Introduction & Welcome

COST Action PEARL PV (CA16235)

Training School on **Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance**

8- 11 March 2022, University of Twente, Enschede, the Netherlands

Angèle Reinders (prof.dr.)

Dept. of Design, Production and Management, University of Twente, the Netherlands, email: a.h.m.e.reinders@utwente.nl

Energy Technology Group, Eindhoven University of Technology, the Netherlands

Introduction & Welcome

Welcome to the Training School of COST Action PEARL PV (CA16235)
by your Training School Managers

Aleksandra Krstic-Furundzic (prof.dr.)

Cedric Caruana (dr.)

Jeffrey Kettle (prof.dr.)

and the entire Local Organizing Committee and all Trainers

Eli Shirazi (dr.)

Angele Reinders (prof. dr.)

Wilfried van Sark (prof.dr.)

For regular updates, keep an eye on the website of this Training School:
[Training School on "Potential of monitoring tools and advanced operation and maintenance practice for security and predictability of PV performance" - PEARL PV (pearlpv-cost.eu)]

Introduction & Welcome

- Maybe you have seen this announcement on Twitter and LinkedIn?

Before we start, some important information

- Covid-19 measures on campus: though most regulations have been lifted we advice the audience to carefully keep some distance and regularly wash your hands. Do not hesitate to wear a face mask in crowds. Do you have symptoms? Stay in and take a self-test, see also Coronavirus measures in brief | Coronavirus COVID-19 | Government.nl which is accessible by the Training School's website.

- Register each day on the attendance list in order to receive reimbursement for long distance travel .

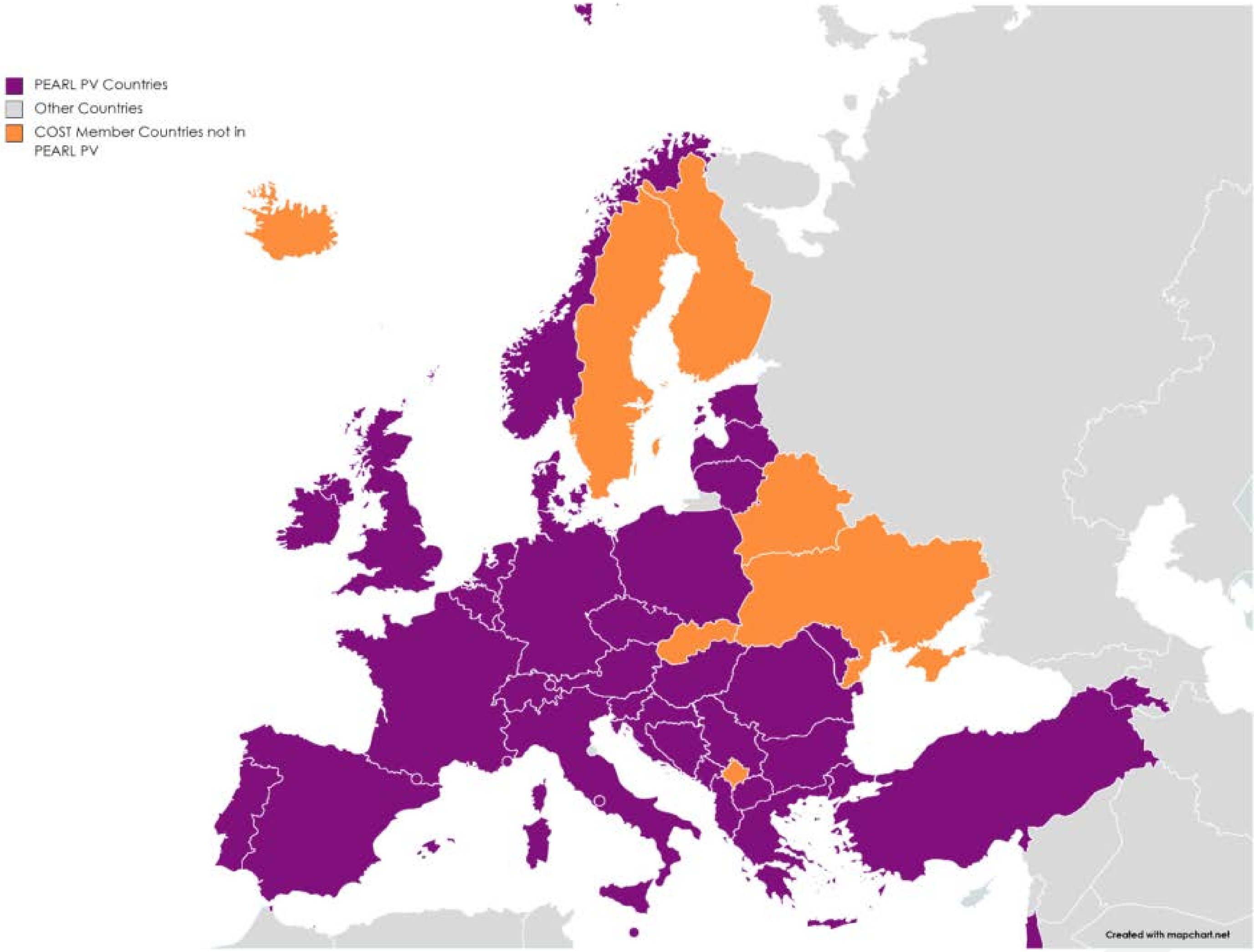
- This meeting will be recorded, by registering you give permission to being recorded.

- Kind request for permission to share email addresses with each other, despite GDPR.

- Lunches and dinners at own expense. Please sign in for dinners at the registration desk until 2 o'clock. Dining locations will be communicated by email…practical questions? please contact Ms. Saskia Groenendijk s.m.groenendijk@utwente.nl

- Main contact persons on behalf of University of Twente on location during the Training School: Eli Shirazi, email: e.shirazi@utwente.nl and Cedric Caruana, email: cedric.caruana@um.edu.mt

PEARL PV Network



38 European countries take part in COST Action PEARL PV by December 2021, indicated in purple.
Not shown on this map, but participating, are the USA and Australia.

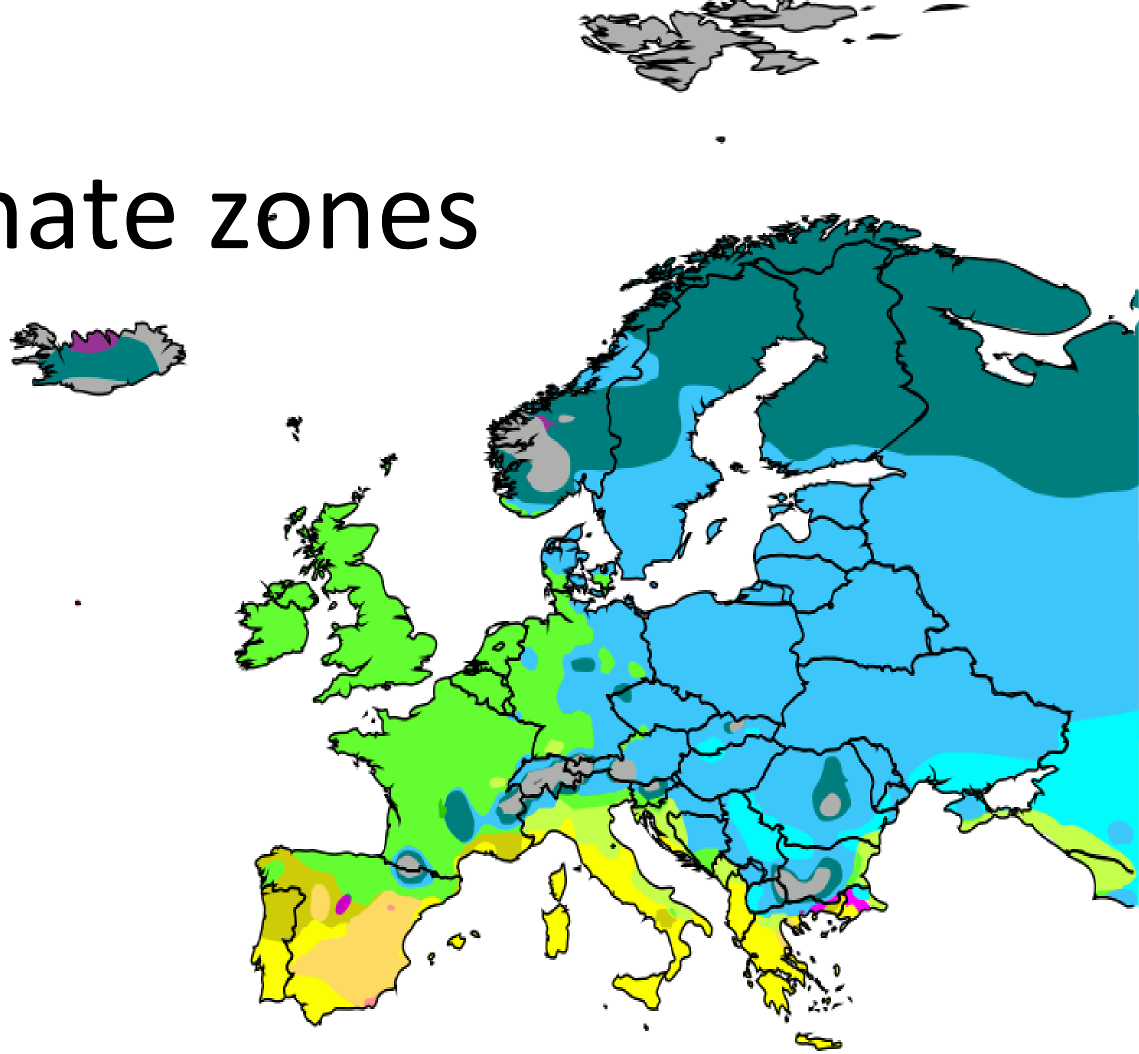
Activities in this network
- Bottom-up Research on PV systems
- Training Schools
- Seminars & Workshops,
- STSM grants & ITC conference grants

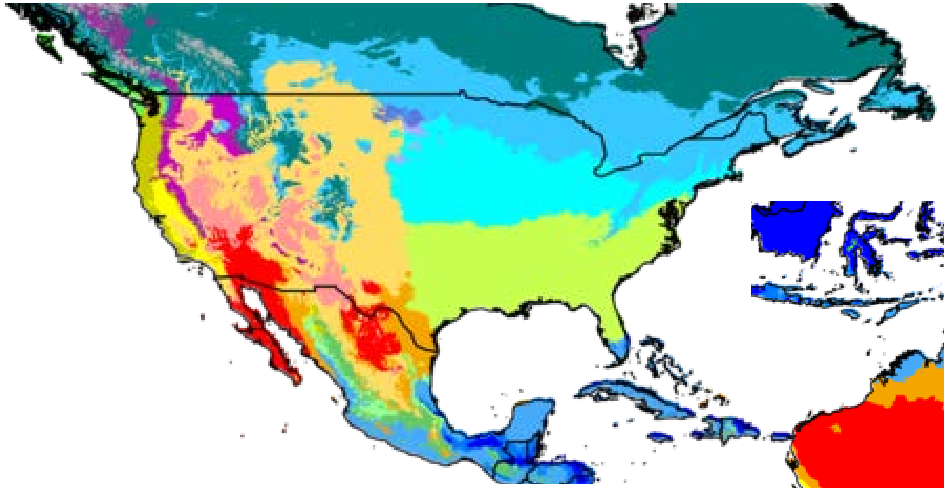
Aim to collaborate by
- Research
- Country reports
- Joint papers and other publications
- Joint research proposals
- Shared data bank

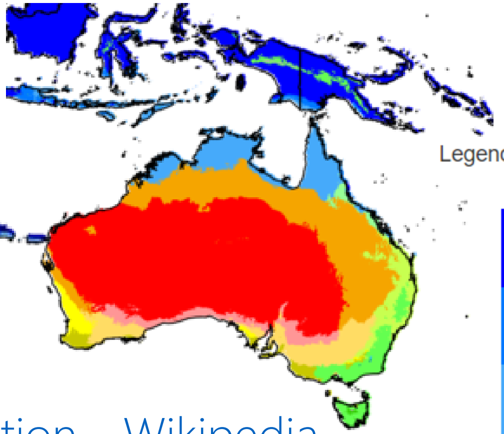
PEARL PV network’s climate zones

The geographic coverage of the PEARL PV member countries comprises almost all climate zones according to the Köppen–Geiger climate classification system:
A: Tropical, B: Arid, C:Temperate, D: Continental, E: Polar.

Therefore the network seems very suitable for solar PV research







[Maps from Köppen climate classification - Wikipedia]()

Objectives of PEARL PV

COST
EUROPEAN COOPERATION
IN SCIENCE & TECHNOLOGY

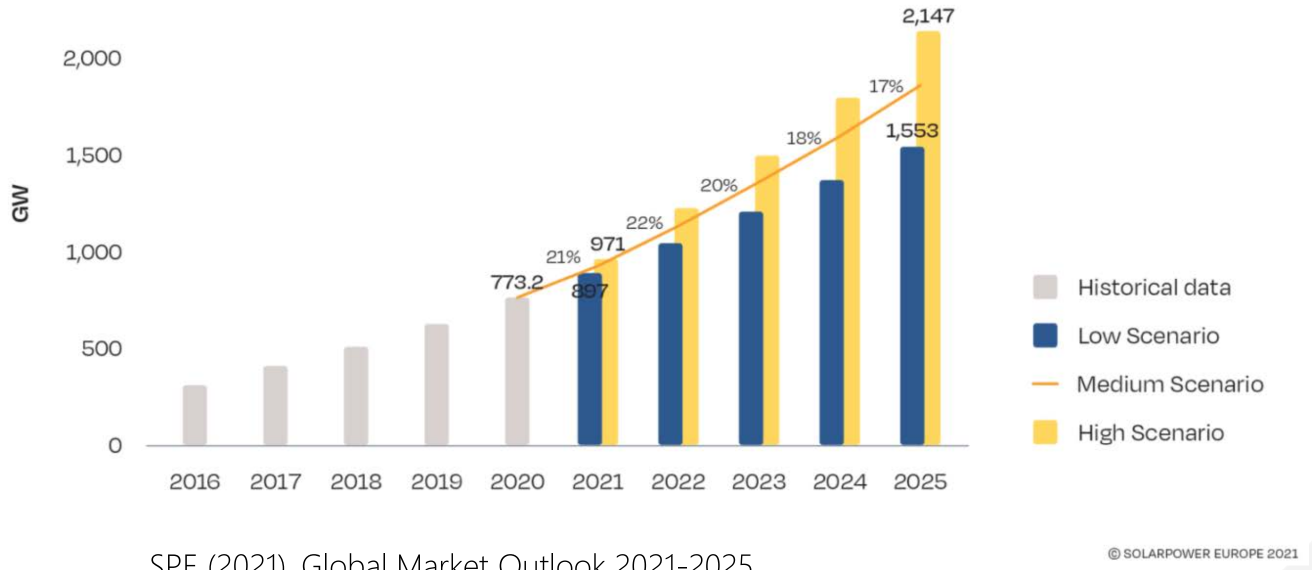
To **improve** the **energy performance** and **reliability** of PV systems leading to (i) **lower costs** by a higher yield, (ii) a **longer lifetime** and (iii) a **reduction of perceived risk**;

- By analyzing data of the long time monitored long-term performance of PV systems and of their defects and failures;
- To quantitatively determine the absolute influences of (i) components' rated performance, (ii) system design, (iii) installation type, (iv) operation and maintenance practice, (v) interactions with grids, (vi) geographic location and (vii) weather and climate conditions, on performance degradation over time and failure modes;
- To (i) improve the electrical design of PV systems, (ii) achieve optimal sizing via the use of simulation models, (iii) enhance expected system efficiency, (iv) ease maintenance, (v) achieve high reliability and (vi) demonstrate excellent durability.

