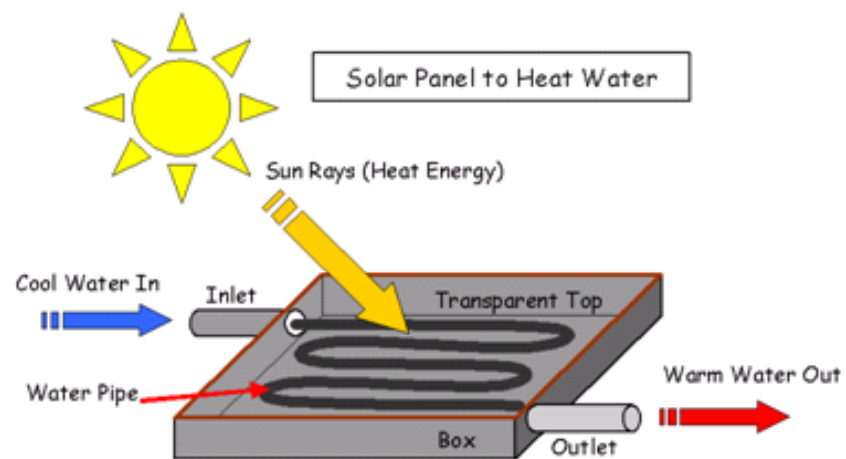
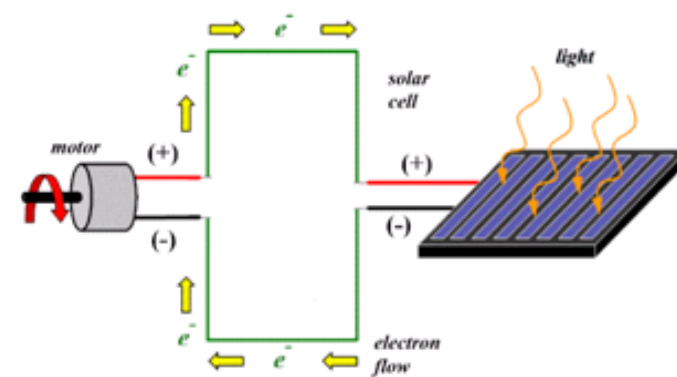


# **Solar energy and climatology**

**Robert Pasicko, UNDP**



Solar Cell Circuit



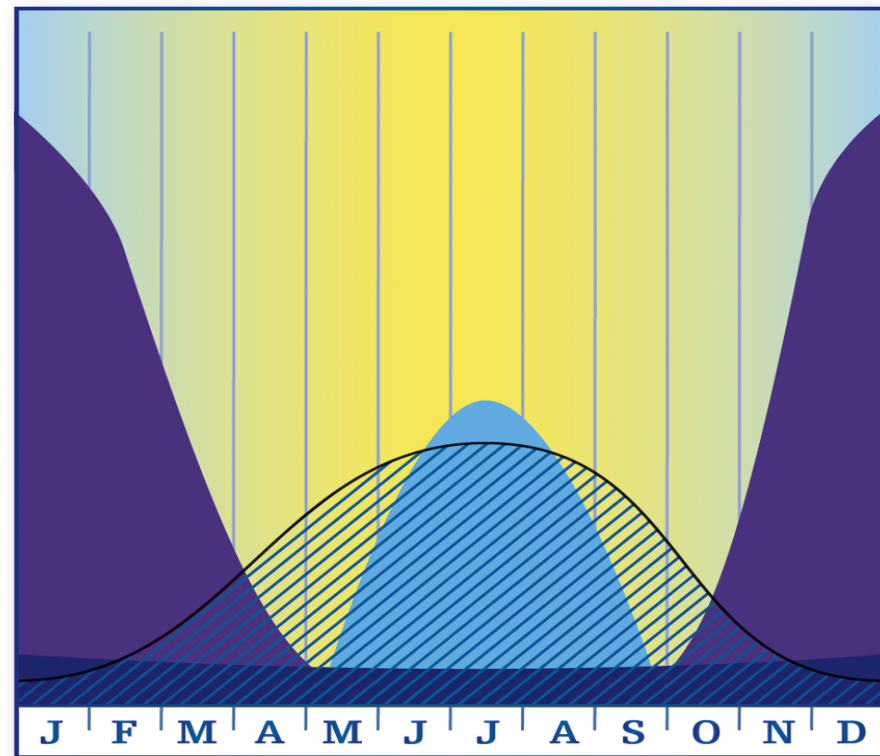
Copyright © 2004 [www.makeitsolar.com](http://www.makeitsolar.com) All rights reserved.





