What is the impact of climate change and geoengineering on PV electricity output?

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° they did most of the work

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Solar technology
Temperature and irradiance

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$$P_{\mathrm{pv}} = A_{\mathrm{pv}} G_{\mathrm{tot}} \eta_{\mathrm{cell}}$$

$$\frac{\eta_{\mathrm{cell}}}{\eta_{\mathrm{ref}}} = \left[1 - \beta(T_{\mathrm{cell}} - T_{\mathrm{ref}})\right]\left(1 + \frac{k_{\mathrm{B}} T_{\mathrm{cell}}}{e} \frac{\ln X}{V_{\mathrm{oc}}}\right)$$

For crystalline silicon, $\beta = 0.0045\ \mathrm{K}^{-1}$

Assuming a horizontal panel

Climate change
Temperature

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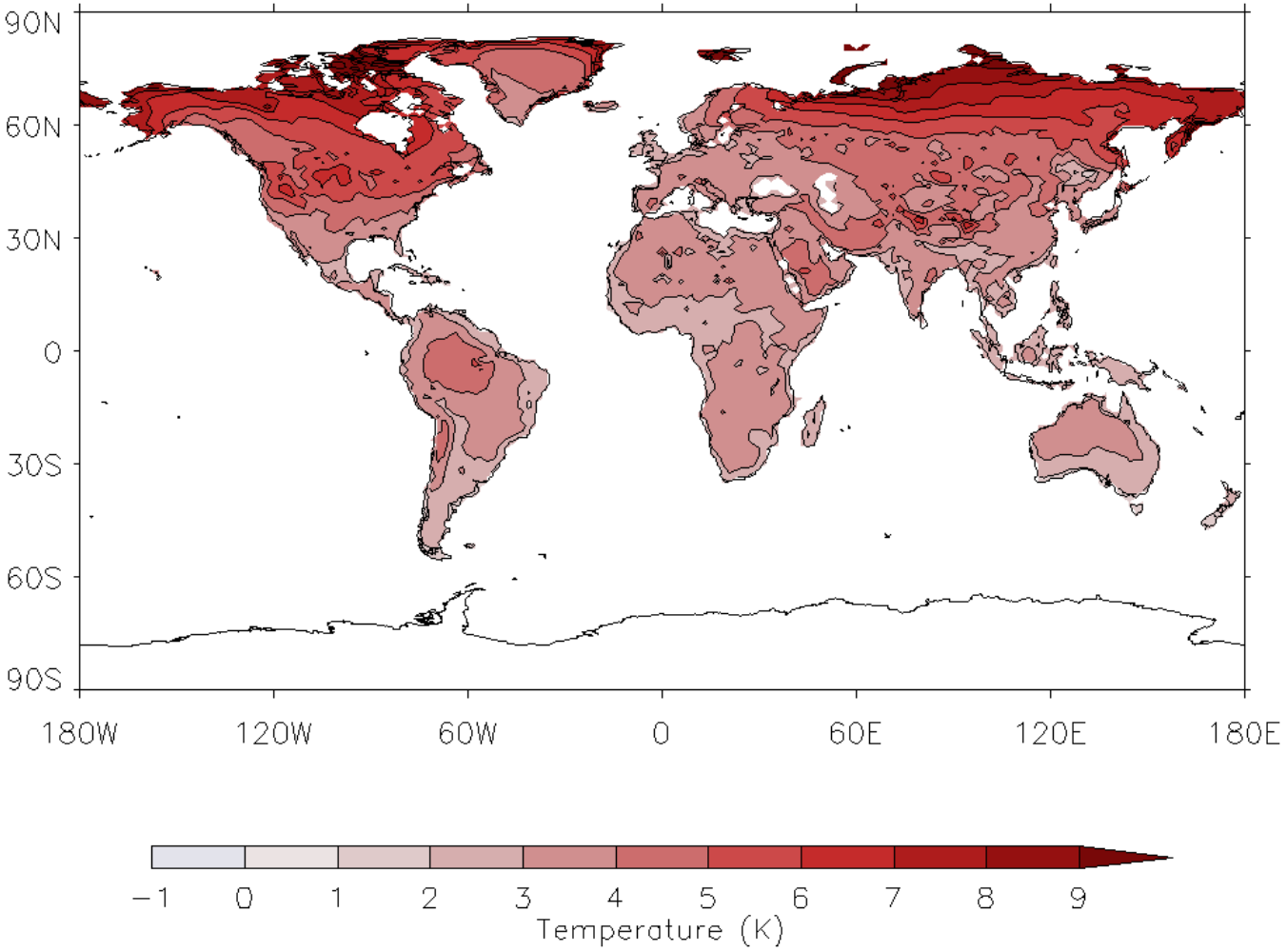
10-year mean centred on 2080. Baseline: 1980 to 1999 mean.



J Crook et al., Energy Environ. Sci., 2011, 4, 3101

Climate change
Direct insolation

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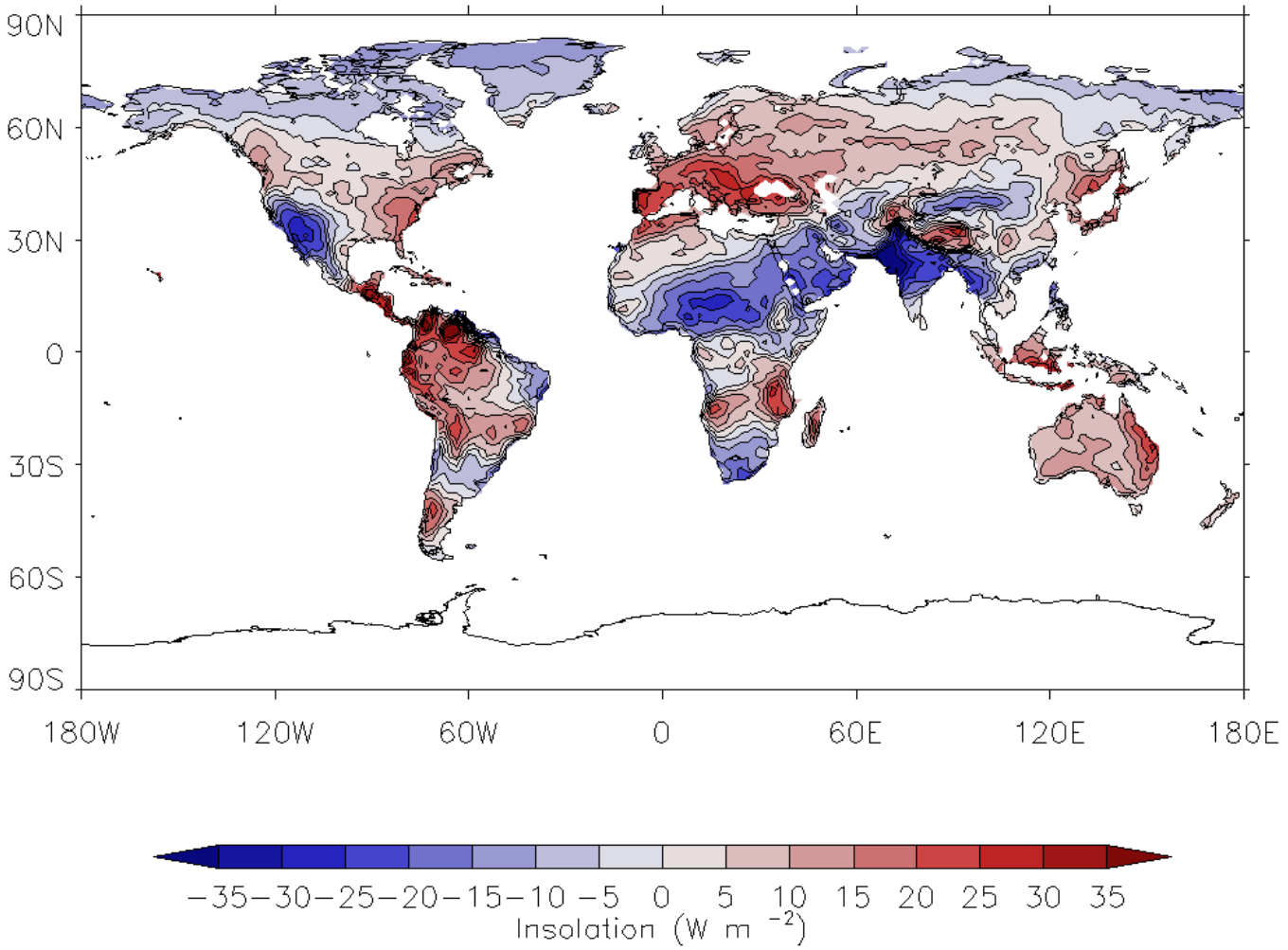
10-year mean centred on 2080. Baseline: 1980 to 1999 mean.