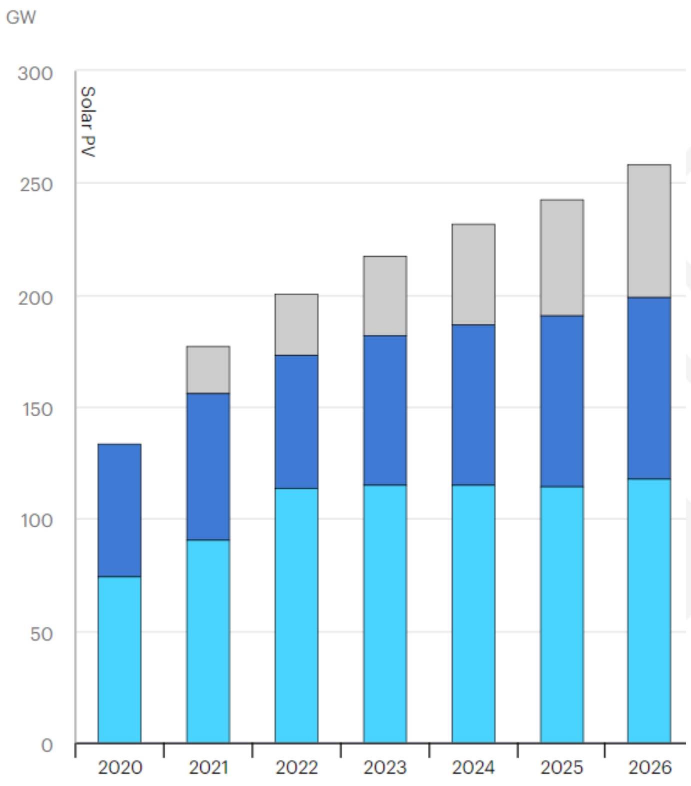
All information about PEARL PV can be found on the website: [Welcome - PEARL PV (pearlpv-cost.eu)](pearlpv-cost.eu) including the MoU with research plan.

Relevant because of growth PV market!

- Cumulative globally installed PV capacity will exceed 1 terawatt in 2022
- Expected global additions ~200 gigawattpeak per year
- This is a market of millions of PV systems that are connected to grids



SPE (2021), Global Market Outlook 2021-2025
[Global Market Outlook 2021-2025 – SolarPower Europe]



IEA (2021), Renewables 2021, IEA, Paris
https://www.iea.org/reports/renewables-2021

P A R L P V

8 – 11 March 2022: 4th Training School

Topic: Potential of monitoring tools and advanced operation and maintenance practice for security and predictability of PV performance

The intention is to discuss how the analysis of data on actual long-term monitored performance, defects and failures in photovoltaic (PV) systems allows to quantitatively determine the absolute effects of

- nominal component characteristics,
- system design,
- installation,
- operation,
- maintenance practices on
- efficiency, reliability and durability of solar PV energy systems
- as well as their forecasting.

Including the use of monitoring tools and various (including future) products which will enable PV system owners (residential and utility-scale) to control the quality of their PV systems.

8 – 11 March 2022: 4th Training School

- **2022:** 4th Training School of COST Action PEARL PV on **Potential of monitoring tools and advanced operation and maintenance practice for security and predictability of PV performance,** Enschede, the Netherlands, 30+ trainees (?)

- This is a follow-up of previous Training Schools:
- 2020: 3rd Training School of COST Action PEARL PV on *Simulation tools and models for the analysis of PV system performance*, Brasov, Romania, 30 trainees.

- 2019: 2nd Training School of COST Action PEARL PV on *Evaluation of the performance degradation of PV-systems – influence factors, failure modes and their detectability and effect on economic viability*, Malta, 50 trainees.

- 2018: 1st Training School of COST Action PEARL PV on *Monitoring and Simulation of the Performance and Reliability of Photovoltaics in the Built Environment*, Nicosia, Cyprus, 40 trainees.

Schedule of Events

- PEARL-Training-School4_Twente-2022_Schedule-of-Events-07032022.pdf (pearlpv-cost.eu)

Schedule of events

Tuesday 08 March 2022 – Day 1 – Room T1300, Horst Building

Time	Activity	Lecturer
09:30-10:00	Registration and Opening of the Training School	Angèle Reinders / University of Twente Wilfried Van Sark/ Utrecht University, Copernicus Institute Jeffrey Kettle / University of Glasgow Cedric Caruana/ University of Malta Eli Shirazi / University of Twente
10:00–11:30	Participants introduction – training school participants introduce themselves and their research activities / team building	Chair: Cedric Caruana/ University of Malta
11:30-12:00	*Coffee break*	
12:00-13:00	Product development for PV performance control	Angèle Reinders / University of Twente
13:00-14:00	*Lunch break*	
14:00-15:00	Data monitoring & analytics for better PV performance and grid integration	Jonathan Leloux / Polytechnic University of Madrid, Spain
15:00-15:45	Fabrication of Al-BSF cells; assembly of crystalline-silicon-based modules	Jurriaan Schmitz / University of Twente
15:45-16:15	*Coffee break*	
16:15-17:00	PV reliability review	Jurriaan Schmitz / University of Twente

Wednesday 09 March 2022 – Day 2 – Room T1300 Horst Building

Time	Activity	Lecturer
09:30-10:30	PV performance monitoring in a 100% renewable society	Wilfried Van Sark/ Utrecht University, Copernicus Institute
10:30-11:30	Understanding potential-induced degradation (PID) of photovoltaic (PV) modules	Mahmoud Dhimish / University of York, UK
11:30-12:00	*Coffee break*	
12:00-13:00	PV Module forensics and characterization of material degradation in the field	Gernot Orenski / Polymer Competence Center Leoben GmbH (PCCL)
13:00-14:00	*Lunch break*	
14:00–14:45 14:45-15:45	Excursion at University of Twente Campus – visit to PV plants and energy projects	Ray Klumpert / University of Twente, start at Linde Building
15:45-16:15	*Coffee break*	
16:15-17:00	Workshop - explanation of the task Facilitated discussion	Cedric Caruana, Univ. Malta

Thursday 10 March 2022 – Day 3 - Room T1300, Horst Building

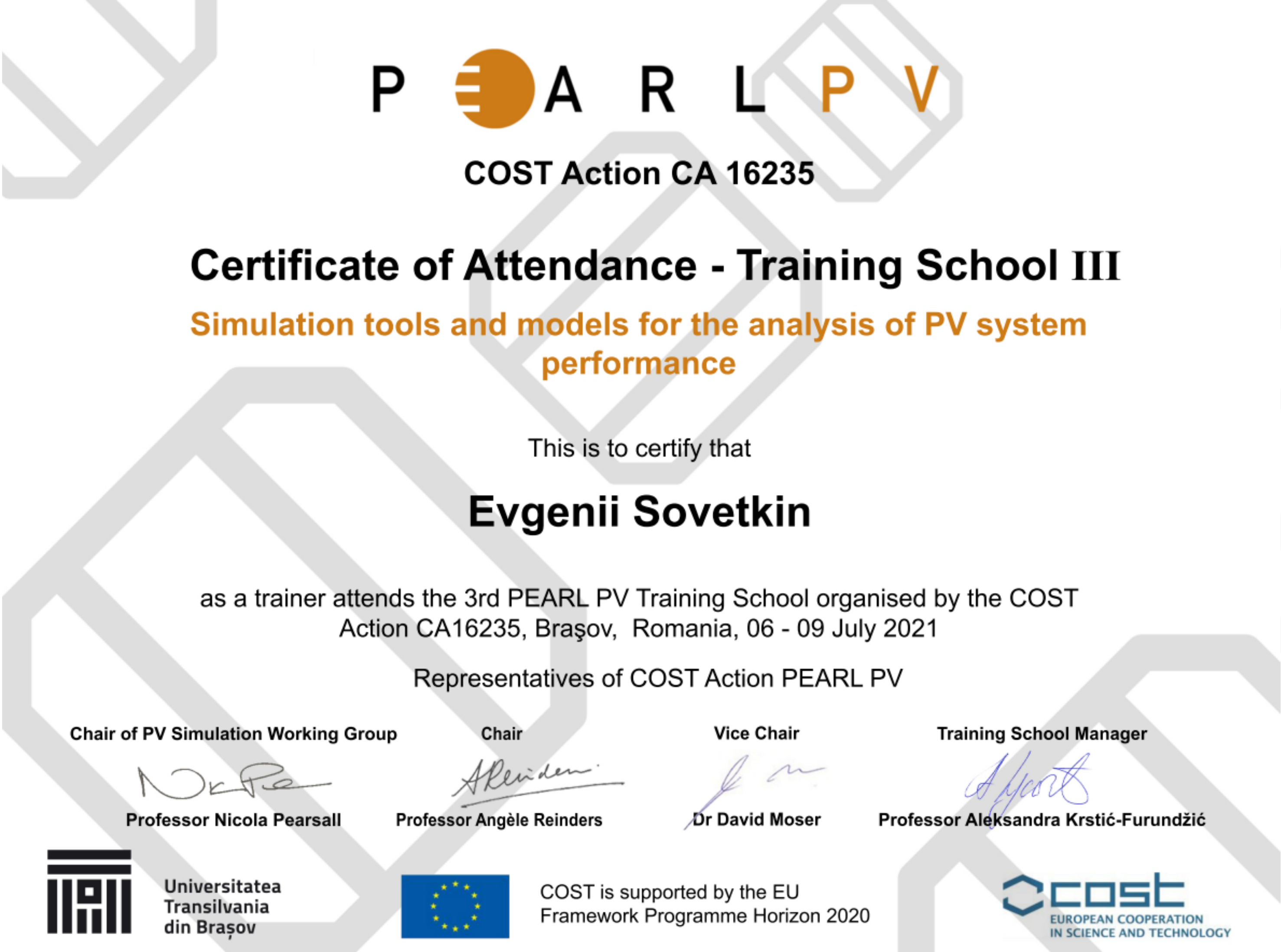
Time	Activity	Lecturer
09:30-10:30	Monitoring system for floating solar	Sara Mirbagheri Golroodbari / Utrecht University, Copernicus Institute
10:30-11:30	Photovoltaic and Solar Forecasting	Eli Shirazi / University of Twente
11:30-12:00	*Coffee break*	
12:00-13:00	The role of digitalization in advanced operation and maintenance practices	Atse Louwen / EURAC Research
13:00-14:00	*Lunch break*	
14:00-14:15	Workshop - Group exercise	Cedric Caruana/ University of Malta Eli Shirazi / University of Twente
14:15-15:30	Workshop - Group exercise	Cedric Caruana/ University of Malta Eli Shirazi / University of Twente
15:30-16:00	*Coffee break*	
16:00-17:00	Workshop - Group exercise Preparation of group presentations for wrap-up session on Friday	Cedric Caruana/ University of Malta Eli Shirazi / University of Twente

Friday 11 March 2022 – Day 4 Room W3, Waaier Building

Time	Activity	Lecturer
09:30–10:15	Preparation of group presentations for wrap-up session	Cedric Caruana/ University of Malta Eli Shirazi / University of Twente
10:15-11:00	Preparation of group presentations for wrap-up session	
11:00-11:30	Coffee break	
11:30-12:45	Interactive poster session and reports on task	Cedric Caruana/ University of Malta Angèle Reinders/University of Twente, Wilfried Van Sark/ University of Utrecht, Jeffrey Kettle / University of Glasgow Eli Shirazi / University of Twente
12:45-13:30	Wrap-up and closure of the training school/ joined lunch for on-site participants	Angèle Reinders / University of Twente, Wilfried Van Sark/ University of Utrecht, Jeffrey Kettle / University of Glasgow Cedric Caruana/ University of Malta

You will receive a certificate of attendance!

- You will receive this beautiful certificate after successful completion of this Training School
- By email..
- It will take a bit of time though...



PEARL PV

COST Action CA 16235

Certificate of Attendance - Training School III

Simulation tools and models for the analysis of PV system performance

This is to certify that

Evgenii Sovetkin

as a trainer attends the 3rd PEARL PV Training School organised by the COST Action CA16235, Braşov, Romania, 06 - 09 July 2021

Representatives of COST Action PEARL PV

Chair of PV Simulation Working Group	Chair	Vice Chair	Training School Manager
Professor Nicola Pearsall	Professor Angèle Reinders	Dr David Moser	Professor Aleksandra Krstić-Furundžić

Universitatea Transilvania din Braşov

COST is supported by the EU Framework Programme Horizon 2020

COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

PEARL PV

Locations of Events

[Find your way on the campusmap.pdf (utwente.nl)](campusmap.pdf)

<u>8-10 March: Horst Building (20)</u>

-Training School in T1300

-Lunch in Canteen Horst, room Z.209

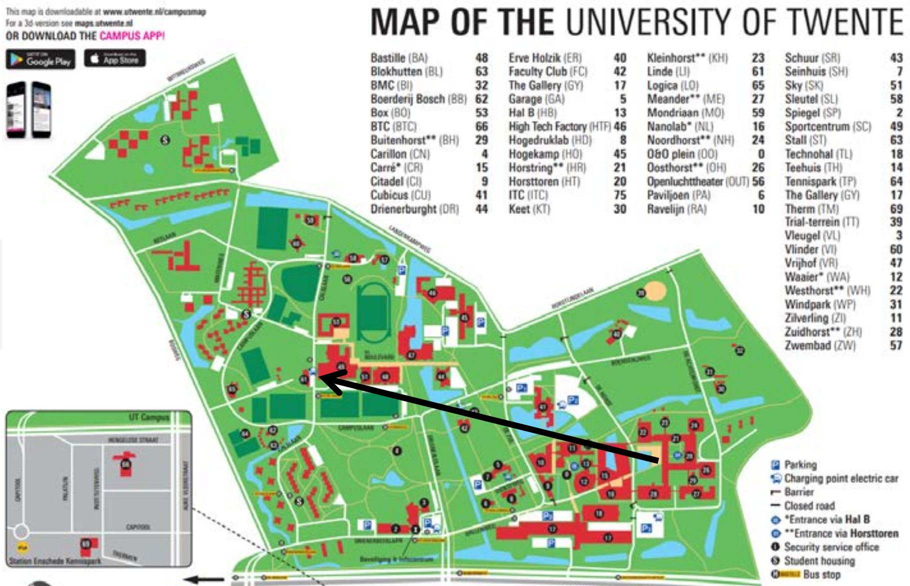
<u>11 March: Waaier building (12) entry at Hal B (13)</u>

-Training School in Waaier 3

-Lunch in Canteen Waaier

<u>Excursion 9 March, 14h, at Linde building (61)</u>

Departure from lunch room Horst at 13:45h

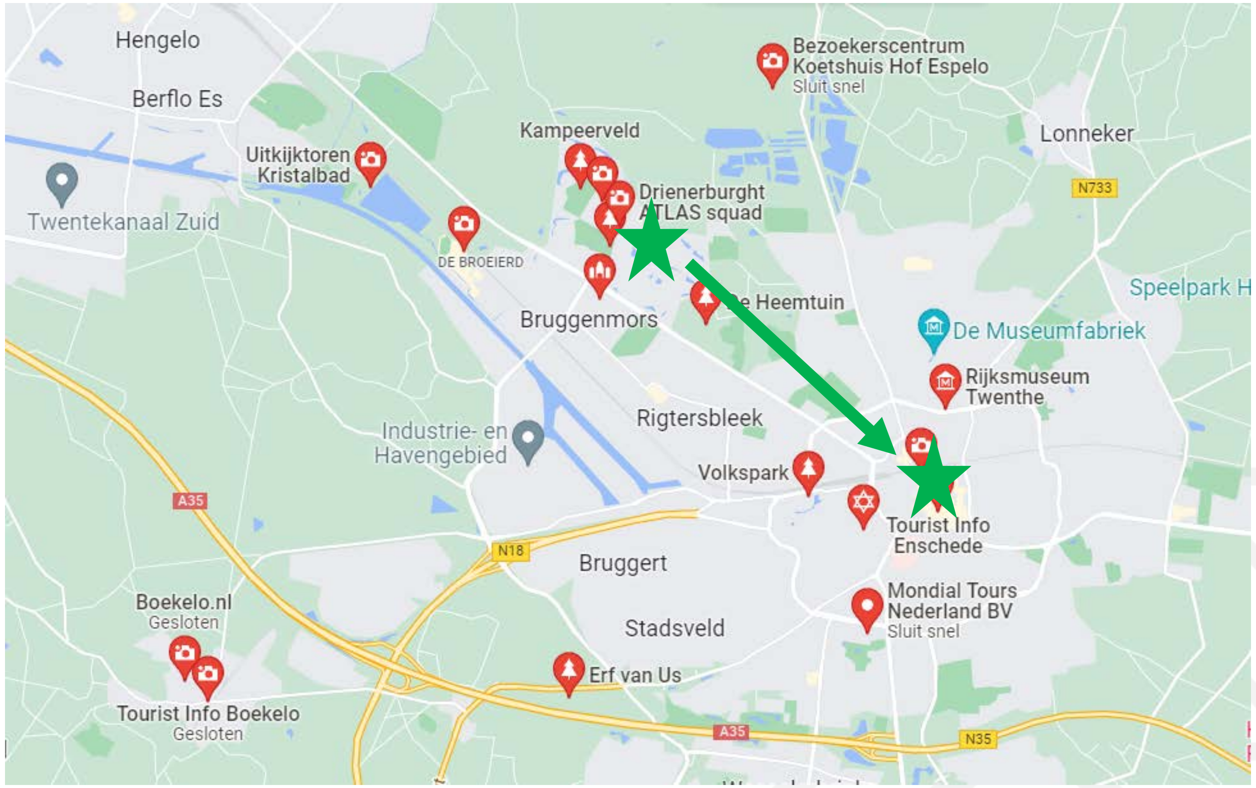


P A R L P V

Training School Task Coordination

Roles	Tuesday 8 March	Wednesday 9 March	Thursday 10 March	Friday 11 March
Training School Manager 1 On location	Cedric Caruana	Cedric Caruana	Cedric Caruana	Cedric Caruana
Other Training School Managers Online	Jeff Kettle Aleksandra Krstic-Furundzic	Jeff Kettle Aleksandra Krstic-Furundzic	Jeff Kettle Aleksandra Krstic-Furundzic	Jeff Kettle Aleksandra Krstic-Furundzic
Local Organizer 1 On location	Eli Shirazi	Eli Shirazi	Eli Shirazi	Eli Shirazi
Other local Organizers On location	Angèle Reinders Wilfried van Sark	Angèle Reinders Wilfried van Sark	Michael Wong	Angèle Reinders
Registration On location	Saskia Groenendijk	Eli Shirazi	Eli Shirazi	Eli Shirazi

City of Enschede



Have a great Training School!