**EXAMPLE:**  
Correlation between hot  
water demand and  
irradiated solar energy



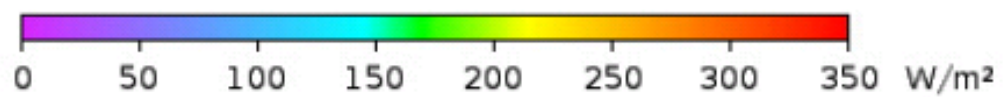
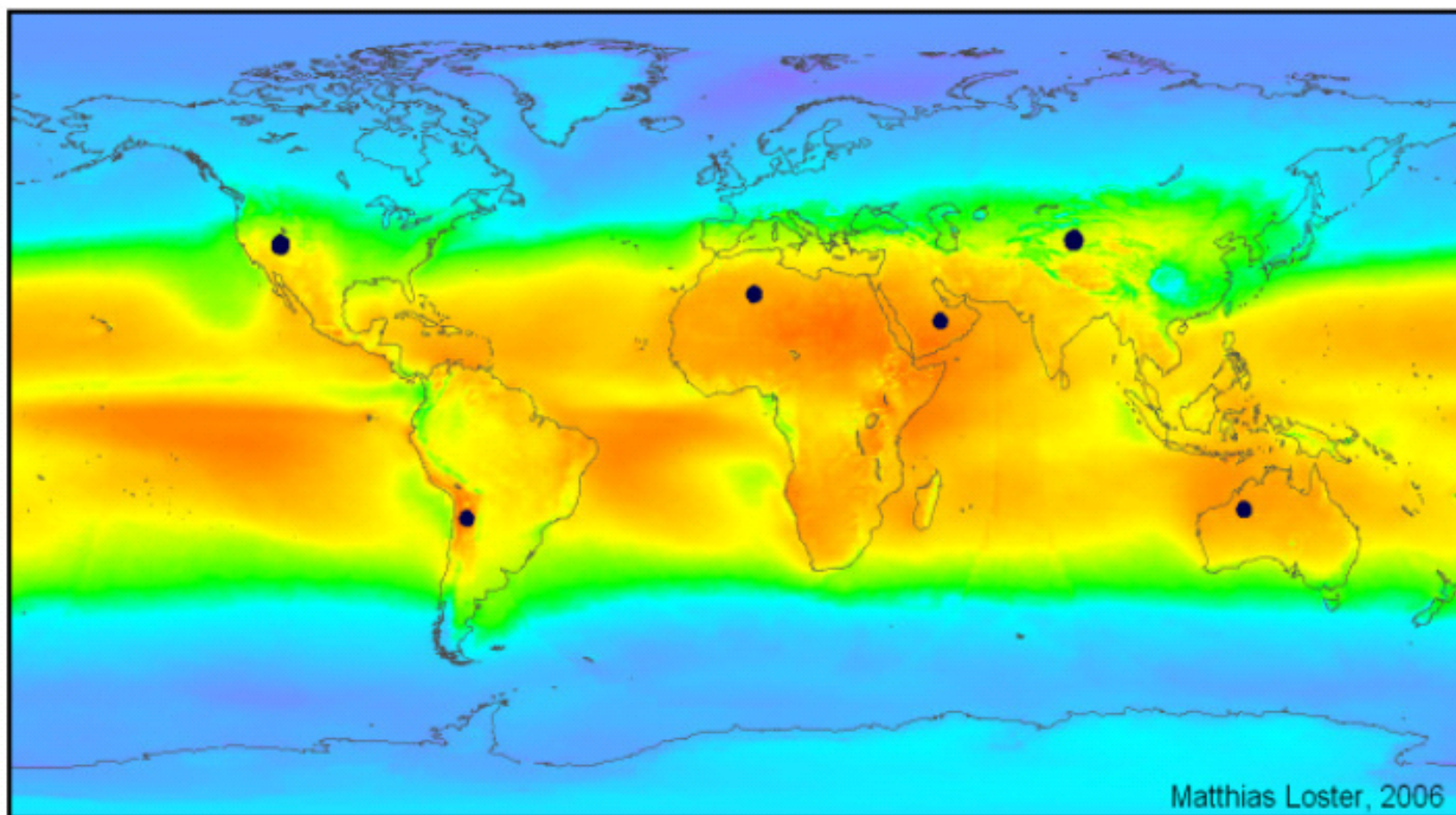
European  
Solar  
Thermal  
Industry  
Federation

Solar cooling & heating system: demand & supply



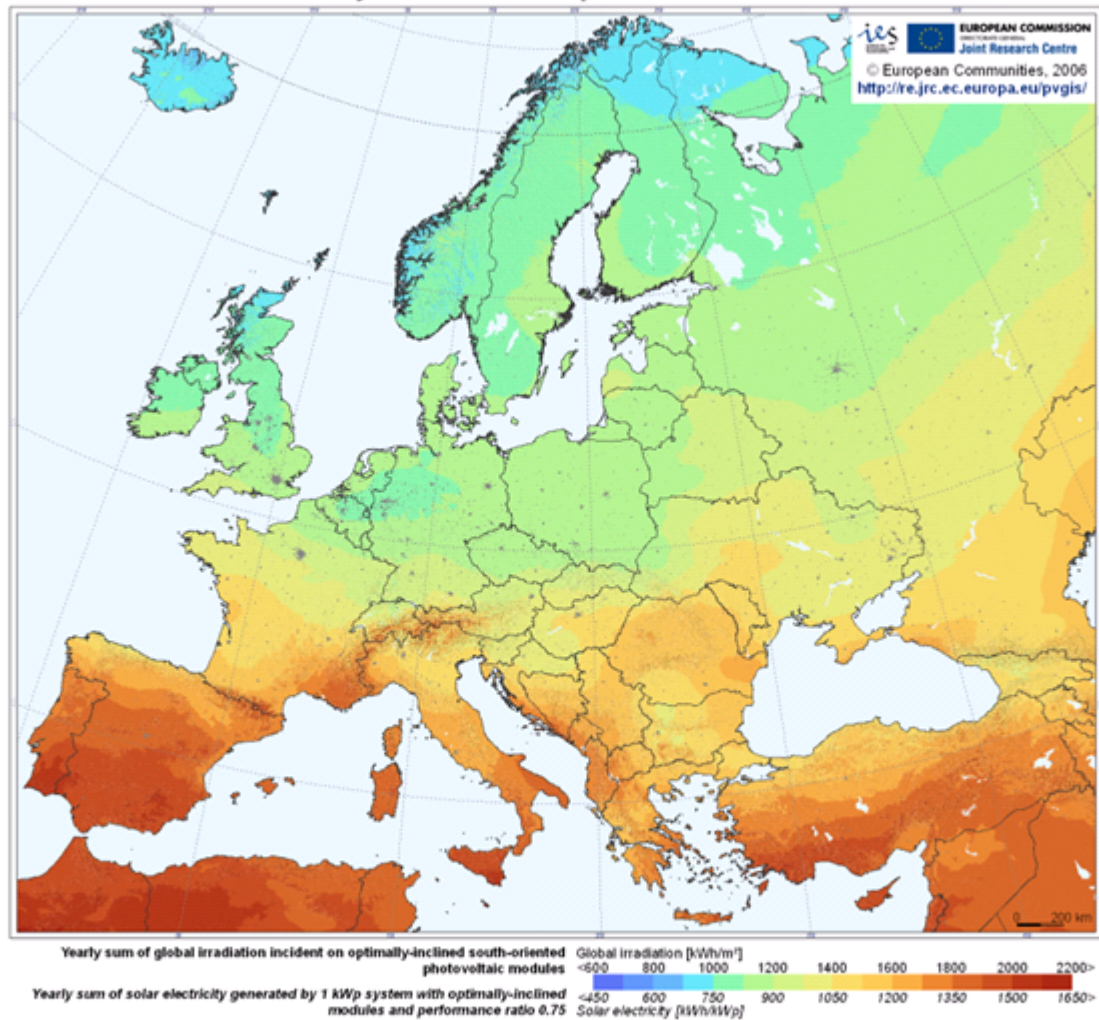
-  Solar collector yield
-  Domestic hot water demand
-  Space heating demand
-  Cooling demand

Solar thermal can cover a substantial part of the heating and cooling demand in a typical Central European building.