J Crook et al., Energy Environ. Sci., 2011, 4, 3101

Impact
Temperature and insolation

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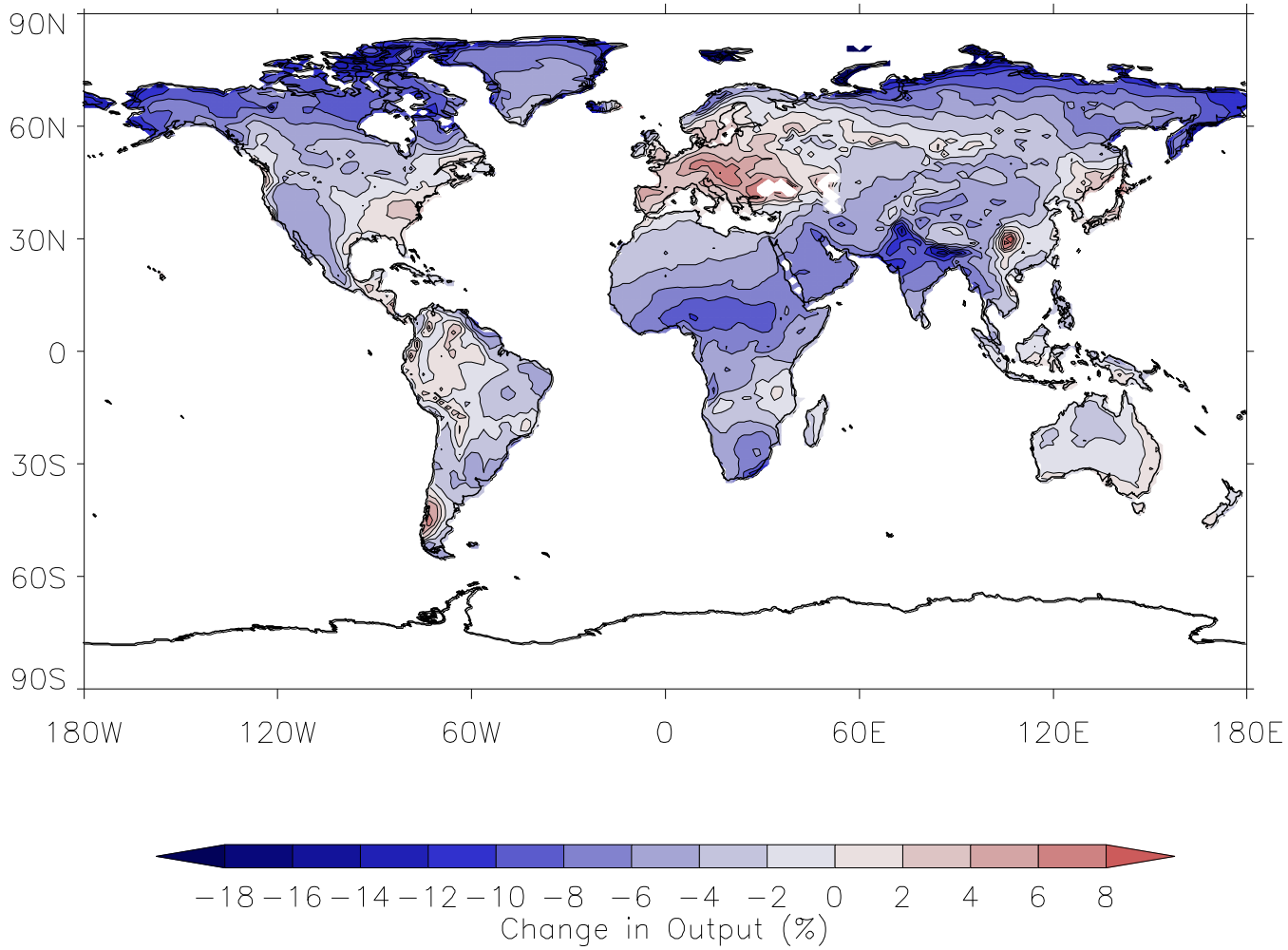
10-year mean centred on 2080. Baseline: 1980 to 1999 mean.



$\Delta E_{PV} / E_{PV(2010)}$	
California	-2.7%
Nevada	-4.0%
Spain	2.4%
UK	1.2%
Algeria	-1.5%
Germany	3.2%
Saudi Arabia	-5.5%
China	3.0%
Australia	-1.1%

J Crook et al., Energy Environ. Sci., 2011, 4, 3101

Solar technology
Spectral irradiance

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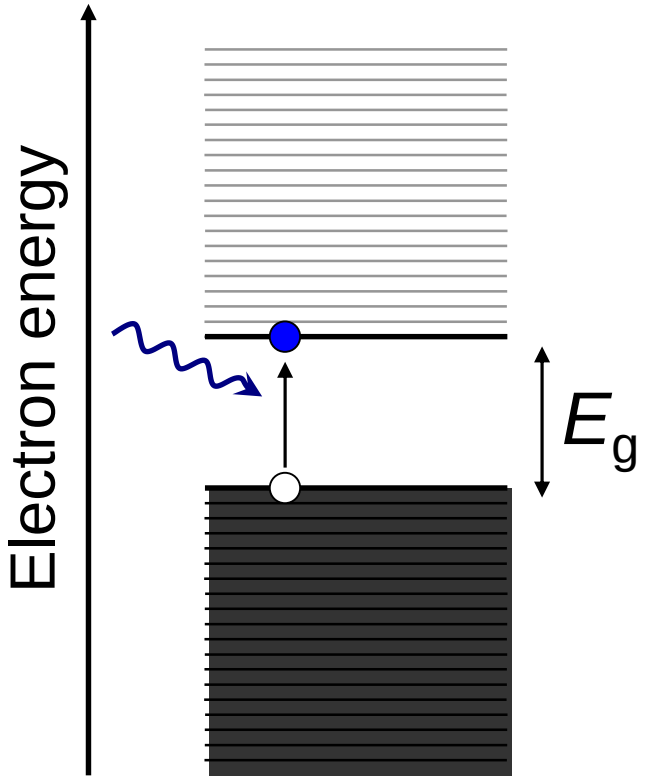
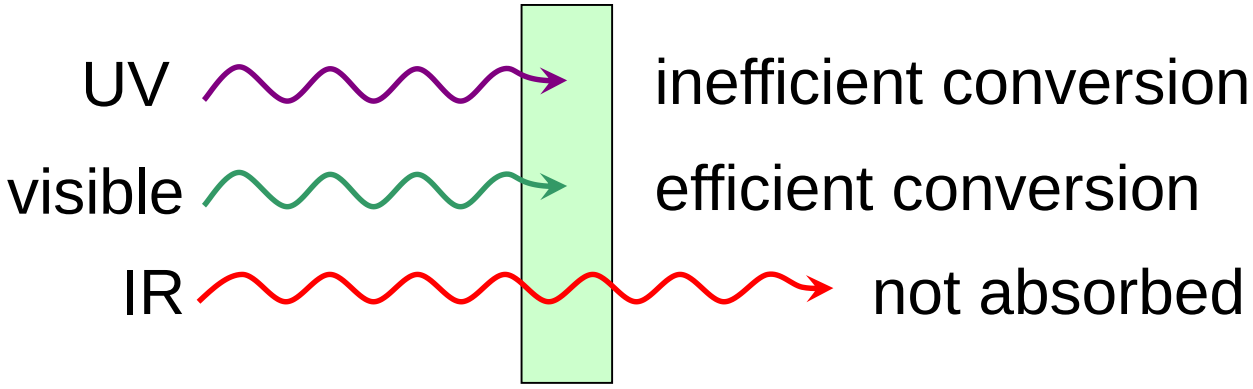


