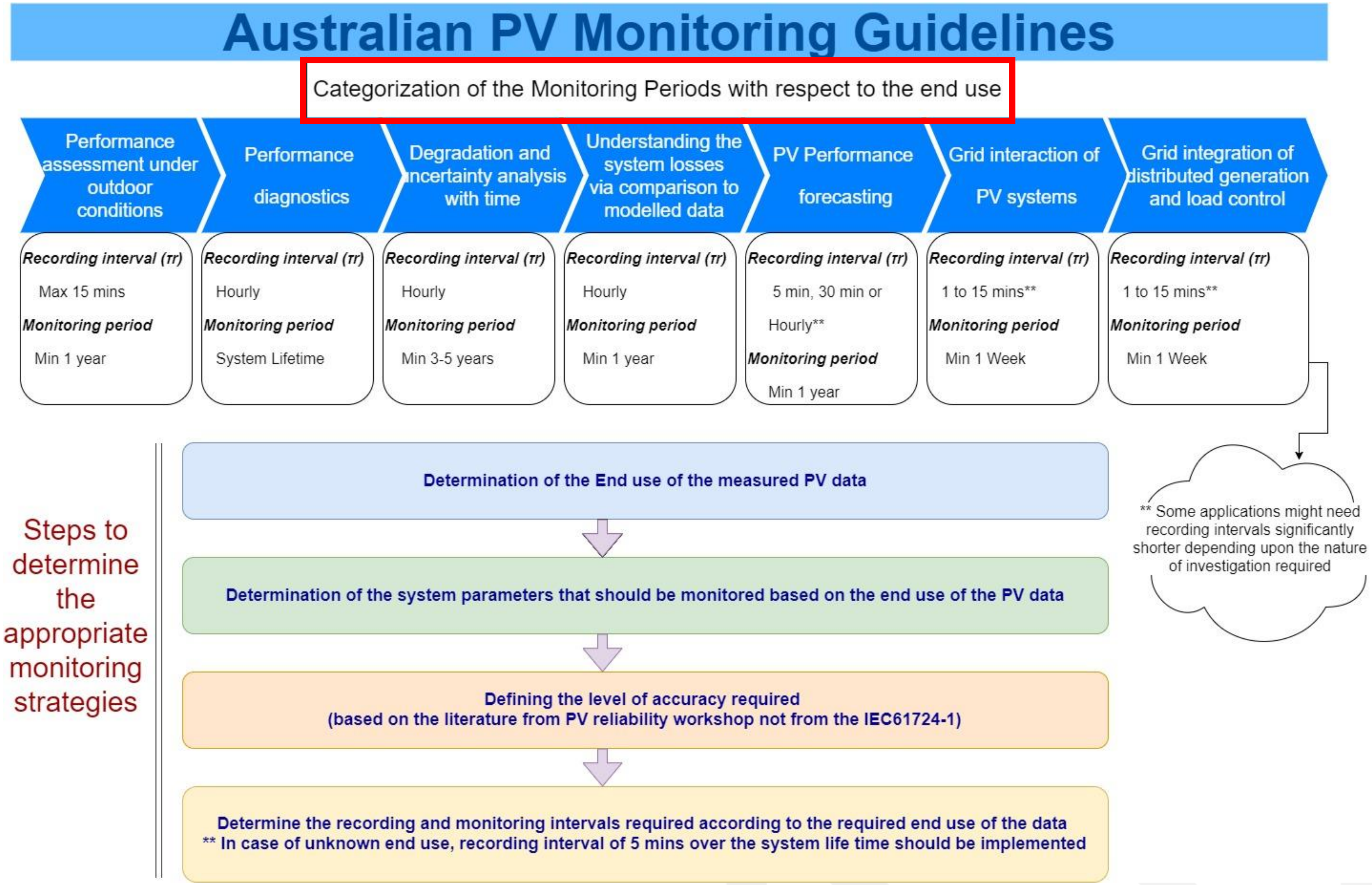
- Photovoltaic system performance standard:
  - Part 1: Monitoring
  - Part 2: Capacity evaluation method
  - Part 3: Energy evaluation method
  - Part 4: Degradation rate eval. method