$\Sigma \bullet = 18 \text{ TWe}$

### Photovoltaic Solar Electricity Potential in European Countries

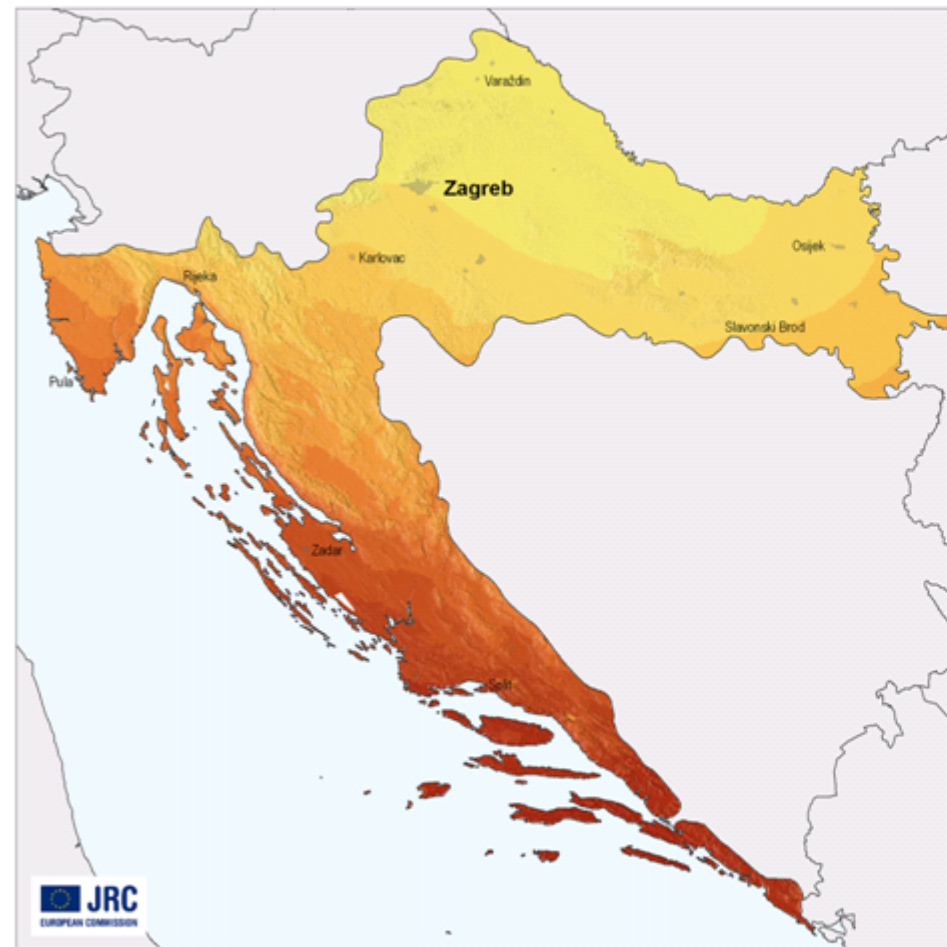


Šúri M., Huld T.A., Dunlop E.D. Ossenbrink H.A., 2007. [Potential of solar electricity generation in the European Union member states and candidate countries](#). *Solar Energy*, 81, 1295–1305, <http://re.jrc.ec.europa.eu/pvgis/>.



**Global irradiation and solar electricity potential  
Optimally-inclined photovoltaic modules**

**Croatia**



Yearly sum of global irradiation [ $\text{kWh/m}^2$ ]

1300 1400 1500 1600 1700 1800 1900  
975 1050 1125 1200 1275 1350 1425

Yearly electricity generated by  $1\text{kW}_{\text{peak}}$  system with performance ratio 0.75 [ $\text{kWh/kW}_{\text{peak}}$ ]

Authors: M. Šuri, T. Cebecauer, T. Huld, E. D. Dunlop  
PVGIS © European Communities, 2001-2008  
<http://re.jrc.ec.europa.eu/pvgis/>

0 25 50 km

25 postaja za Hrvatsku

Global irradiation [ $\text{Whm}^{-2}$ ] ,monthly  
means, 1981-1990

Sunshine duration [hours] ,monthly  
means, 1981-1990

Sunshine duration, monthly, 1981-1990

Izvor podataka: European Solar Radiation Atlas  
(ESRA, 2000, Ecole des Mines de Paris), glavnina  
podataka za razdoblje 1981–1990.

<http://re.jrc.ec.europa.eu/pvgis/>

# Interactive map for identifying solar energy potential

http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php#

JRC CM SAF Photovoltaic Geographical Information System - Interactive Maps

EUROPA > EC > JRC > IE > RE > SOLAREC > PVGIS > Interactive maps > europe

Search: e.g., "Ispra, Italy" or "45.256N, 16.9589E"

cursor position: 44.822, 16.040  
selected position: 45.055, 13.920

Monthly radiation

Monthly global irradiation data

Radiation database: Classic PVGIS

☒ Horizontal irradiation  
☐ Irradiation at opt. angle  
☐ Irradiation at chosen angle: 90 deg.  
☐ Linke turbidity  
☐ Dif. / global radiation  
☐ Optimal inclination angle

Monthly ambient temperature data

☐ Average daytime temperature  
☒ Daily average of temperature  
☐ Number of heating degree days

Output options

☐ Show graphs ☐ Show horizon  
☒ Web page ☐ Text file ☐ PDF

Calculate [help]

Monthly Solar Irradiation

PVGIS Estimates of long-term monthly averages

Location: 45°3'19" North, 13°59'10" East, Elevation: 276 m a.s.l.