$$\lambda_{\text{photon}} = \frac{hc}{E_{\text{photon}}}$$



Solar technology
Spectral irradiance

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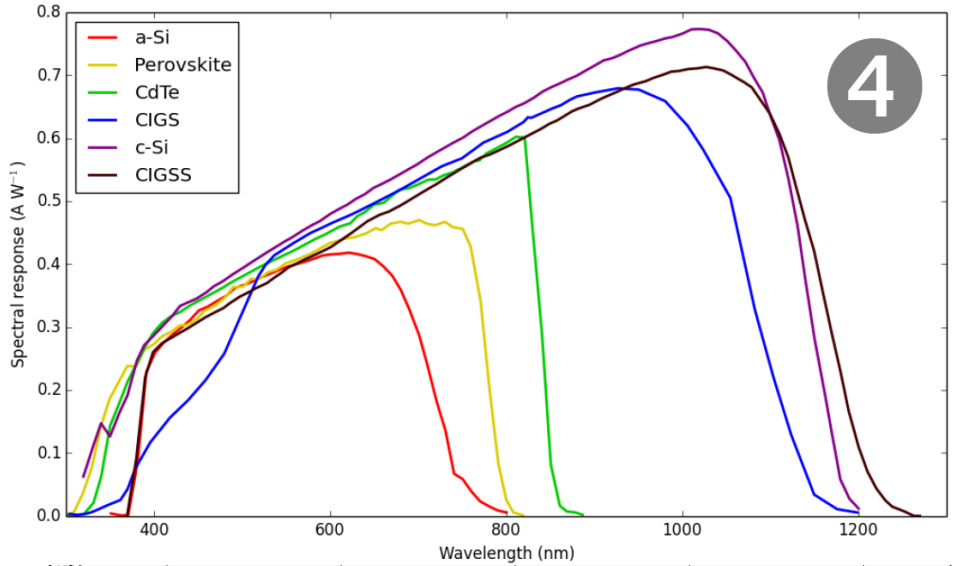

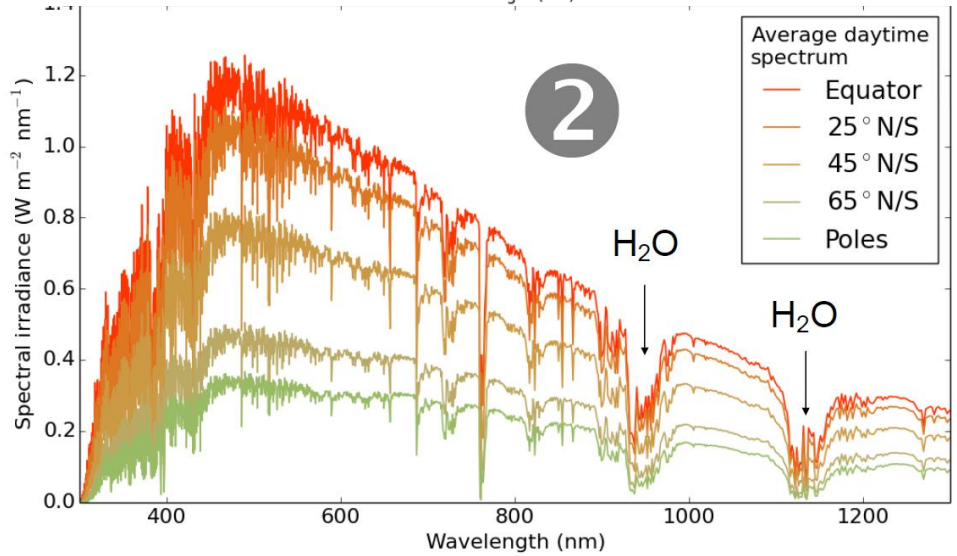

10 mm
water vapour

CJ Smith, R Crook, P Forster,
EU PVSEC, 2102 (2015).

Climate change
Water vapour

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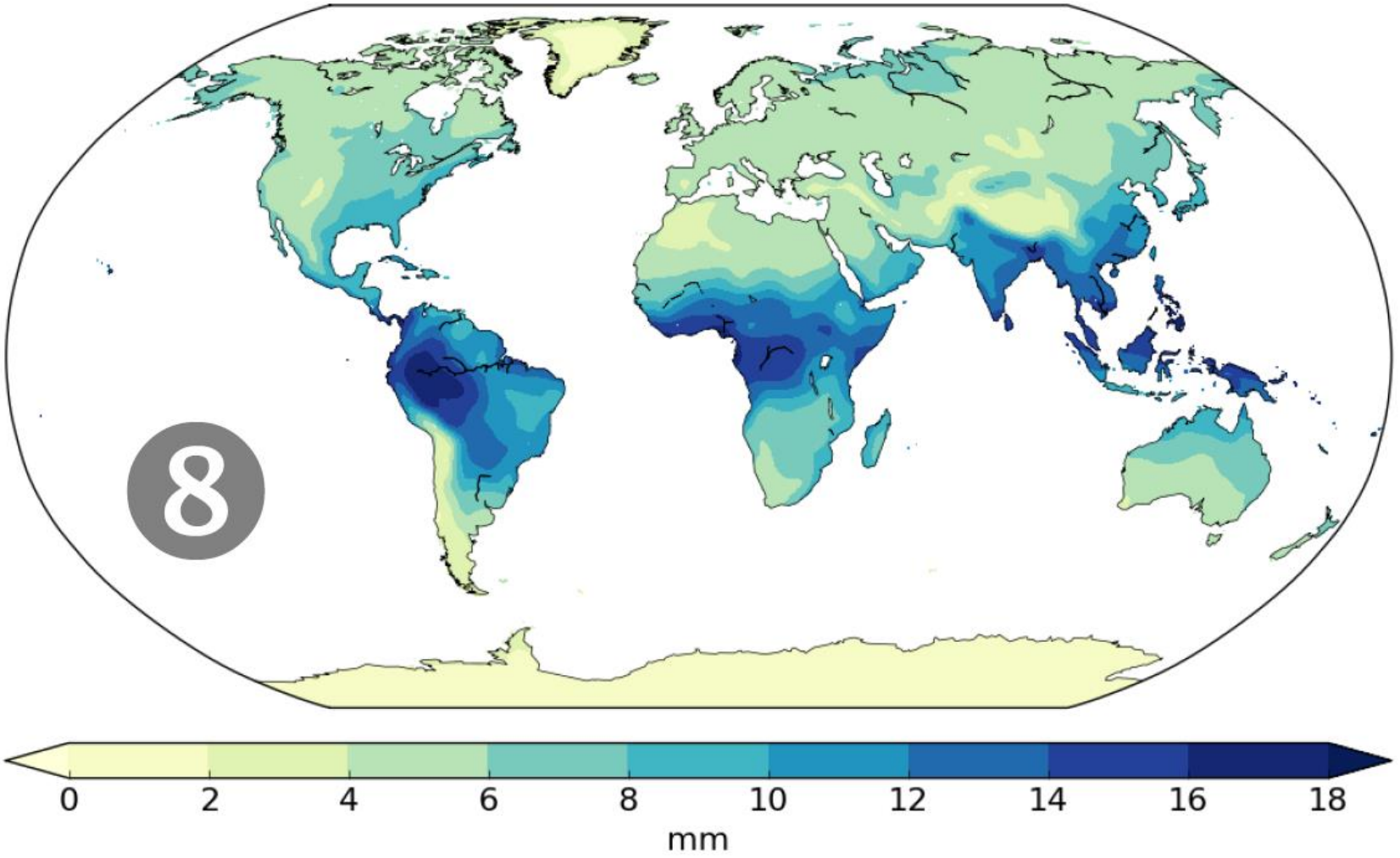
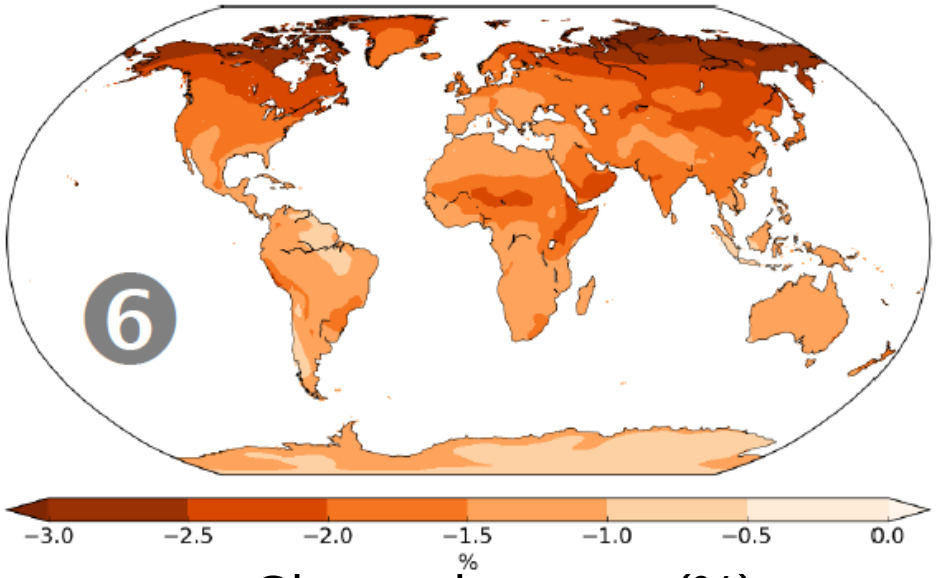
10-year mean centred on 2090. Baseline: 1985 to 2005 mean.



