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Evaluating spill-over benefits from low-carbon energy investments

UKCCSRC Biannual meeting

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The project

- **Support: curiosity-driven, no funding**
- **Project**: What is the case for subsidizing renewables and how much subsidy is justified?
  - Cases: solar PV vs CCS
- The need for collective action

  ⇒ ***Global Apollo Programme*** 2015
- Factors influencing benefits and subsidy rates

Why support low-C energy?

- Producing immature technologies creates learning
  - Not captured by producer
- Learning-by-doing depends on *cumulative* production
  - not output from each unit once installed
- cost reduction per doubling of cum. prod
  - solar PV 20-22% over past 40 yrs, grew 28% last year
  - on-shore wind 12%, CCS: 1-5% (Rubin
- Hard to disentangle R&D and production
  - two-factor rates attribute less to LbD, more to R&D
  - solar PV 12%, on-shore wind 9%

But much R&D stimulated by the same factors

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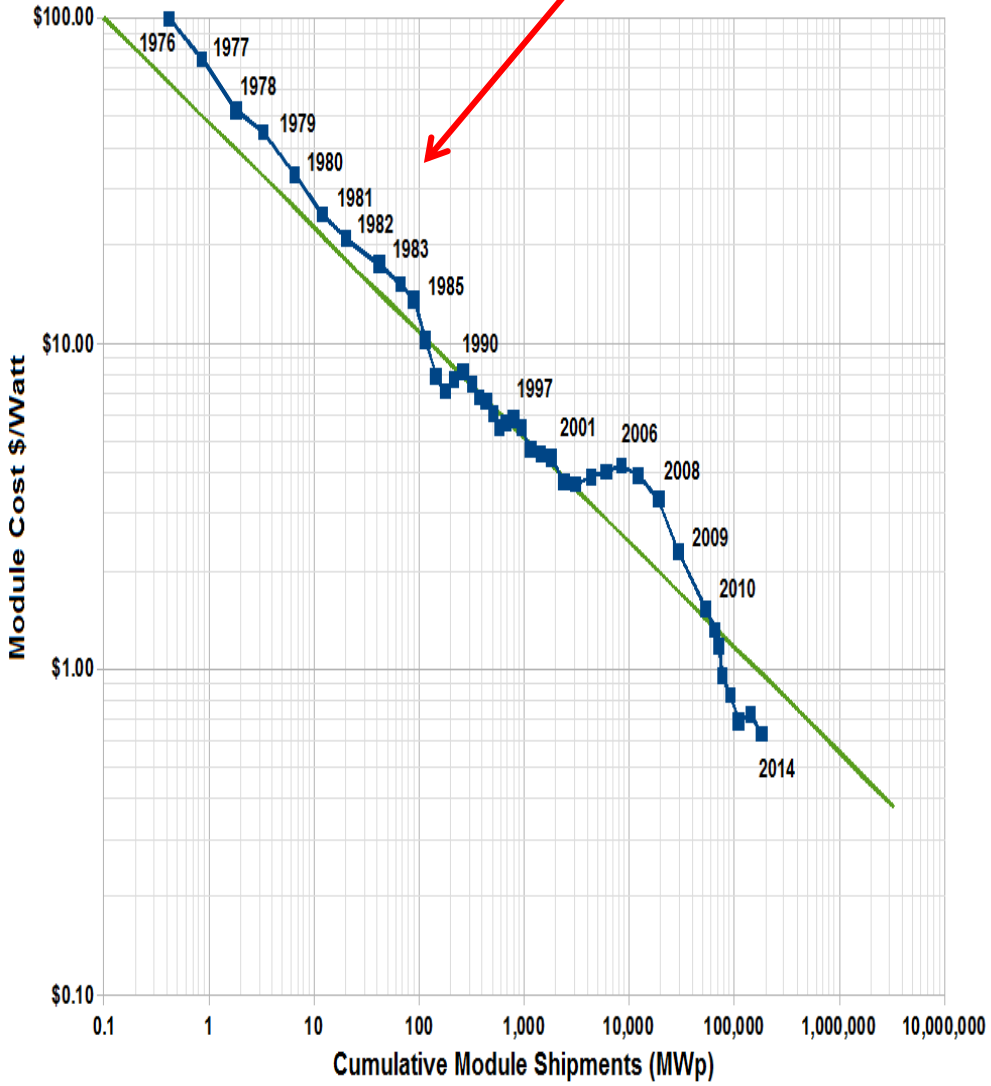
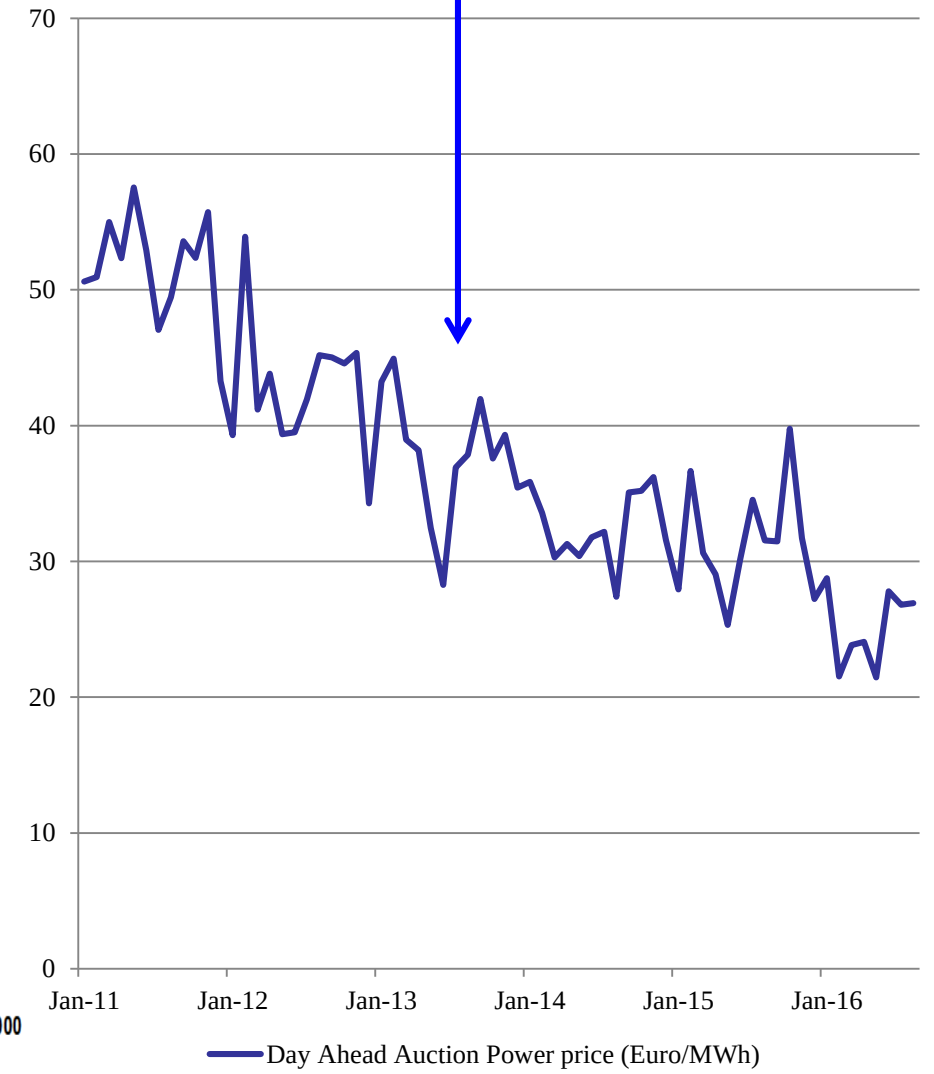
Solar PV cost fall 20% as capacity x2

German wholesale prices fall 50% in 5 yrs, 40% of which due to RES





Undertaking a social CBA

- Specify program: investment trajectory
- Specify scope – e.g. *Global Apollo Programme*
- Specify counterfactual absent technology
- Predict penetration allowing for:
  - Cannibalisation given local market area
  - Sequencing of resource exploitation (for PV, wind, …)
  - Ultimate saturation (e.g. solar PV < 20%?)
- Determine social value of output: displaced fuel, CO_2
- Does program have a **positive net social benefit?**
- If yes, what is the maximum justifiable **subsidy**?

