Potsdam-Institut für Klimafolgenforschung

Using the sun to decarbonize the power sector: The economic potential of photovoltaics and concentrating solar power

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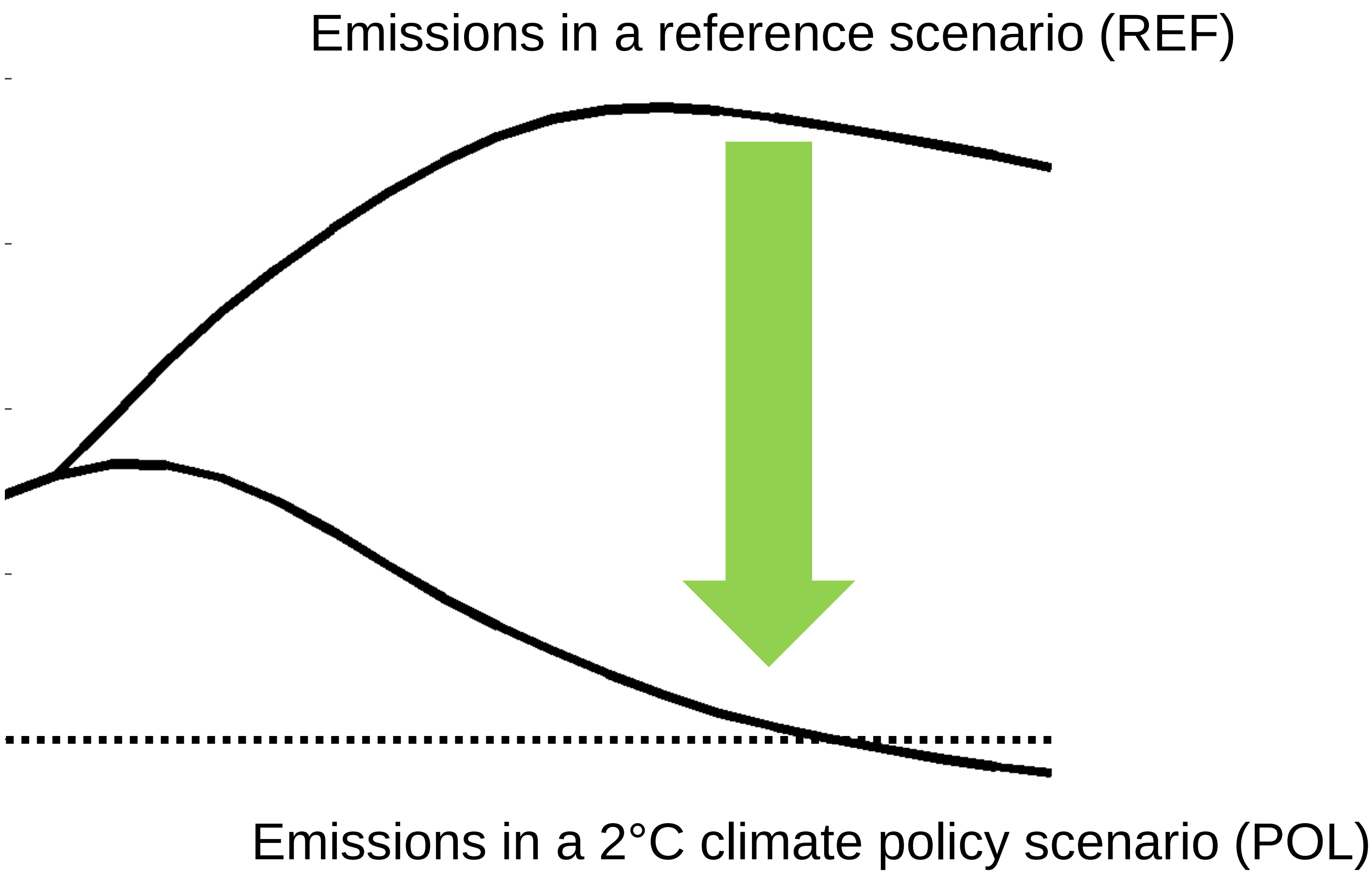
Scope of the challenge to achieve 2°C target



Many options to decarbonize the power sector

Option	Challenges / Bottlenecks/ Risks
Gas	Limited emission reductions
Nuclear	Costs, limited uranium, security issues, waste disposal, proliferation
Biomass	Strong competition from other sectors, sustainability issues
CCS	Strong competition from other sectors, public opposition
Wind	Variability, potential, public opposition
Solar	Variability, costs, potential
Geothermal	Costs, exploration risks, limited potential, public opposition

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Fundamentals drive long-term development

- Resource prices 🡐 resource reserves
- Other scarcities: atmosphere, CO_2 sinks, land & water

Different types of energy use compete:

- – Power for appliances
- – Mobility
- – Heating/cooling
- – Industry processes

➔ We need long-term models covering the full energy system and the economic drivers!

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The REMIND model

Hybrid energy-economy-climate model

- Global scope, 11 world regions, international trade
- Time horizon: 2005-2100

Economy:

- Ramsey-type growth model, maximizes intertemporal welfare
- Pareto-optimal solution with intertemporal equilibrium of capital, energy and goods markets

Energy:

- ~70 conversion technologies with full capital vintaging
- Represents endogenous technological improvement (learning curve)

Climate:

- Soft-coupled to MAGICC

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The REMIND model

Code length: > 300.000 lines

Problem Size:

```
MODEL STATISTICS

BLOCKS OF EQUATIONS         107     SINGLE EQUATIONS      176,206
BLOCKS OF VARIABLES          67     SINGLE VARIABLES      193,064  711 projected
NON ZERO ELEMENTS       657,779     NON LINEAR N-Z        125,274
DERIVATIVE POOL              10     CONSTANT POOL           6,782
CODE LENGTH             410,634


GENERATION TIME      =        1.516 SECONDS    199 MB  24.1.2 r40979 WIN-VS8


EXECUTION TIME       =        2.516 SECONDS    199 MB  24.1.2 r40979 WIN-VS8
```

Run times: 2 days - 4 weeks

Contents

Research Questions

1. What is the role of solar power for decarbonizing the electricity sector?
2. Have the recent reductions of PV capital costs decided the competition between the two solar power technologies, or might CSP see a resurgence in the future?

Answer questions with REMIND model

Develop

- Simplified representation of integration challenges for variable renwables
- New resource data & cost data

Running several groups of scenarios:

- With/out climate policy: Budget of 2500 Gt CO_eq budget 2005-2100, equivalent to 67% chance of staying below 2°C
- Technology availability scenarios: noPV, noCSP, noSolar, …
- Sensitivity study on future cost reduction

Analyze:

- Electricity generation
- LCOE metrics

Contents

Solar Power Technologies

Photovoltaics (PV)

- Can use indirect light – high latitudes
- Easily scalable

Concentrating Solar Power (CSP)

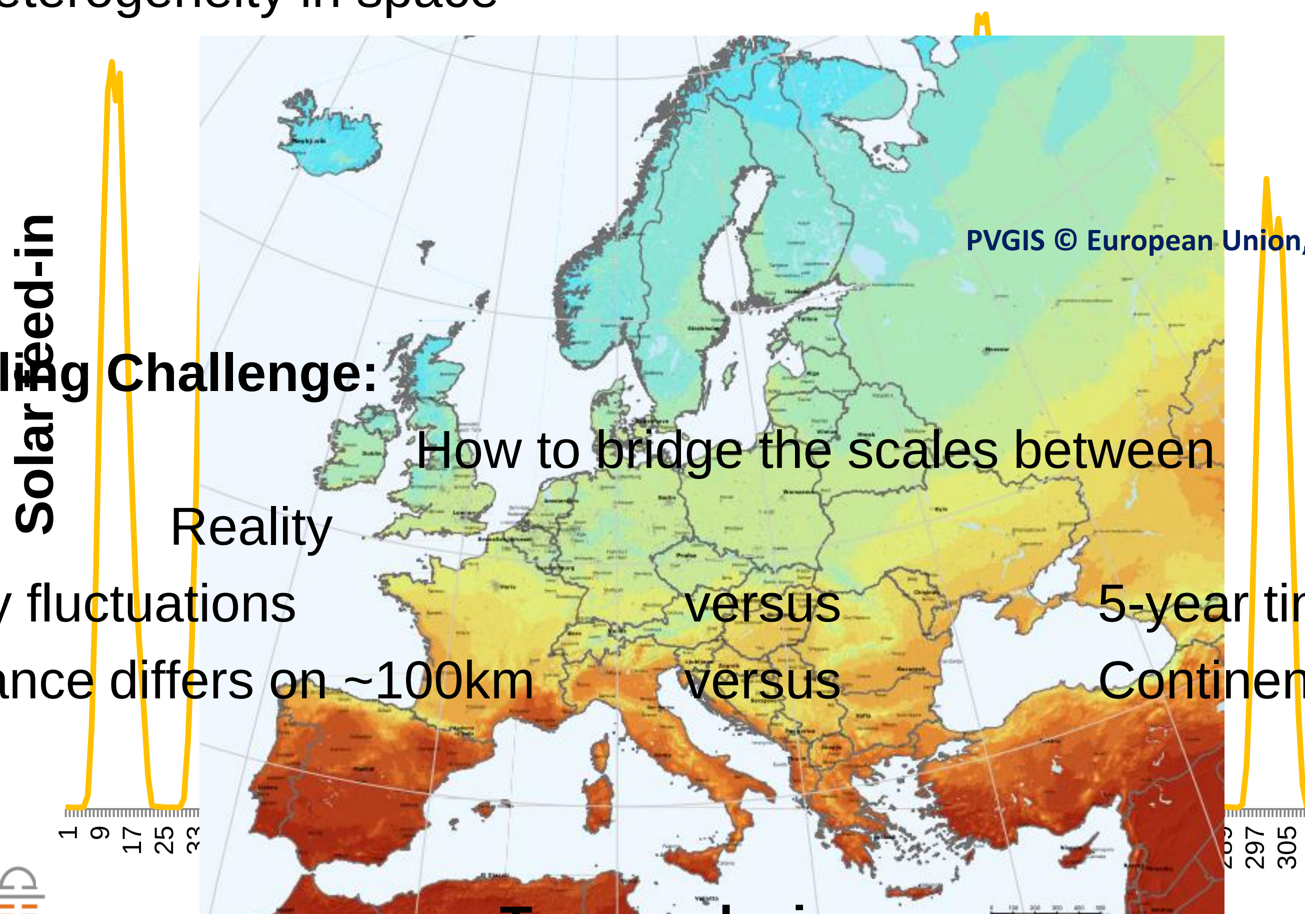
- Needs direct light – low latitudes
- Thermal power production
  ➔ Heat can be stored cheaply