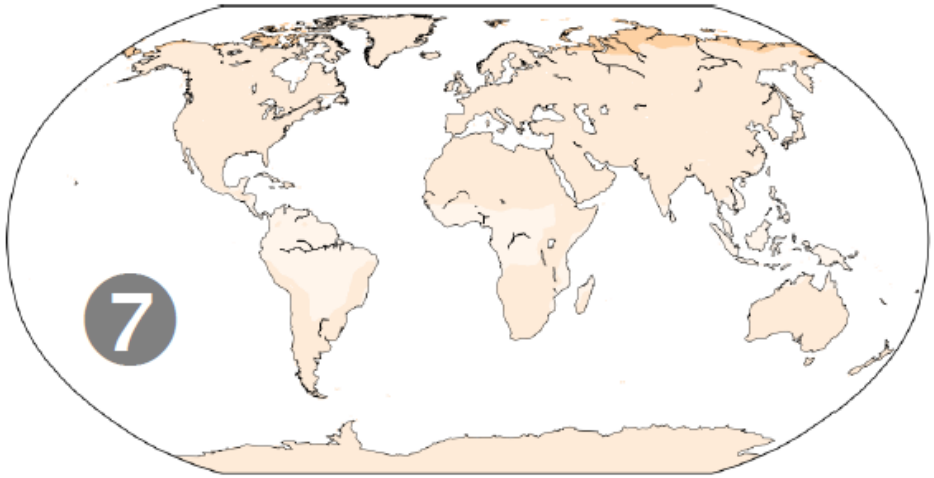
CJ Smith, R Crook, P Forster, EU PVSEC, 2102 (2015).

Impact
Water vapour

UNIVERSITY OF LEEDS



Change in output (%)



10-year mean centred on 2090.
Baseline: 1985 to 2005 mean.

c-Si, E_g = 1.12 eV

a-Si, E_g = 1.7 eV

CJ Smith, R Crook, P Forster,
EU PVSEC, 2102 (2015).

Solar technology
Direct and diffuse irradiance

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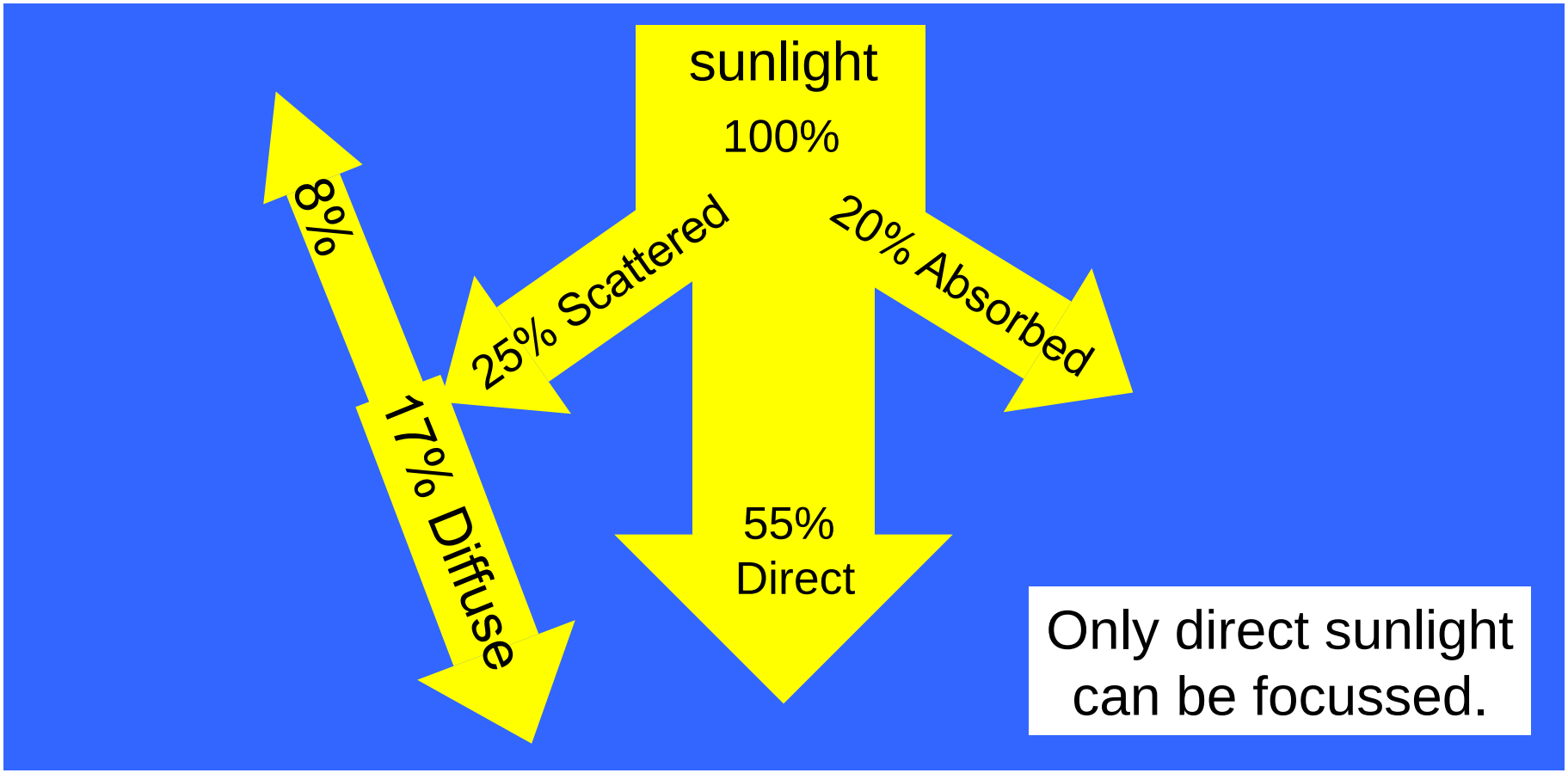

Only direct sunlight can be focussed.