Big thanks to the following people who have been involved in the Preparation of this Training School since Summer 2021

- Aleksandra Krstic-Furundzic
- David Moser
- Saskia Groenendijk
- Inge Dossantos-Smit
- Peter Jansen
- Sara Mirgaheri

And to

- Cedric Caruana
- Eli Shirazi
- Jeff Kettle
- Wilfried van Sark
- All Trainers !!!

And to our dear colleagues at DPM-UT for last minute help!

PEARL PV

Product development for PV performance control

COST Action PEARL PV (CA16235)

Training School on **Potential of monitoring tools, advanced operation and maintenance practice for security and predictability of PV performance**

8- 11 March 2022, University of Twente, Enschede, the Netherlands

Angèle Reinders (prof.dr.)

Dept. of Design, Production and Management, University of Twente, the Netherlands, email: a.h.m.e.reinders@utwente.nl

Energy Technology Group, Eindhoven University of Technology, the Netherlands

Contents

- The PEARL PV network: activities and objectives
- Why PV performance control?
- Indicators to control PV performance
- Big data analysis for PV performance control
- Examples of big data processing for PV performance control
- Product development and design for PV performance control
- Examples of product development and design
- Data sharing and short introduction to the CKAN data server
- Concluding remarks and thoughts

Introducing myself


Angèle Reinders (prof.dr.)

Main research topics

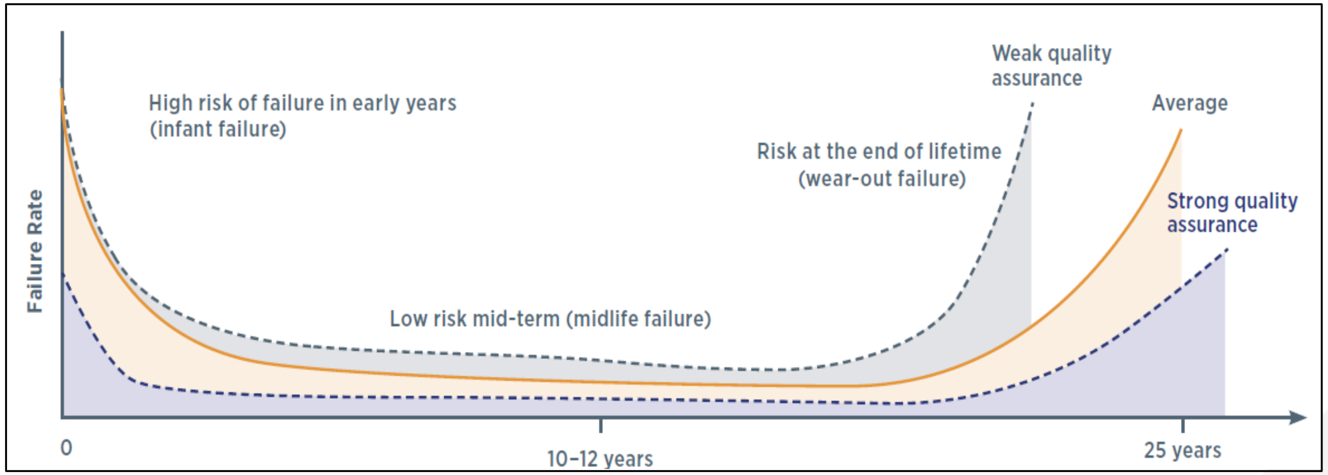
- Performance analysis of PV systems (COST Action PEARL PV)
- Luminescent solar concentrators
- Solar powered mobility with EVs & Design-driven research on smart grids

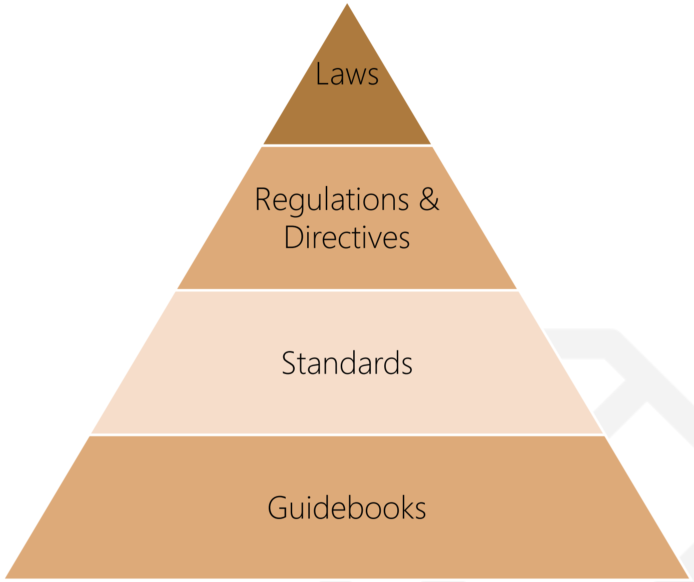
Short resume

- Professor of Design of Sustainable Energy Systems, Energy Technology Group, Fac. of Mechanical Engineering, Eindhoven University of Technology, the Netherlands, 2018 – present
- Associate Professor with ius promovendi, Dept. of Design Production and Management, Fac. of Engineering Technology, University of Twente, 2002 - present
- Professor of Energy Efficient Design, Fac. of Industrial Design Engineering, Delft University of Technology, Delft, 2010 – 2017
- Stayed at Centre for Urban Energy (Canada, 2014), ENEA (2010), Jakarta, Papua, FhG-ISE, World Bank (2000)
- PhD in ‘Performance Analysis of Photovoltaic Solar Energy Systems’, Dept. of Science, Technology and Society, Fac. of Chemistry, Utrecht University, 1999

Why PV performance control?

- PV performance control on the short and long run can **improve** the **QUALITY,** i.e. **energy performance** and **reliability,** of PV systems leading to
  (i) **lower costs** by a higher yield,
  (ii) a **longer lifetime,** and,
  (iii) a **reduction of perceived risk.**





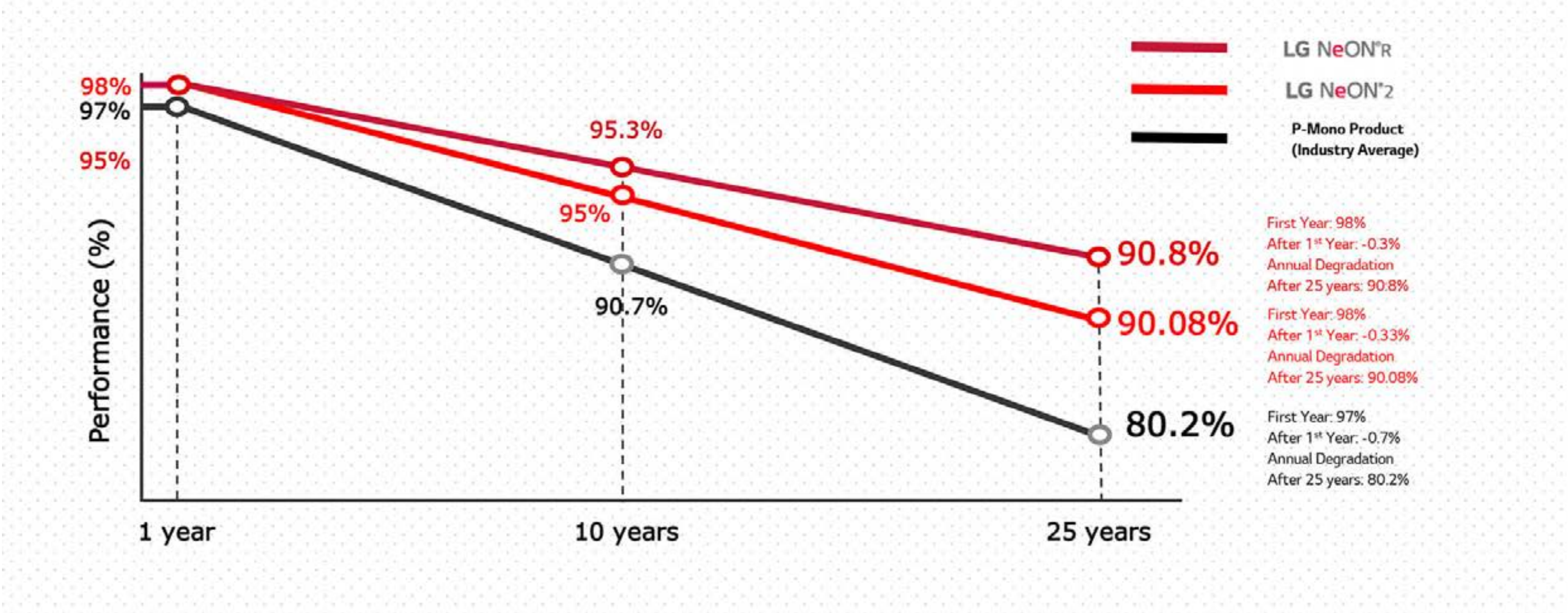
Figures from "Boosting solar PV markets: The role of quality infrastructure,"[Online]. Available: https://www.irena.org/publications/2017/Sep/Boosting-solar-PV-markets-The-role-of-quality-infrastructure

Moser, D., Azpilicueta, L., Salgado, A., Richter, A., Reinders, A., Bihler, F., Bosshell, F., Masson, G., Serra, G., Lin, J., Garreau-Iles, L., Cherradi, N., Moreth, R., Jahn, U. and Ekus, B., White paper on harmonized data collection from the field, SolarUnited Quality Initiative, 2019.

Why PV performance control?

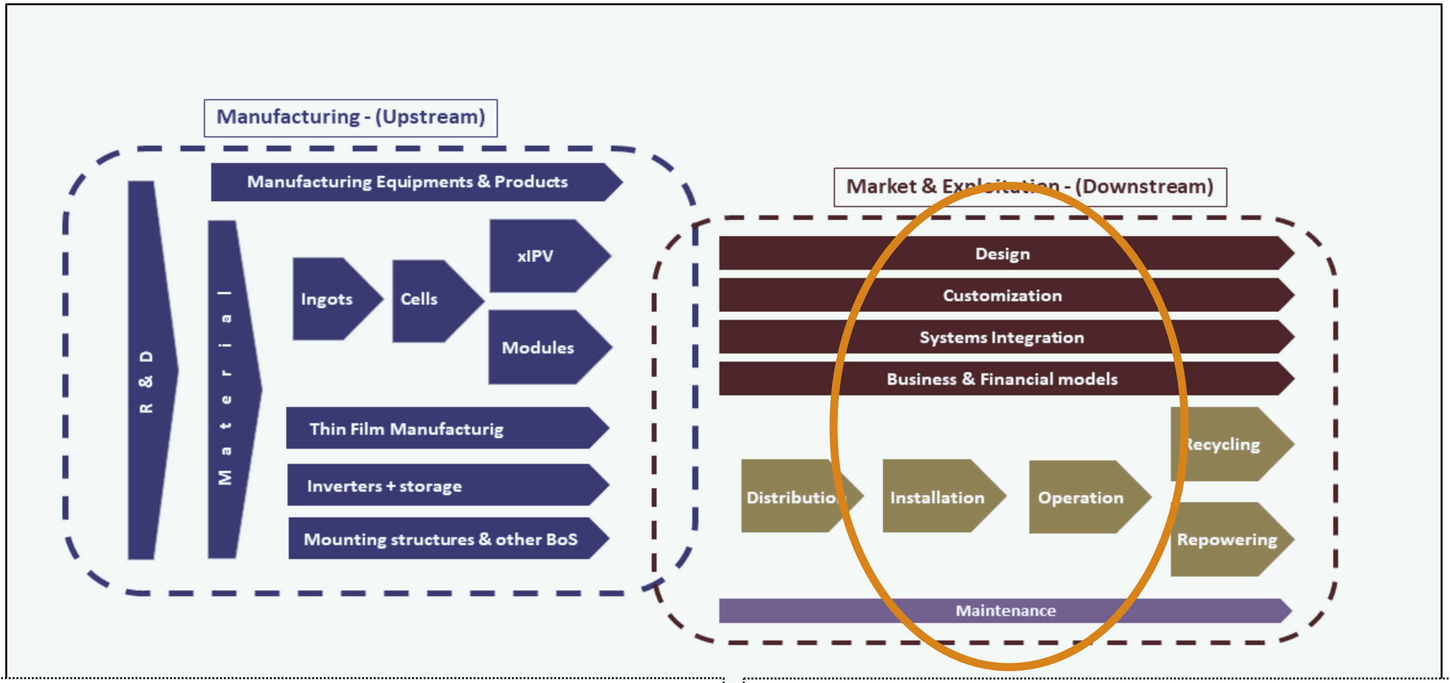
PV modules have two warranties:

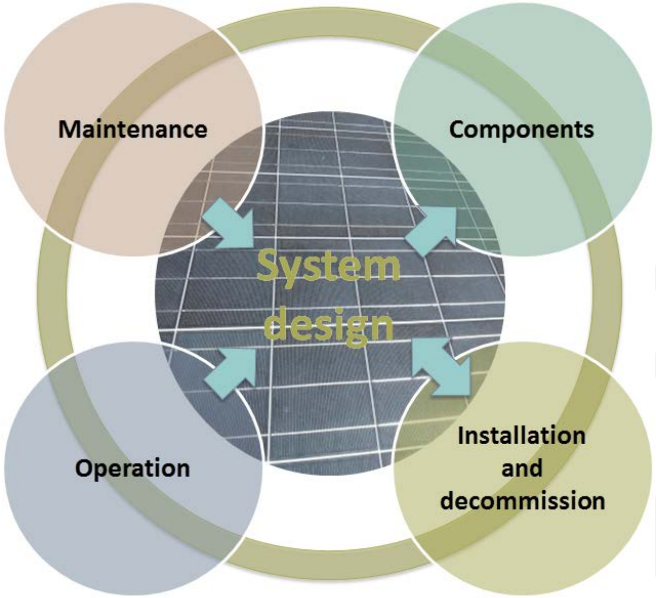
- 1. <u>Product warranty</u>: protects the customer against defects that may have occurred due to manufacturing errors, quality issues, or component and material failures. Usually 10-years but also more: 12, 15, 20 or 25 years
- 2. <u>Performance warranty:</u> is a power output warranty ensures that the solar panel still produces a minimum amount of power output after the expected 25-year life of a panel. Often manufacturers assume that 3% is lost in the first year, while the annual loss over the remaining 24 years is much less, ~0.3% to 0.7% per year. These numbers are of course low for high-end manufacturers.
- The expected lifetime is increasing: now some manufacturers guarantee 30 or even 40 years.



PEARL PV

Why PV performance control?





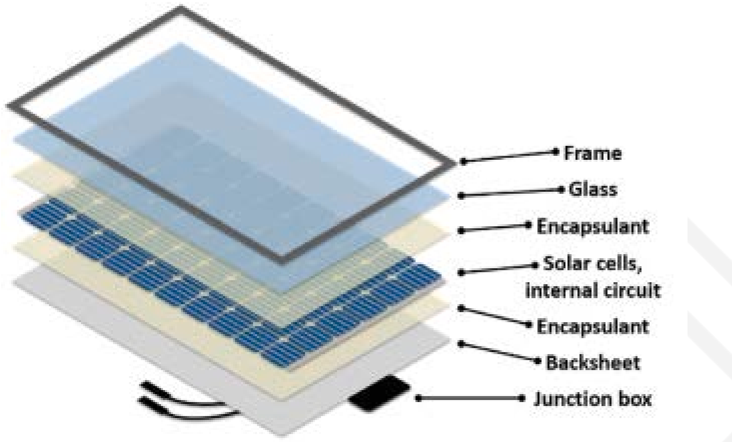
The **upstream part of the PV value chain** intends to play a major role in the improvement of the quality of PV components and installations: through new and improved production processes, the industry will contribute to increase the durability and reliability of PV systems.