Solar radiation database used: PVGIS-classic

Optimal inclination angle is: 35 degrees  
Annual irradiation deficit due to shadowing (horizontal): 0.0 %

Month	$H_h$	$T_{24h}$
Jan	1390	3.3
Feb	2090	4.0
Mar	3290	7.6
Apr	4540	11.2
May	5410	16.3
Jun	6410	20.2
Jul	6670	22.1
Aug	5660	22.1
Sep	4300	17.7
Oct	2540	14.2
Nov	1560	9.0
Dec	1080	4.7
Year	3750	12.7

$H_h$ : Irradiation on horizontal plane (Wh/m<sup>2</sup>/day)  
 $T_{24h}$ : 24 hour average of temperature (°C)

PVGIS © European Communities, 2001-2010  
 Reproduction is authorised, provided the source is acknowledged  
 See the disclaimer [here](#)

© European Union, 1995-2011

<http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php#>

# Softwares available for using solar energy potential

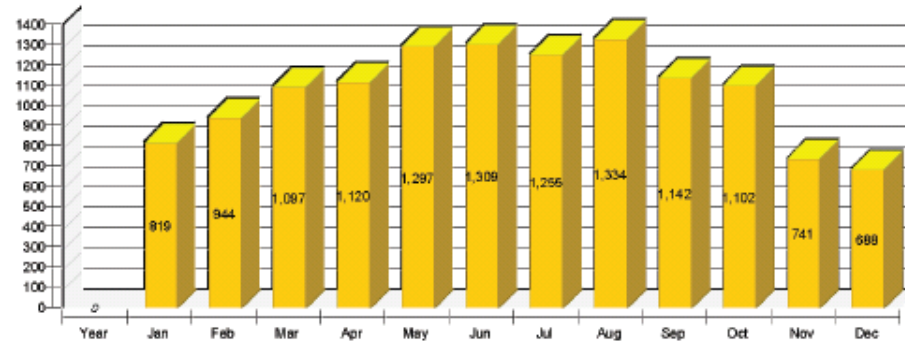
- HOMER
- POLYSUN
- TSOL Pro and PVSOL Pro
- Sunnydesign
- PVSYST
- ...



# POLYSUN (solar thermal)

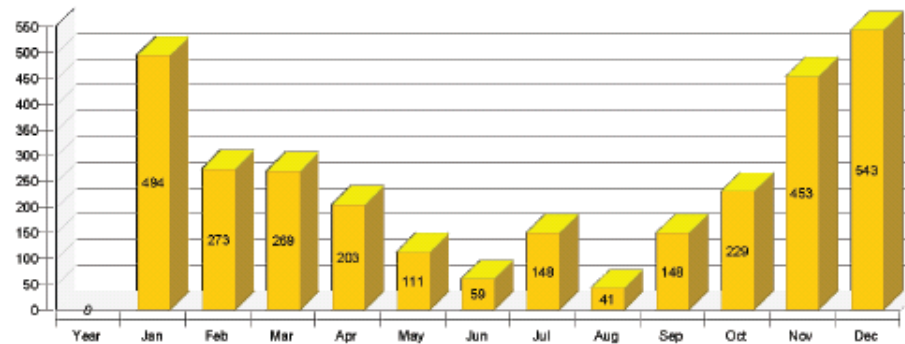
Solar energy to the system [Qsol]

kBtu



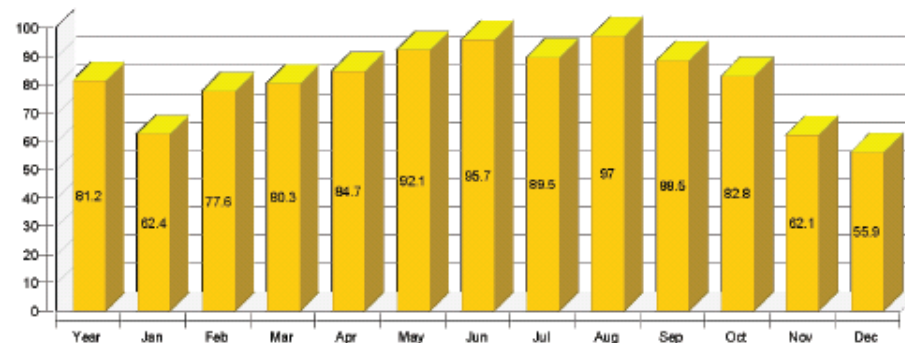
Auxiliary energy to the system [Qaux]

kBtu



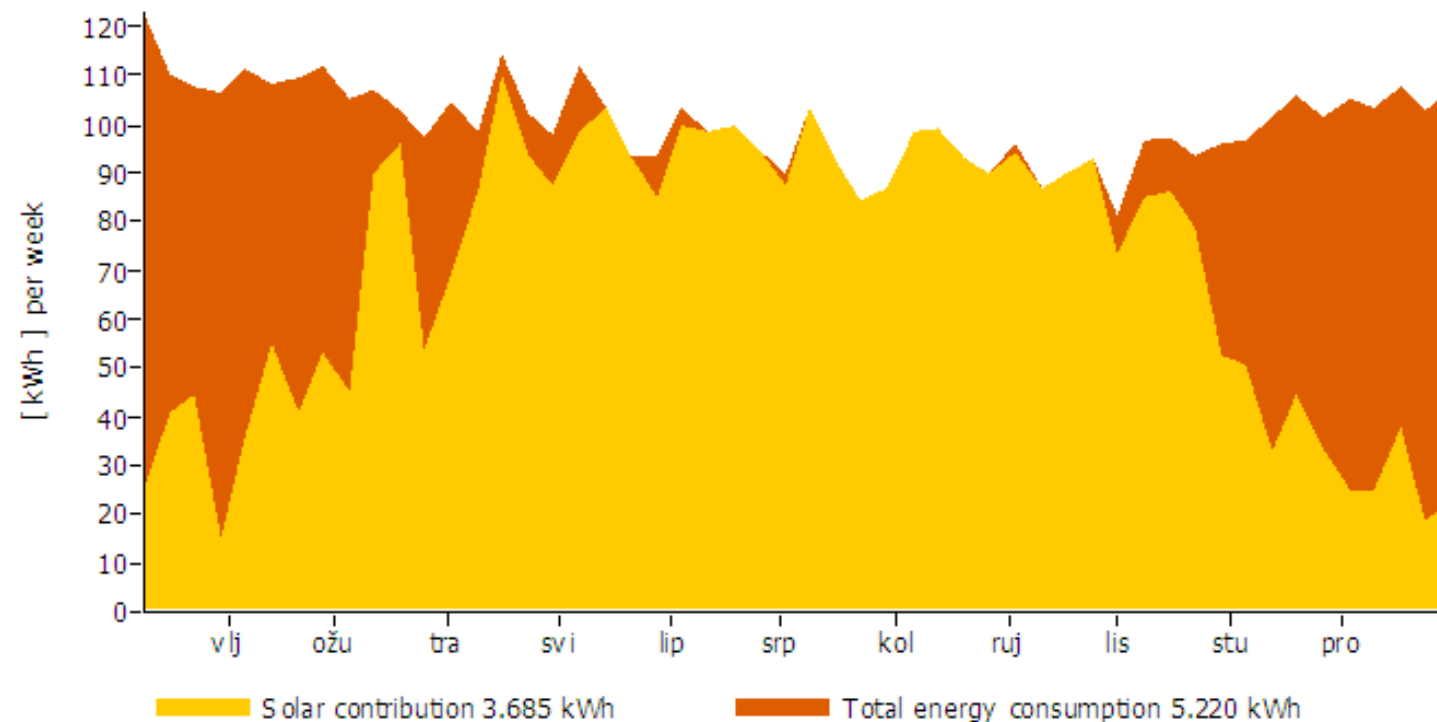
Fraction of solar energy to system (net) [SFn]