Driver 1: VRE Integration

Two main characteristics of Solar

1. Temporal variability

2. Heterogeneity in space



PVGIS © European Union, 2001-2012

Modeling Challenge:

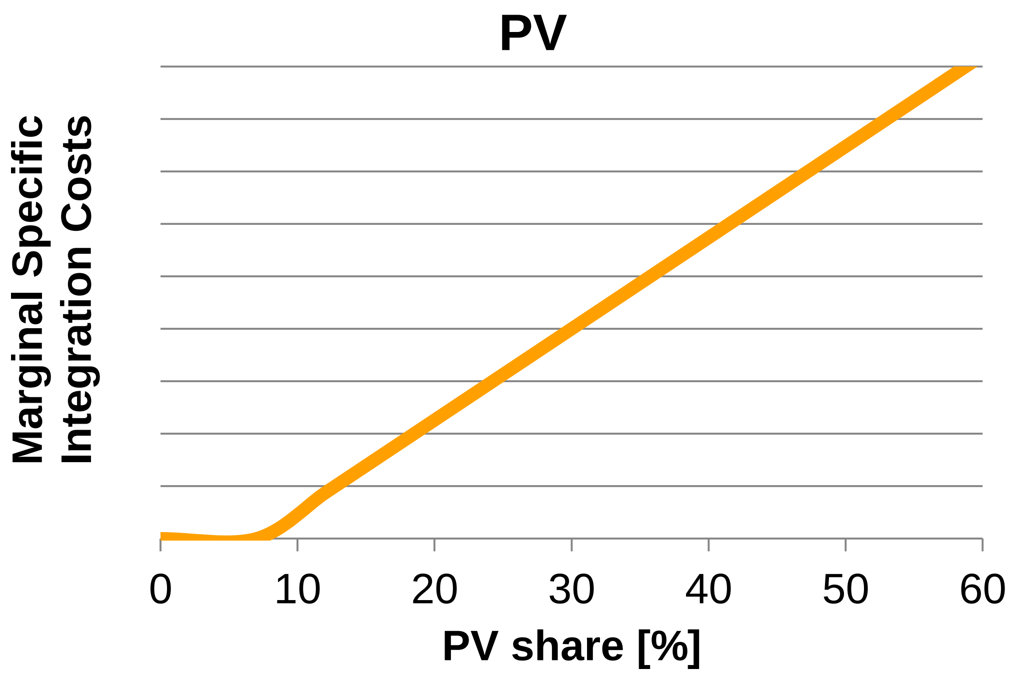
How to bridge the scales between

Reality		IAM
Hourly fluctuations	versus	5-year time steps
Irradiance differs on ~100km	versus	Continental scale

New generic approach – cost markups

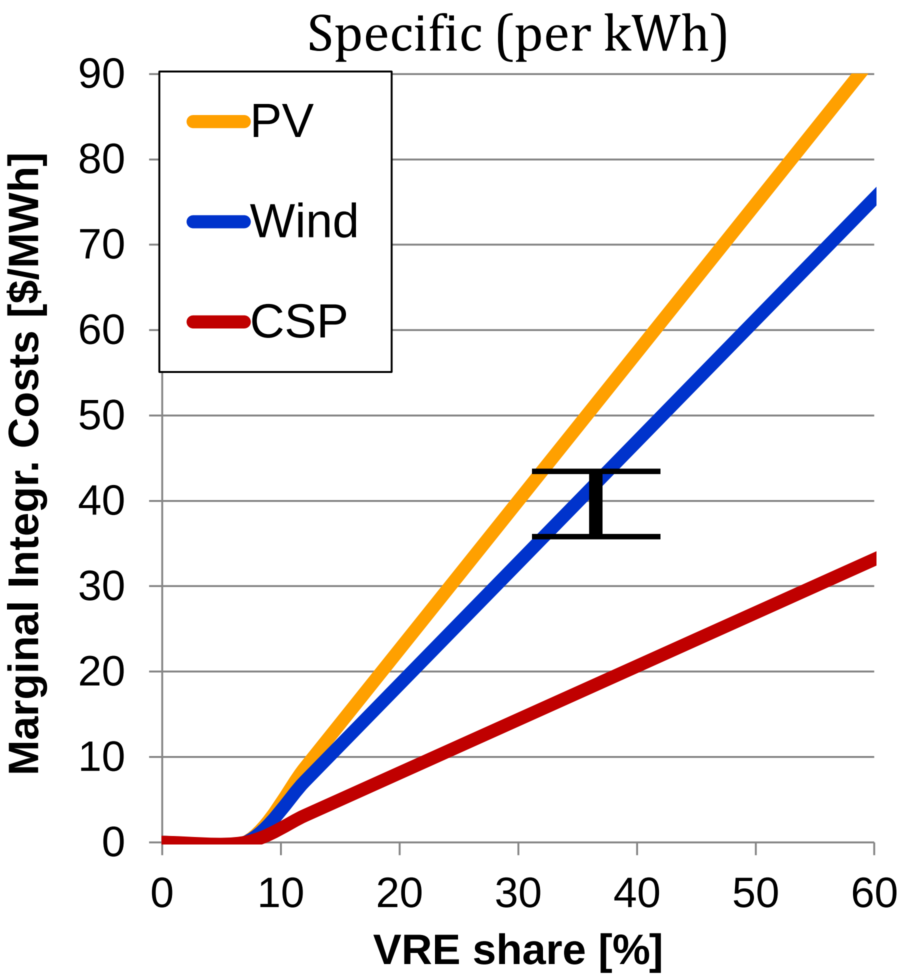
Basic idea of approach:

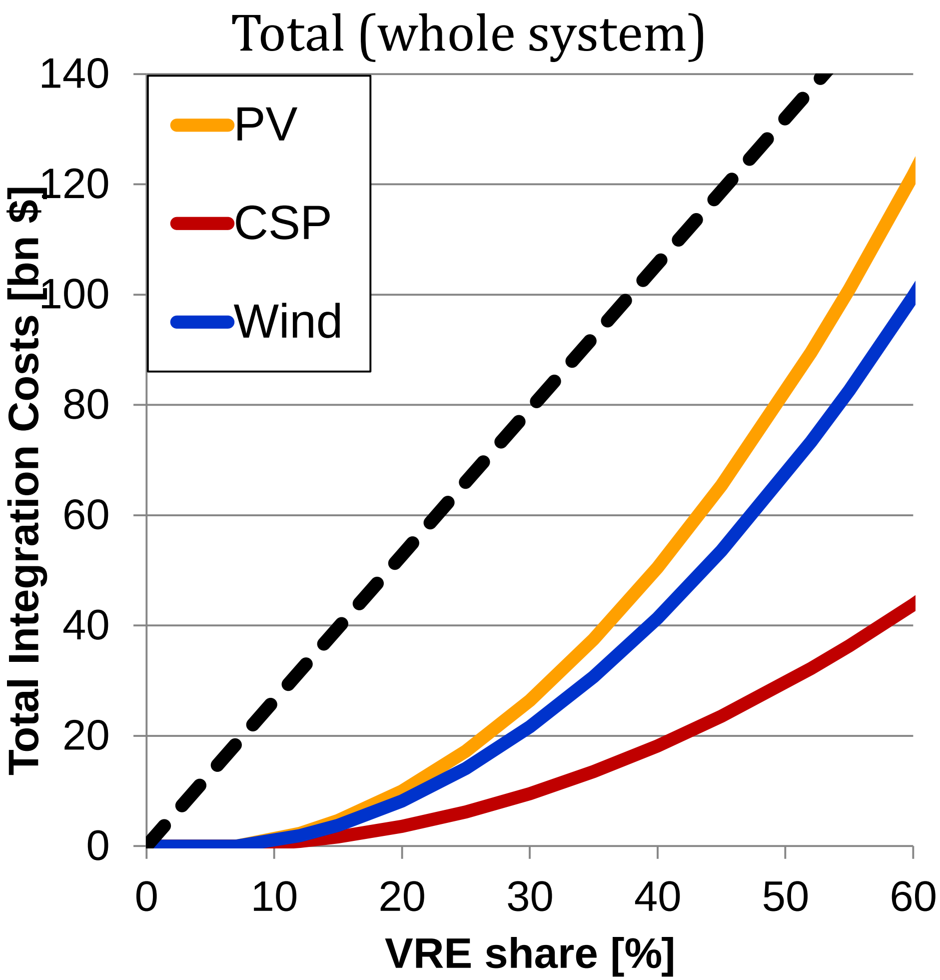
- Integration challenges increase with the share of each VRE