For the **downstream part of the PV value chain** data acquisition is of fundamental importance not only for fast feedback within subsequent steps of the value chain but also between processes which are not directly linked, i.e. manufacturing and installation of components.

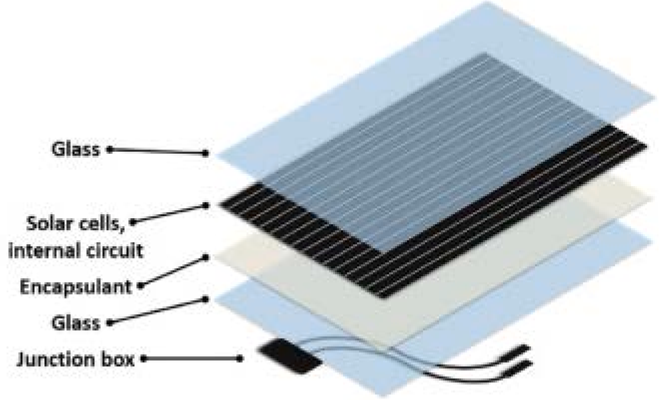
Moser, D., Azpilicueta, L., Salgado, A., Richter, A., Reinders, A., Bihler, F., Bosshell, F., Masson, G., Serra, G., Lin, J., Garreau-Iles, L., Cherradi, N., Moreth, R., Jahn, U. and Ekus, B., White paper on harmonized data collection from the field, SolarUnited Quality Initiative, 2019.

Why PV performance Control?

- Understanding of stressors and their early detection can reduce their (long term) impact on stability of PV modules
- See: Aghaei, M., Fairbrother, A., Gok, A., Ahmad, S., Kazim, S., Kettle, J., Lobato, K., Oreski, G., Reinders, A.H.M.E., Schmitz, J., Yilmaz, P., Theelen, M., Review of degradation and failure phenomena in photovoltaic modules, Renewable and Sustainable Energy Reviews, Vol. 159, 112160, DOI: doi.org/10.1016/j.rser.2022.112160, 2022
- Mono- and multi-crystalline silicon, cadmium telluride, copper indium gallium selenide and emerging low-cost high-efficiency technologies.
- Focus on reliability metrics and how reliability is measured
- Main stress factors and how they influence module degradation
- Review of degradation and failure modes by individual modules components

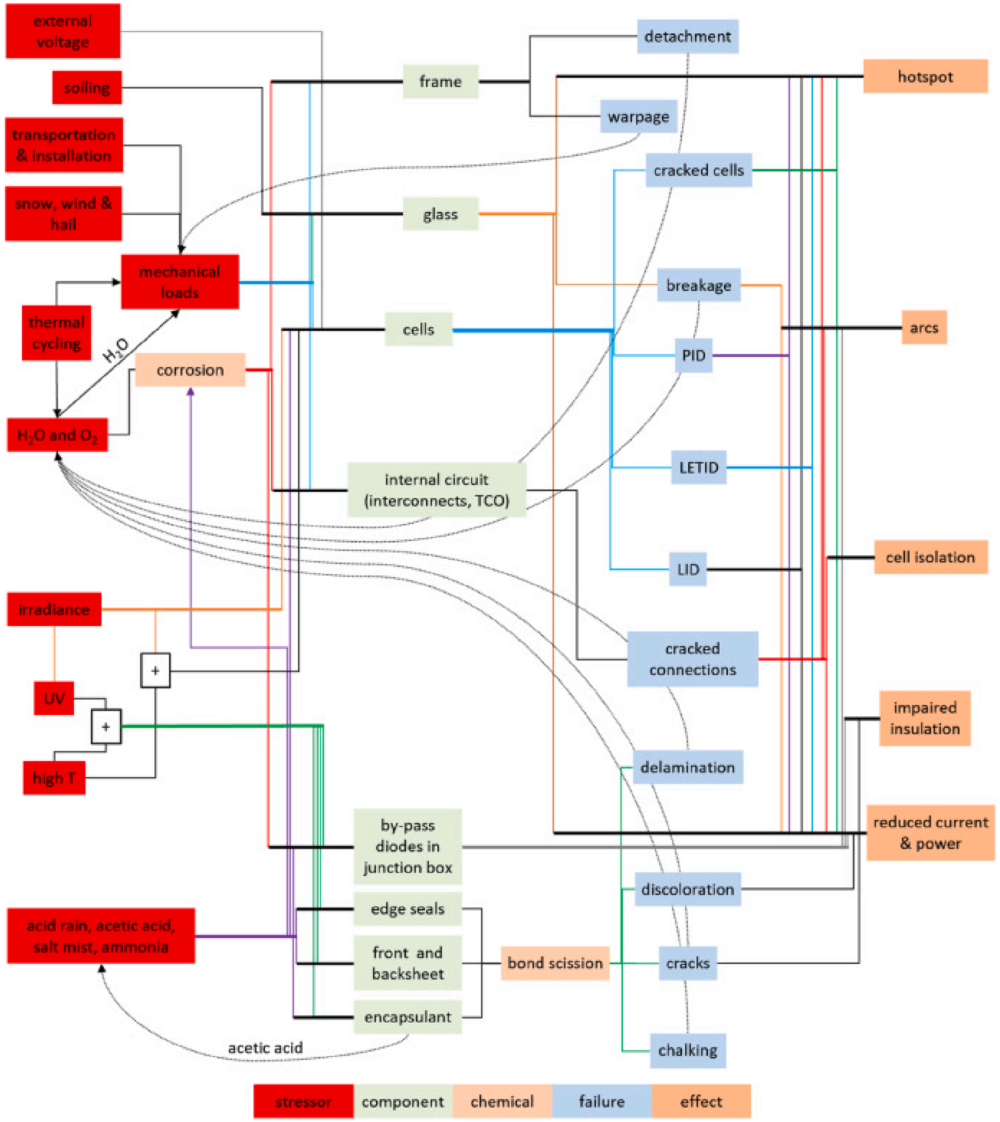


common configuration of crystalline silicon PV modules



common configuration of cadmium telluride PV modules

Why PV performance control



Flow diagram representing the relationships between stressors, components, failures and effects for PV modules.

Mixture of external and internal stress factors makes it difficult to uniquely identify

- causes for failure and effects at the level of PV module output
- each failure in relation to effects and vice versa

Please notice that:

- external stress factors are related to environmental conditions
- internal stress factors related bill of materials of PV modules and processing related effects

Also important, please be aware that also inverter, electronics and other BOS can show failures, and hence affect the system performance.

Indicators to control PV performance

Given the previous information, it makes sense to initially first capture PV system performance by means of indicators, such as:

- Performance Ratio
- Performance Loss Rate
- Incidental Indicators

On the basis of these indicators, in a next evaluation step, causes for less than expected PV performance can be identified.

Indicators to control PV performance

The Performance Ratio (PR) represents the ratio between the final yield Y_f and the reference yield Y_{ref} of a PV system over a certain period.

$$PR = \frac{Y_f}{Y_{ref}} = \frac{E_{AC}/Pnom}{H_{POA}/GSTC}$$

Where E_{AC} is the ac energy of the system (energy equals accumulated power [W to Wh]), H_{POA} the plane-of-array irradiation (irradiation is accumulated irradiance [W/m^2 to Wh/m^2]), and G_{STC} is the irradiance under standard test conditions of 1000 W/m^2.

IEC 61724-1 Ed. 1.0 en: 2017, Photovoltaic System Performance - Part 1: Monitoring

Indicators to control PV performance

- Performance Loss Rate describes a year-to-year change of performance
- STL; Seasonal and Trend decomposition using LOESS
- YoY ; Year-on-Year approach
- SCSF; Statistical Clear-Sky Fitting

Lindig, S., Ascensio, J., Leloux, J., Moser, D. and Reinders, A.H.M.E., Performance analysis and degradation of a large fleet of PV systems, IEEE Journal of Photovoltaics, ISSN: 2156-3403, DOI: 10.1109/JPHOTOV.2021.3093049, 2021.

Indicators to control PV performance

Incidental indicators, some examples:

- Status bits for certain defects and failures
  - inverter on/off
  - string connected or not, etc
- System availability can be defined as an energy weighted metric reflecting the production loss from inverter outages

$$Availability = 1 - \frac{E_{outages}}{E_{outages} + E_{actual}}$$

[PV Fleet Performance Data Initiative: Performance Index-Based Analysis (nrel.gov)](https://www.nrel.gov)

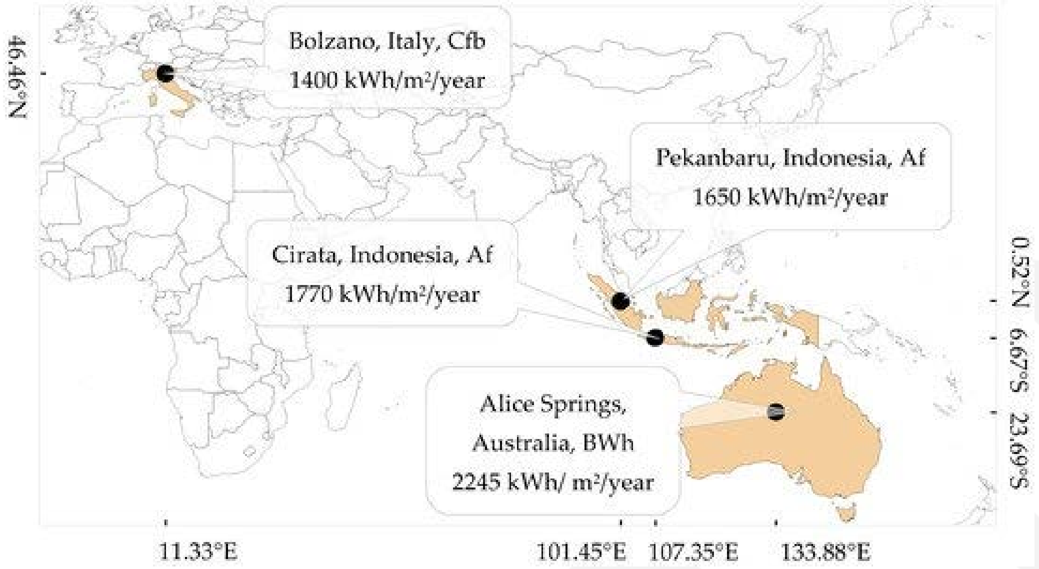
Big data analysis for PV performance control

- In the following, several examples.

Examples of big PV data analysis

Kunaifi, K., Reinders, A.H.M.E., Lindig, S., Jaeger, M., and Moser, D., Operational performance and degradation of PV systems consisting of six technologies in three climates, Applied Sciences, 10(16), 5412, 2020.

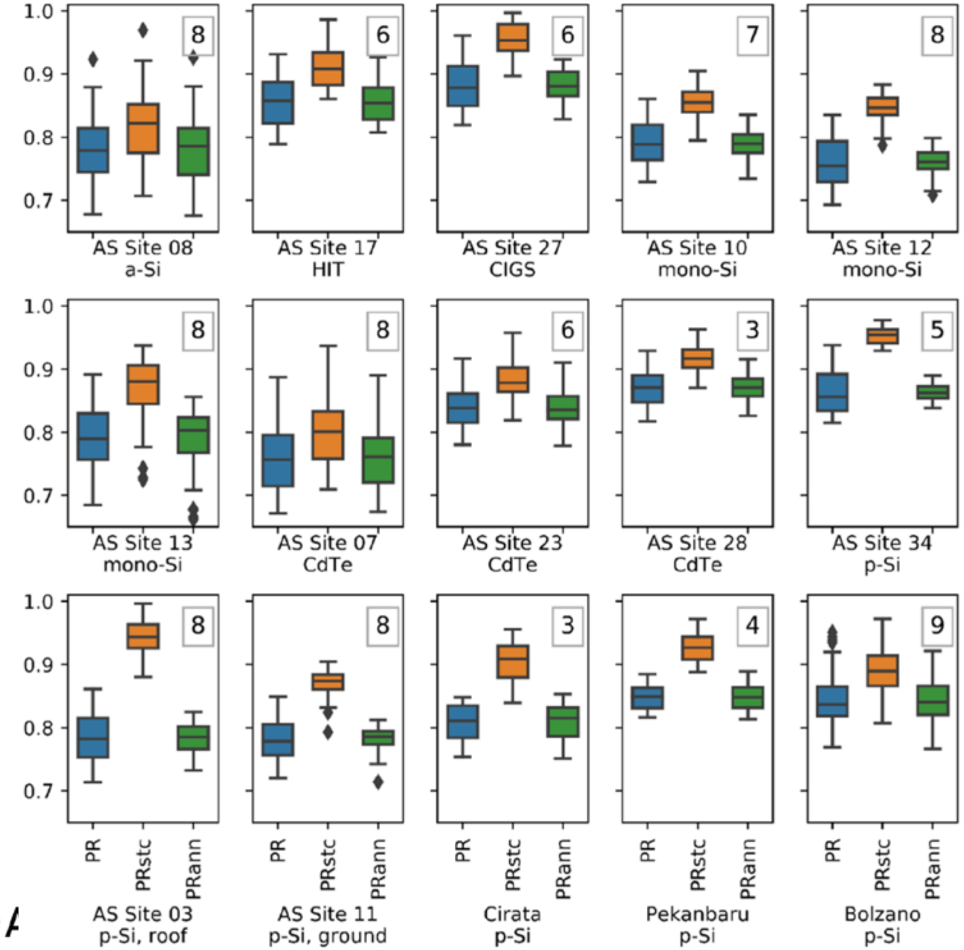
An analysis (and comparison) of monitoring data of PV systems in **Indonesia, Australia and Italy**. Data from **2008 to 2019**, ranging from two to nine years, from **fifteen PV systems with 6 different PV technologies** were analyzed regarding Performance and Ratio and Performance Loss Rate. The study covered CIGS, a-Si, poly-Si, mono-Si, CdTe and HIT PV systems



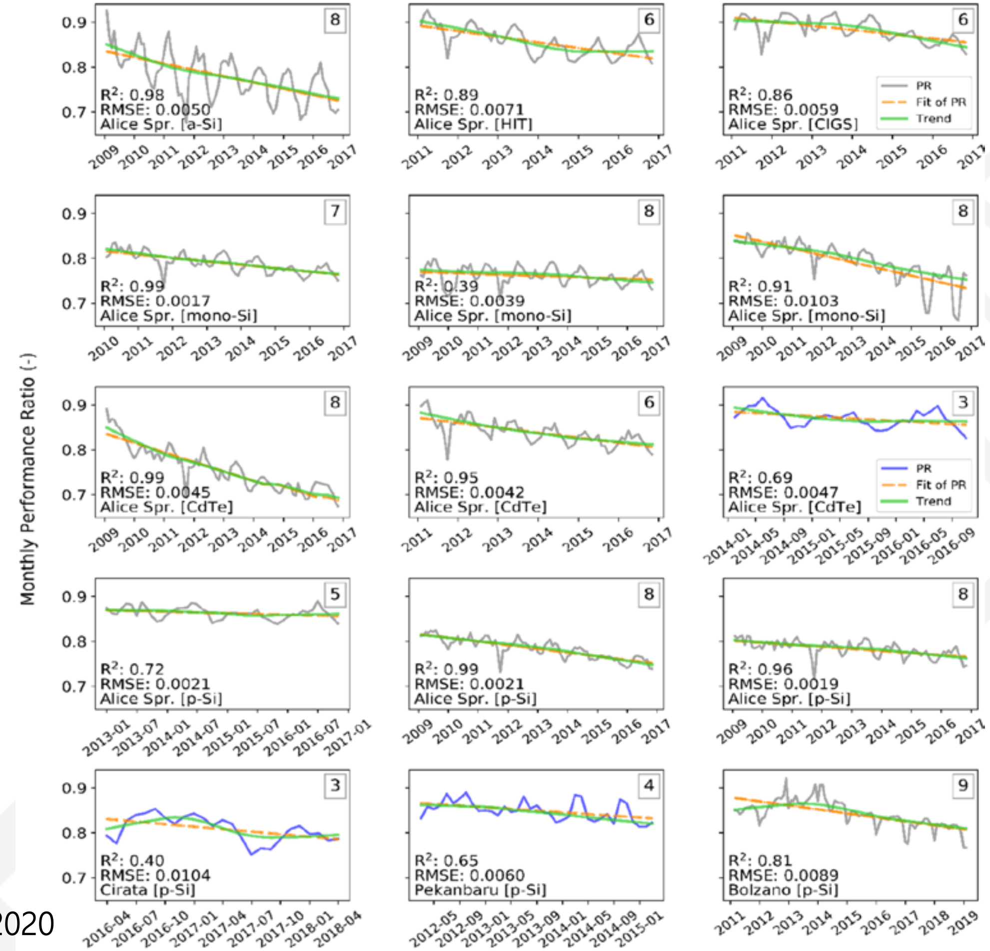
Examples of big PV data processing

EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Box plots of the performance ratio of each PV system. Left/blue: PR, middle/orange: temperature-corrected PR by STC, right/green: annual-averaged temperature-corrected PR. Numbers at the upper right corners in the boxes indicate the duration of the analyzed data in the number of years.



