„Investigation to reliability and yield of photovoltaic modules under extreme climatic conditions“

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Koethen, 08.10.2013

in cooperation with RLI REINER LEMOINE INSTITUT

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Agenda

- Fraunhofer CSP
- Aspects of Module Reliability
- PV Test Field Development in Siberia
- Climate dates and yield prognosis for Tomsk and some places in Central Asia

Fraunhofer Center for Silicon Photovoltaics CSP

- founded in 2007 as a joint venture of Fraunhofer ISE and Fraunhofer IWM Halle
- Heads of Center
  - Prof. Dr. Jörg Bagdahn
  - Prof. Dr. Peter Dold
- 68 researchers + students and guests
- Budget 2012: 6,5 Mio. €
- Fraunhofer CSP sites:

  Weinberg Campus Halle

  Module Technology Center
  (Dow ValuePark®, Schkopau)

  Wafer line (Technology Park Thalheim)

Institute

Module Technology Center Schkopau

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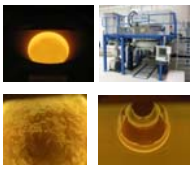
Reliability and Technology for Grid Parity
Prof. Jörg Bagdahn

- Diagnostic Solar Cells — Dr. Christian Hagendorf
- Silicon Wafers — Dr. Hartmut Schwabe
- Module Technology — Dr. Jens Schneider
- Module Reliability — Dr. Matthias Ebert

Laboratory Silicon Crystallization
Prof. Dr. Peter Dold

- Crystallization — Dr. Roland Kunert
- Silicon Recycling — Prof. Dr. Peter Dold



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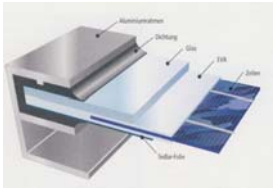
Aspects of Module Reliability
Crystalline solar modules



- Typical crystalline solar module:
  - Glass front sheet (prestressed)
  - Encapsulant sheets (two layers)
  - Solar cell strings
  - Polymer back sheet

Typical layout of a single glass PV module

Material	Young's Modulus [GPa]	CTE [ppm/K]
Silicon (multi)	162.5	2.6
Glass	70.0	8.5
Copper	85.7	16.8
Encapsulant	0.001	300

5 *Source: Matthias Pander, Fraunhofer CSP*

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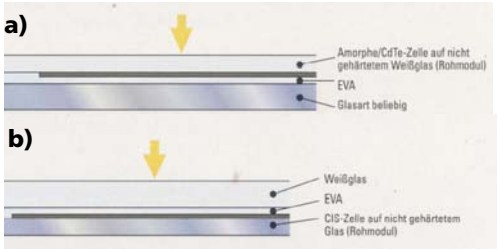
Thin film solar modules



Typical layout of thin film double glass solar modules
a) Double glass module (CdTe in EVA)
b) Double glass module (CiS Cells in EVA)

- Typical thin film solar double glass module:
  - Glass front sheet (e.g. in case of CdTe processed)
  - Encapsulant
  - Glass back sheet (e.g. in case of CiGS processed)

6 Source: Deutsche Gesellschaft für Sonnenenergie (DGS; Hrsg.): Leitfaden Photovoltaische Anlagen, Berlin 2008 (3. Auflage, überarb. Nachdruck)

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Basics for the required module reliability

- ✓ requirements for reliable function over 25 years
- ✓ product certification after IECs for applicability and permission of kind of construction (IEC 61646 - thin film and IEC 61215- crystallin) and IEC 61730 (safety qualification)
- ✓ up to 10 years product guarantee
- ✓ up to 25 years electrical performance guarantee (90 % for 10 years, Jahre, 80 % for 20 years, degradationen between 0.3- 1%, higher values in first years for thin film