- Variability can be reduced by storage, else results in curtailment
- Parameters based on battery and H2 electrolysis costs, detailed modeling

Resulting integration cost markups

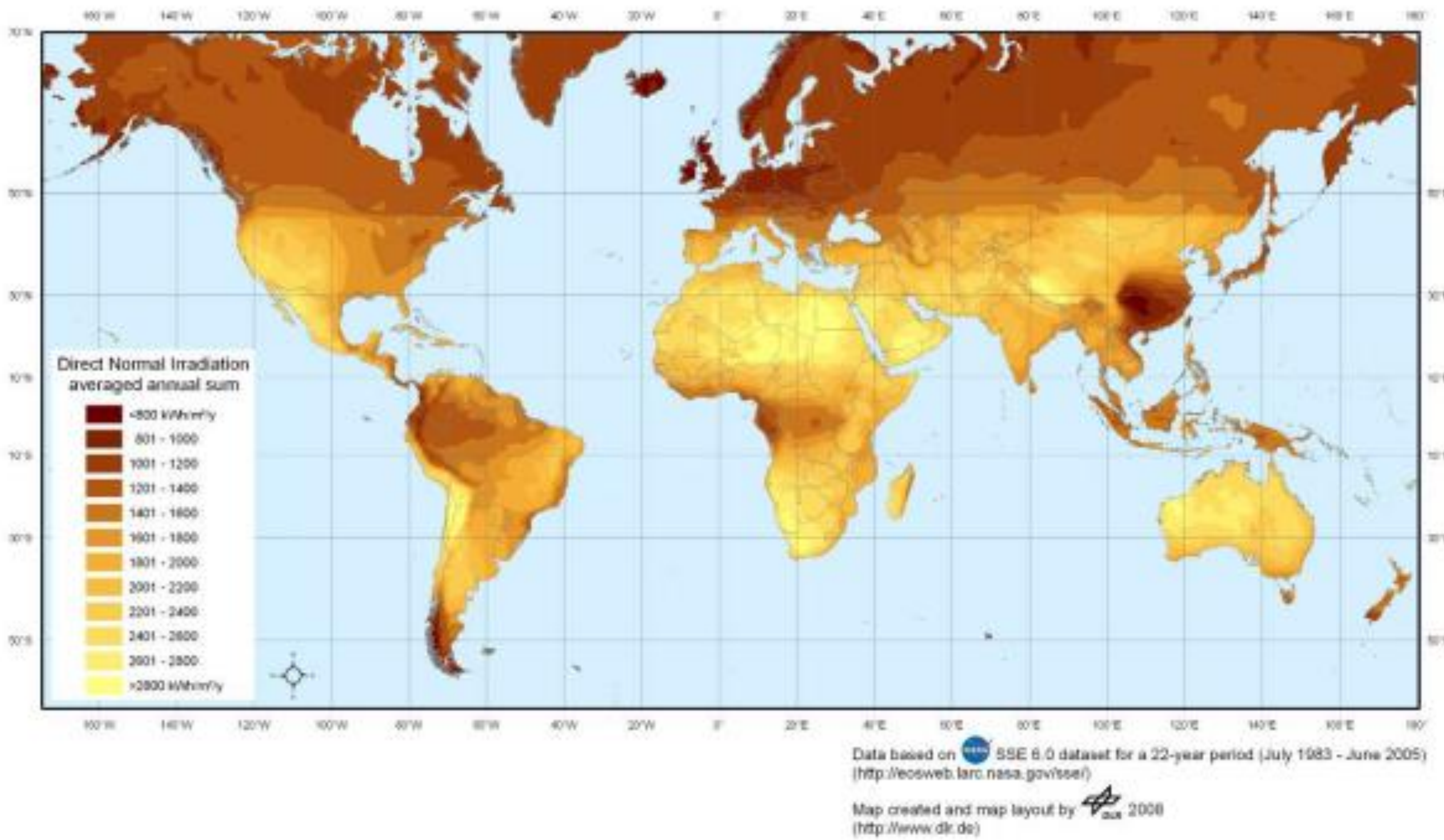




➔ Our values are conparable to current literature ranges

Hirth, Ueckerdt, Edenhofer (2015): „Integration costs revisited“

Driver 2: Resource Potential



Existing resource datasets not sufficient

Trieb et al (2009): Global potential of concentrating solar power

Driver 2: New Resource Potential for PV and CSP

Method (mostly performed by Daniel Stetter from DLR):

- NASA GHI Data (SRB release 3.0) for solar data
- Use DLR clear sky model for further processing
- Calculate hourly DNI/GTI values
- Use GIS filters to exclude unsuitable area (PV max slope: 45°, CSP max slope: 2°)
- Aggregate by country/region

➔ consistent dataset for PV and CSP

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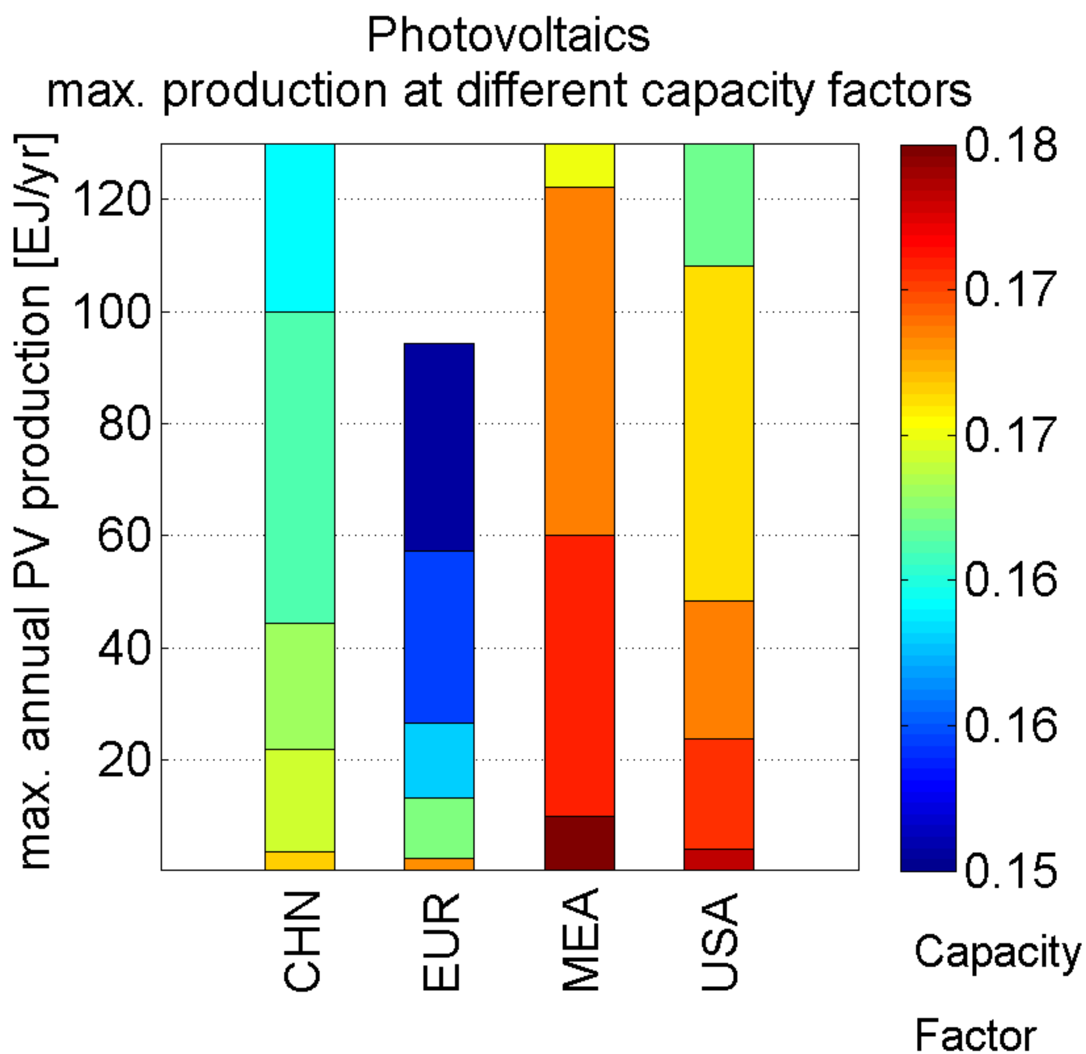
Resulting resource potential for PV