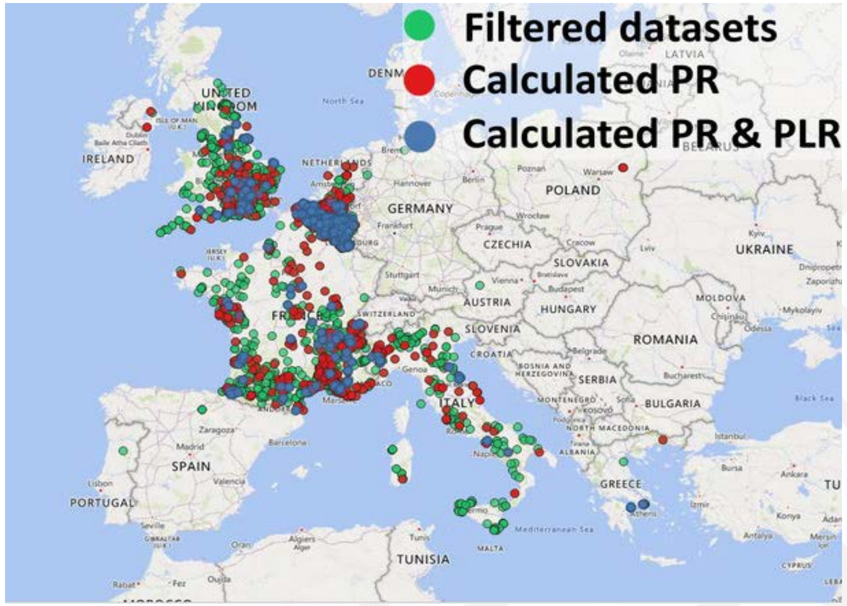
Annual-averaged monthly temperature-corrected performance ratios, $PR_{ann.}$, of the PV systems (grey or blue lines), their linear fit (dashed orange line), and trend components (green line) over the monitoring period. period. Numbers at the top right of the charts indicate the lengths of the data in years.



Kunaifi et al, 2020

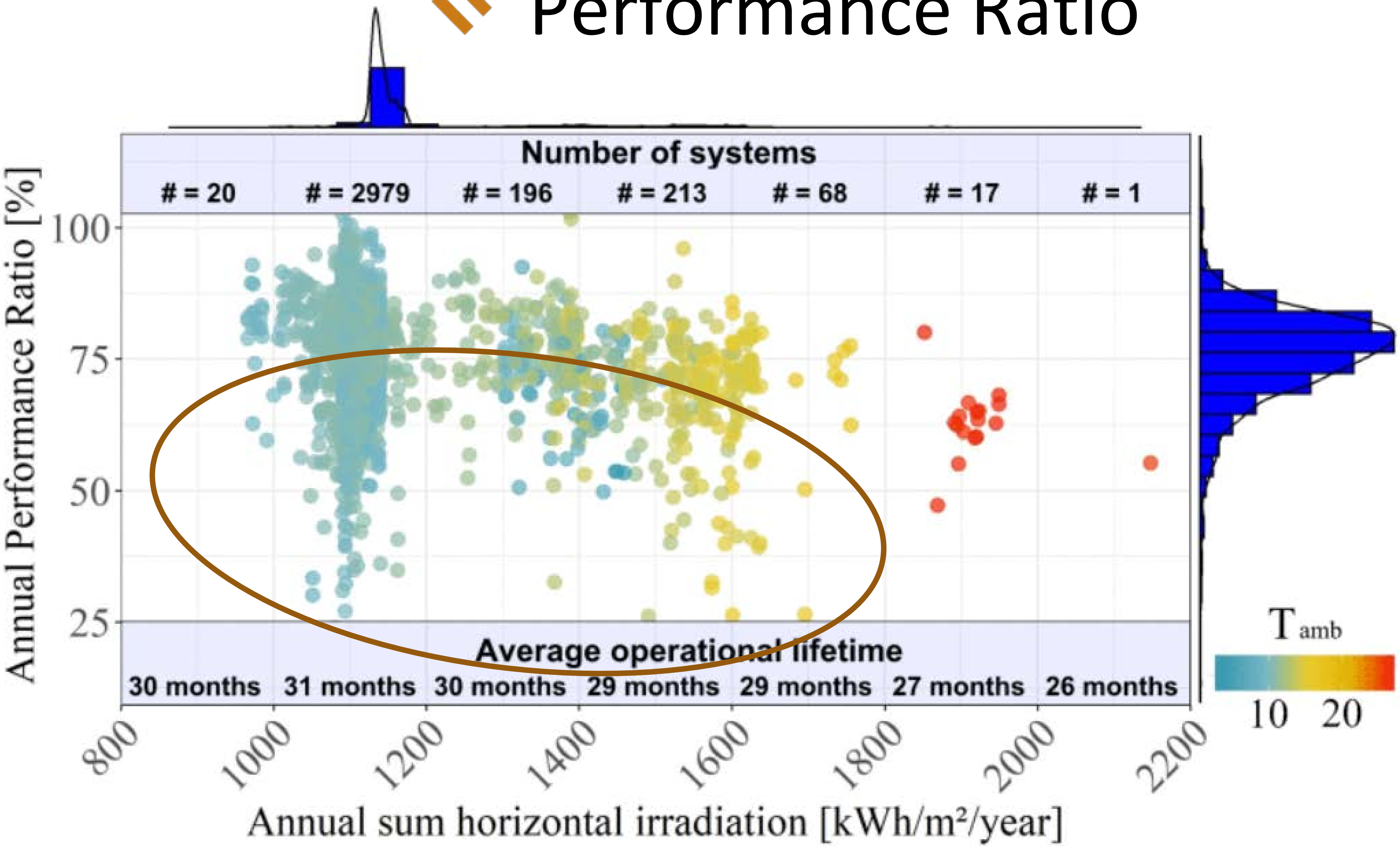
Examples of big PV data analysis

Lindig, S., Ascensio, J., Leloux, J., Moser, D. and Reinders, A.H.M.E., Performance analysis and degradation of a large fleet of PV systems, IEEE Journal of Photovoltaics, ISSN: 2156-3403, DOI: 10.1109/JPHOTOV.2021.3093049, 2021.



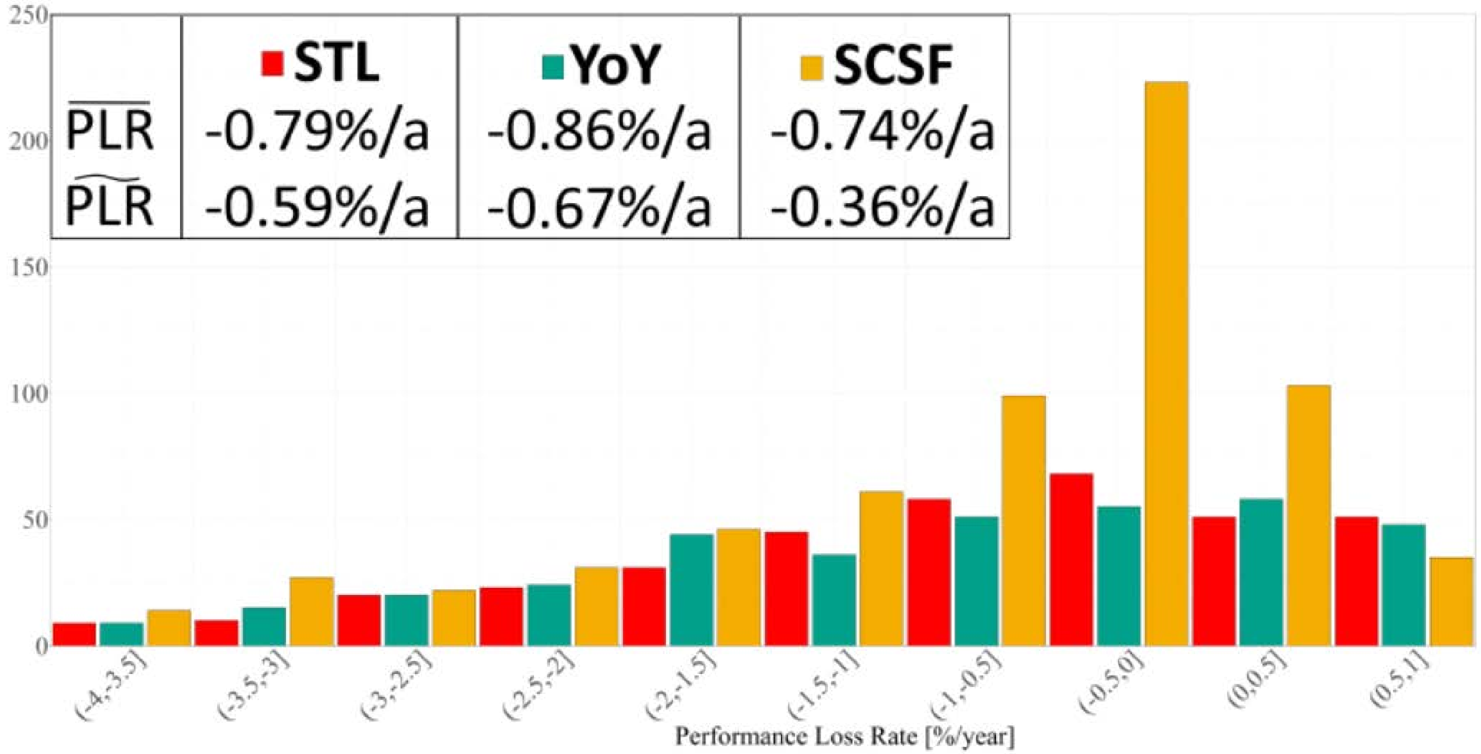
Analysis of monitoring data of **~8400 PV systems with 10-minute recordings for 2010-2016** with mainly crystalline Si PV modules taken from data bank (data from Rbee Solar + ERA5 satellite), with a focus on the determination of Performance and Ratio and Performance Loss Rate

Performance Ratio



Performance Loss Rate

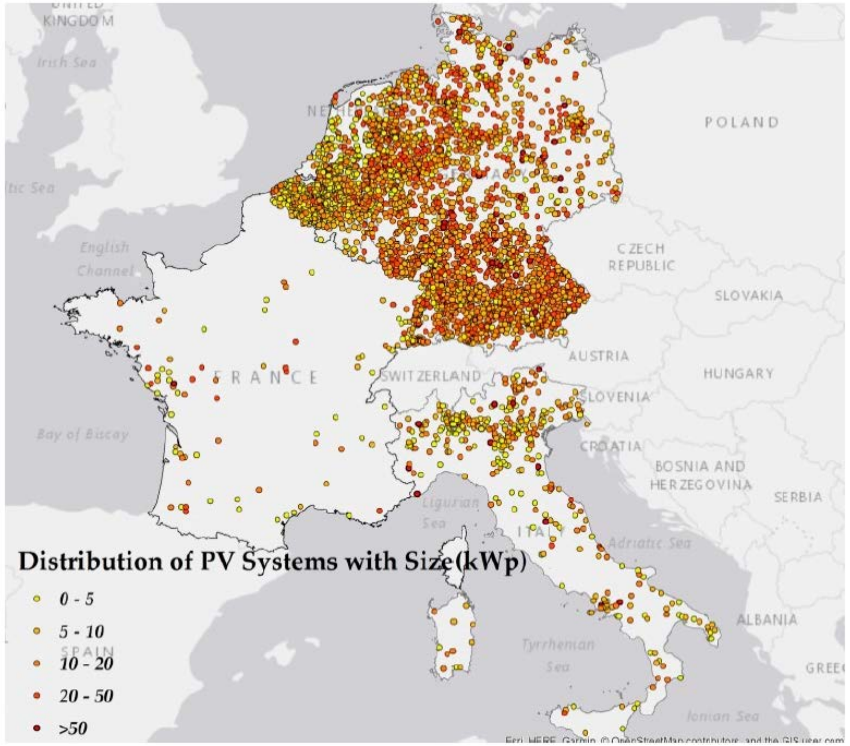
Performance loss rate distribution of Pearl-PV performance database; red: calculated with STL; turqouise: calculated with YoY; yellow: calculated with SCSF.



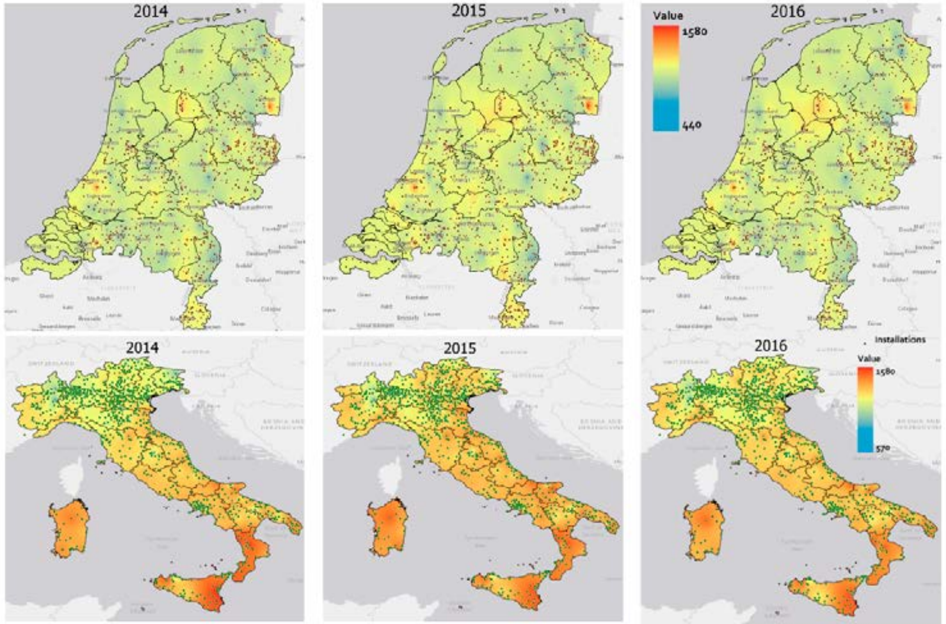
Examples of big PV data analysis

Bala Bhavya Kausika, Panagiotis Moraitis and Wilfried G. J. H. M. van Sark, Visualization of Operational Performance of Grid-Connected PV Systems in Selected European Countries, Energies, doi:10.3390/en11061330, 2018

Web scraping techniques were employed to collect detailed yield data at high time resolution (5–15 min) from a large number (31,844) of small-scale systems (each at least 1 year of monitoring data) for the analysis of their operational performance by means of performance ratio.