	Class A	**Class B**	**Class C**
Description	Greatest precision	Medium-level precision	Basic precision
Typically targeted PV system size	Utility-scale	Commercial-scale	Residential and small commercial
Suitable applications			
System performance assessment	X	X	X
Documentation of a performance guarantee	X	X	
Forecasting performance	X	X	
Electricity network interaction assessment	X	X	
Monitoring integration of distributed generation, storage, & loads	X	X	
System losses analysis	X		
PV technology assessment	X		
PV system degradation measurement	X		



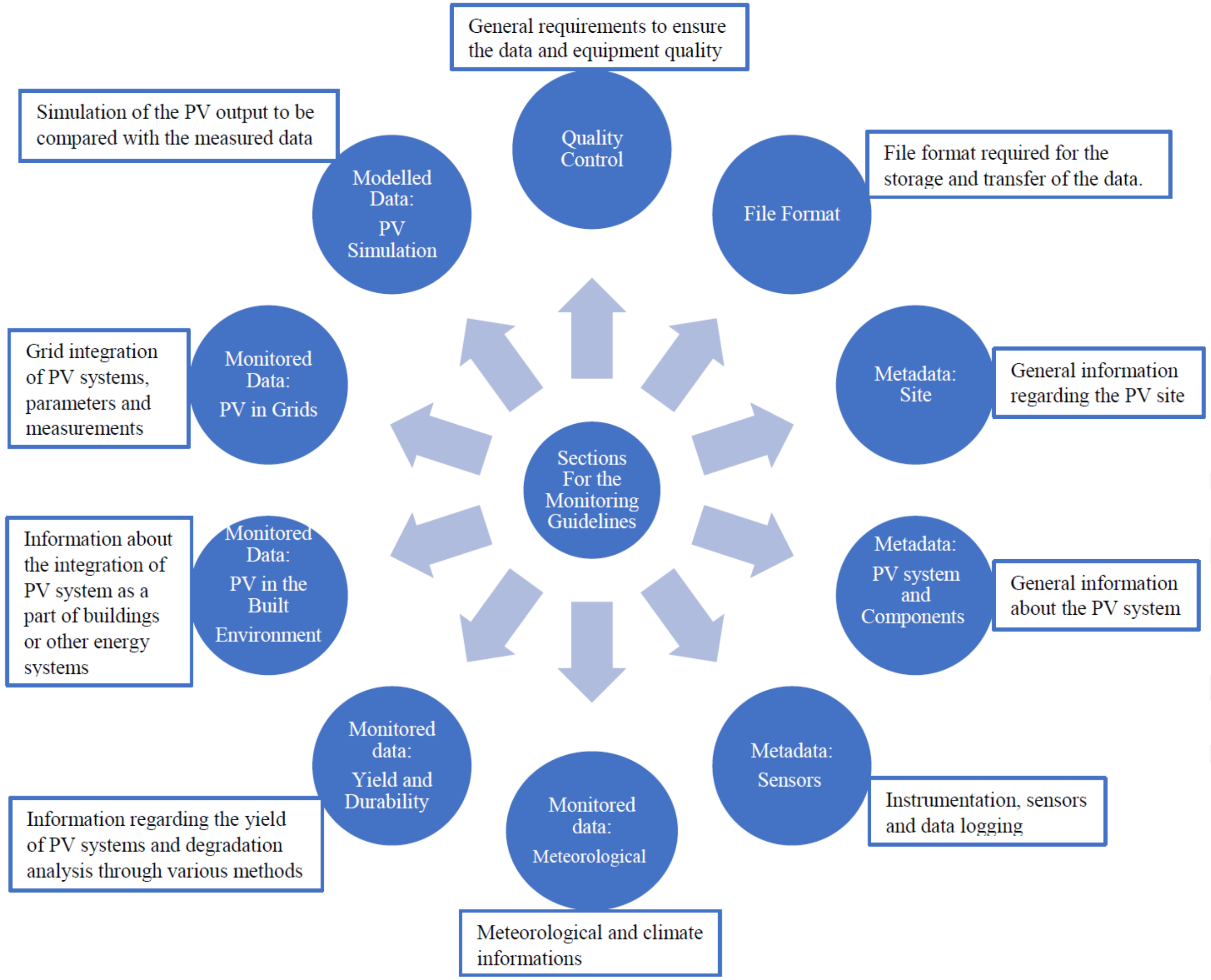
Australian PV monitoring guidelines (2013):

Copper, J., et al., *Australian Technical Guidelines for Monitoring and Analyzing Photovoltaic Systems*. 2013, Australian PV Institute.