%



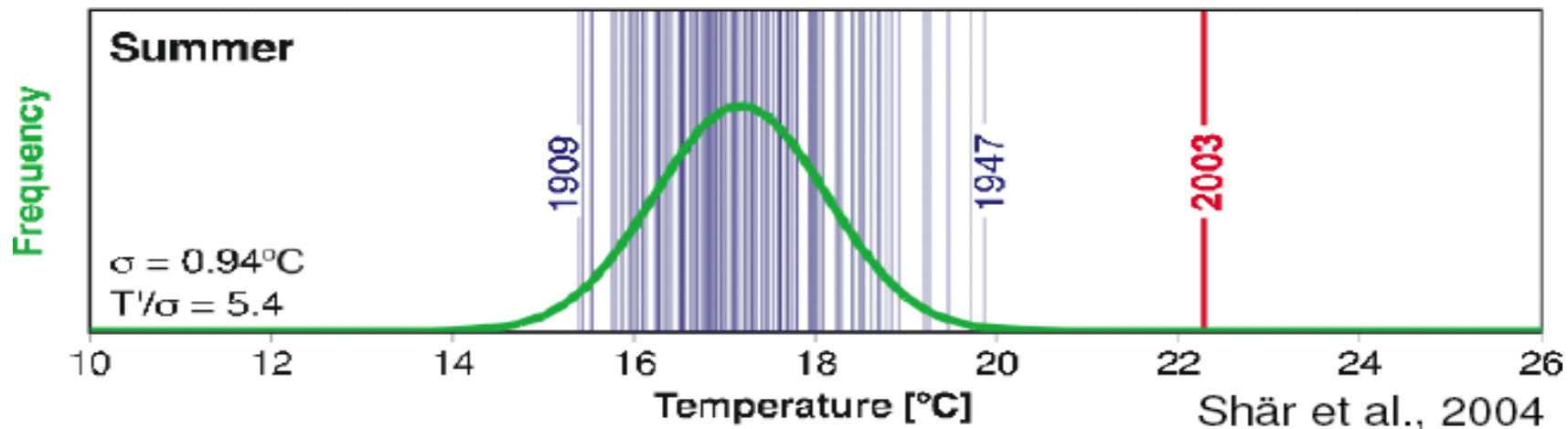
# TSOL Pro and PVSOL Pro (using METEOSyn)

## Solar energy consumption as percentage of total consumption



# Photovoltaics – impact from CC

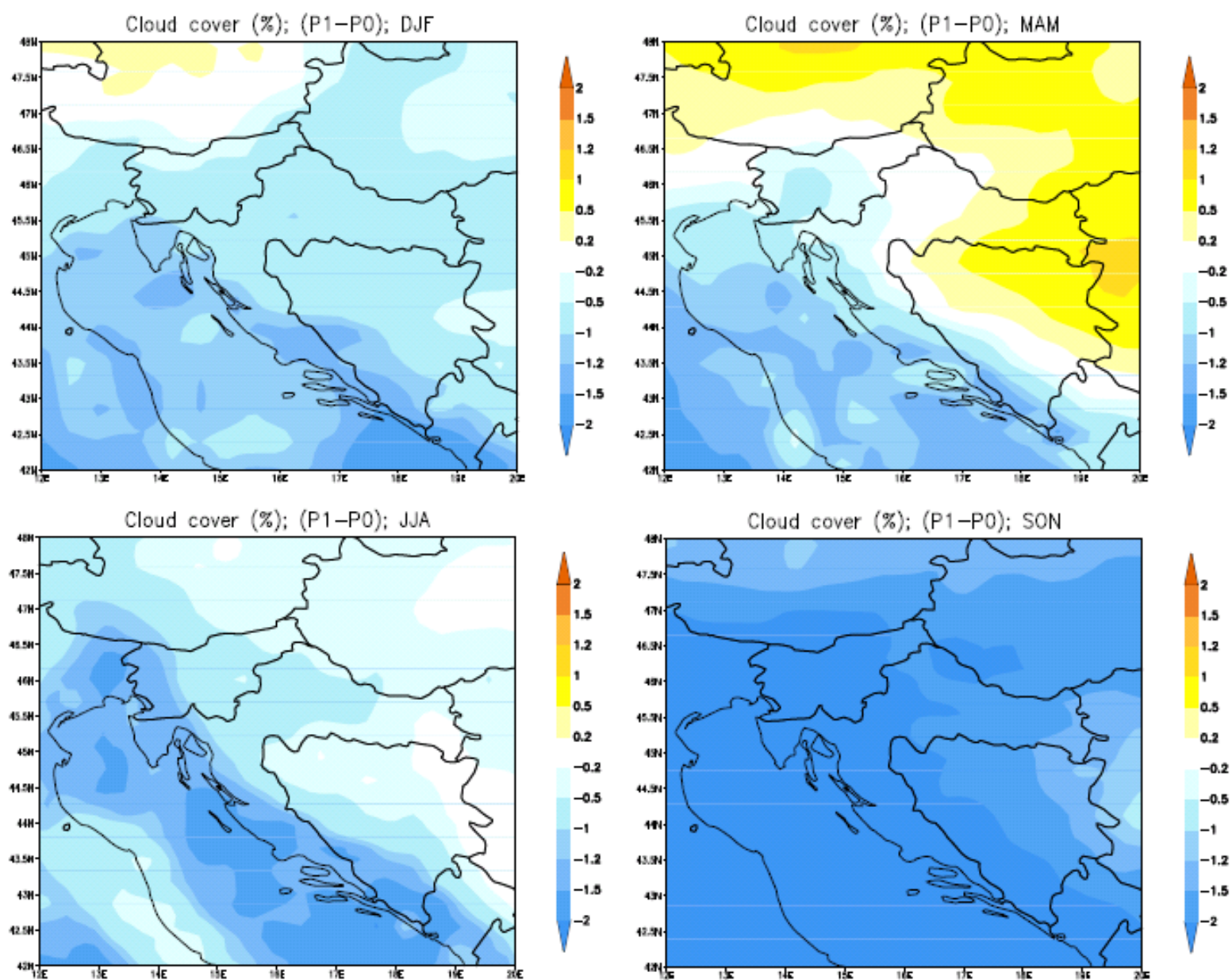
- Temperature
- Number of days under snow cover
- Annual irradiated energy
- Extreme events