Annual specific yield variation in the Netherlands and Italy using visual interpolation techniques



Product development and design for PV performance control

- Product development and design: what is it?
- What can you achieve with it and why is it necessary?
- Some view on the next phases of product development for PV

Design: "the human capacity to shape and make our environment in ways without precedent in nature, to serve our needs and give meaning to our lives"

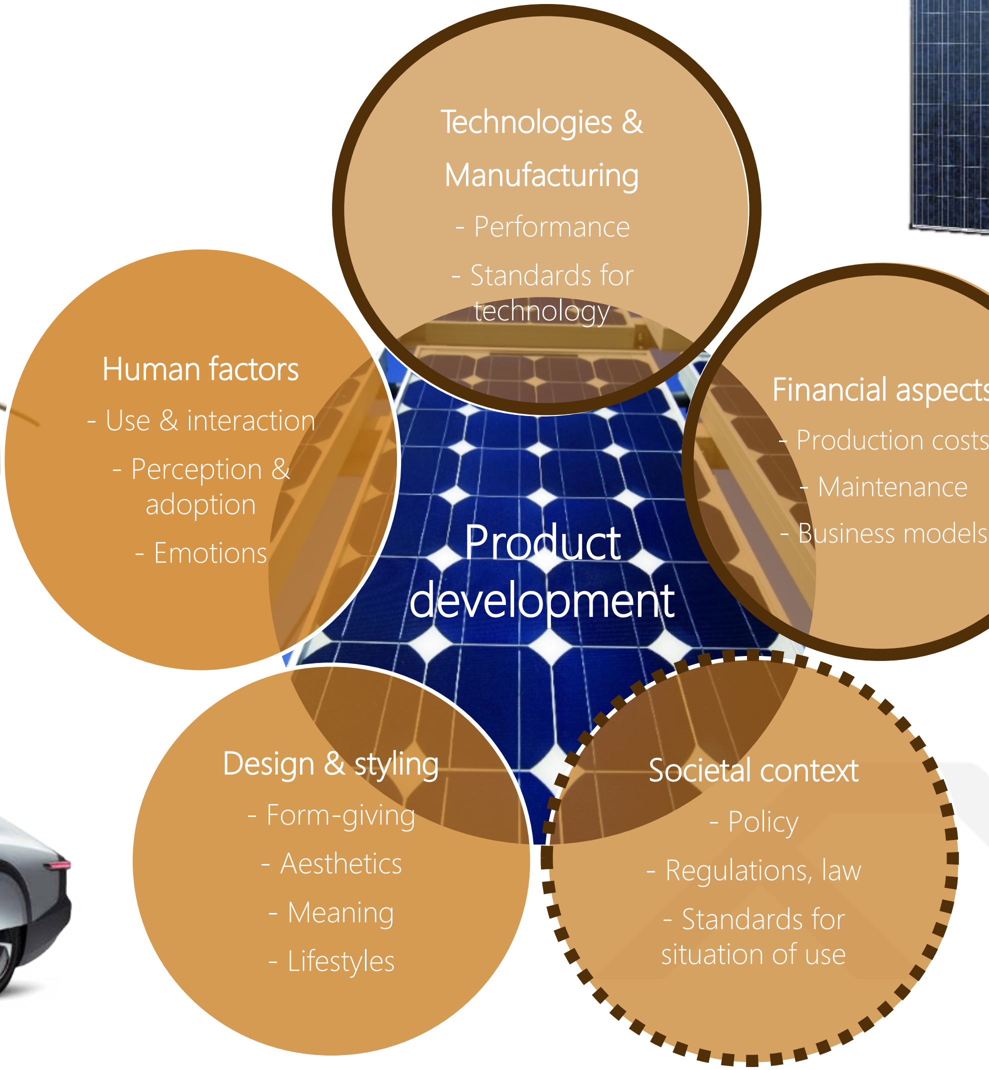
Product development with photovoltaics

Virtue of blue
DeMakersVan

Solid Grey

Electree mini

Lightyear One



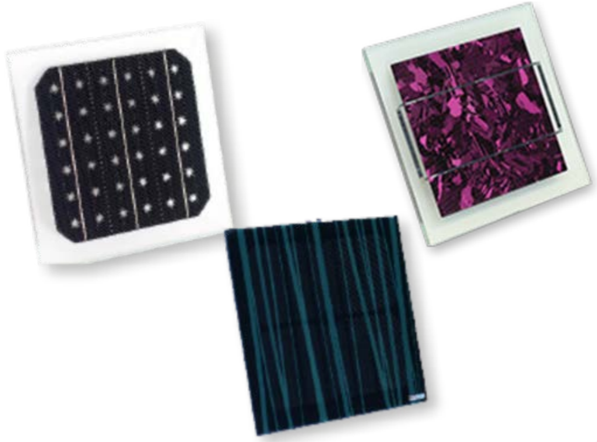
Brunner-Bapst House, solarchitecture.ch

Source: A.H.M.E. Reinders et al. The Power of Design, 2012

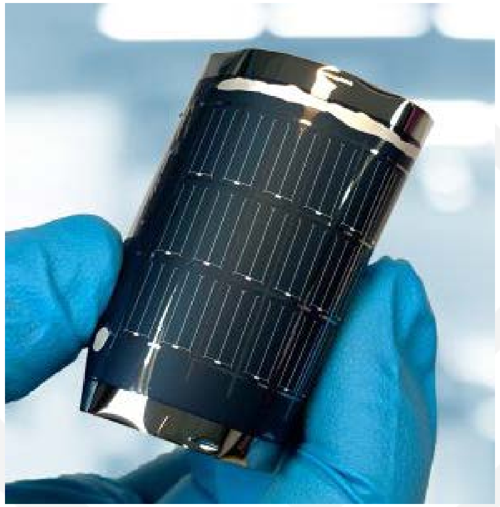
Enhancing the design features of PV technologies

- The more PV technologies will be integrated in buildings, products and automotive applications, the more design freedom will be required. This will drive innovation and research that can enhance design features such as color, transparency, curvature etc.

Sion, curved silicon, Sono Motors



Holes, digiprint and color, silicon, Ertex

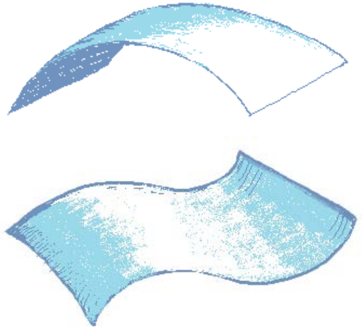


Flexible CIGS, EMPA, FhG-ISE

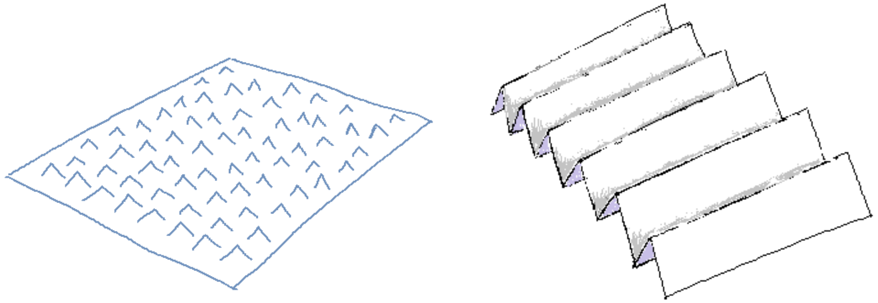
Design features

Color

Curvature

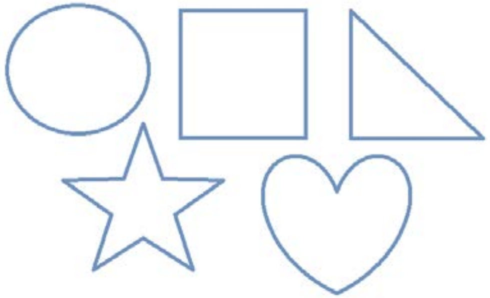


Surface structures

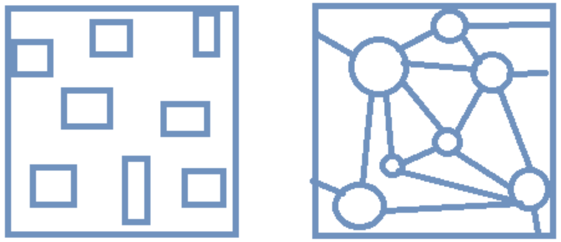


Transparency
Translucency
Reflectance
etc

2D Shape

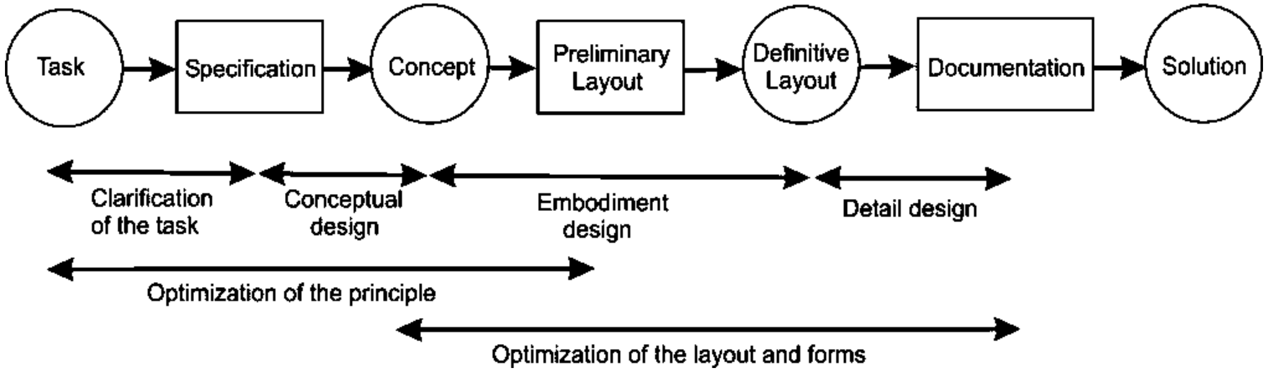


Patterns

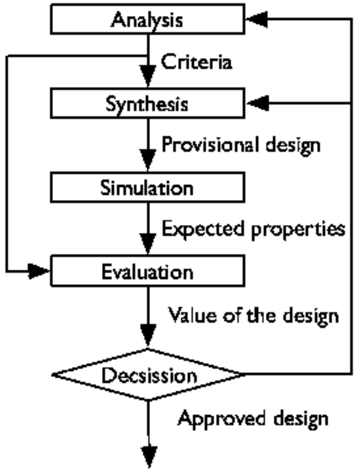


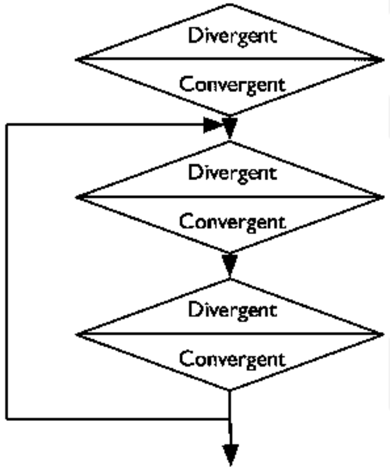
Design is an iterative creation process resulting in solutions and things

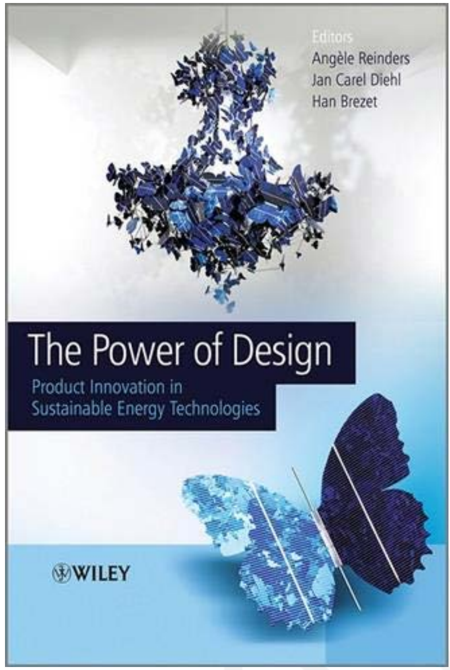
- Flow chart representing the basic industrial design method of Pahl and Beitz.

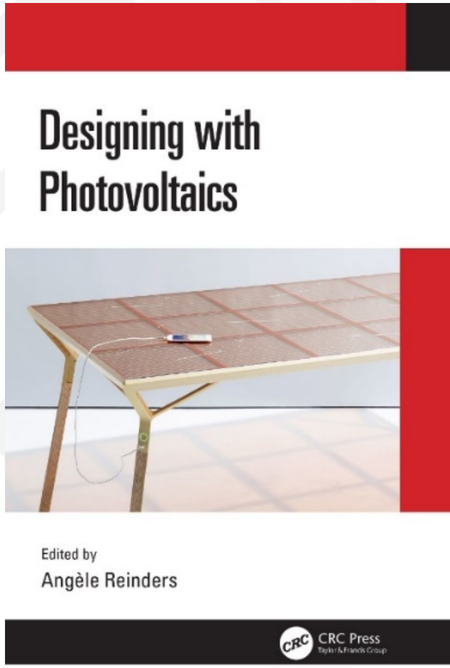


- The basic cycle of design (Roozenburg and Eekels 1998) characterized by divergent, convergent, and iterative activities



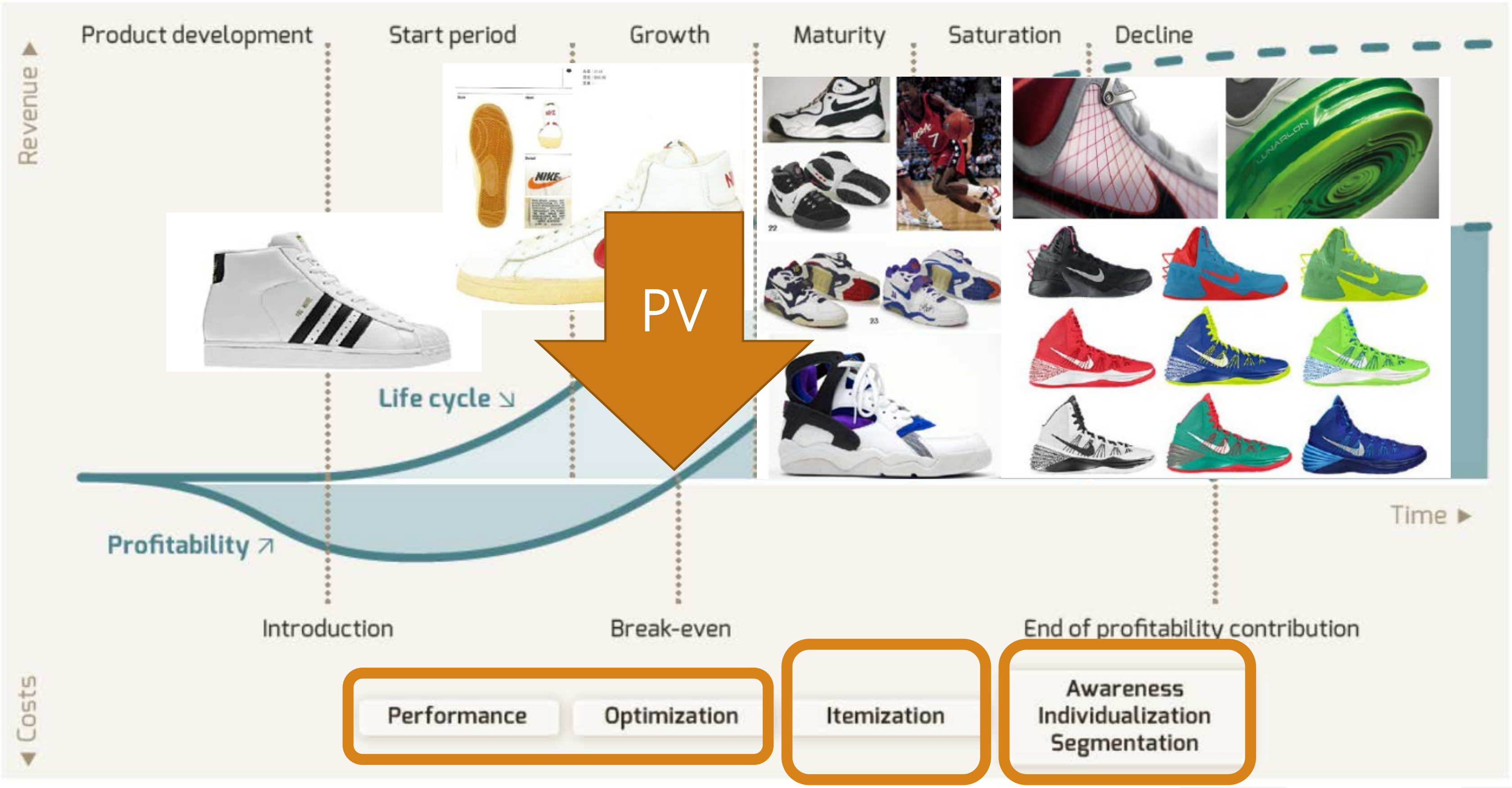






P A R L P V

Patterns in evolving products



Itemization: functionality & performance of a product are good. Prices are falling. Design and styling become more important

Segmentation: customers have a lot of choice, service organizations, marketing through various channels, Design and styling become very expressive.