T1.1 Questionnaire:

- 20 responses
- Questions on:
  - General
    - Quality control
    - File format
  - Metadata
    - Site
    - PV system and components
  - Monitored data
    - Meteorological
    - Yield and durability
    - PV in the built environments
    - PV in grids
  - Modelled data
    - PV simulation



Paudyal, Imenes, Saetre, Poster 6DV.1.32, 35EUPVSEC 2018.

1. «Absolutely necessary»
2. «Highly desired»
3. «Nice to have»
4. «Not required»

Lessons learned:

- If you ask experts, they will say ‘everything is necessary’….
- If the database can be dynamically changed, the sky is the limit

Sources:
Compilation of questionnaire replies for the monitoring of PV systems, 6 Nov 2018.
Presentation by Wilfried van Sark at PEARL-PV’s WG1 Seminar “Matching PV data and PV performance research questions” Nicosia, Cyprus, 23 Oct 2018.

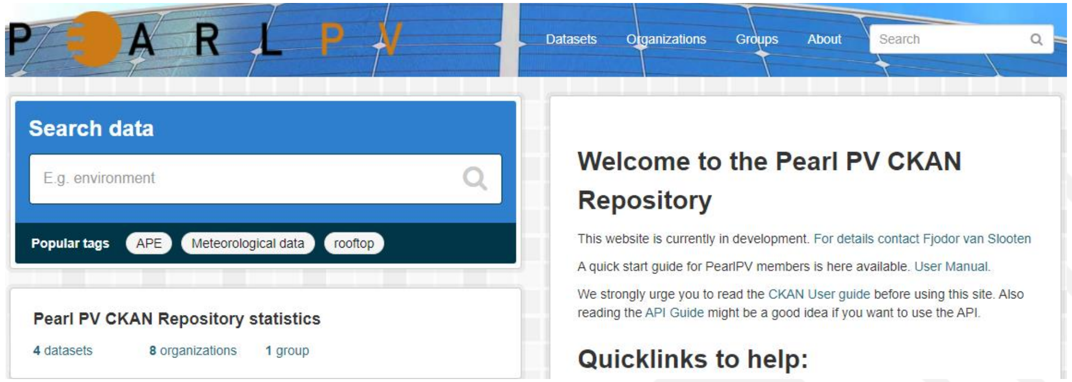
Main conclusions ‘must have’:

- Metadata: Site, system design, all PV components (BOS, inverter, battery). *(Many comments on metadata!!)*
- Quality control required for data! *(Raw data quality is priority: all processing depends on application)*
- Monitored data:
  - Meteorological: , Irradiance GHI/POA, albedo, air temperature, wind. Sample/record rate: 1 min
  - Yield and durability: DC/AC power, module temperature, IR/EL imaging, system status, cleaning. Minimum 1 year data, register failures.
  - PV in the built environment: Design, ventilation, cost.
  - PV in grids: Inverter power factor, voltage/current per phase, (net) active power, reactive power, storage.
- Modelled data:
  - PV simulation: Metadata, models used, validated models.

Sources:
Compilation of questionnaire replies for the monitoring of PV systems, 6 Nov 2018.
Presentation by Wilfried van Sark at PEARL-PV’s WG1 Seminar “Matching PV data and PV performance research questions” Nicosia, Cyprus, 23 Oct 2018.

