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NERA ECONOMIC CONSULTING

Evaluating RES support: the case of PV

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http://www.eprg.group.cam.ac.uk

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Outline

- Why subsidize low-carbon electricity?
- The need for collective action
  - ⇒ ***Global Apollo Programme*** 2015
- Factors influencing benefits and subsidy rates
  - – learning rate, resource, growth rate, cannibalisation, saturation, fossil and carbon prices
- how much subsidy is justified?
  - – For solar PV, on-shore wind and CCS

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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, 2014)
- 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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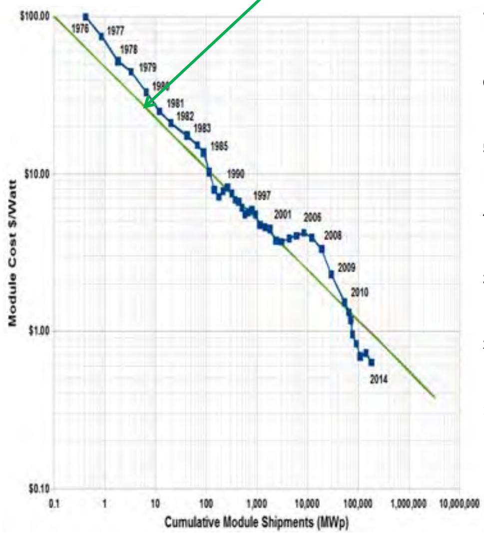
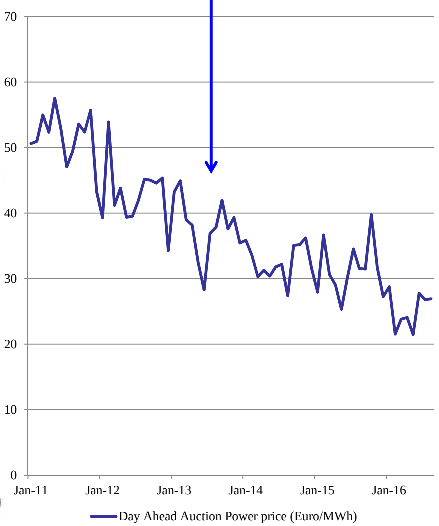
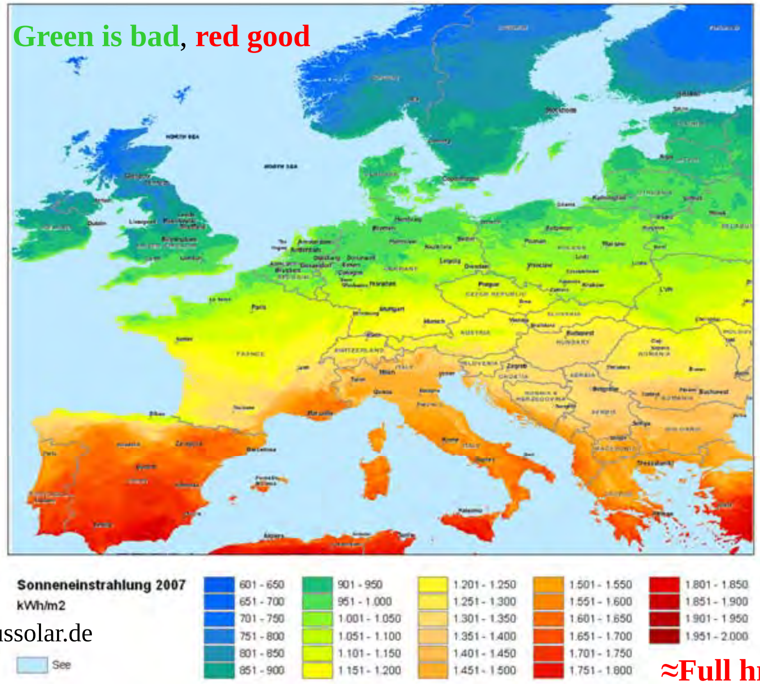
Solar PV cost fall 20% as capacity x2