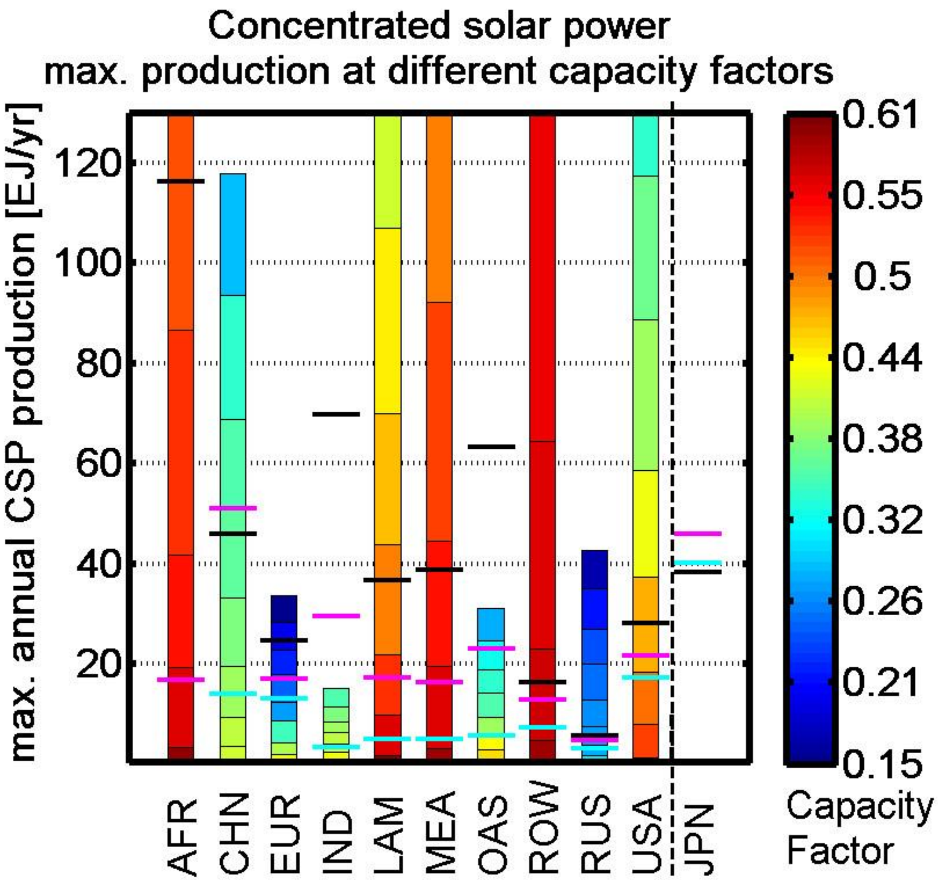
27,800 TWh

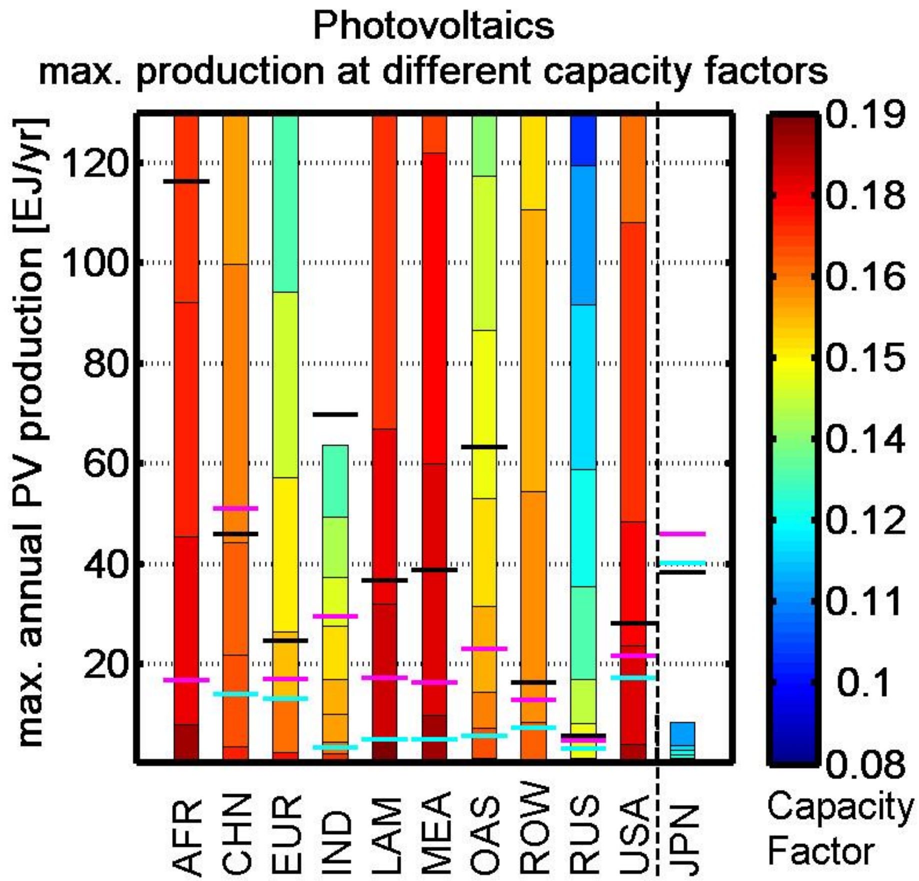


(x 278 to convert EJ -> TWh)

Pietzcker et al (2014): „Using the sun to decarbonize the power sector“, Applied Energy

Resource Potentials CSP and PV





Horizontal lines are electricity demand in 2010 (cyan), 2050, 2100 (black)

➔ All regions except for Japan & India have more than enough solar potential

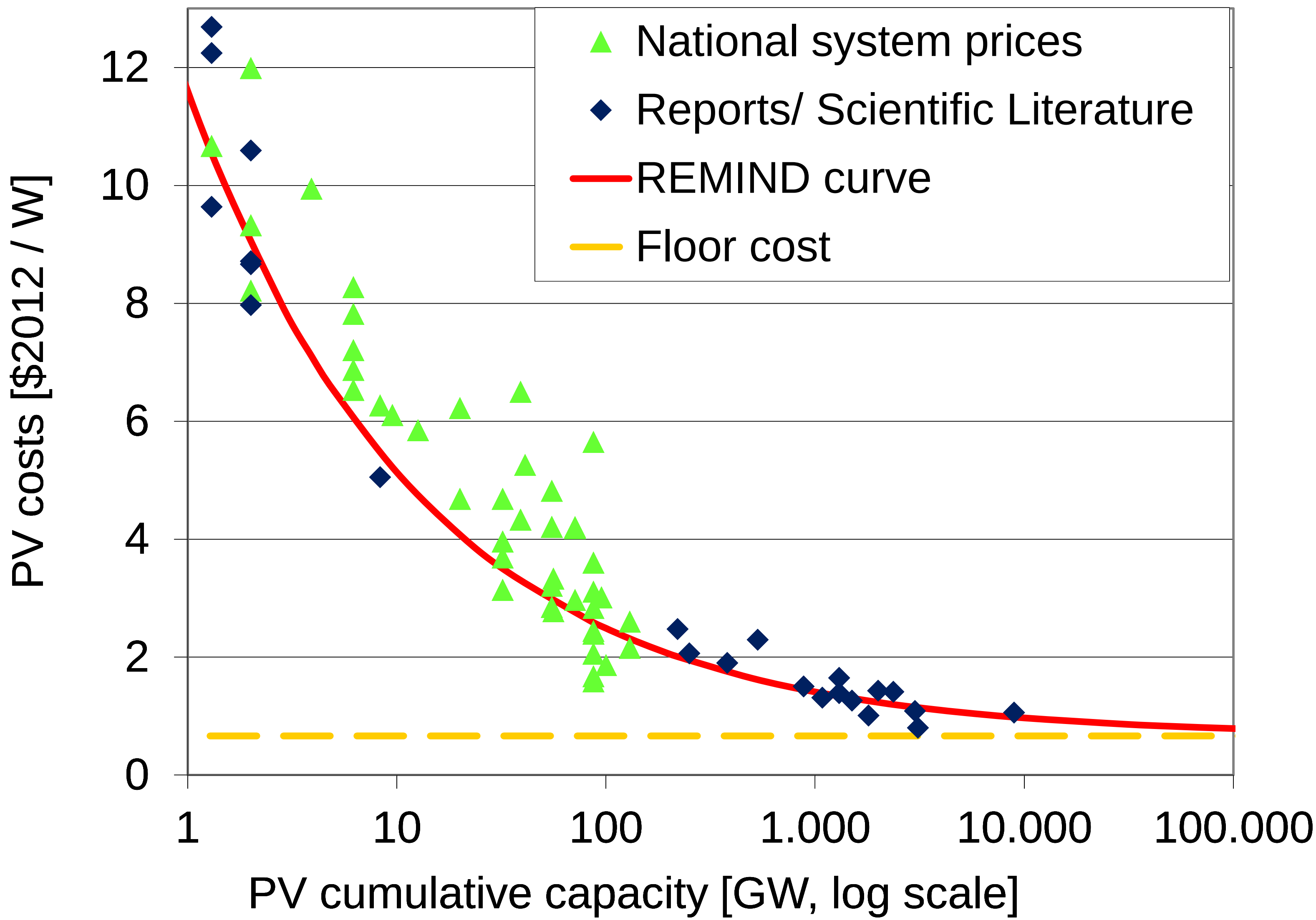
Pietzcker et al (2014): „Using the sun to decarbonize the power sector", Applied Energy