The resulting PEARL PV CKAN database:

- CKAN (Comprehensive Knowledge Archive Network, open source platform) was selected as it allows inclusion of different data and formats.
- Datasets have two different elements: metadata (information) and resources (the data: CSV, Excel, XML, PDF, image file, linked data RDF, etc.)
- ST1.3: Generally accepted approaches and guidelines for the use, analysis, interpretation of meteorological data and data about the performance of PV modules and systems (*subtask leaders: Carolin Ulbrich, HZB, Germany, Atse Louwen, Eurac, Italy)*



Requested Information	Type/Options	*Example*
System status	all optional	
sensor outages	free text	*temperature sensors all fell off on Feb. 2nd 2004 and were reattached on Feb3rd*
cleaning events	free text	*Jan 1st 2003, Feb. 3rd 2019, March 19th 2019, ...*
monitoring fraction		*0.4* *hours in the month (t) /hours of monitoring activity (t_MA):* *M = t_MA / t* *The range is 0, for no monitoring to 1, for full monitoring.*

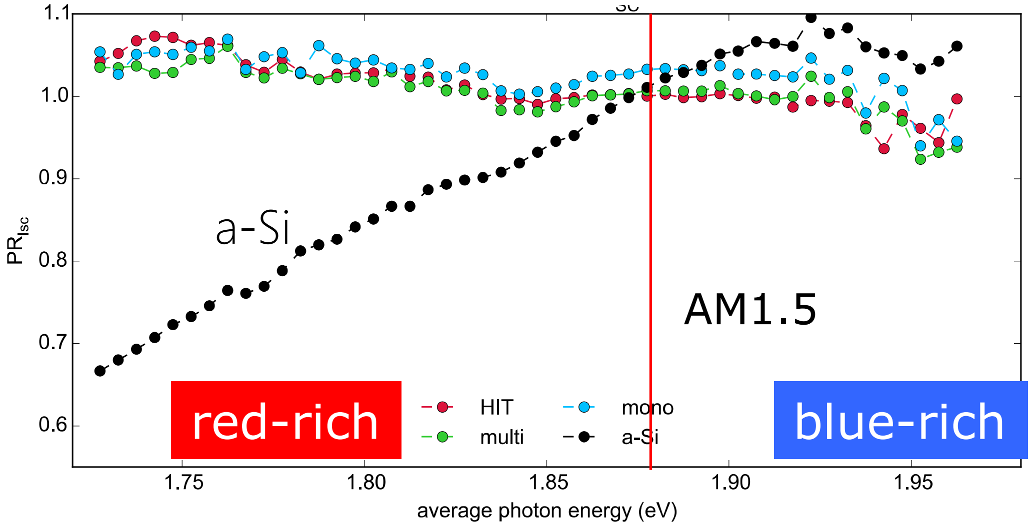
Examples of the use of data in the CKAN database

Comparison of spectral data from across Europe

- Spectral measurements are scarce – especially in Nordic Europe.
- Significant effect of spectral variation on performance on (thin-film, tandem) PV technologies, links to spectral response differences.
- PEARL PV collaboration on comparison of spectral measurements: (more data to come) Berlin GE, Merklingen (Stuttgart) GE, Utrecht NL, Enschede NL; Grimstad NO

APE: Average photon energy

Performance ratio of Isc vs APE



$$APE = \frac{\int_a^b E(\lambda)\,d\lambda}{q\int_a^b \phi(\lambda)\,d\lambda}$$

photon flux

- Average Photon Energy (APE) commonly used as indicator for spectral variation, but different other indicators are also used.

- Integration interval MUST be stated
- AM1.5: APE = 1.878 eV for [350-1050 nm] interval
(other intervals give different APE values)

Figure: Wilfried van Sark, own measurements, Louwen, 2016.
Source: Wilfried van Sark, PEARL-PV Training School presentation 09.03.2022

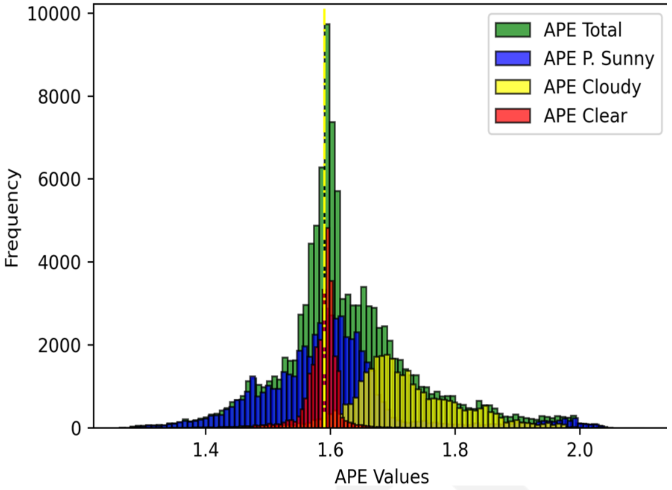
Reference: Minemoto, Takashi et al. (2009)
"Uniqueness verification of solar spectrum index of average photon energy for evaluating outdoor performance of photovoltaic modules." Solar Energy 83 (2009): 1294-1299.