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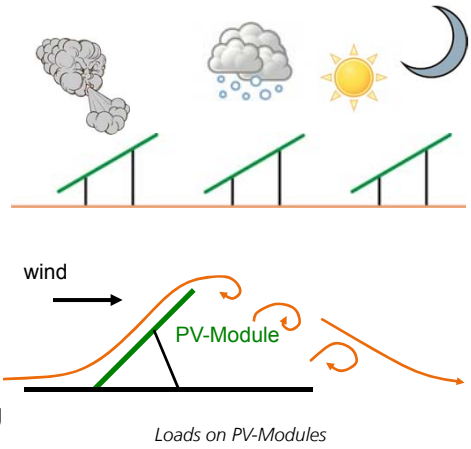
Loads on PV modules

- Loads during production:
  - mechanical (handling)
  - thermo-mechanical (lamination, soldering)
- Loads during operation:
  - static and dynamic mechanical (transportation, handling, wind, snow, ice, hail,)
  - thermo-mechanical (day/ night shift, seasons, operating temperatures)



Loads on PV-Modules

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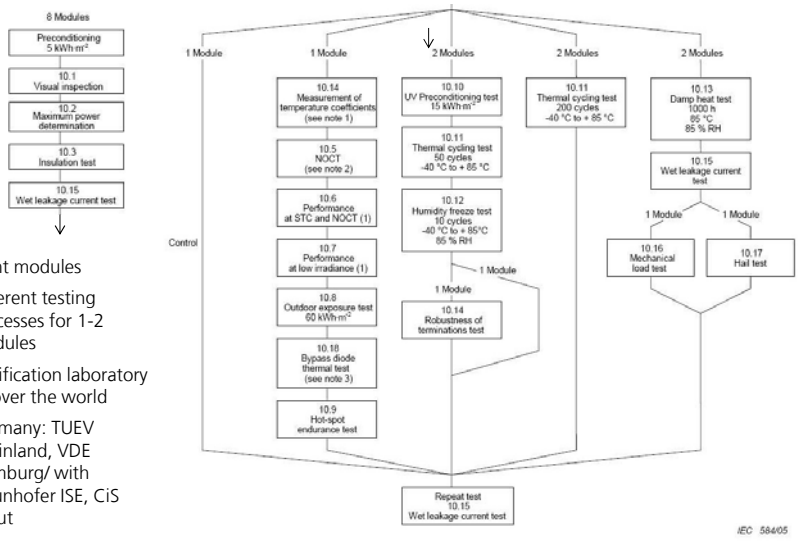
Certification of modules (IEC 61215)



- eight modules
- different testing processes for 1-2 modules
- certification laboratory all over the world
- Germany: TUEV Rheinland, VDE Homburg/ with Fraunhofer ISE, CiS Erfrut

Source: IEC 61215 : 2005 Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval

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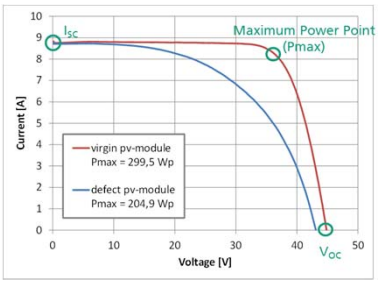
Power Measurement of PV-Modules



indoor IV-curve measurement under (STC)

Short Circuit Current I_{SC}, Open Circuit Voltage V_{OC},

Maximum Power Point (MPP) P_{max}

- **Standard measurement procedure** for electrical module evaluation according to IEC 60904-1.
- Characterization is done with a **pulsed solar simulator** (artificial light source).
- The measurements are done under defined & repeatable conditions **(STC - Standard Test Conditions)**.
  - Irradiance: E = 1000 W/m²
  - Temperature: T = 25°C
  - Spectrum: AM1.5
- **Procedure:**
  - connection of a variable electrical load to the pv module
  - load passes through every operating point during a defined flash of a **pulse duration of 10 ms** from short circuit until open circuit
  - I-V measurements in every operating point (volt- & ampere meter)