Source: A.O. Eger and A. Ehlhardt: On the origine of products – The evolution of product innovation and design, 2018

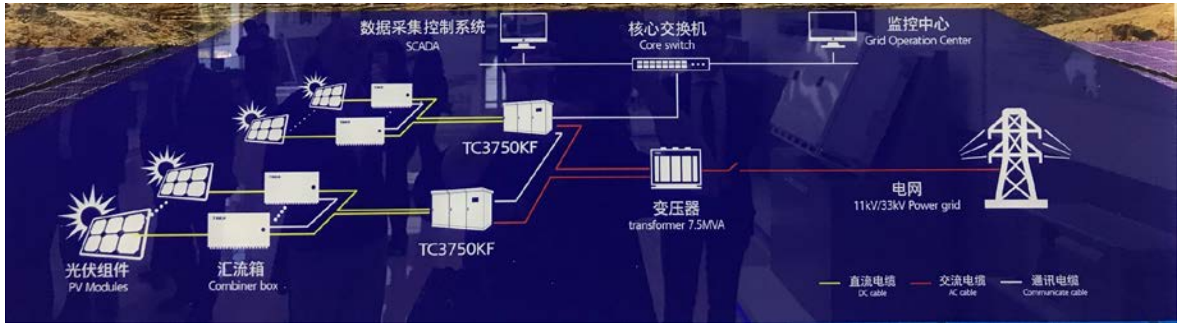
Examples of product development and design for PV performance control

- VLS: Performance control cockpit
- Smart Apps: PowermatchingCity
- Smart Apps: SMA Inverters
- Smart Apps: Zonneplan
- Physical products: Smart meters
- Physical products: Innovation

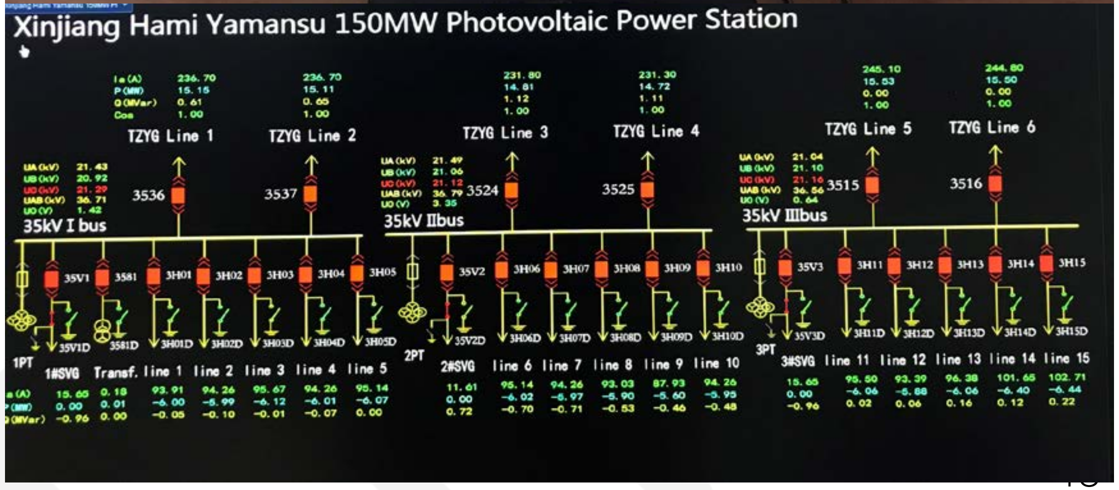
VLS: Performance control cockpit

- O&M Platform at installer in Xi'an, China, 2019


Monthly electricity
158.60
Month Completion Rate
89.91MW
Year electricity
20294.20
Year Completion Rate
Year Generation Bar Chart


数据采集控制系统
SCADA
核心交换机
Core switch
监控中心
Grid Operation Center
TC3750KF
变压器
transformer 7.5MVA
电网
11kV/33kV Power grid
光伏组件
PV Modules
汇流箱
Combiner box
TC3750KF
直流电缆
DC cable
交流电缆
AC cable
通讯电缆
Communicate cable

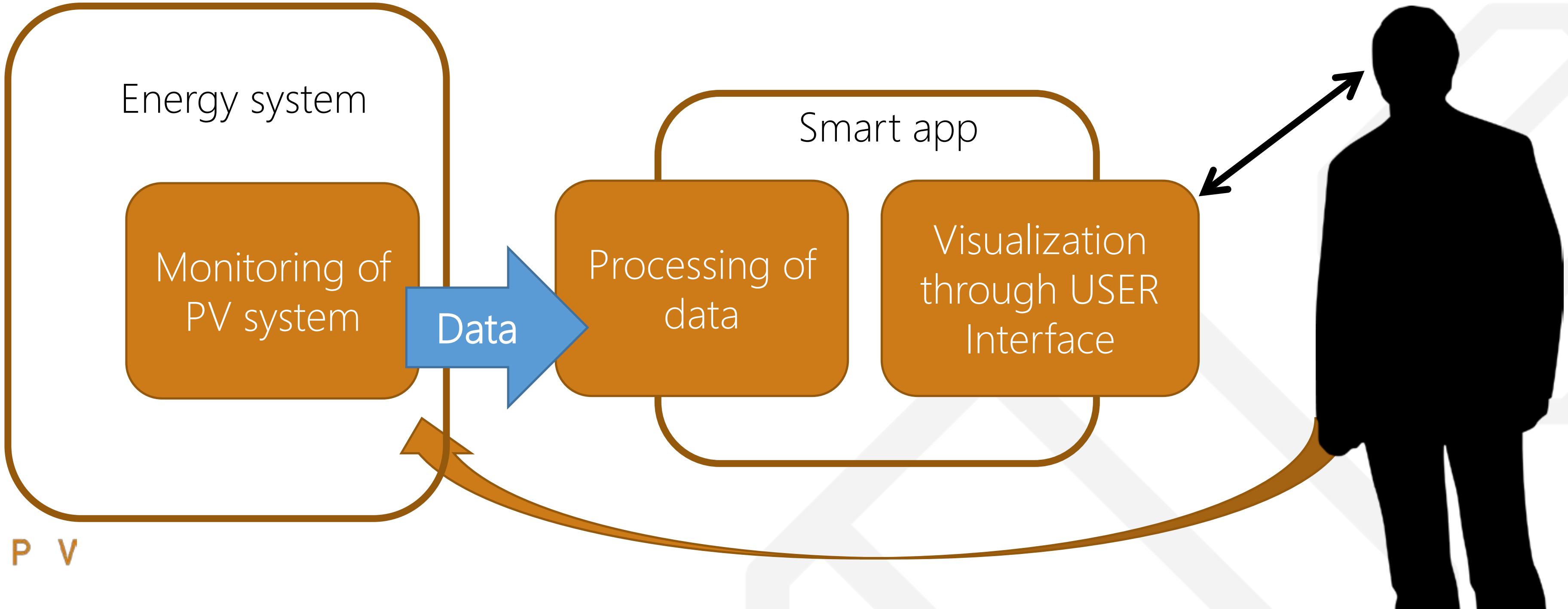

Monthly electricity
158.65
10MWh
Month Completion Rate
8.8%
Total Inverter Power
89.77MW
Inverter Status
Month Generation Bar Chart
Year electricity
20294.25
10MWh
Year Completion Rate
81.8%
Power-Irradiance Curve
Year Generation Bar Chart
ON
Remote
PHILIPS


Xinjiang Hami Yamansu 150MW Photovoltaic Power Station
TZYG Line 1
TZYG Line 2
TZYG Line 3
TZYG Line 4
TZYG Line 5
TZYG Line 6
35kV I bus
35kV Ⅱbus
35kV Ⅲbus

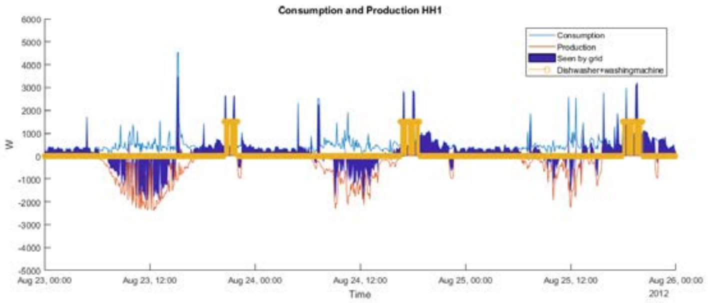
PEARL PV

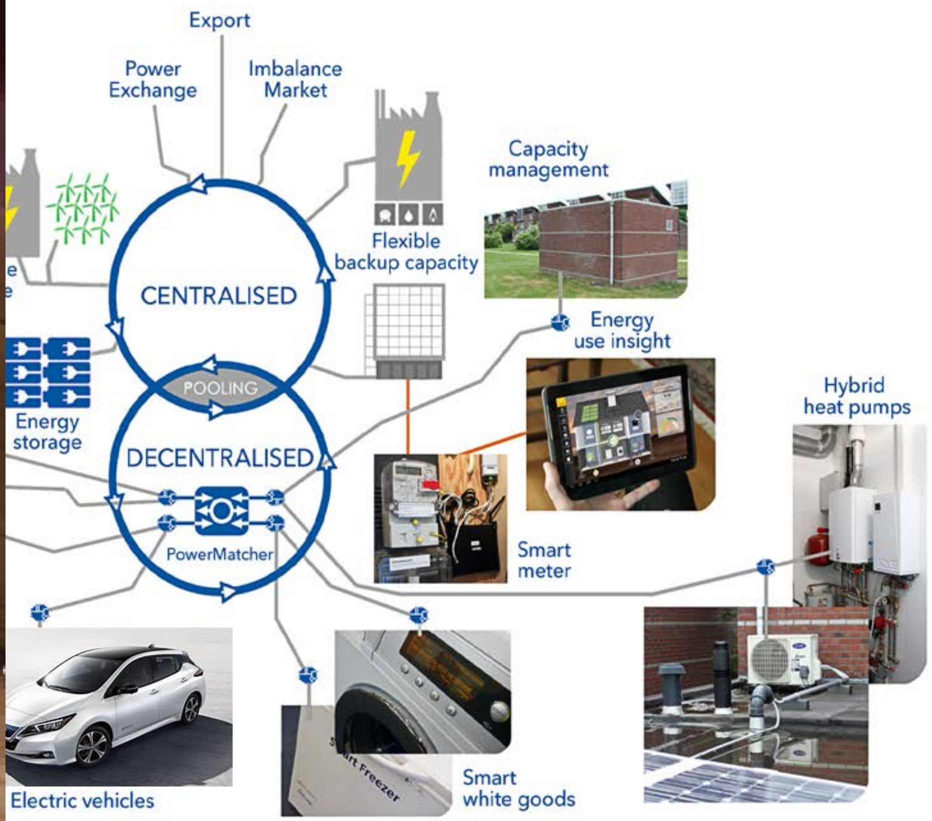
Smart Apps

- PowerMatchingCity
- SMA Inverter App
- Zonneplan



Smart Apps: PowerMatchingCity





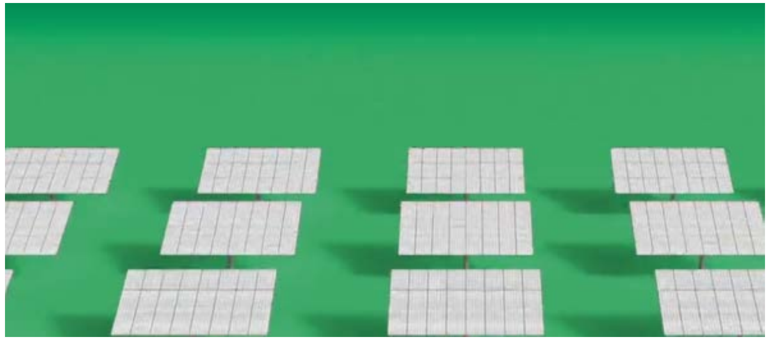
owerMatching City, with Enexis, Essent, Humiq, TNO, Gasunie,
, Technische Universiteit Eindhoven, NXP Semiconductors en I-NRG,
ng City: Smart Energy Systems - YouTube

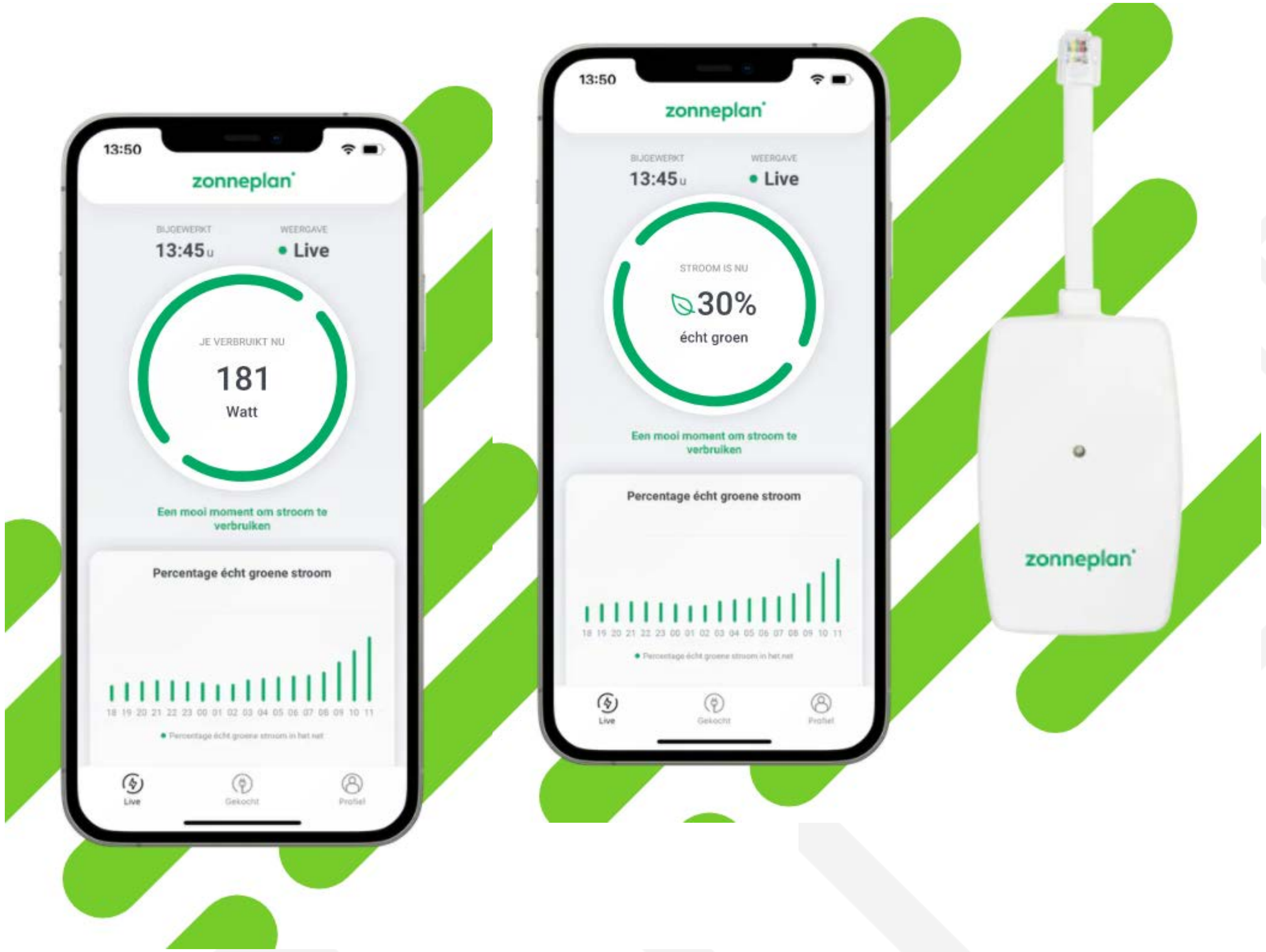
Smart Apps: SMA Inverter

- See [SMA Energy App | SMA Solar]()
- View solar power production and usage
- Daily and historical figures
- Overview of residual current usage
- Display battery state of charge (if available)
- View carbon footprints
- View up-to-date forecasts for solar power production
- Follow recommended actions for optimized energy use
- Reduce grid-supplied power and save on electricity costs

Smart Apps: Zonneplan

- Buying and selling power with dynamic energy prices



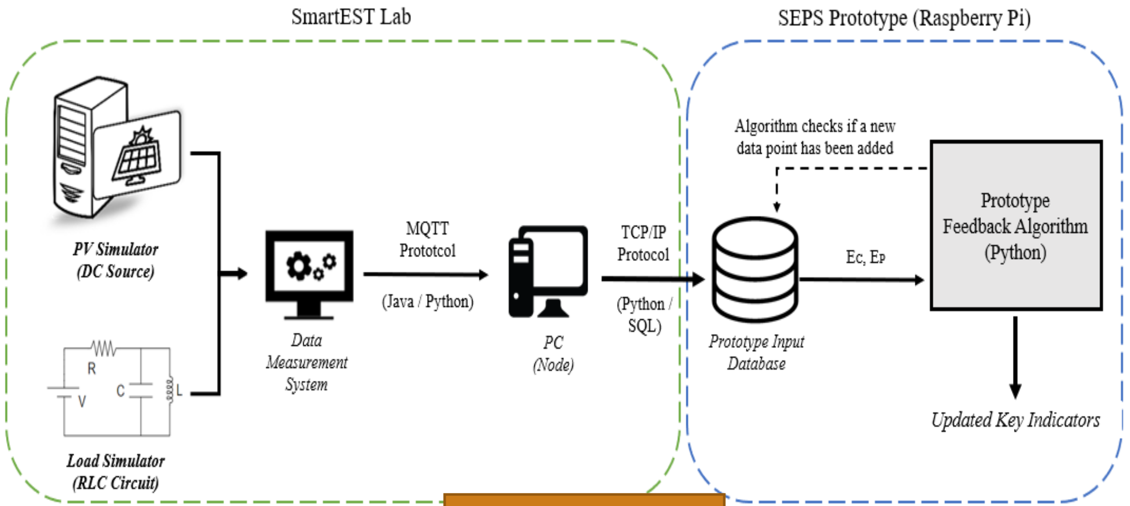


Physical products: smart meters

- A smart meter is an electronic device that records information such as consumption of electric energy, voltage levels, current, and power factor.
- Typically record energy near real-time, and communicates by mobile telephone networks (GPRS of CDMA)
- Smart meters enable two-way communication between the meter and the central grid system.
- The smart meter can be connected to a home energy management system
- A smart meter keeps track of electricity fed into the grid because it has separate counters. In case of PV system owners, returned power is settled with purchased power. This is regulated in so-called net-metering arrangements.