Determinants of PV subsidy B_t/c_0

$$\frac{B_t}{c_0} = \frac{bge^{-(bg+r)t} - (2bg + r)e^{-(bg+r)T}]}{bg + r}.$$

unit cost c_0 in 2015, \$1,050/kW$_p$

T: saturation date

r: social discount rate

g: rate of growth of cumulative capacity

b: coefficient on cost decline $(K_t/K_0)^{-b}$

b = -ln(1-λ)/ln(2), where **λ is the learning rate**

Justified subsidy very sensitive to learning b, λ

Spill-over value by country for solar PV

Table Spillover contributions by country — total $ million/yr

Country	2010	2011	2012	2013	2014	2015	cumulative
China	$624	$1,606	$1,823	$5,336	$2,690	$3,562	$15,641
Germany	$13,544	$4,810	$3,961	$1,365	$772	$363	$24,816
Japan	$2,821	$833	$895	$2,878	$3,078	$2,521	$13,025
USA	$1,971	$1,192	$1,505	$1,985	$1,967	$1,701	$10,321
Italy	$2,730	$5,981	$1,899	$669	$122	$108	$11,509
UK	$60	$531	$519	$610	$548	$886	$3,154
France	$939	$1,137	$581	$266	$294	$216	$3,433
subtotal	$22,689	$16,091	$11,184	$13,108	$9,472	$9,355	$81,900

spillover per kWp	$780	$643	$521	$413	$317	$232
as % of efficient cost, c_t	47%	43%	38%	33%	28%	22%

80% of total?

Illustration for (footloose) CCS

$$\frac{B_t^*}{c_0} = bg(1-\phi)\left(\frac{e^{-(bg+r)t} - e^{-(bg+r)T_1}}{bg+r} + \frac{e^{-(bm+r)T_1}}{bm+r}\right)$$

Share of initial cost experiencing LbD

T_1 Date growth falls from g to m

For **λ= 5%,** b=0.074, g=10%, T_1=25 yrs, m=2%, r=3%, subsidy rate = 11%.

At **λ=2%**, subsidy falls to 7%

Global Apollo Programme

- Learning spill-overs are global
- PV delivers global climate change mitigation

=> ideally **collectively support** global programme

- Each member subscribes in proportion to GDP
  - or more progressively? relate to GHG emissions?
- Funds allocated competitively per kW_p
  - e.g. premium subsidy for 20,000 kWh/kW_p

=> invest where the subsidy needed is minimized

- stimulate CCS by emissions intensity?

Conclusions

- Solar PV varies with location, has limited penetration that affects justified subsidy:
  - Benefits maximized by choosing right places
- CCS footloose, growth constrained by market
- Global benefits need global support = Apollo
  - regional benefits capture only part of cost fall
- Results sensitive to fossil and carbon prices, PV learning and growth rates, discount rate, resource