Solar technology
Direct and diffuse irradiance

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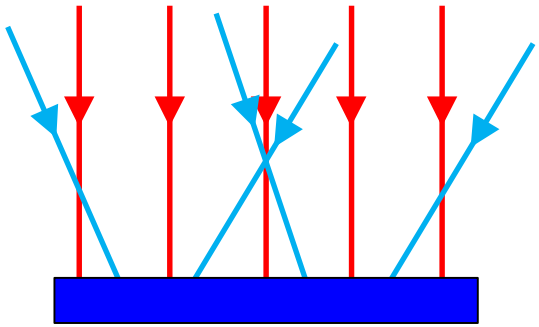

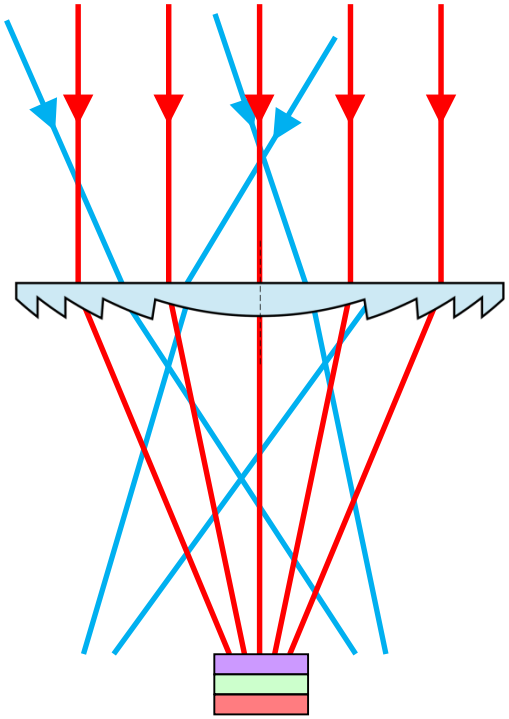

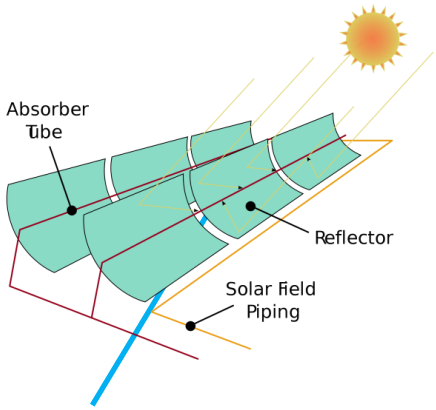

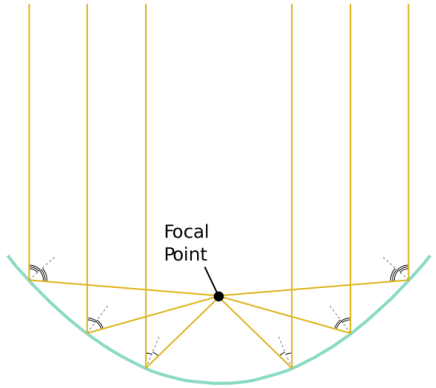

CPV

CSP

Flat panel technologies

Concentrating technologies

Climate change
Stratospheric aerosols

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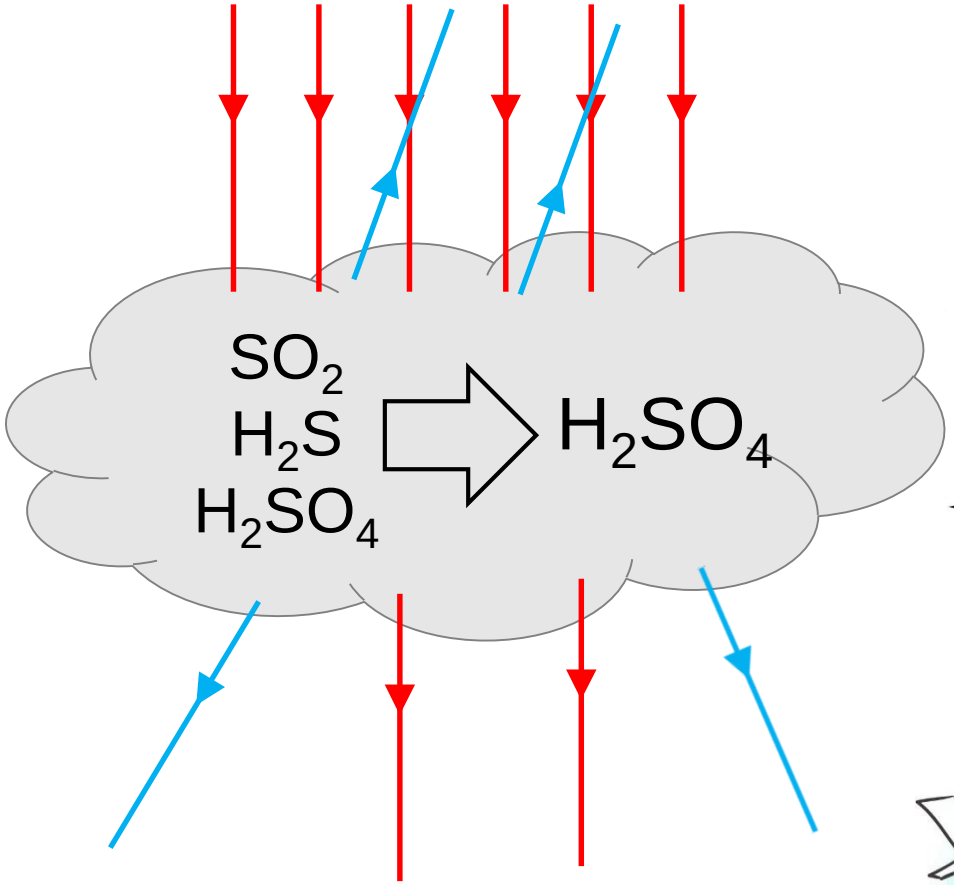