Country-level resource potential (for general use)

2	Country Inf	Information about area usable by both PV and CSP, binned by PV Full Load hours												
3	Name	Total Usable Area		Installation Density										Usab
4		1-50km	50-100km	PV	750-800	800-850	850-900	900-950	950-1000	1000-1050	1050-1100	1100-1150	1150-1200	1200-1250
5	Unit:	[km^2]	[km^2]	[MW/km^2]	[km^2]	[km^2]	[km^2]	[km^2]	[km^2]	[km^2]	[km^2]	[km^2]	[km^2]	[km^2]
65	Ghana	9,076	17,970	111	0	0	0	0	0	0	0	0	0	0
66	Guernsey	0	0	78	0	0	0	0	0	0	0	0	0	0
67	Germany	20,161	0	70	746	6,196	6,754	3,479	1,757	1,512	346	0	0	0
68	Greece	888	0	88	0	0	0	0	0	0	0	9	37	166
69	Guatemala	1,200	1,515	109	0	0	0	0	0	0	0	0	0	0
70	Guinea	1,666	2,953	111	0	0	0	0	0	0	0	0	0	0
71	Guyana	107	1,403	112	0	0	0	0	0	0	0	0	0	0
72	Haiti	0	7	108	0	0	0	0	0	0	0	0	0	0

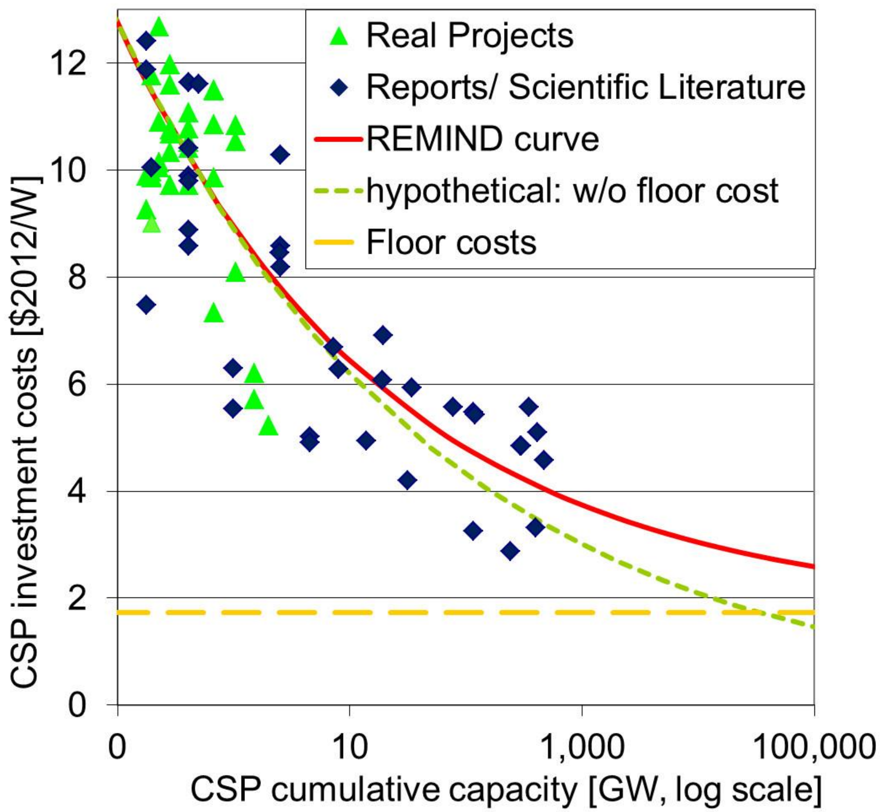
Pietzcker et al (2014): „Using the sun to decarbonize the power sector“, Applied Energy

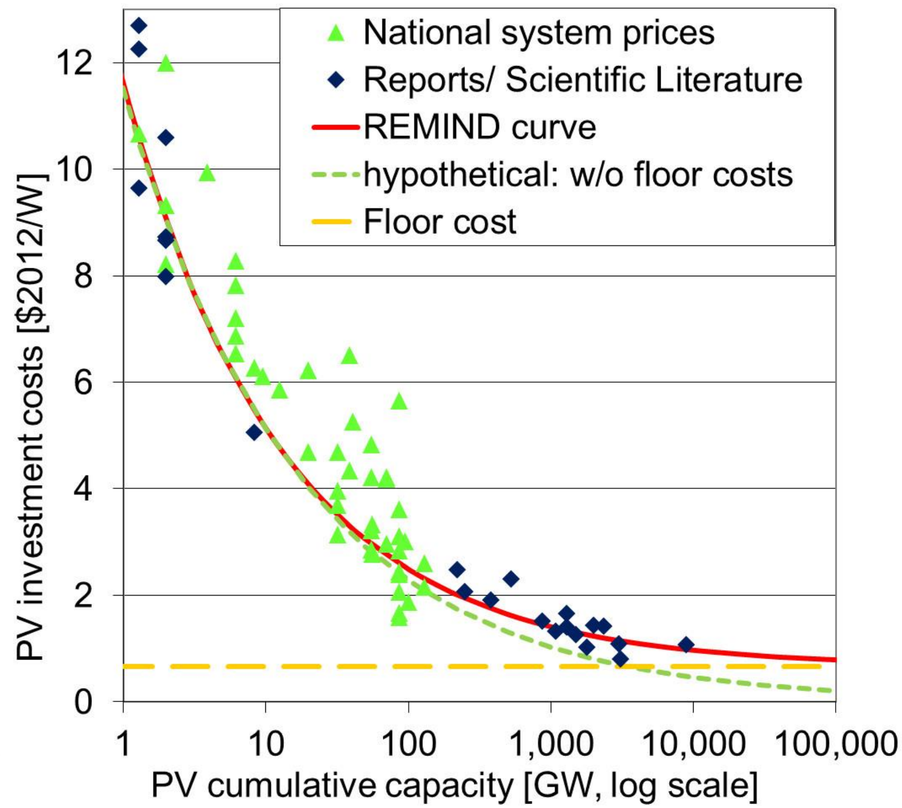
Driver 3: Technology Costs



Pietzcker et al (2014): „Using the sun to decarbonize the power sector“, Applied Energy