Physical products: innovation

Sierra, A., Gercek, C., Übermasser, S., and Reinders, A.H.M.E., *Simulation-supported testing of smart energy product prototypes*, *Applied Sciences*, Special Issue Advanced Applications for Smart Energy Systems Considering Grid-Interactive Demand Response, 9(10), 2030, 2019.



SEPS Designs

Co-simulator: SmartE

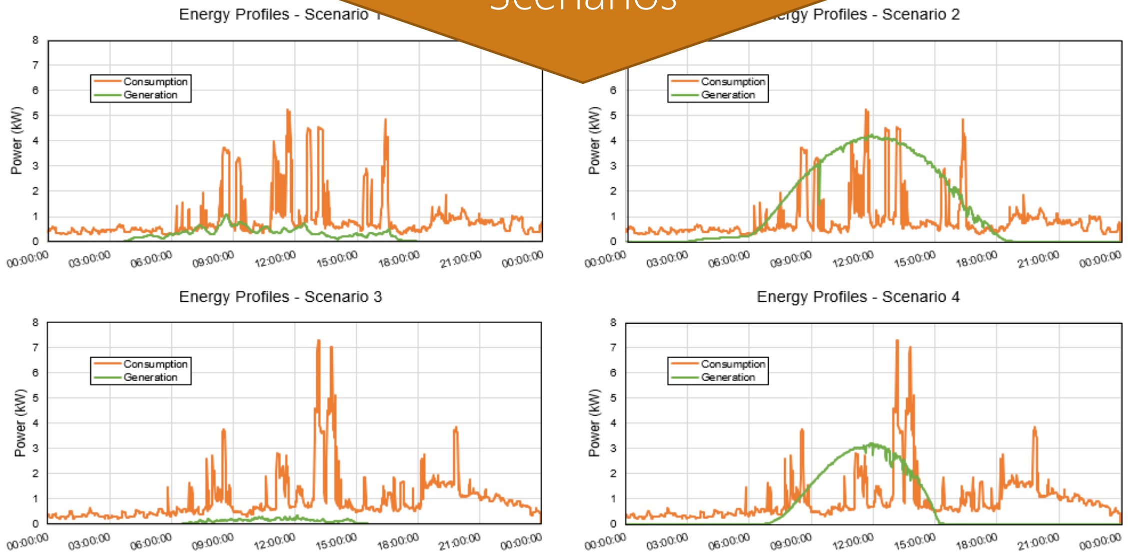
Simulation Scenarios

stallation (AIT)

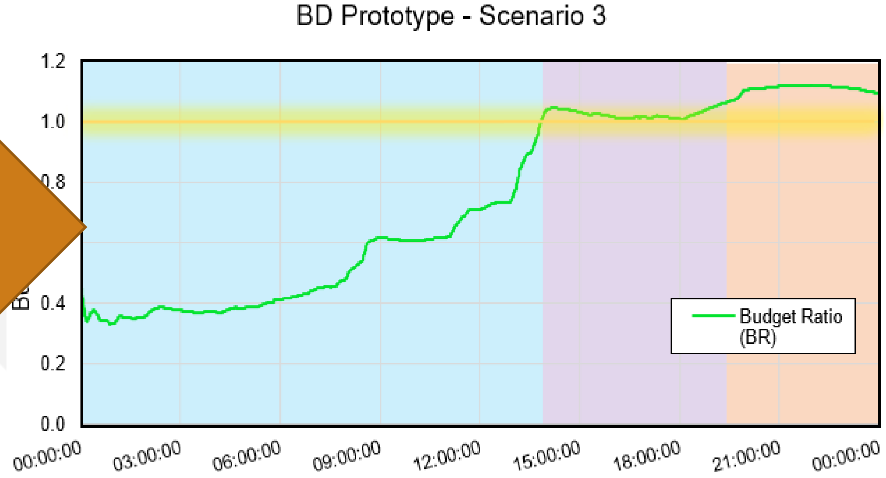
Designs of Home Ene

Product Improvements

ent Products (UT)



Product Performance



Data sharing and short introduction to the CKAN data server

Why it is relevant to share data?

EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

- <u>Four good reasons:</u>

- To be able <u>to compare and control</u> the performance and reliability of (fleets of) PV systems installed in different climate zones, with different components in various installation categories, different age and different conditions of operation and maintenance (called different meta-data)
- <u>To exchange knowledge</u> and tools regarding PV monitoring, methods for data processing, data analytics and machine learning, and different simulation approaches, and, in that way, enhance international collaboration and the quality of PV system research in general
- <u>To develop a professional research infrastructure</u> for PV system research
- <u>To increase the statistical validity</u> of PV system research results

Working Groups' PV data processing

Each Working Group has specific data processing activities based on the focus of the WG's research, see [1]

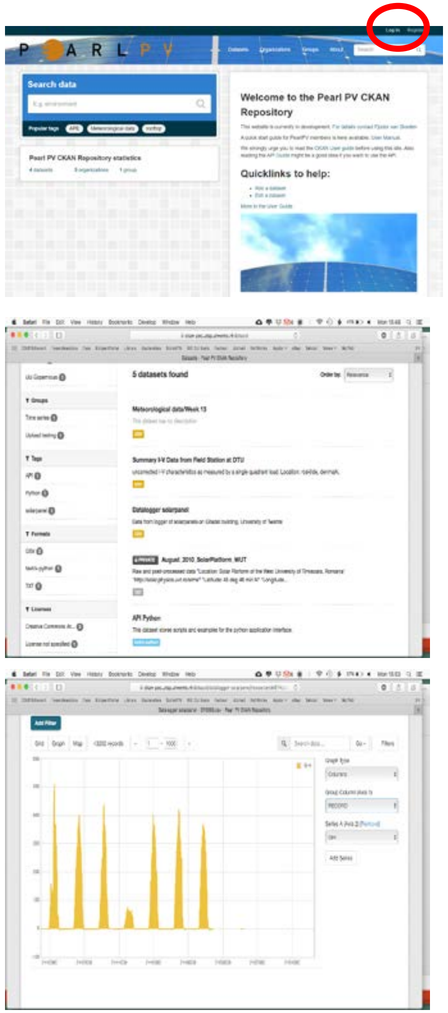
- WG1 PV Monitoring has set requirements for essential data and nice-to-have data that can be entered in a central data bank. These data will be analyzed regarding actual monitored long-term performance, defects and failures in PV systems. Close collaboration with IEA-PVPS-Task 13
- WG2 Reliability and Durability of PV objectives, to define reliability and durability metrics for PV modules, components and systems, to identify relevant data to be collected in order to measure reliability and durability, and to share knowledge on mass PV data analysis methods for the identification of issues causing decrease in power output (e.g. shading, physical degradation…) and correlations of failure modes with climatic conditions.
- WG3 PV simulation considers the use of modelling tools to simulate the performance of photovoltaic devices and systems. WG3 uses data from a central data server as an input to and to validate simulation results
- WG4 PV in the Built Environment will focus on data coming from various built contexts, i.e. urban and rural environments from which information on urban morphology and discrete urban geometry can also be obtained. Integration in a 2D GIS, 3D GIS and BIM systems will be examined and implemented. The data of particular interest are derived from BIPV (Building Integrated PV) systems, by type of building and position of PV systems (rooftops, facades, shades, window glazing, etc.).
- WG5 PV in Grids: analyzes data and metadata of thousands of PV systems connected to grids in Europe, studies are conducted on the relationship between the PV production and the local consumption, the possible use of batteries, or the economic viability of alternative options. Fault detection toolbox to improve the energy yield of grid-connected PV systems and reduce their power instability.

[1] Reinders, A., Slooten, F. van, Moser, D., Sark, W. van, Oreski, G., Ottersboeck, B., Pearsall, N., Devetaković, M., Leloux, J., Capeska Bogatinoska, D., Braun, C., Gerd Imenes A., Driesse, A., DEVELOPMENT OF A BIG DATA BANK FOR PV MONITORING DATA, ANALYSIS AND SIMULATION IN COST ACTION 'PEARL PV', Conference Proceedings of EU PVSEC, 2019

Thoughts about shared data

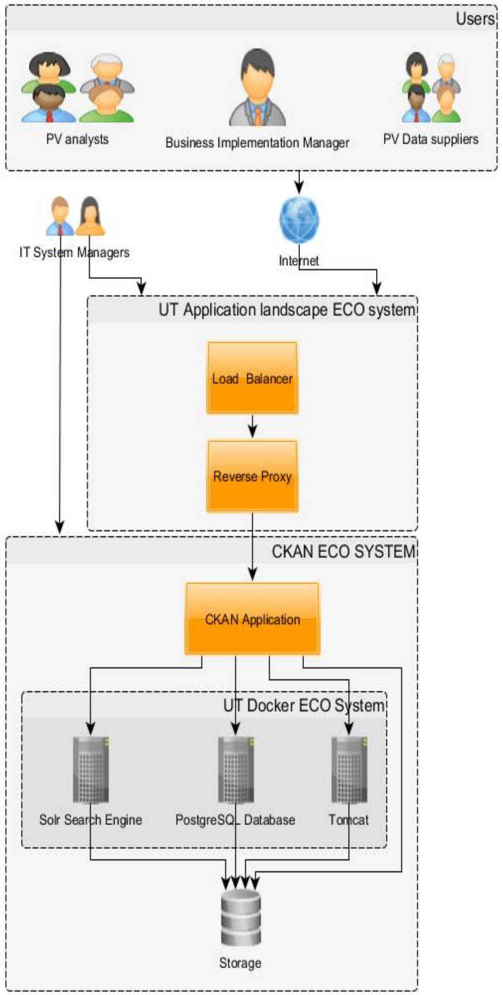
- Different quality of data monitoring systems
- Component faults and operation & maintenance practices are unknown
- This also applies to specific local conditions: shading and animals
- Modern problems such as congestion of grids and the related disconnection of PV systems, are not monitored, neither is the measurement of curtailment well embedded in monitoring systems.
- Data streaming of many PV monitoring systems to a central data server would be well possible, but hardly happens, as we have seen during this presentation.

Introduction to CKAN data server



- PEARL PV's CKAN data server was been implemented in 2019 in order to share data in COST Action PEARL PV
- This means in practice: a database server (4 CPUs, 16 GB memory, max 4 TB diskspace) was installed successfully, on which CKAN is running. Upload setting: max. 200 MB/file can be easily increased.
- It can store data and run software in the data server
- In principle it will remain available after this Action has been completed and can be used for the next decades
- Access by https://ckan.pearlpv-cost.eu/ and next **login** (see red circle)
- Suitable for data uploads incl. meta-data
- This is not the only data sharing initiative, others: DuraMAT, IEA PVPS Task13, , BDPV, Sonnenertrag, PVOutput, as well as NREL's PV Fleet Performance Data Initiative

See also: Reinders, A., Slooten, F. van, Moser, D., Sark, W. van, Oreski, G., Ottersboeck, B., Pearsall, N., Devetaković, M., Leloux, J., Capeska Bogatinoska, D., Braun, C., Gerd Imenes A., Driesse, A., DEVELOPMENT OF A BIG DATA BANK FOR PV MONITORING DATA, ANALYSIS AND SIMULATION IN COST ACTION 'PEARL PV', Conference Proceedings of EU PVSEC, 2019



P A R L P V

Data of interest to the CKAN data server

- **Dedicated meteo-data,** for instance data of spectrally distributed irradiance
- **PV monitoring data** with short recording intervals (< 10 minutes) and a long monitoring period (> 1 year).
- PV monitoring data of **fleets with PV systems with different meta-data**
- **Artificial or synthetic data sets** for PV system research

Contact persons for CKAN data server: Dr. Eli Shirazi, e.shirazi@utwente.nl and Dr. Atse Louwen, atse.louwen@eurac.edu

Concluding remarks and thoughts

- Data collection and data processing by means of quantifiable indicators will be very important for PV Quality Control
- Products that will be developed for PV Quality Control must connect to the next step in the evolution of PV technologies
- Hence itemization, individualization and segmentation will become leading, because "one size fits all", won't work anymore in the 21st century
- User interfaces will be important for communications with PV system users
- Product development and design is an interdisciplinary creative activity involving design and styling and behavioral sciences, besides required physics, engineering and as such PV data analysis.

References

These references provide useful background information

- Moser, D., Azpilicueta, L., Salgado, A., Richter, A., Reinders, A., Bihler, F., Bosshell, F., Masson, G., Serra, G., Lin, J., Garreau-Iles, L., Cherradi, N., Moreth, R., Jahn, U. and Ekus, B., White paper on harmonized data collection from the field, SolarUnited Quality Initiative, 2019.
- Aghaei, M., Fairbrother, A., Gok, A., Ahmad, S., Kazim, S., Kettle, J., Lobato, K., Oreski, G., Reinders, A.H.M.E., Schmitz, J., Yilmaz, P., Theelen, M., Review of degradation and failure phenomena in photovoltaic modules, Renewable and Sustainable Energy Reviews, Vol. 159, 112160, DOI: doi.org/10.1016/j.rser.2022.112160, 2022
- IEC 61724-1 Ed. 1.0 en: 2017, Photovoltaic System Performance - Part 1: Monitoring
- Deline, Chris, Kevin Anderson, Dirk Jordan, Andy Walker, Jal Desai, Kirsten Perry, Matt Muller, Bill Marion, and Robert White. 2021. PV Fleet Performance Data Initiative: Performance Index–Based Analysis. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5K00-78720. https://www.nrel.gov/docs/fy21osti/78720.pdf.
- Kunaifi, K., Reinders, A.H.M.E., Lindig, S., Jaeger, M., and Moser, D., Operational performance and degradation of PV systems consisting of six technologies in three climates, Applied Sciences, 10(16), 5412, 2020.
- Lindig, S., Ascensio, J., Leloux, J., Moser, D. and Reinders, A.H.M.E., Performance analysis and degradation of a large fleet of PV systems, IEEE Journal of Photovoltaics, ISSN: 2156-3403, DOI: 10.1109/JPHOTOV.2021.3093049, 2021.
- Bala Bhavya Kausika, Panagiotis Moraitis and Wilfried G. J. H. M. van Sark, Visualization of Operational Performance of Grid-Connected PV Systems in Selected European Countries, Energies, doi:10.3390/en11061330, 2018
- Reinders, A.H.M.E., Designing with photovoltaics, Hard-cover book, 226 pages, ISBN: 978-1-315-09792-3, Taylor and Francis Group, CRC Press, Boca Raton, USA, 2020.
- Reinders, A.H.M.E., Diehl, J.C. and Brezet, J.C., The power of design: Product innovation in sustainable energy technologies, Hard-cover book, 368 pages, ISBN: 978-1-1183-0867-7, John Wiley & Sons, London, UK, 2013.

PEARL PV

Thanks to all for listening

Question or comments? Please email me at a.h.m.e.reinders@utwente.nl or feel welcome to respond now.