50 km

Stratosphere

15 km

Troposphere

Some direct irradiance becomes diffuse

Climate change
Stratospheric SO_2 injection

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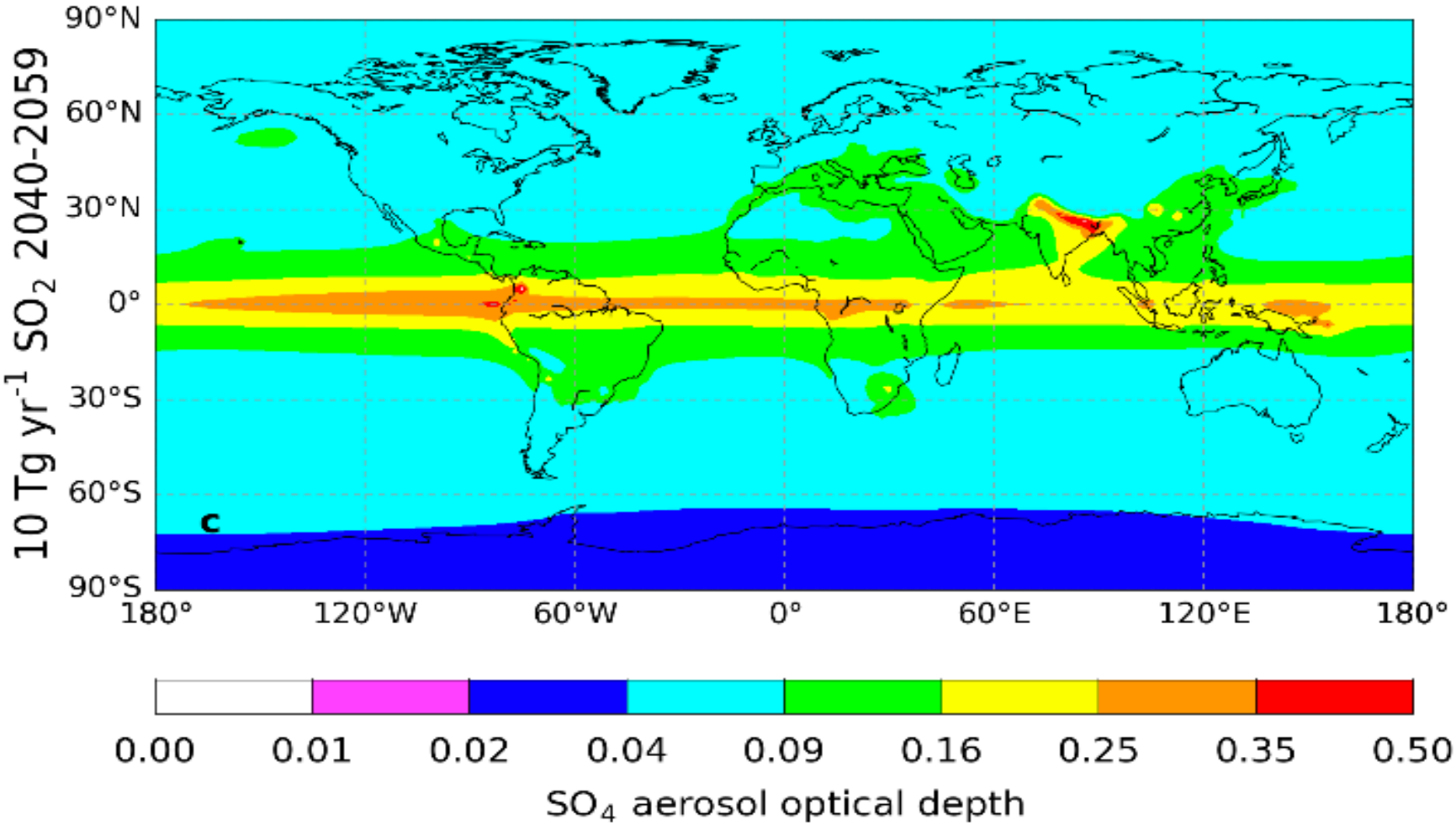

CJ Smith et al., submitted for publication.

Impact
Stratospheric SO_2 injection

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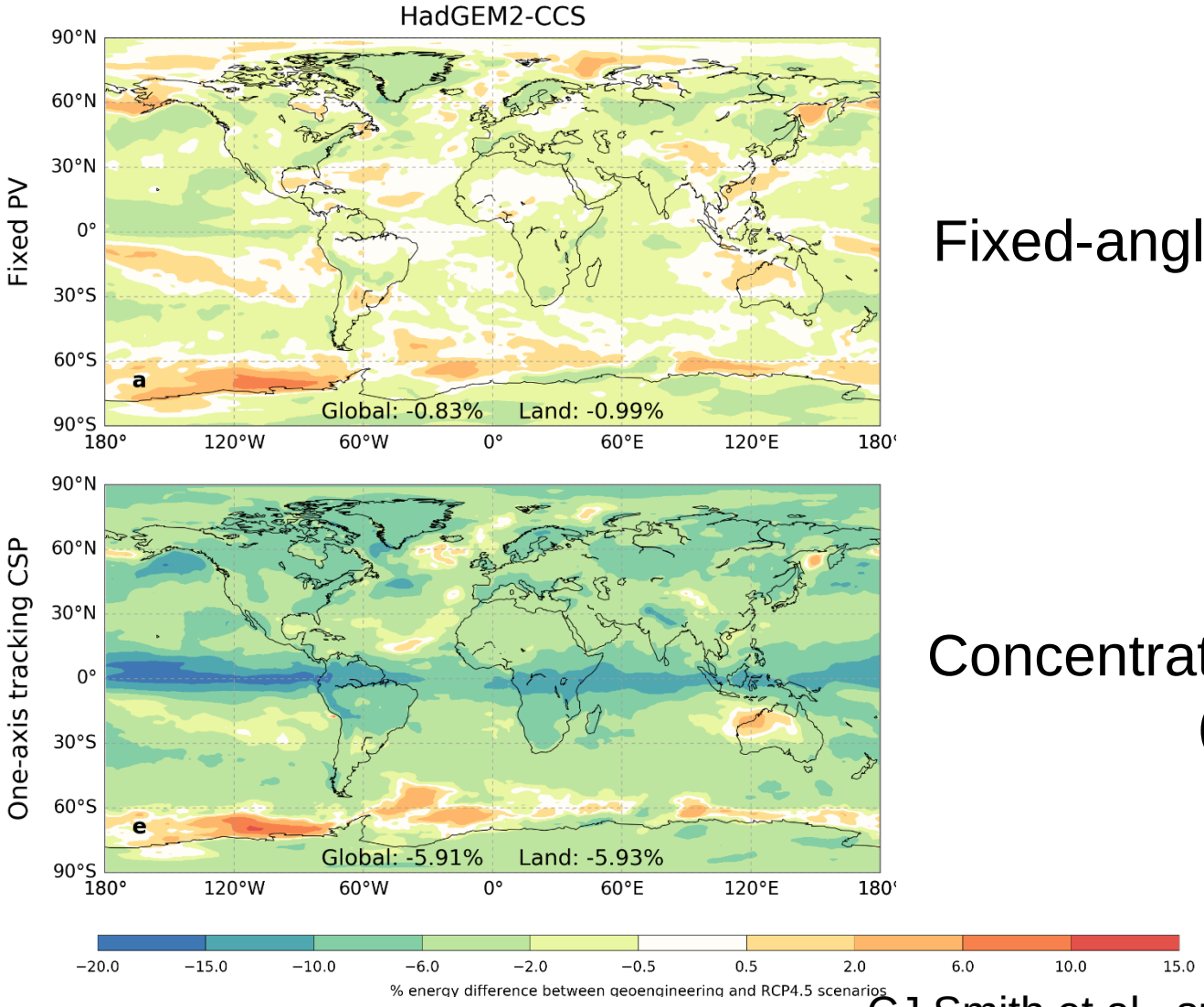

Fixed-angle flat-panel PV

Concentrating solar power (CSP)

CJ Smith et al., submitted for publication.