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



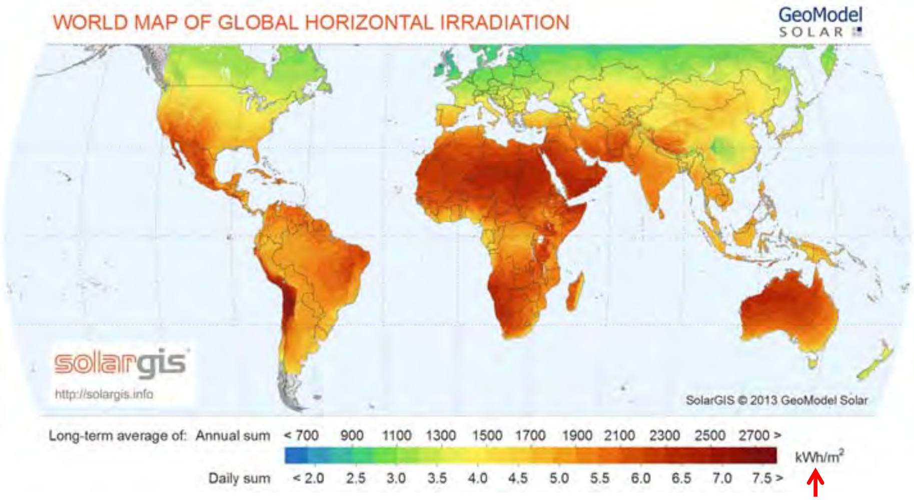




focussolar.de

≈Full hrs/yr

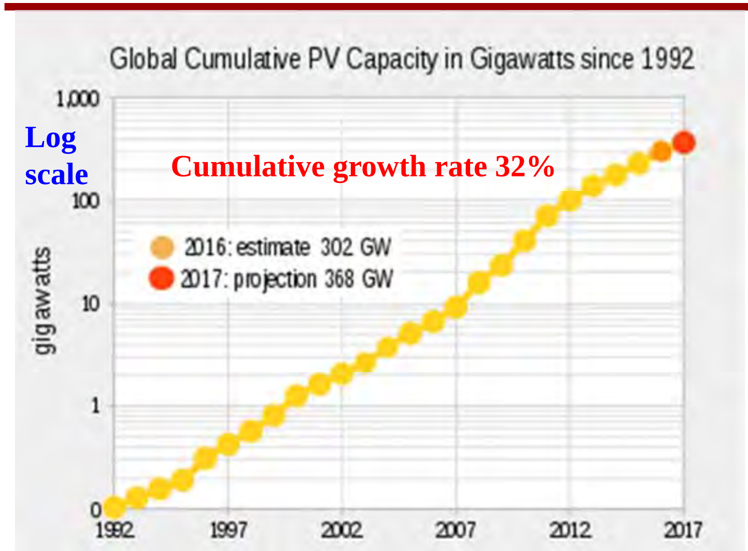
Doubling the irradiance halves the cost



Roughly Full hrs/yr

http://geosun.co.za/solar-maps/

Steady growth of PV capacity

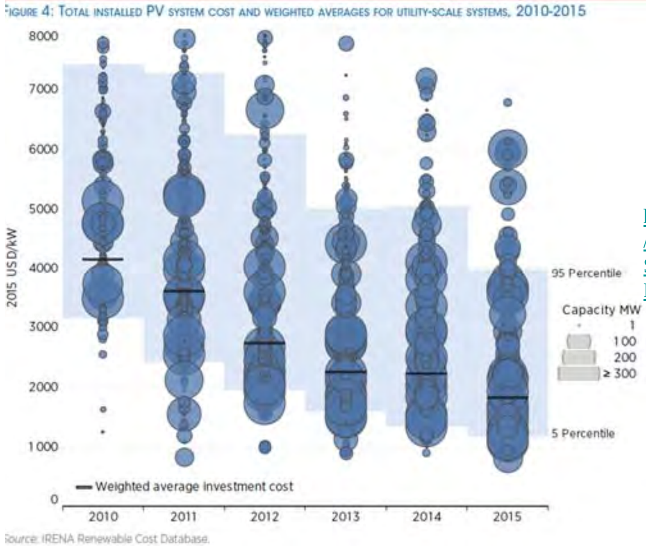


Log scale

Cumulative growth rate 32%

Source: Wikipedia

PV learning rates are high econs of scale important



Module learning rate 18-22%
BOS cost excl inverter now 60% of total

http://www.irena.org/publications/2016/Jun/The-Power-to-Change-Solar-and-Wind-Cost-Reduction-Potential-to-2025

The learning model

Let K_t be cumulative installed capacity at t, c_t be unit PV cost

$$c_t = aK_t^b, \text{ so } \frac{\Delta c}{c} = (1+\Delta K/K)^b - 1,$$

The learning rate is $\lambda = -\frac{\Delta c}{c} = 1 - 2^b.$

$$c_t = c_m + aK_t^b = c_m + (c_0 - c_m)\left(\frac{K_t}{K_0}\right)^b.$$

Assume steady growth at rate g, then unit costs at date t are

$$= c_m + (c_0 - c_m)e^{gbt},$$

For PV λ= 22 and current growth rate is 30+%

If λ= 22%, b = 0.36, g = 30%, then initially costs fall by **11% p.a**.