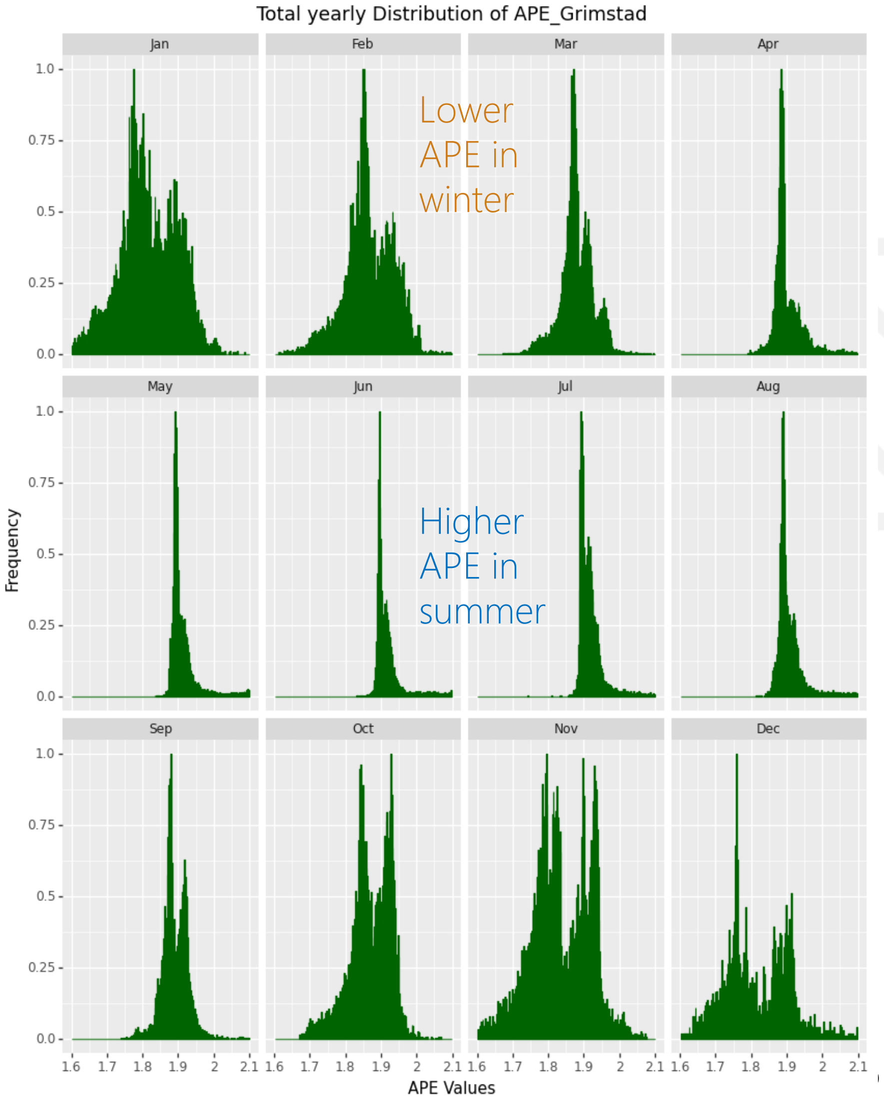
APE results, spectral data Grimstad, Norway (2020)

B. R. Paudyal and A. G. Imenes, "Analysis of spectral irradiance distribution for PV applications at high latitude," 2020 47th IEEE PVSC, 2020, pp. 1834-1841, doi: 10.1109/PVSC45281.2020.9300532.
B.R. Paudyal, S.G. Somasundaram, A. Reinders, A. Louwen, W.G.J.H.M. van Sark, D. Stellbogen, C. Ulbrich, A.G. Imenes, Analysis of spectral irradiance variation in northern Europe using average photon energy as a single parameter, Solar Energy (submitted).