Impact Summary

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Climate change	
temperature }	-5% to +3% (PV)
irradiance }	-5% to +10% (CSP)
water vapour	-3% to -1% (Si-PV)
Stratospheric SO_2 injection	
flat-panel PV	-4% to +1%
CSP	-15% to +4%

% change in PV output

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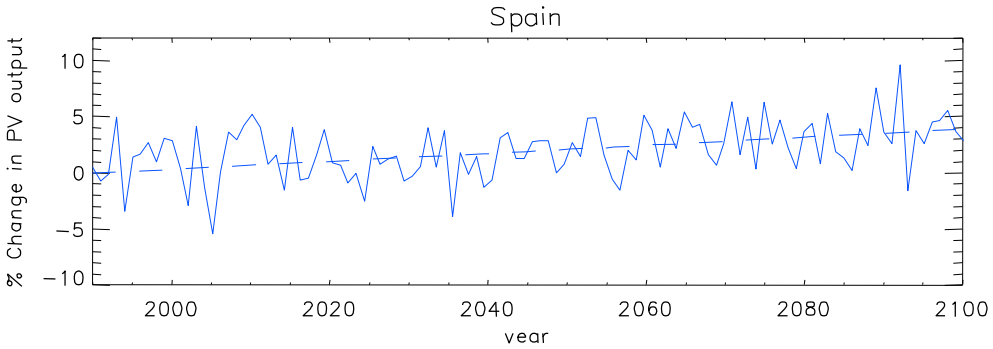
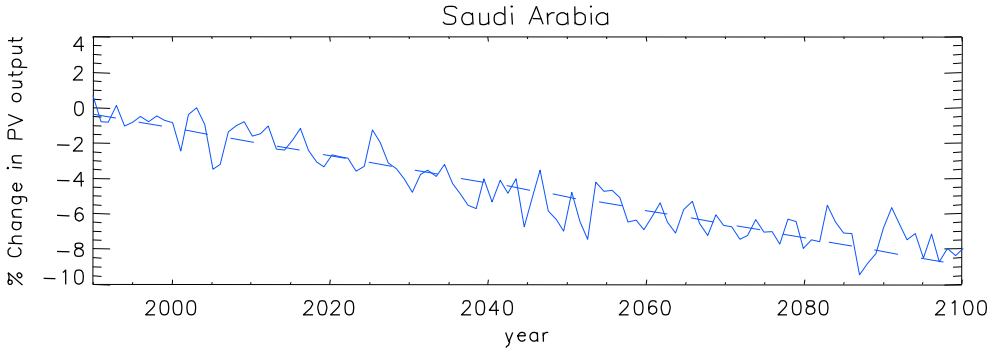
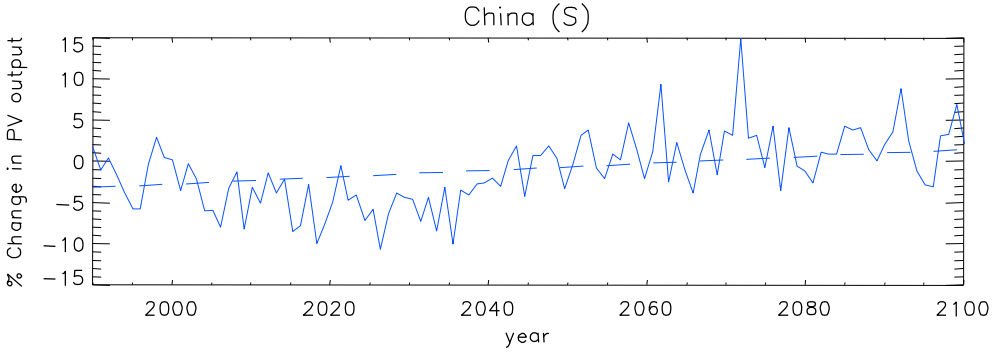
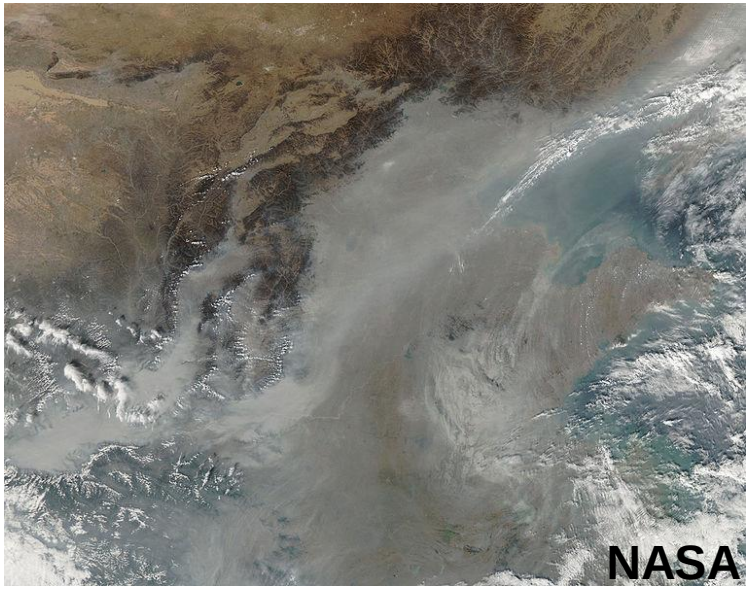






Best fit linear curve
Baseline: 1980 to 1999 mean



% change in output (CPV)

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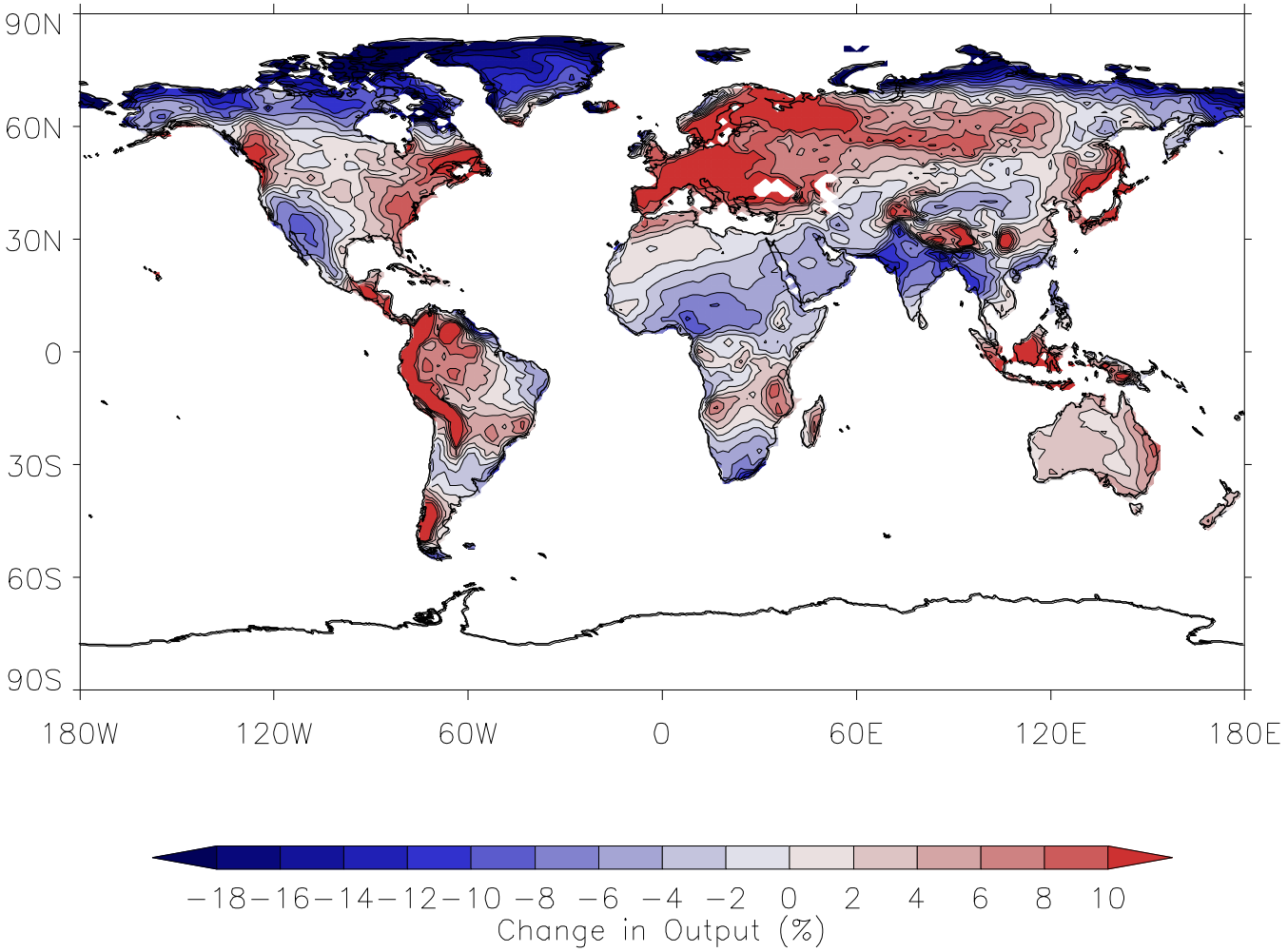
10-year mean centred on 2080. Baseline: 1980 to 1999 mean.