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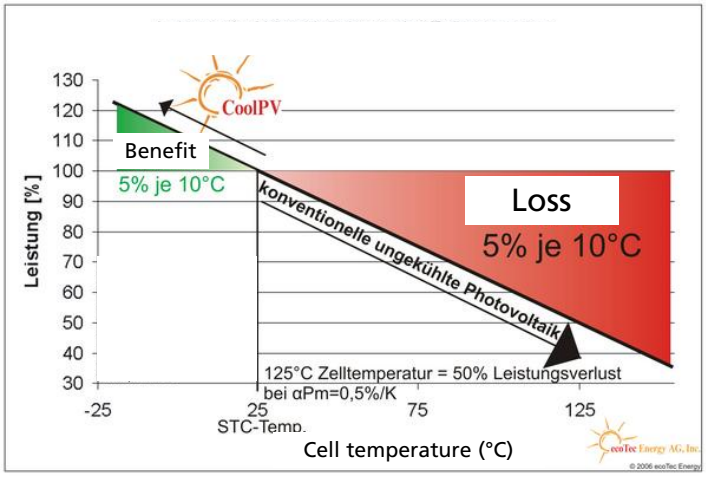
Power in dependece of cell temperature- the temperature coefficient



http://ecotec-energy.com/gekuehlte_photovoltaik/leistungsverlust.htm

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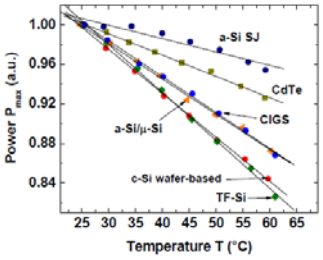
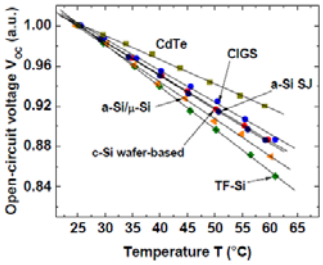
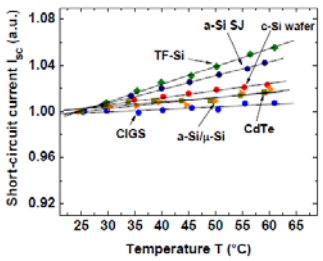
Temperature behaviour of different PV-Technologies





TCO's	Pmax γ_{rel} (%/°C)	Voc β_{rel} (%/°C)	Isc α_{rel} (%/°C)	FF κ_{rel} (%/°C)
Error	± 0.027	±0.021	±0.019	-
a-Si (SJ)	-0.13	-0.33	+ 0.12	+ 0.10
CdTe	-0.21	-0.24	+ 0.04	- 0.01
Microm. (a-Si/µcSi)	-0.36	-0.37	+ 0.05	- 0.04
CIGS	-0.36	-0.31	+ 0.02	- 0.08
c-Si wafer-based	-0.45	-0.33	+ 0.06	- 0.19
TF - Si	-0.48	-0.41	+ 0.15	- 0.22



- *P_{max}, V_{OC}, I_{SC} as a function of temperature for different pv-technoloies.*
- *For comparison the values are normalized to STC values.*
- *Linear fits to these data provide the relative temperature coefficient (slope corresponds to the temperature coefficient).*
- *Temp. coefficients are measured according to IEC 61215 (c-Si) & IEC 61646 (Thin-Film)*

Source: A. Virtuani et all, Overview of temperature coefficients of different thin film photovoltaic technologies, in Proc. Of the 25th EU-PVSEC, Valencia 2010

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Modules in extreme climates of Siberia and Central Asia

- Adapted module structure and indoor qualification beyond the IEC is necessary
- Testing temperature cycles for lower temperatures
- Mechanical test under temperature in the climate chamber
- Effects on the module (assessed for the region), parts of modules and the challenges are shown in the next table