CCS: justified subsidy much less than solar PV

References

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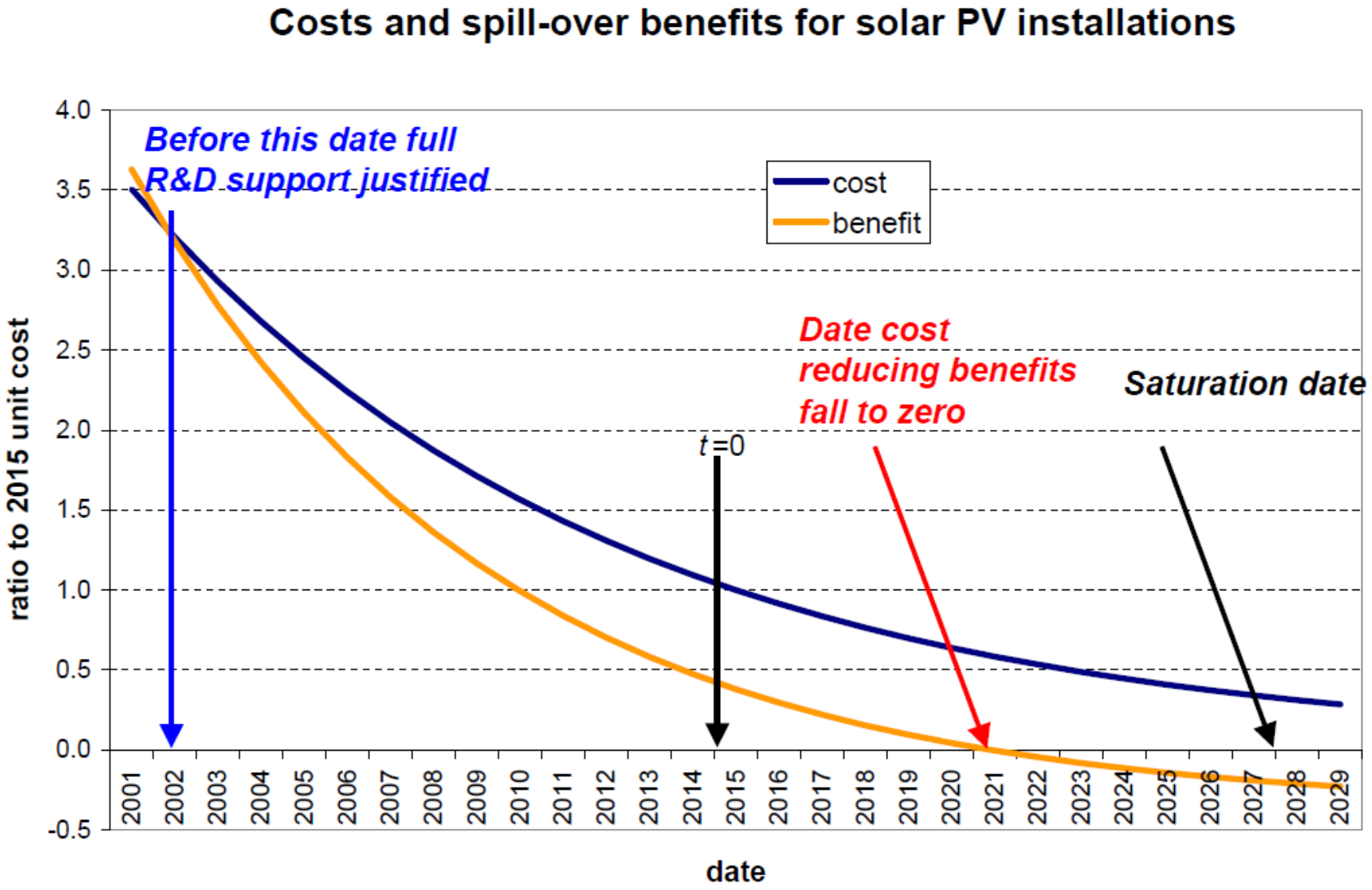
• NREL, (2016). *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2016*, by Fu et al., National Renewable Energy Laboratory

• King, D., J. Browne, R. Layard, G. O'Donnell, M. Rees, N. Stern & A. Turner (2015). *A global Apollo programme to combat climate change*, LSE, at cep.lse.ac.uk/pubs/download/special/Global_Apollo_Programme_Report.pdf

• Rubin, E.S., 2014. Reducing the cost of CCS through "Learning by doing", presentation to Clearwater Coal Conference, June 2, at http://www.cmu.edu/epp/iecm/rubin/PDF%20files/2014/Reducing%20the%20Cost%20of%20CCS%20through%20Learning%20by%20Doing.pdf

Illustration for solar PV



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Emissions of CO_2 by country and share of total emissions 1950-2013

country	cum CO_2 1950-2013	share	cumulative share
United States	280,249	25%	25%
China	156,643	14%	39%
Russian Federation	97,243	9%	47%
Germany	56,844	5%	52%
United Kingdom	35,789	3%	55%
Japan	51,470	5%	60%
India	35,049	3%	63%
France	22,941	2%	65%
Canada	24,185	2%	67%
Ukraine	25,591	2%	70%
Poland	19,312	2%	71%
Italy	19,884	2%	73%
Mexico	14,334	1%	74%
South Africa	14,099	1%	76%
Australia	13,968	1%	77%
Korea, Rep. (South)	13,557	1%	78%
Iran	11,856	1%	79%
Spain	11,424	1%	80%

CAIT Climate Data Explorer. 2017. Washington, DC: World Resources Institute. Available online at: http://cait.wri.org