# GHI - Global Horizontal Irradiance

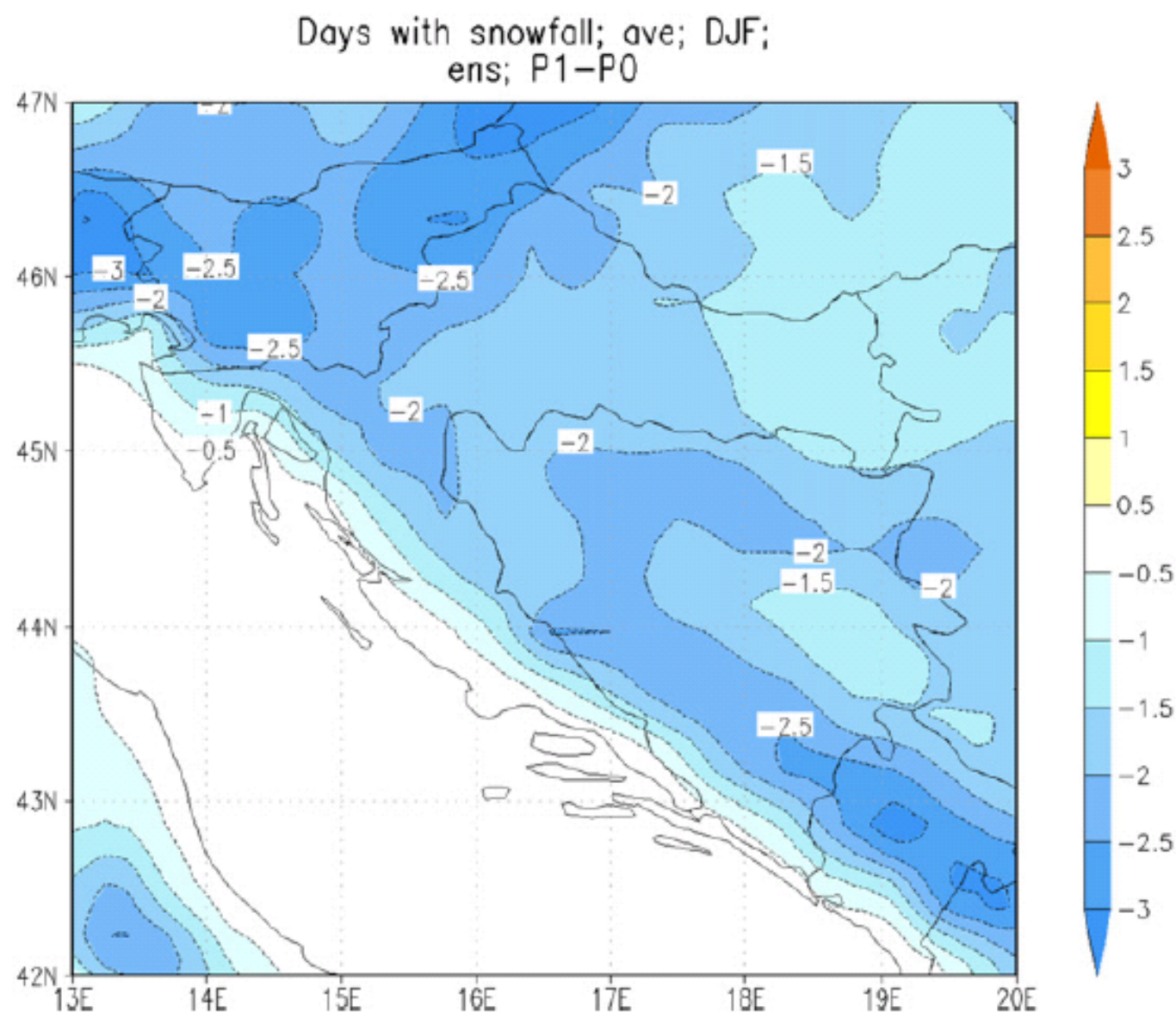
## Global Horizontal Irradiance

- A sum of Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DIF)
- Mostly influenced by cloudiness
- **Less precipitation** (rain and snow) generally leads to lower cloudiness and more direct irradiation



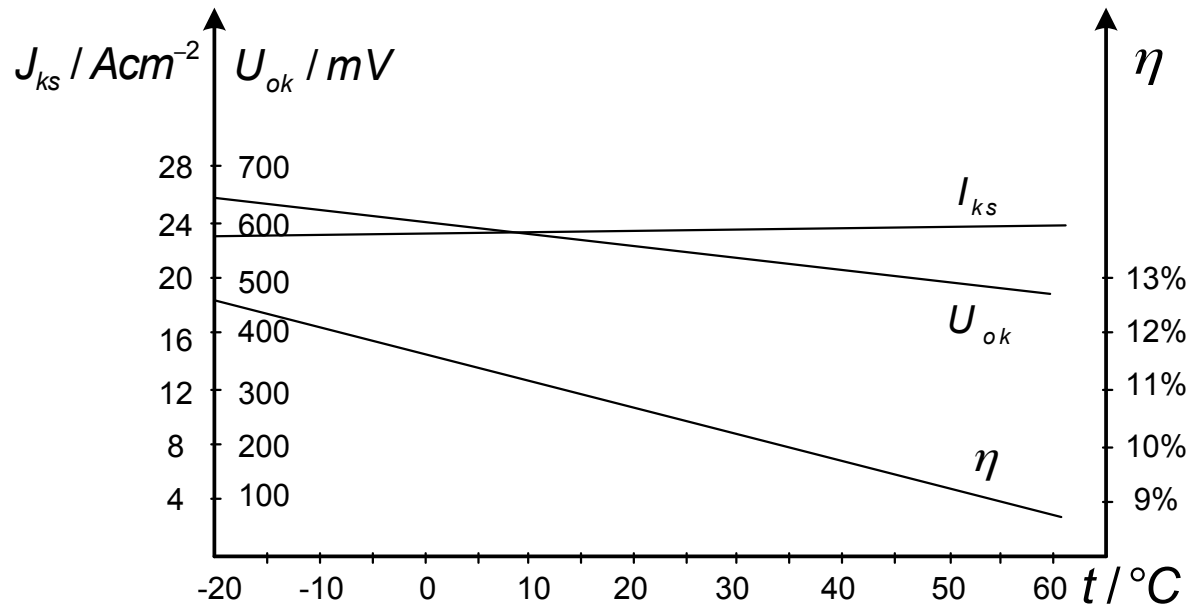
**Fig. 1.** Cloud-cover change (in %) due to climate change in the period between 2011 and 2040 (P1) when compared to 1961–1990 (P0), for different seasons (DJF: December–February, MAM: March–May, etc), with A2 IPCC scenario.