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	frame	glass	encap-sulant	back-sheet	inter-connect	cell layout	junction box	subcon-struciton
abrasion =	-	surface hardness	-	-	-	-		
snow ↑	mechanics	mechanics	-	-	-	-		
temperature winter ↓ summer ↑	-	-	mechanics	mechanics	-	cell technology	mechanics	mechanics
Tempera-ture changes ↑	mechanics	-	material	-	mechanics	cell technology		
humidity =	-	-	material	material	-	-		
light intensity =	-	ARC	-	back reflection	Rs losses, LHS	-		
UV =	-	ARC	material	material	-	cell technology		

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PV Test Field Development in Siberia
Motivation

- For PV module development in a global context, the indoor & outdoor characterization in the region is necessary.
- A better understanding of the behavior of different pv module technologies and systems under extreme outdoor conditions leads to an accelerated development of solar power use in the country.
- It is a first step to establish decentralized systems to achieve the energy demand of the rural population.

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Concept for a test field

First Step:

- Conception and Design of a outdoor test site for solar modules and module like samples
- Support of the technical implementation of the test field

Second Step:

- Systematic outdoor testing of PV modules and material samples
- Performance testing of solar modules
- Material testing regarding aging behavior
- Performance testing of solar modules connected to the power plant

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Data Analysis

$$E_{specific} = \frac{E_{module}}{P_{module,STC}}$$

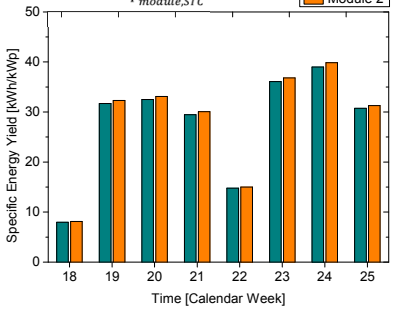

Fig. 1: Specific energy yield is displayed for two modules, aggregated per Calendar Week.

$$PR = \frac{E_{module} \times G_{STC}}{P_{module,STC} \times E_{irradiance}}$$

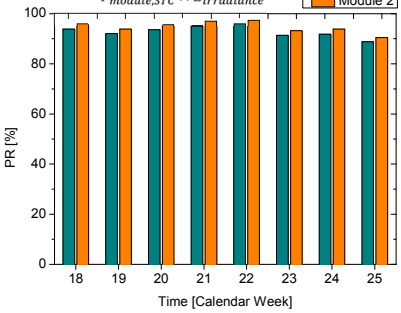

Fig. 2: Performance ratio (PR) is displayed for two modules, aggregated per Calendar Week. PR on module level was determined with reference cell irradiance measurements in plane of module array.

Parameter	Description
$E_{specific}$	Specific Energy Yield [kWh/kWp]
PR	Performance Ratio [%]
E_{module}	energy yield of the module [kWh]
G_{STC}	irradiance at STC [kW/m²]
$P_{module, STC}$	indoor measured power of the [kWp]
$E_{irradiance}$	energy of the outdoor measured irradiance [kWh/m²]

Tab.: Description of used parameters

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Outdoor testing

- Cooperation Fraunhofer CSP & Moroccan Research Institute IRESEN
  Institut de Recherche en Energie Solaire et Energies Nouvelles
- "Development of outdoor research measuring set-ups and tests on photovoltaic modules"

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IRESEN

http://www.csp.fraunhofer.de/presse-und-veranstaltungen/details/id/65/

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Yield forecasts of PV-systems for Siberia and Central Asia
Introduction

PV-module yield is the power output of the module in a space of time

PV-system yield is the energy output behind the inverter

PV-module power is the product of the solar irradiance on the PV-module plane and the efficiency of the module

PV-system power is PV-module power multiplied with loss factors of the system especially the inverter

Efficiency of PV-modules is a function of STC-efficiency, module temperature and irradiance*

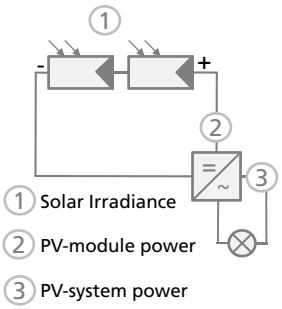

Fig. 1: Definitions of power terms for PV-systems.