Predicting costs

- 2015 global av. module price \$580/kW$_p$ for 234 GW$_p$ cum.
- only 55% of installed cost of \$1,050/kW$_p$
- NREL (2016) total unit cost utility-scale tracking unit in cheapest state \$1,190kW$_p$
- Adjust for high cost of US labour => **\$1,050/kW$_p$**
- ITRPV (2016) 2,000 hrs (23% CF) **\$44/MWh**
  - some 20yr PPAs signed in Chile for \$25/MWh,
  - Mexico \$21 (no subsidy)
  - Europe lower 1,000 hrs (11.4% CF) \$87/MWh
- Capacity value depends on coincident peak
  - Quite high in CA, zero in Europe

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 subsidy needed is minimized

Project Innovation – 22 countries pledge to **double** clean energy R&D

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**?

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Specifying the PV project

- Steady growth g=25% until saturation at T=2028
  - Thereafter at global demand growth of m =1.75%
  - Start with highest insolation sites h_0 = 2,500hrs/yr
  - Local cannibalisation/saturation => move to next site
  - Saturation at 15% globally, last site h_T = 900hrs/yr
  - Fossil displaced decreases 1% p.a. from $35/MWh
  - CO_2 price $15/Mwh$_e$ rising at 1% p.a.
- No external benefits (C or LbD) after N (2035)
  - **Other low-C options could have replaced PV**
  - **and PV output value falls thereafter at 1% p.a.**
- Output site-specific, no degradation until N
- Capacity credit $75/kWyr (summer peaking)

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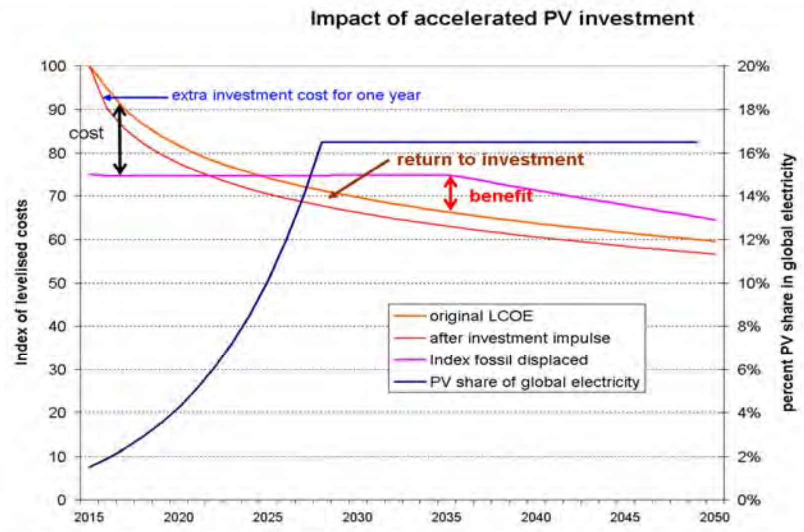
Is program worthwhile? Is acceleration worthwhile?



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Determinants of PV subsidy B^*_t/c_0

$$\frac{B^*_t}{c_0} = b(1-\phi)e^{rt}\left(g\int_t^T e^{-(bg+r)u}du + me^{-b(g-m)T}\int_T^N e^{-(bm+r)u}du\right)$$