Driver 3: Technology Costs



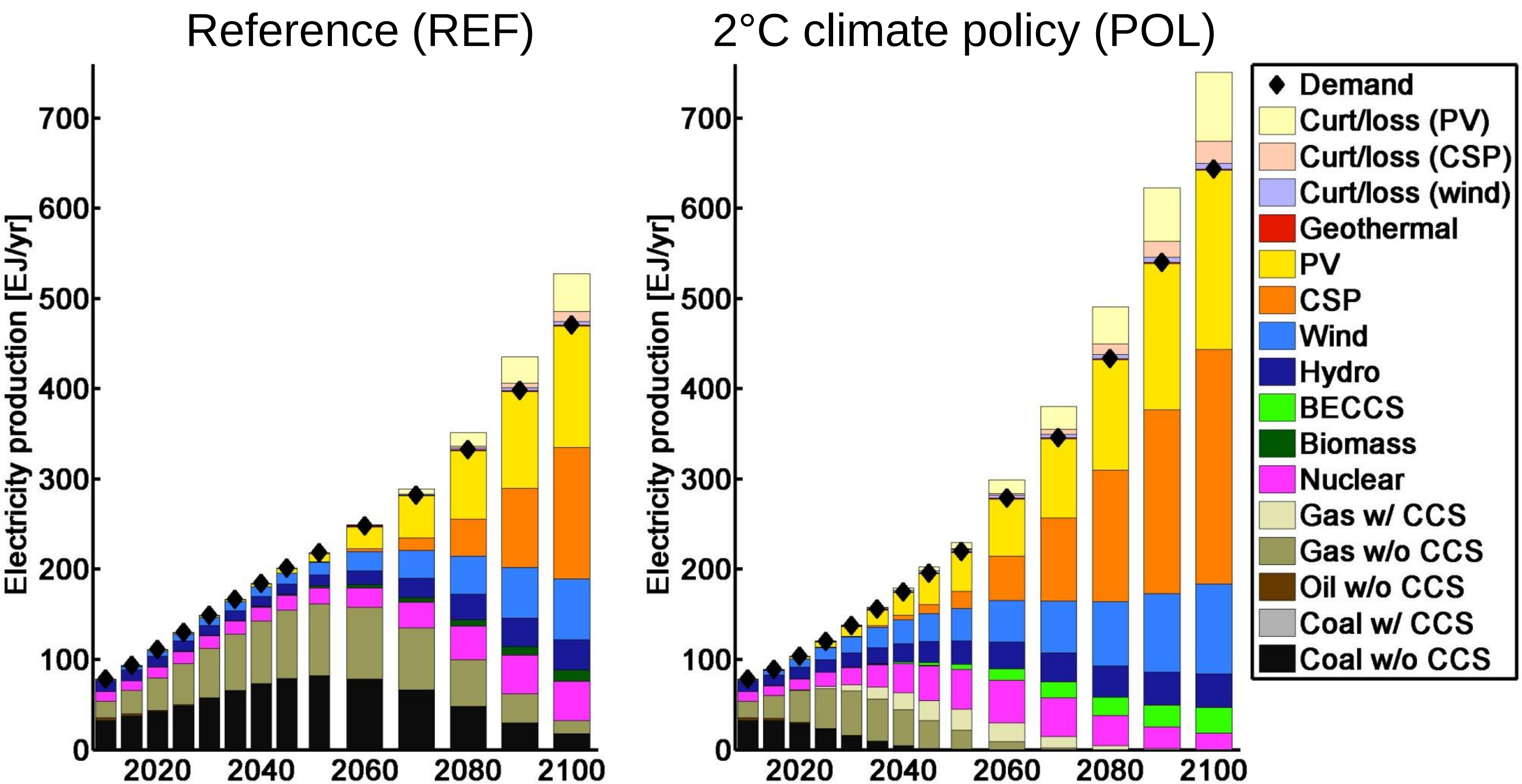


	Inv. Costs end 2013	Cum. cap end 2013	Yearly O&M	Learn rate 2002-2013	Floor cost	Life time
	$2012/Wp	GW	% of Capex		$2012/Wp	yr
PV	2.3	140	1.5%	20%	0.7	30
CSP (SM3, 12h stor)	8.5	1.7	2.5%	10%	1.7	30

Pietzcker et al (2014): „Using the sun to decarbonize the power sector“, Applied Energy

Contents

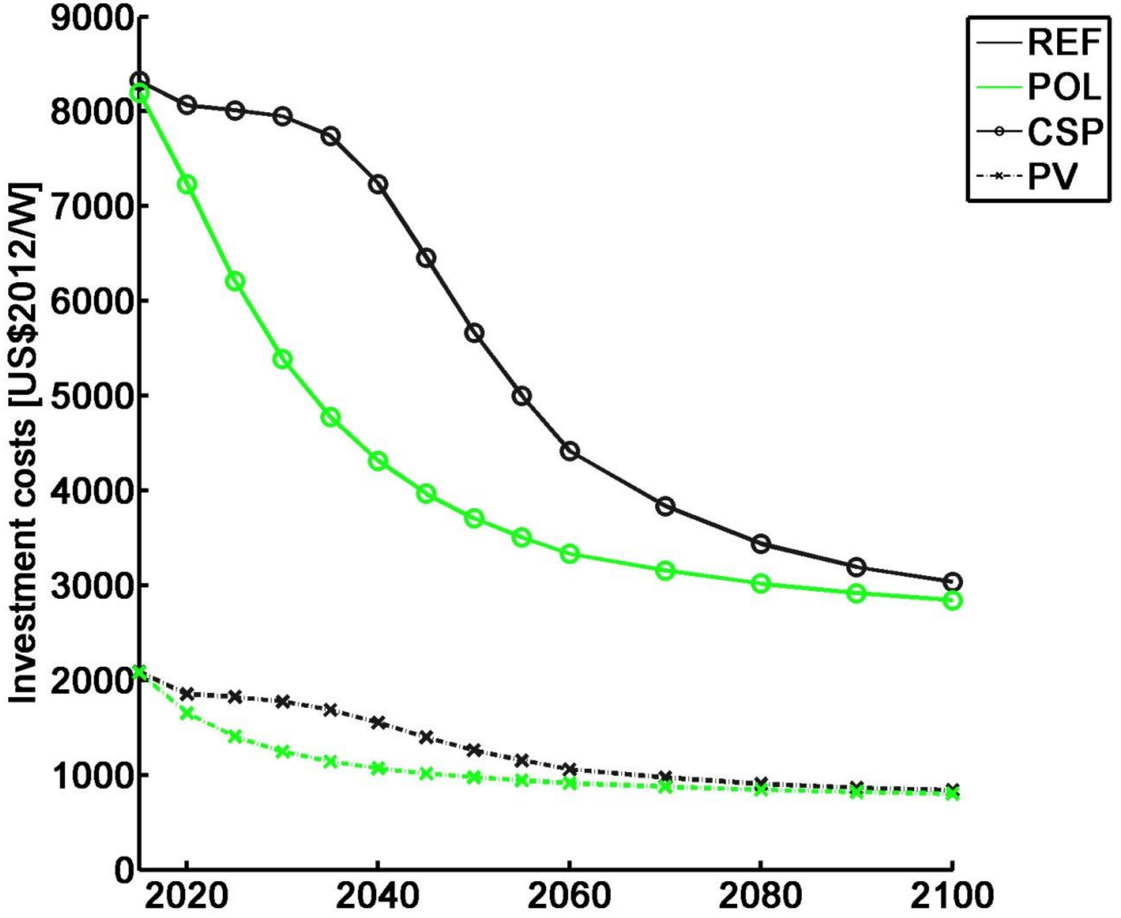
Solar main source of low-carbon electricity



➔ In cost-optimal climate policy scenarios,
- PV, CSP and wind are scaled up much earlier and to a larger extent
- Solar supplies 48% of cumulated 2010-2100 power

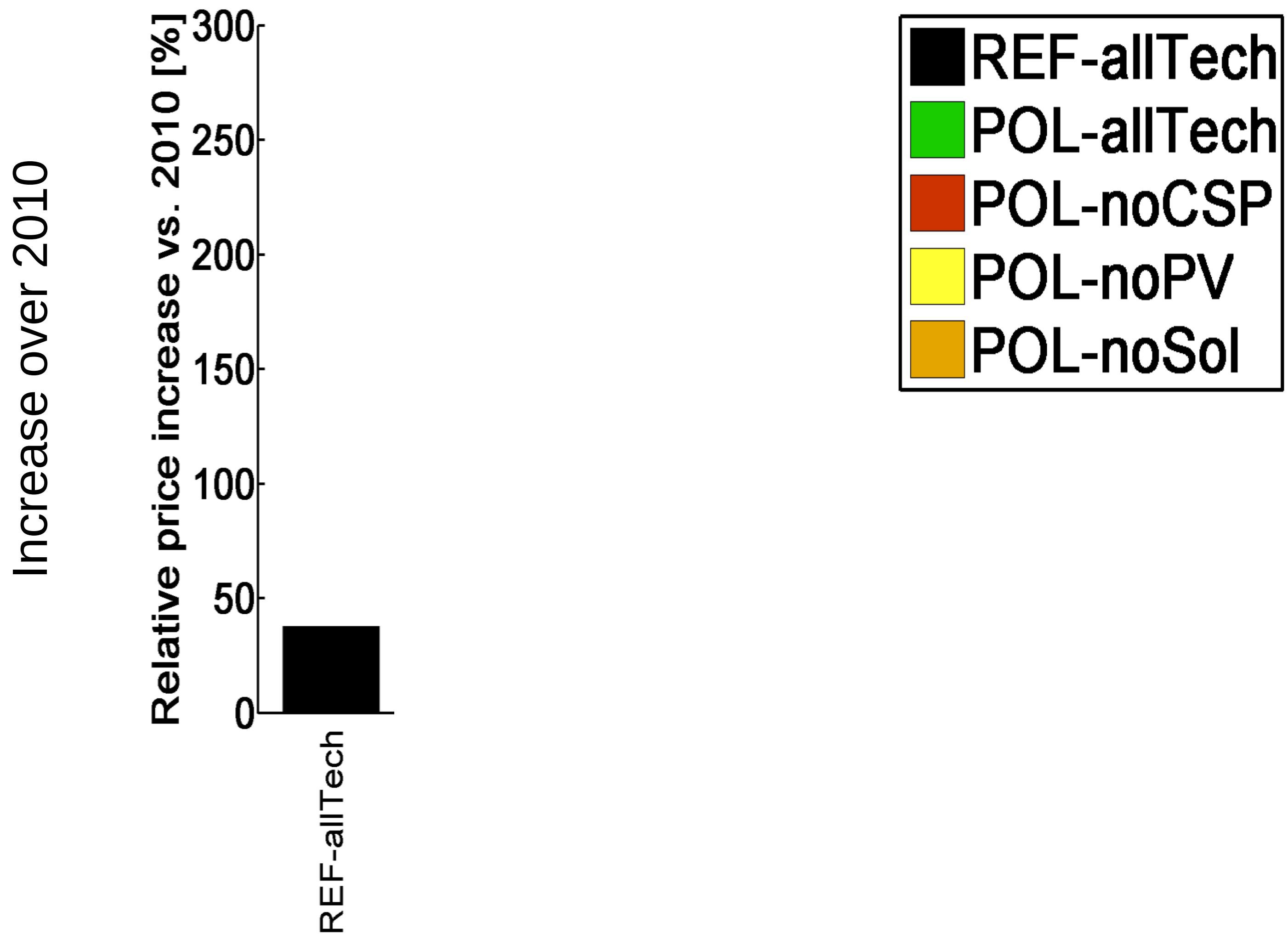
Pietzcker et al (2014): „Using the sun to decarbonize the power sector“, Applied Energy