*Wind speed, irradiance and temperature are hourly data in local resolution of 1°; Source: Reiner Lemoine Institute gGmbH in cooperation with Deutsches Luft- und Raumfahrtzentrum, data based on meteonorm (global, 1 hour resolution)

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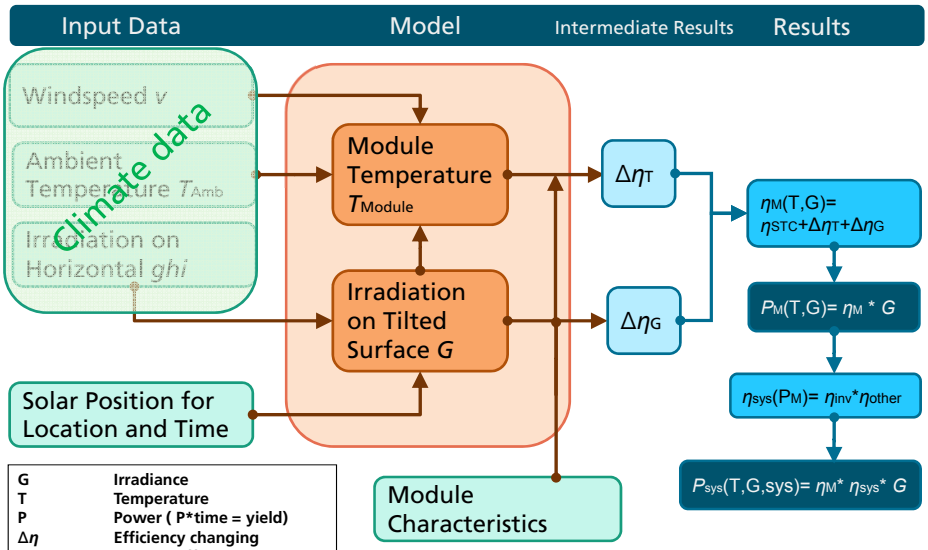
Model Structure



G	Irradiance
T	Temperature
P	Power (P*time = yield)
$\Delta\eta$	Efficiency changing
η_M	Module efficiency
η_{Sys}	System efficiency

Source: H. Müller, Weltweite Modellierung des Ertragsverhältnisses verschiedener Photovoltaik-Module, Master thesis TU Berlin, 2012

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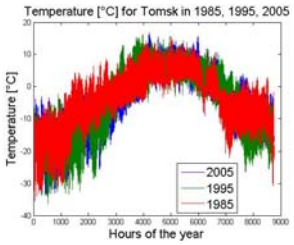
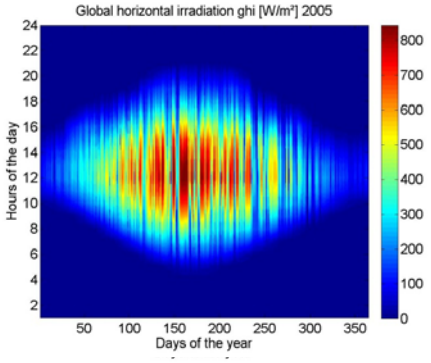
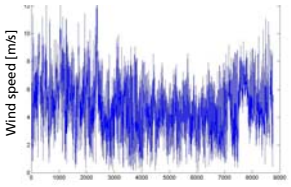
Climate data Tomsk





Wind speed hourly mean values [m/s] in Tomsk 2005



Weather in Siberia is known for **deep temperatures** in winter time, **less humidity** and, relative to other locations at this latitude, a **high solar irradiation** over a long period.
Irradiation of different years gives a picture of **variability of solar irradiation.**