Parameters	Values
Latitude	58.33°
Longitude	8.58°
KG Climate	Cfb
Instrument	Spectrafy SolarSIM-G
Spectral range	280-4000 nm
Time series	2019 - 2021
Temporal resolution	1 min
Angular orientation	45° S

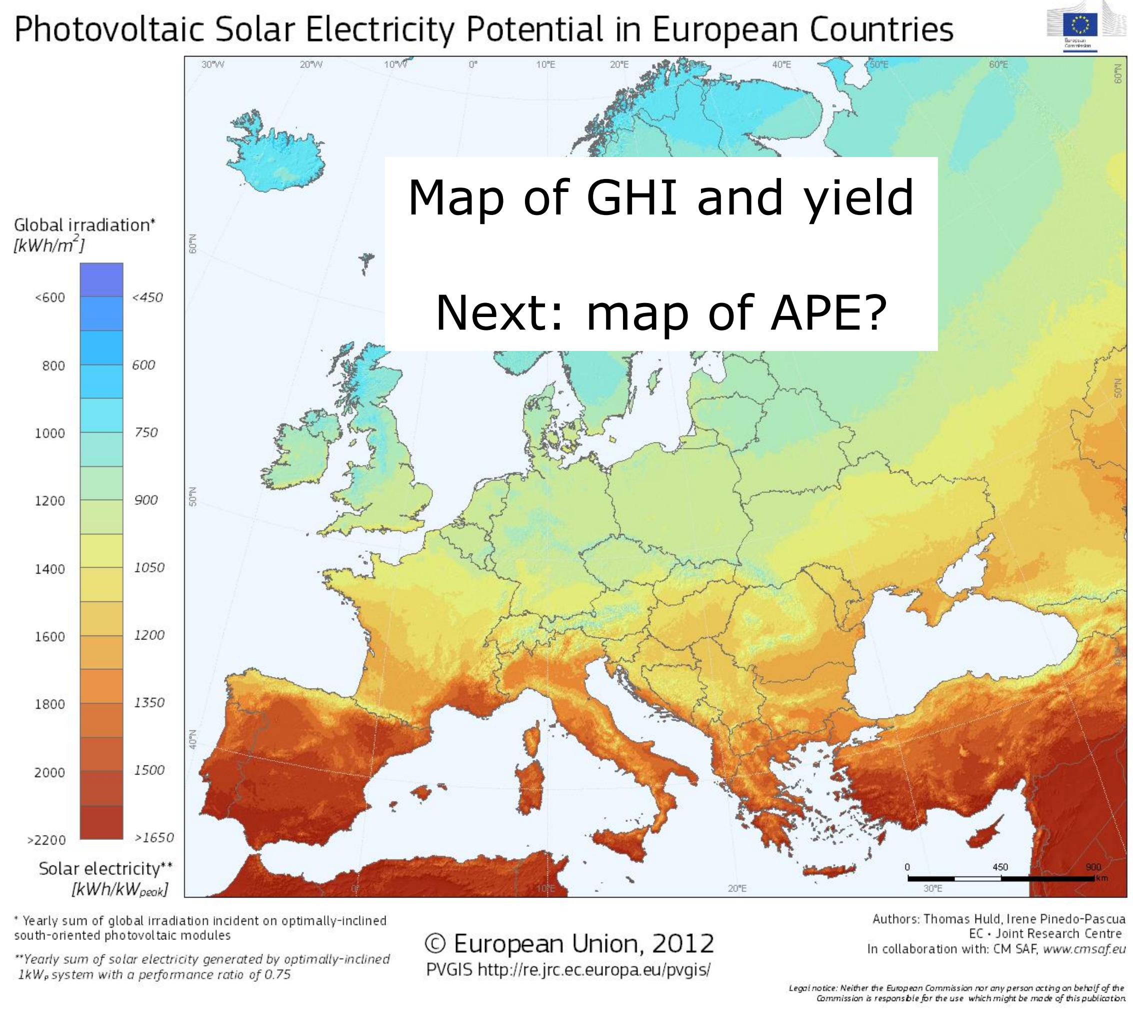
Data: 01.01-31.12.2020
Data points: 265,420
(missing data 7 days in July)
Filtering: G_{POA} > 25W/m^2





Future directions:

- Gather more data from the southern European locations and compare the spectral distributions → volunteers wanted!
- Quantify the impact of these 'measured' spectral distribution on PV performance
- Quantify the spectral distributions into a 'number' that can be used into existing PV modeling tools like PVsyst, PVlib etc..