Dynamic PV and CSP Costs



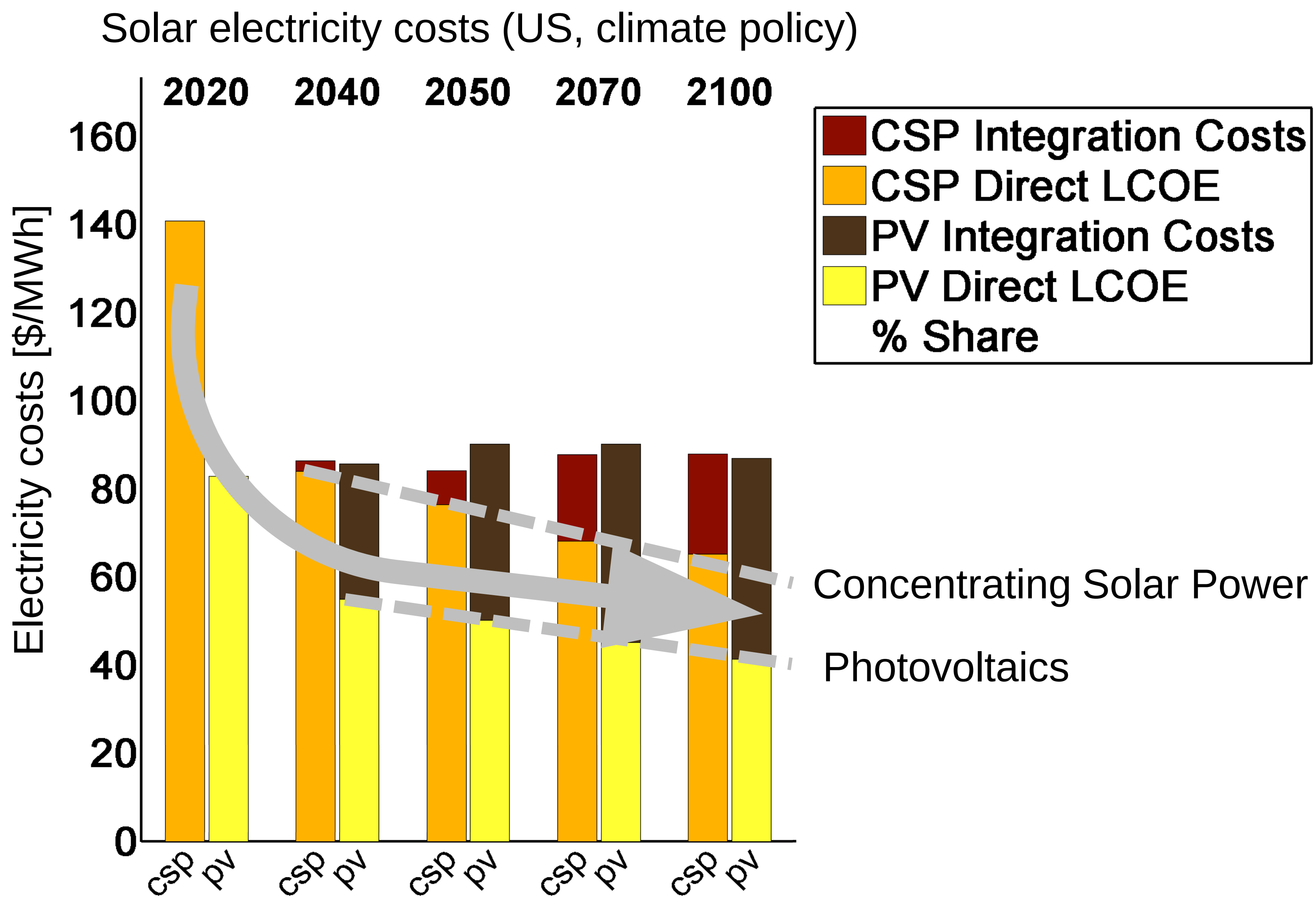
Solar power has large impact on electricity prices

Average electricity price 2050-2100



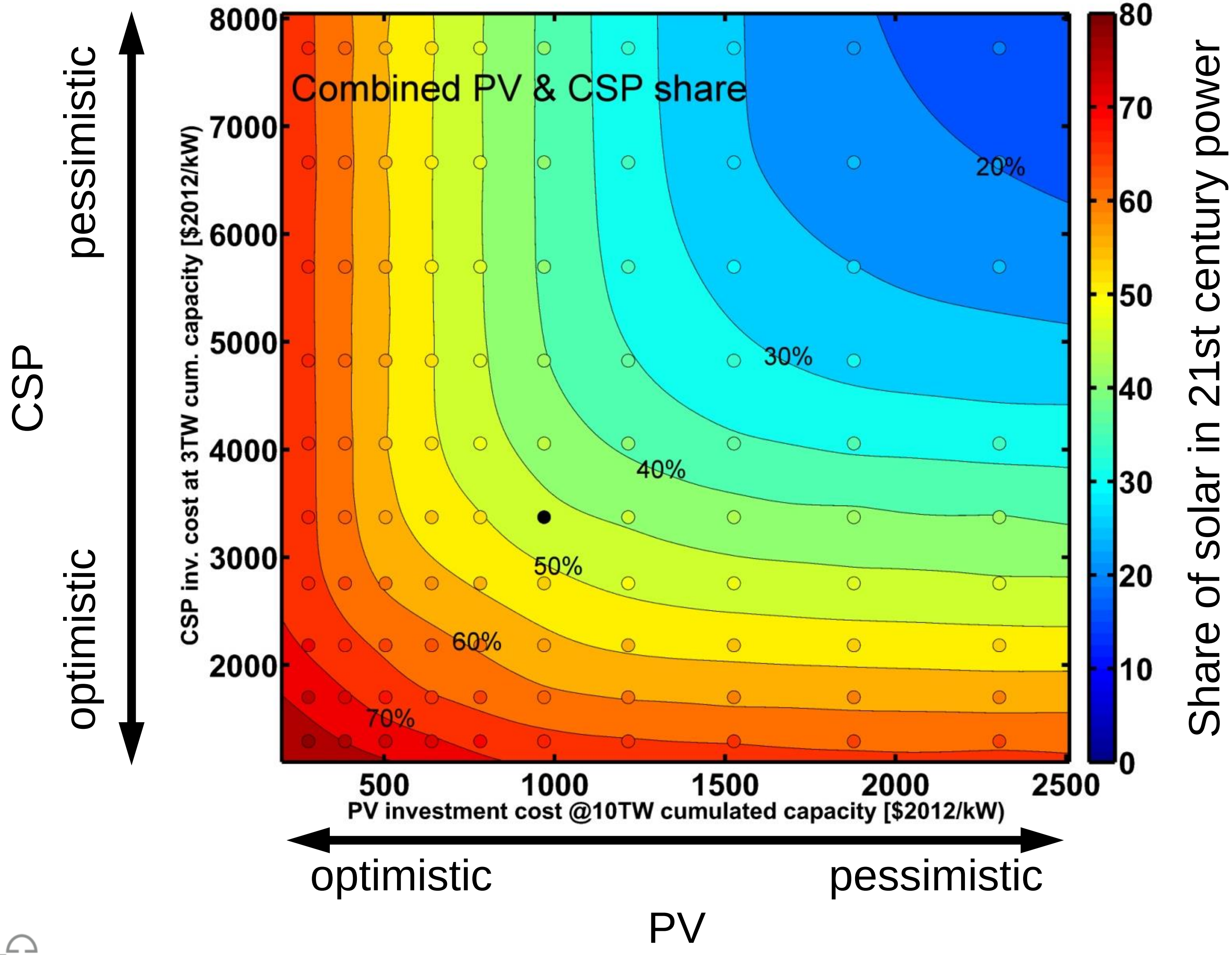
Pietzcker et al (2014): „Using the sun to decarbonize the power sector“, Applied Energy

What decides competition between PV and CSP?