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Source: Reiner Lemoine Institute gGmbH in cooperation with Deutsches Luft- und Raumfahrtzentrum, data based on meteonorm

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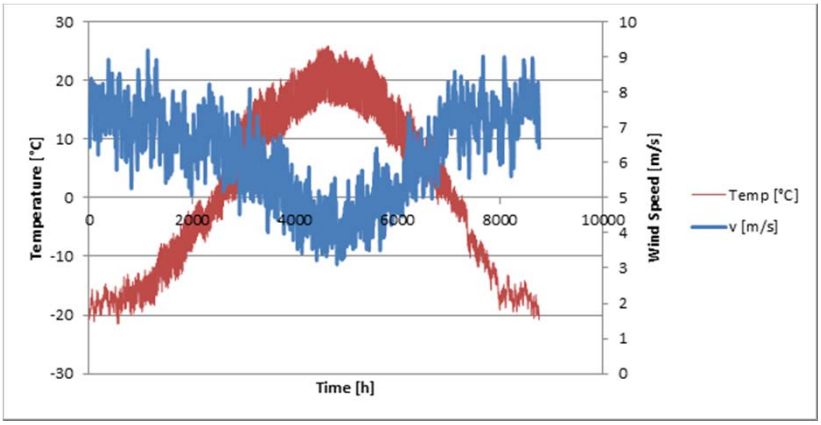
Average climate values over 20 years in Tomsk



Average over 20 years (1985 - 2005) of hourly data:
Data of wind speed and temperature shows possible complementary behaviour of PV and wind power.

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Source: Reiner Lemoine Institute gGmbH in cooperation with Deutsches Luft- und Raumfahrtzentrum, data based on meteonorm

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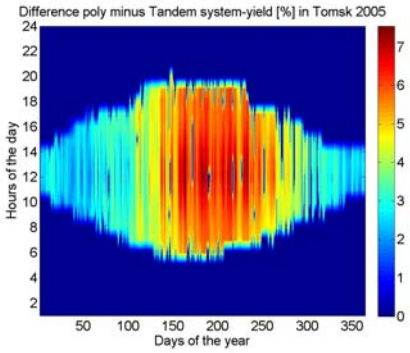
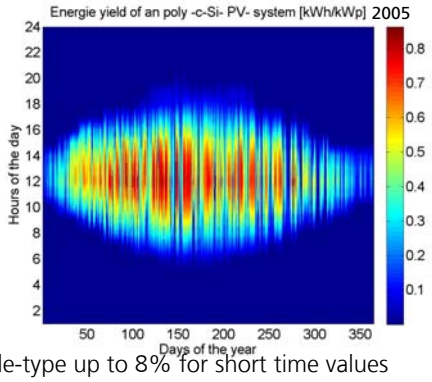
Simulated PV-system yields for different years and module types in Tomsk (Siberia)

Yield difference between **poly c-Si** and **Tandem** modules 2005*



PV-system yield of **poly c-Si** modules (Q-Cells) for **1985, 1995** and **2005***



- PV-system yields differ by year and module-type up to 8% for short time values
- Poly-modules earn around 5% more yearly yield per kWp as thin film Tandem modules.

**Yield calculation based on data from Reiner Lemoine Institute gGmbH in cooperation with DLR, data based on meteonorm*

Source: H. Müller, Weltweite Modellierung des Ertragsverhältnisses verschiedener Photovoltaik-Module, Master thesis TU Berlin, 2012