P A R L P V

Other uses of the CKAN database:

- WP1:
  - Climate dependent **degradation** of PV systems (Lead: Steve Ransome)
  - **Uncertainties** in determination of degradation, satellite base data and recorded data (Lead: Alessandro Virtuani)
  - Geographic locations of installations, factors to influence **stability** across Europe (Lead: Jeff Kettle)
  - PV data analysis for **performance** assessments of roof top PV systems in relation to losses due to system failures, soiling and maintenance schemes (Lead: Carolin Ulbrich)
  - Variation of **floating PV** performance across Europe (Lead: Wilfried van Sark)
  - Performance analysis in **Agrivoltaics** (Lead: Tareq Abu Hamed)
  - Effect of fast power fluctuation of PV systems on the **grid**? (Lead: Jovan Todorovic)

- WP2: (Task 2.3, new) Understand how advancements in big data analytics (BDA) approaches can be used to assess **reliability. Make use of the CKAN (and other) repositories** to understand how key factors in performance degradation to be identified and explore how the installation, operation, maintenance practice, geographic location or test conditions affect degradation over time.

- WP5: (PearlSoil= Mapping annual and seasonal soiling in Western Europe. As part of the effort on soiling, the task, led by University of Jaén, Spain, is working to extract the **soiling** losses from the sites available on the PearlPV dataset, using standard and novel soiling extraction techniques.

- And many more… WE NEED BIG DATA, VARIED DATA, AND LONG-TERM QUALITY DATA in the database!

Challenges, trends, and future needs for PV monitoring

Monitoring challenges: Data access

- Access to performance data due to cost & competitiveness
  - Small-scale PV: Proprietary software & hardware of inverter company
  - Large-scale PV: Performance data “commercially sensitive”; value for money
- Maintaining databases for long periods of time
  - Vulnerable to funding and resource availability!
  - Data storage requires energy!
    - What data is needed to be kept for future use?
    - What data can be discarded, releasing space for new data?
  - Can things be done differently?
    - Adaptive learning systems instead of historical analysis?
    - Distributed data analysis (integrated sensors/smart apps for home-owners)?
- Data taxonomy (common terminology and semantics for AI)


Big data storage

Monitoring challenge: Data quality

- Residential data:
  - Why are there so many systems located in Afghanistan?
  - Why are there so many systems with orientation exactly 0° or 45°?
  - Is the power data reliable?
- Power plant data:
  - How to tackle unforeseen faults and events?
  - How to accurately measure POA irradiance and temperature? (Bifacial…)
  - How to identify module reliability issues from aggregated string data?
- All data: Random variations, noise, sensor & system faults
  - Data cleaning procedures, missing data (bias)
  - Data filtering / smoothing procedures
  - Artificial intelligence/machine learning requiring large representative datasets

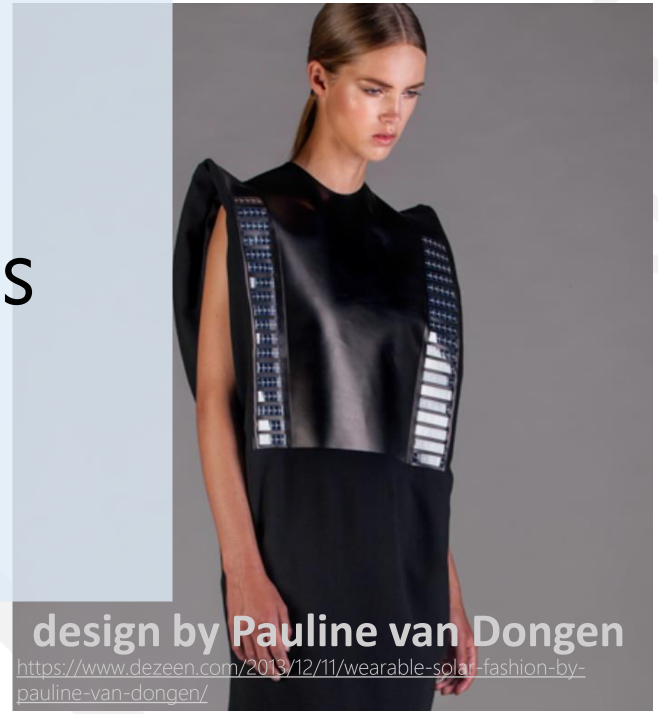
Goats on Florida PV farm
https://www.youtube.com/watch?v=3kOEKGKv9bA

⇒ Need common procedures and quality marks!