$\Delta E_{CPV} / E_{CPV(2010)}$	
California	-3.5%
Nevada	-4.9%
Spain	8.7%
UK	5.5%
Algeria	2.8%
Germany	10.0%
Saudi Arabia	-4.4%
China	4.7%
Australia	2.0%

Fractional contributions (PV)

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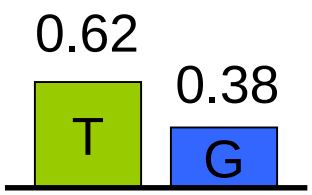
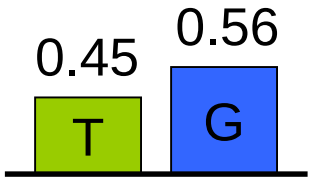
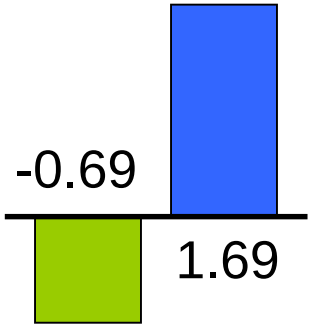


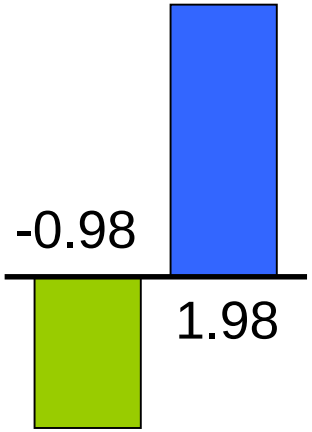
California
(-2.7%)



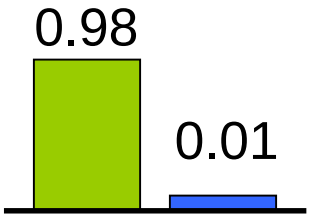
Nevada
(-4.0%)



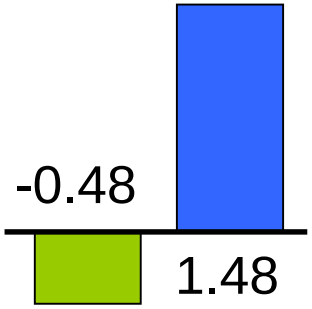
Spain
(+2.4%)



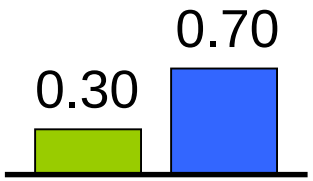
UK
(+1.2%)



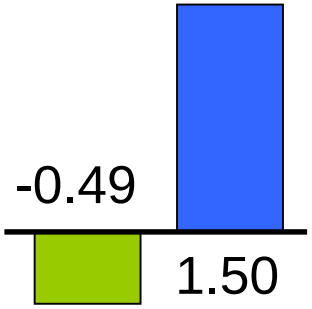
Algeria
(-1.5%)



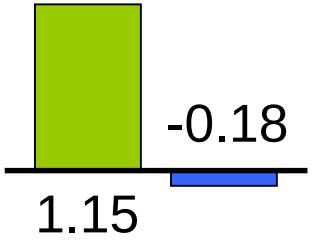
Germany
(+3.2%)



Saudi Arabia
(-5.5%)



China
(+3%)



Australia
(-1.1%)

Fractional contributions (CPV)

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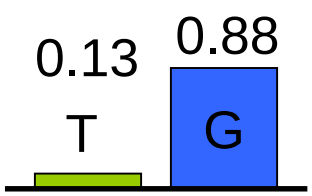
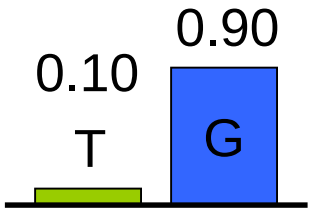
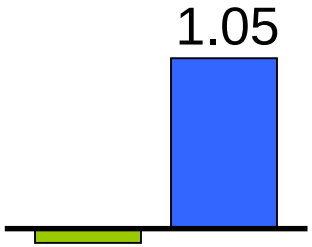


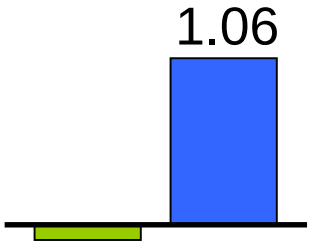
California
(-3.5%)



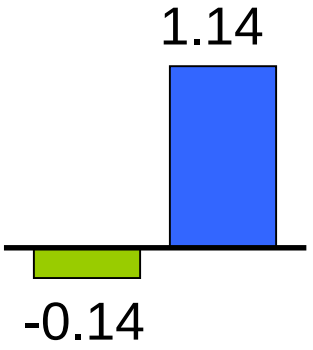
Nevada
(-4.9%)



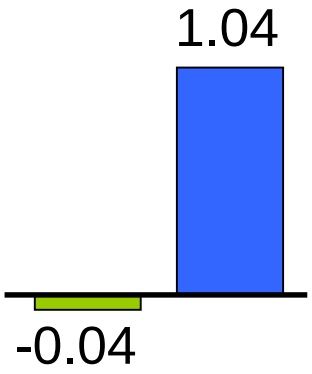
Spain
(+8.7%)



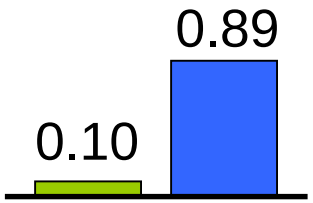
UK
(+5.5%)



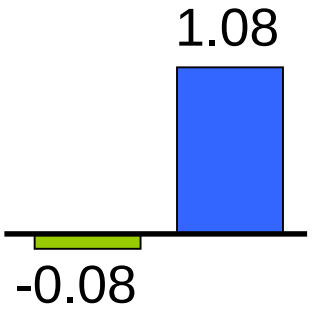
Algeria
(+2.8%)



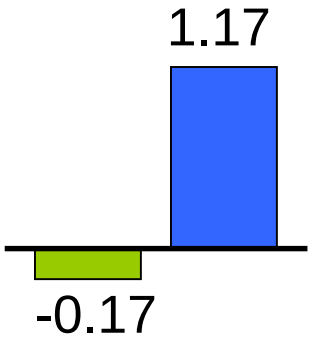
Germany
(+10.0%)



Saudi Arabia
(-4.4%)



China
(+4.7%)



Australia
(+2.0%)

Uncertainty

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Uncertainty in scenario
Uncertainty from model

Uncertainty in temperature
Uncertainty in insolation

Uncertainty in PV output
Uncertainty in CPV output

Temperature ±0.8°C

PV output ±0.5%
CPV output ±0.1%

Change in cloud amount:
Good agreement in Europe,
Saudi Arabia, and Australia.
Poor agreement in America.