T: saturation date

m: rate of growth of world electricity

r: social discount rate = 3%

g: rate of growth of cumulative capacity

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

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

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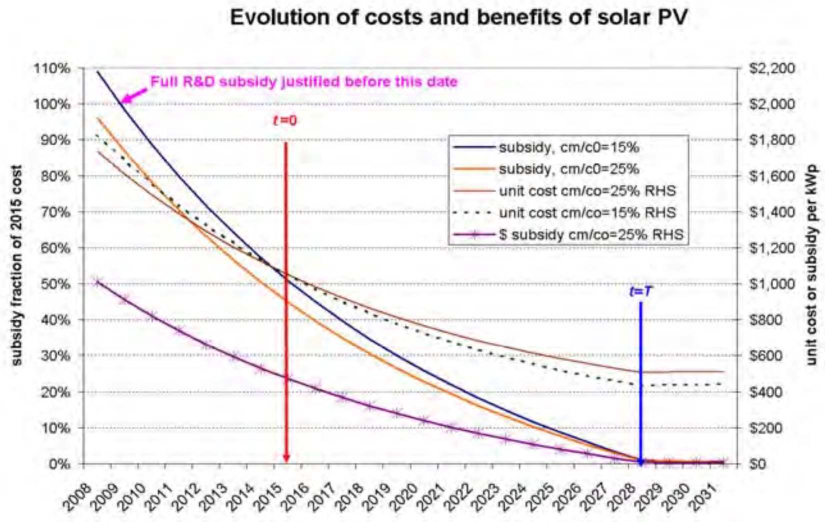
Illustration for solar PV



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Contributions to global cumulative capacity

$$\frac{B_t^*}{c_0} = b(1-\phi)e^{rt}\left(g\int_t^T e^{-(bg+r)u}du + me^{-b(g-m)T}\int_T^N e^{-(bm+r)u}du\right)$$

					GWp cumulative	
Country	2010	2011	2012	2013	2014	2015
China	0.8	3.3	6.8	19.7	28.2	43.5
Germany	17.4	24.9	32.5	35.8	38.2	39.8
Japan	3.6	4.9	6.6	13.6	23.3	34.2
USA	2.5	4.4	7.3	12.1	18.3	25.6
Italy	3.5	12.8	16.5	18.1	18.5	18.9
UK	0.1	0.9	1.9	3.4	5.1	8.9
France	1.2	3.0	4.1	4.7	5.7	6.6
subtotal	29.1	54.1	75.6	107.3	137.2	177.5
Global cumulative capacity	*47.0*	*78.0*	110.0	144.0	184.0	234.0
spillover per kWp	$911	$822	$740	$664	$595	$531

Justifies £20/MWh for first 20,000 MWh/MW$_p$

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Spill-over value by country

Table Spillover contributions by country					total $ million/yr		
Country	2010	2011	2012	2013	2014	2015	cumulative
China	$729	$2,055	$2,588	$8,579	$5,041	$8,135	$27,127
Germany	$15,833	$6,152	$5,624	$2,194	$1,447	$829	$32,079
Japan	$3,297	$1,065	$1,271	$4,626	$5,768	$5,758	$21,784
USA	$2,304	$1,524	$2,137	$3,192	$3,687	$3,884	$16,728
Italy	$3,192	$7,649	$2,696	$1,076	$229	$246	$15,087
UK	$70	$680	$737	$980	$1,027	$2,023	$5,517
France	$1,097	$1,455	$825	$427	$551	$493	$4,848
subtotal	$26,522	$20,579	$15,877	$21,073	$17,750	$21,369	$123,170

80% of total

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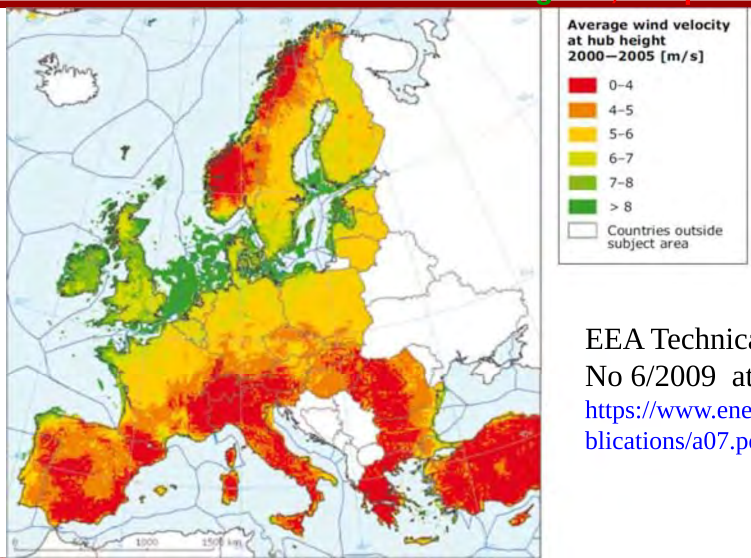
Wind resource up to 50m depth, hub ht 80m onshore, 120m offshore
Green is good, red poor