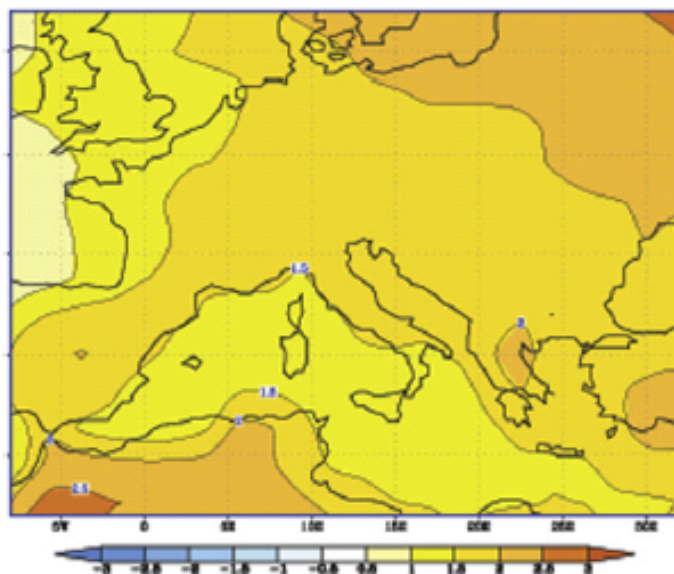
**Fig. 4.** Change in number of days with snowfall due to climate change in the period between 2011 and 2040 (P1) when compared to 1961–1990 (P0), for December–February (DJF), with A2 IPCC scenario [8].

# PV – temperature impacts

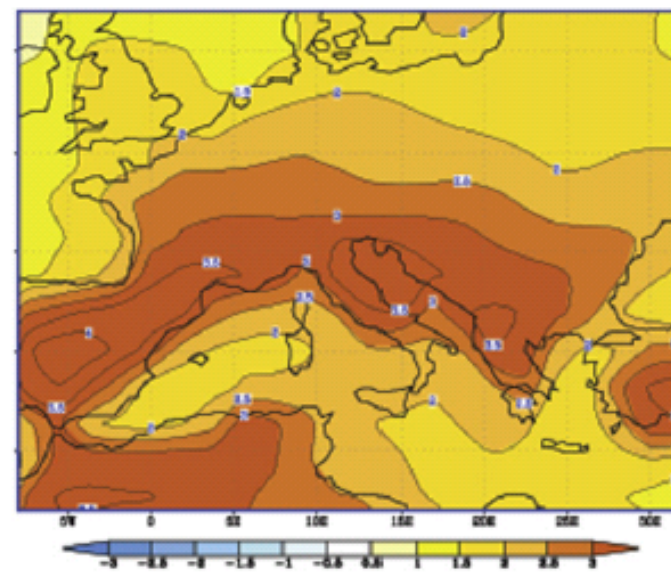


- “Cell temperature coefficients” differ according to technology and producer (efficiency, power, current, voltage)
- For silicon based cells, for each  $^{\circ}\text{C}$  temperature rise - efficiency lowers for 0,5%
- For thin film technology, this factor is 0,3%