Monitoring needs for emerging technologies and applications

- Floating PV

- Vehicle Integrated PV
- Wearable PV



- Emerging PV

Need for:

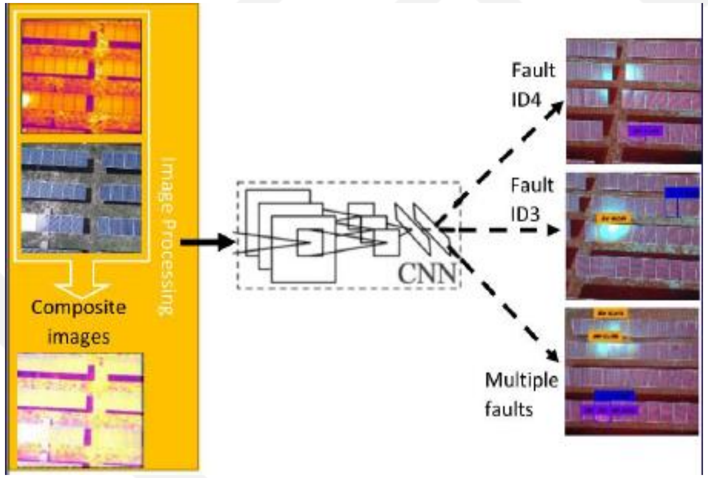
- New test standards
- New bill of materials
- New integration methods
- New simulation models
- Monitoring data!

P EARL PV

Monitoring trends: Not just electrical data!

- (Autonomous) drone imaging techniques, outdoor IRT (+EL, PL)
- Currently mainly used in large-scale utility scale systems (future also increased market for residential inspection?)
- Combining different data sources (e.g. images and electrical data) will be important for efficient diagnostics, O&M planning and optimization of resources.
- Must be accompanied by advanced analysis, AI/ML etc.

Bilde: Greentechmedia https://www.greentechmedia.com/articles/read/why-drones-are-game-changing-for-renewable-energy#gs.6gc10t



Imenes et al, Deep Learning Approach for Automated Fault Detection on Solar Modules Using Image Composites, IEEE PVSC 2021.

Monitoring trends: Digitalization (AI)
(Ralph Gottschalg, Fraunhofer CSP)

- Digitalization has great potential! However:
- Existing repositories may not meet future AI requirements:
  - Missing key information, faults, poor data quality, limited transferability…
  - Not only *collect* data; also need to *qualify* data
- Repositories must be planned for their purpose: E.g. to qualify the robustness, transferability, bias-freeness of digital diagnostics.

Without appropriate repositories we will not be able to capitalize on the benefits of digitalization in PV, not realise potential cost savings and hamper research into performance of PV

Fraunhofer CSP

Prof. Dr. Ralph Gottschalg
Head of Department "Reliability and Technology for Grid Parity«, Fraunhofer Center for Silicon Photovoltaics

Future prospects for use of PEARL PV database?

- Datasets used as quality marks for analysis
  - Performance and degradation analysis of different technologies/systems
  - Filtering procedures, anti-biassing, new/modified key indicators
- Datasets used to qualify the accuracy of AI algorithms
  - Known failure modes
  - Independent training datasets
  - Transferability; common taxonomy
- Datasets used for grid stability and predictability in the terawatt transition
  - Large-scale central generation (and storage?)
  - Distributed generation and self-consumption
  - Forecasting, security of supply
- Datasets used to develop efficient O&M strategies
  - Optimize periodic and corrective maintenance
  - Minimize failures before they occur
  - Holistic quality management, from planning phase to end-of-life

Thank You!

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