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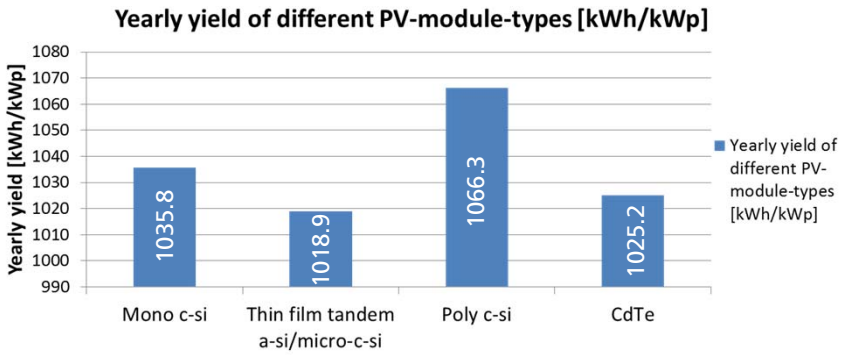
Comparison of yearly yields of 4 different module types in Tomsk (Siberia), year 2005



Module type poly c-Si shows the best yearly yield. The **yields** of the module types **differs** by the **temperature and low light behavior** of the measured modules.

Source: H. Müller, Weltweite Modellierung des Ertragsverhältnisses verschiedener Photovoltaik-Module, Master thesis TU Berlin, 2012

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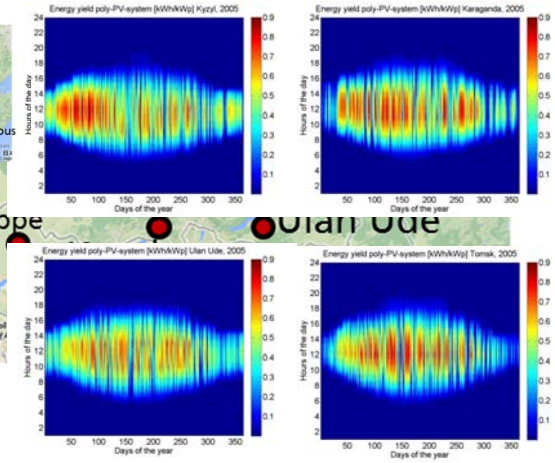
Simulated PV-system yields for different locations in Central Asia



Yearly yield (poly-modules) for the different locations in 2005, starts with top earning location:

1. Kyzyl : 1255.7 kWh/kWp
2. Karaganda: 1221.4 kWh/kWp
3. Ulan Ude: 1163.9kWh/kWp
4. Tomsk: 1066.3 kW/kWp

Karaganda and Kyzyl profit of southernly location. The yearly yield in Kyzyl is around 15% higher than in Tomsk.

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Source: H. Müller, Weltweite Modellierung des Ertragsverhältnisses verschiedener Photovoltaik-Module, Master thesis TU Berlin, 2012

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Other sources for Siberian weather data

Without costs

- DWD (monthly values of temperature and sunshine duration, global): http://www.dwd.de/bvbw/appmanager/bvbw/dwdwwwDesktop?_nfpb=true&_pageLabel=_dwdwww_klima_umwelt_klimadaten_deutschland&T82002gsbDocumentPath=Content%2FOeffentlichkeit%2FKU%2Fallgemeines%2Fklimadaten__weltweit%2Fdownload__xlsdatei.html
- Data wind speed and temperature in 6-hour resolution (global) http://meteo.infospace.ru/wcarch/html/e_day_stn.sht?stn=1921
- Climate data maps for Asia : http://www.meteocentrale.li/de/wetter/profiwetter/niederschlag/asien.html
- University Tomsk (for Tomsk, 1 hour resolution, global horizontal irradiation (ghi), wind speed, temperature, pressure …): http://lop.iao.ru/activity/?id=tor http://lop.iao.ru/activity/?id=eye1993

With costs

- http://solargis.info/doc/3 (ghi, direct normal irradiation (dni), temperature, wind speed, possible 15 minute data)
- http://meteonorm.com (ghi, dni, temperature, wind speed)

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Acknowledgement

to the “Reiner Lemoine Institut” Berlin for the support with climate and yield data

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Folie 27

froe10 Layout überarbeitet
Jens Fröbel; 07.10.2013