EEA Technical report No 6/2009 at https://www.energy.eu/publications/a07.pdf

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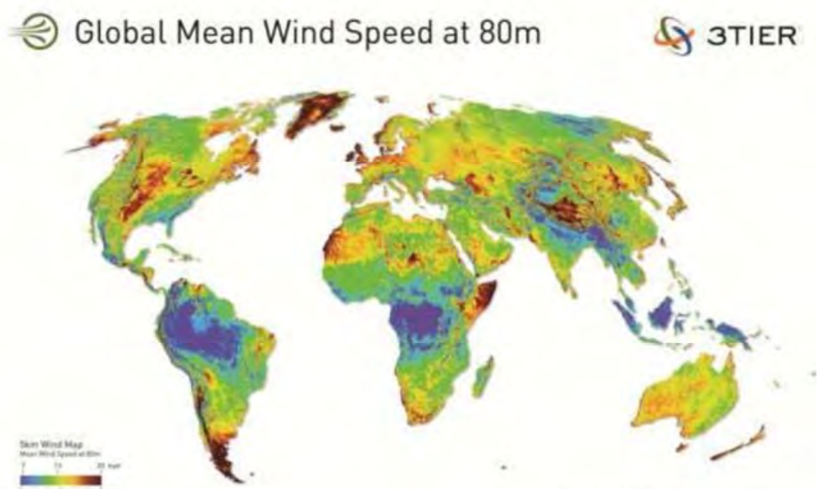
Global potential 94 TW @2,000 hrs = 188,000 TWh, global power = 24,000 TWh

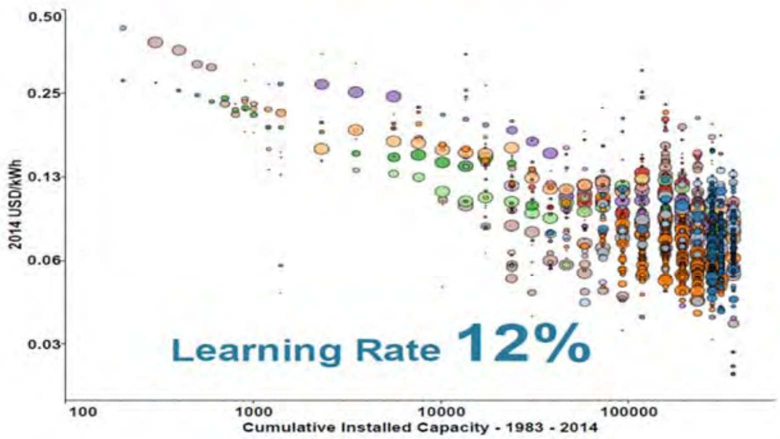


http://www.inscc.utah.edu/~krueger/5270/3tier_5km_global_wind_speed.pdf

On-shore wind: taller towers give higher capacity factors

FIGURE 8: IRENA ONSHORE WIND LEARNING RATE

Log scale



https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Wind_2016.pdf

On-shore wind

- If λ = 12%, *g*=12%, T=N= 27yrs, after 1.75%
  - saturates at 29% (Ireland plans about 40%)
- 2015 subsidy could be **24% of initial cost of $1,560/kW = $375/kW**
- Over 20,000 hrs = £14/MWh
- If λ = 7%, 2015 subsidy could be **15%** = £9/MWh
- Optimal auction is a price/MWh for N hrs – equivalent to a capacity support targeted on LBD

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%

Conclusions

- Solar PV varies with location, has limited penetration that affects justified subsidy:
  - Benefits maximized by choosing right places
  - Justified subsidy substantial
- On-shore wind – high potential, lower support
- CCS footloose, subsidy rates much lower
- 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

Subsidies are technology specific

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- 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

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Estimating spill-over benefits

- Cost of doubling cum prod is low at 10 GW, much higher at 200 GW => **early investment valuable**
- But cannot instantly raise low base by high amt.
  - **constraints** on building production capacity
  - **limits** to rate of dissemination of learning
  - **uncertainty** whether past LbD is good guide to future
- **is program as whole NPV positive** compared to fossil?
- Consider modest temporary increase in investment

=> has a current cost but lowers all future costs

- Is it worth it - is NPV positive in terms of costs?
- If so then maximize rate of investment
- If worth it then calculate spill-over benefits

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