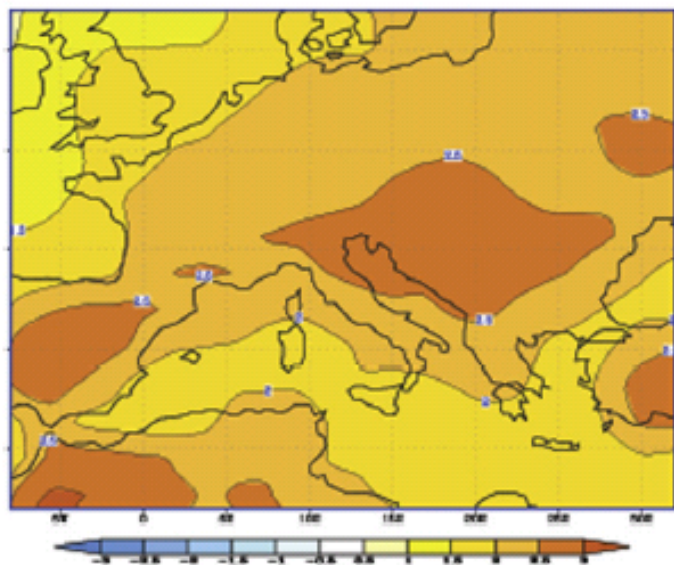
Spring



Summer



Autumn



Winter

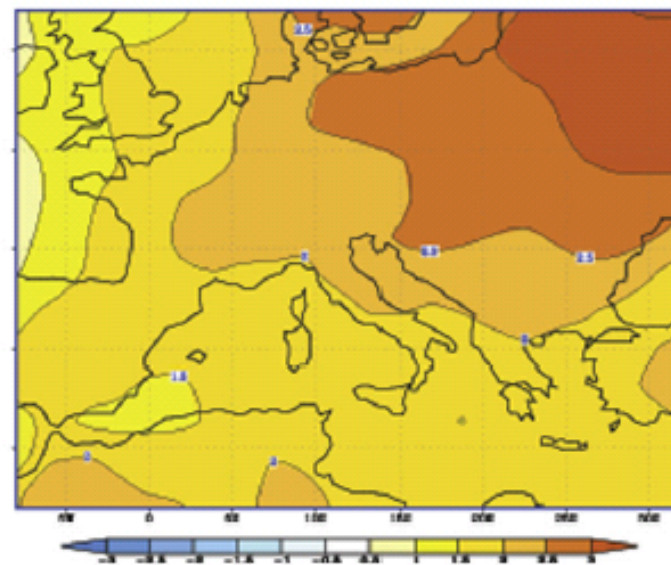
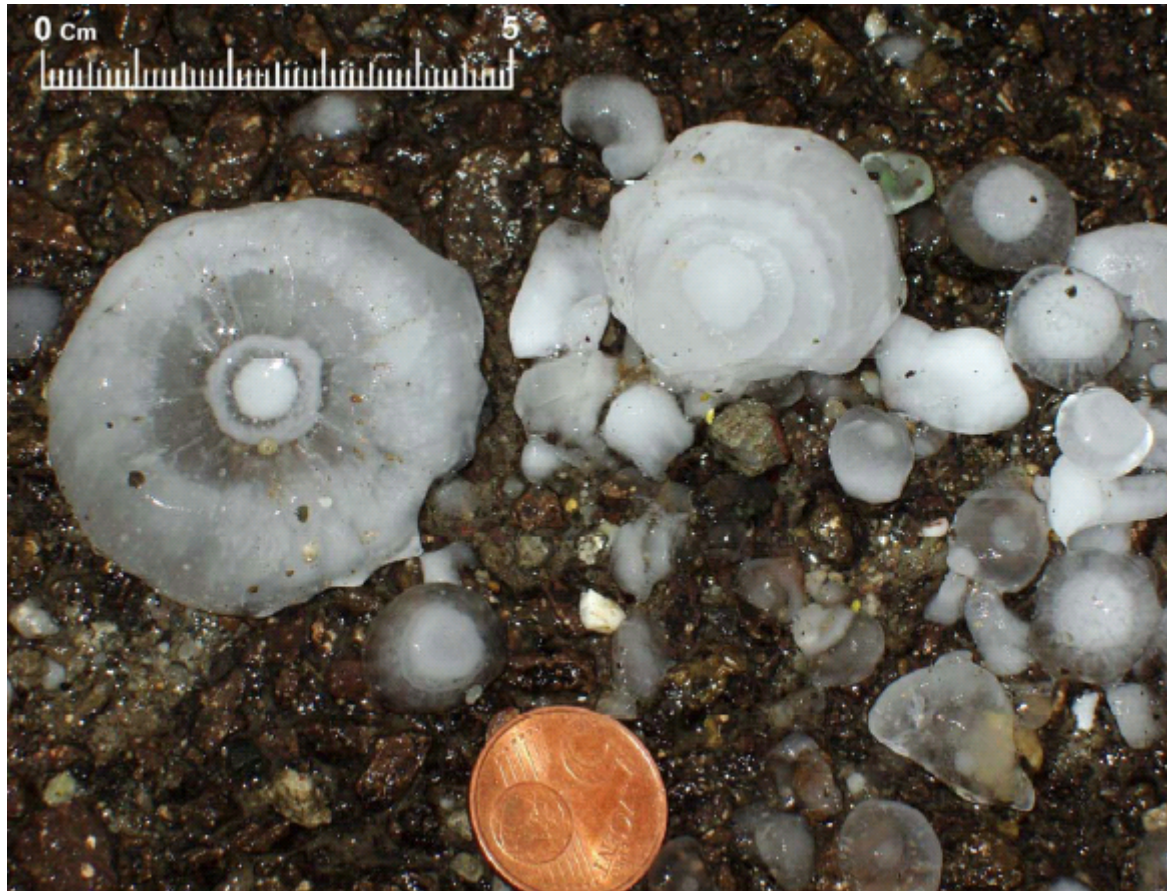


Fig. 2. Comparison of the changes in an average temperature between the period 1961–1990 and period 2041–2070 [5].



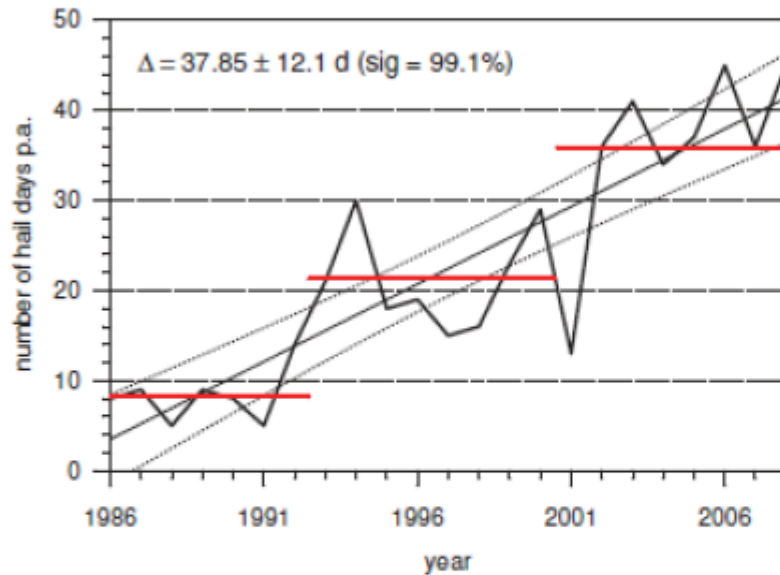
## PV – other impacts



Current standard:  
withstand 11  
impacts  
of 25 mm  
hailstones

# Changes in climate extremes

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Data from southwest Germany  
Kuntz & Mohr, 2009

- 26 - 46% increase in hailstorm damage in the Netherlands associated with a 2°C temperature increase (Botzen et al., 2009)
- No significant change in hailstorm risk for Australia (Niall & Walsh, 2005)



## Technical aspects leading to vulnerability: thermal

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Flat plate



Evacuated tube

## Technical aspects leading to vulnerability: thermal

---

Flat plate	Hailstorm vulnerability low (up to 35mm) Up to 50% loss of efficiency at very low temperatures
Evacuated tube	Hailstorm vulnerability higher (25mm destroys one third) 20% loss of efficiency at very low temperatures

## Technical aspects leading to vulnerability: CSP

---



Tower



Parabolic trough



## Technical aspects leading to vulnerability: CSP

---



# conclusions

## **Temperature**

For an increase in average temperature of 6°C, the efficiency and production of energy would decrease 3 to 5 %

## **Global horizontal irradiance**

Electricity generation increase by 3% during the summer and 1-2% during spring and winter months in the period to 2040.

## **Days under snow cover**

An increase in electricity generation due to less snow on the panels.

## **Extreme weather events**

A cautious choice of locations due to strong winds and forest fires.

## **Hailstorms**

Large-size hail stones can damage some types of PVs