Pietzcker et al (2014): „Using the sun to decarbonize the power sector“, Applied Energy

Results quite robust to learning curve assumptions



Pietzcker et al (2014): „Using the sun to decarbonize the power sector“, Applied Energy

Contents

What we did

1. Develop a simplified mechanism to represent integration challenges in IAMs
2. Develop a consistent resource base for CSP and PV
3. Compile current technology costs for PV and CSP
4. Run large ensemble of scenarios

Conclusions (1)

1. Under stringent climate policy, PV and CSP supply ~45% of cumulated 2010-2100 electricity generation in optimal scenario
2. Altough PV is cheaper, lower integration costs of CSP due to thermal storage lead to growth of CSP once PV share is >15-25%
3. Excluding both solar technologies more than tripples future electricity prices
4. PV/CSP deployed even if future costs reductions are not realized

➔ **Solar technologies are paramount for the long-term decarbonization of the power system**

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Follow-up research questions:

- What is the importance of nuclear and CCS for power sector decarbonization?
- What is the importance of nuclear and CCS for climate change mitigation?
- Do the results on solar change with more detailed VRE representations?

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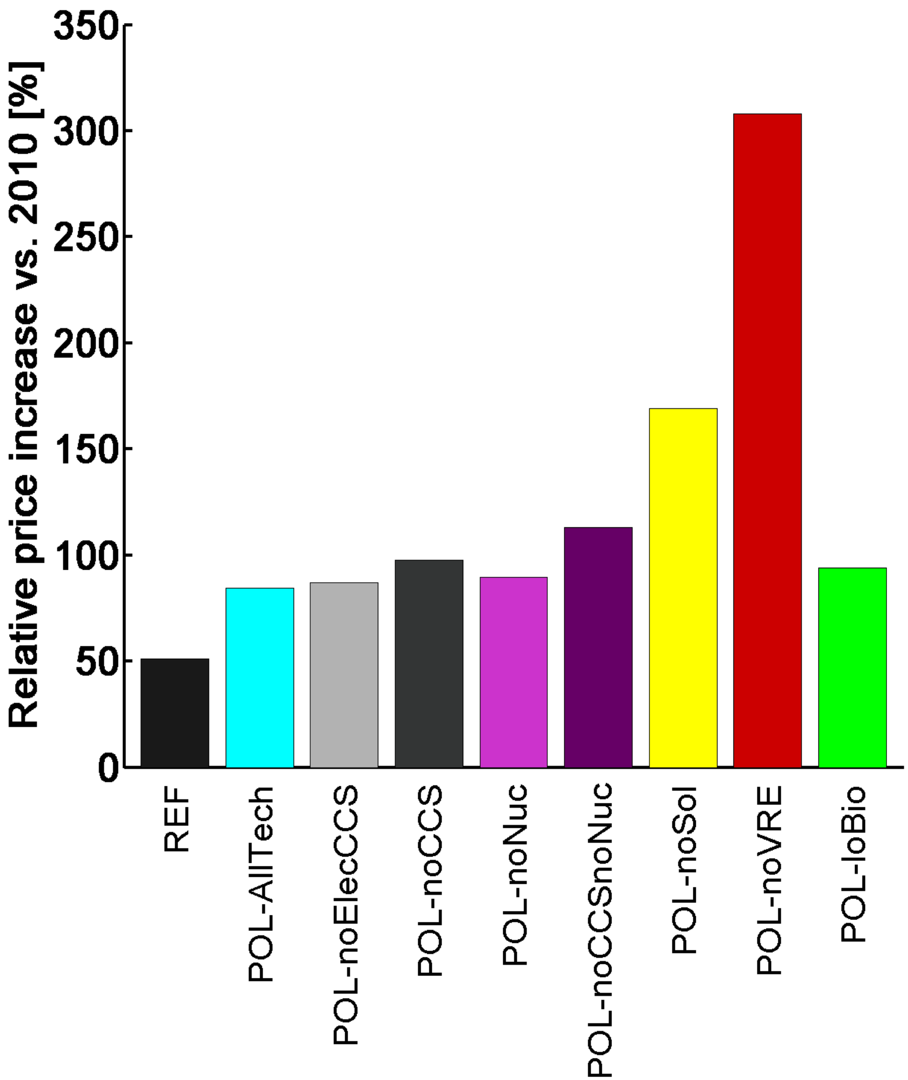
Impact on long-term electricity prices

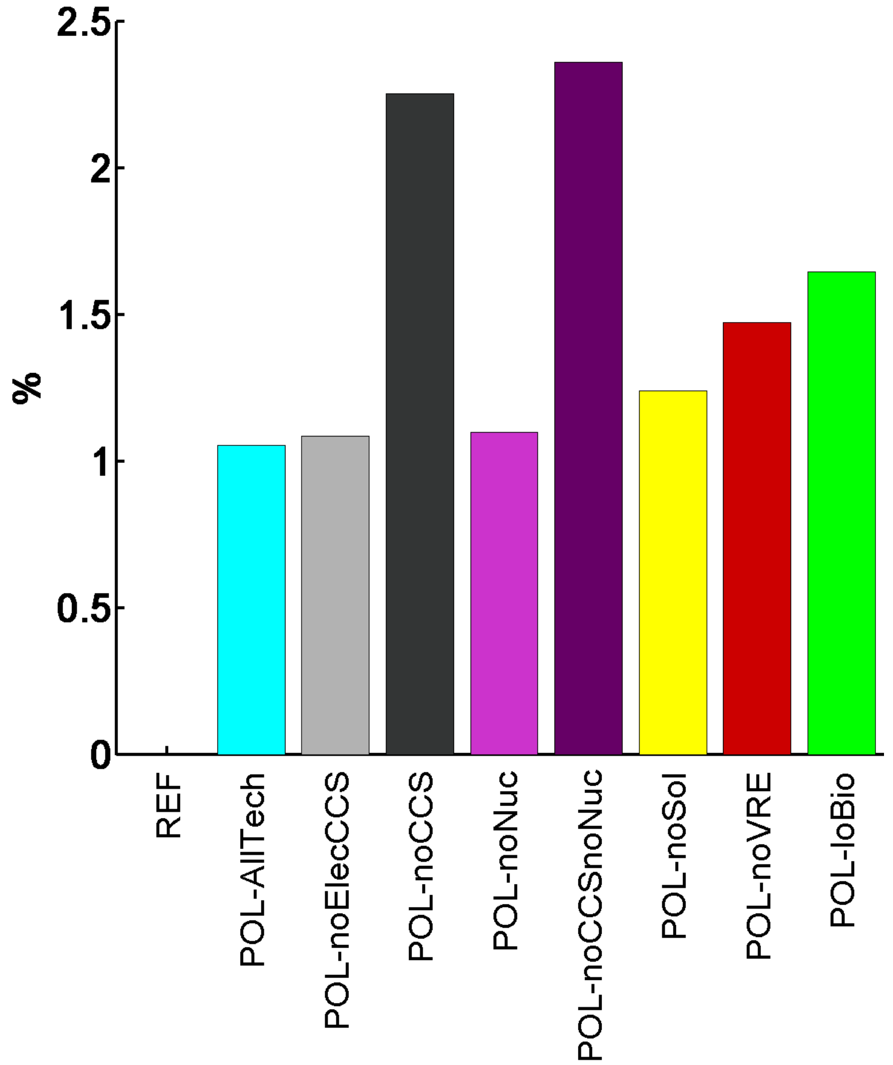
Average electricity price 2030-2080

Price increase vs. mitigation costs

Average electricity price 2030-2080



Total mitigation costs in % of GDP



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Conclusions (2)

Long-term modeling framework of full energy system and economy necessary to represent crucial scarcieties and interactions

Preliminary results:

- Neither nuclear nor power sector CCS have any substantial impact on long-term decarbonization of the power sector

Caveats:

- Deeper analysis of CCS bottleneck required
- More complex representation of integration challenge underway, as well as validation with bottom-up model

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Thank you for your attention!

References

Pietzcker, R.C., Stetter, D., Manger, S., Luderer, G., 2014. Using the sun to decarbonize the power sector: The economic potential of photovoltaics and concentrating solar power. Applied Energy.

Hirth, L., Ueckerdt, F., Edenhofer, O., 2015. Integration costs revisited – An economic framework for wind and solar variability. Renewable Energy 74, 925–939. doi:10.1016/j.renene.2014.08.065

Trieb, F., 2009. Global potential of concentrating solar power, in: Conference Proceedings.

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The REMIND production structure