




Energy research Centre of the Netherlands

Technology Learning for Energy Policy Making

Technology Learning and Deployment Workshop

A collage of four images: top-left shows high-voltage power lines against a blue sky; bottom-left shows solar panels and a green fern leaf; center is a sunset over the ocean with birds in flight; right shows waves crashing and a factory with smokestacks.

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ECN and Columbia University

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Outline

ECN's learning-curve methodology work involves:

- Using learning curves;
- Developing learning curves;

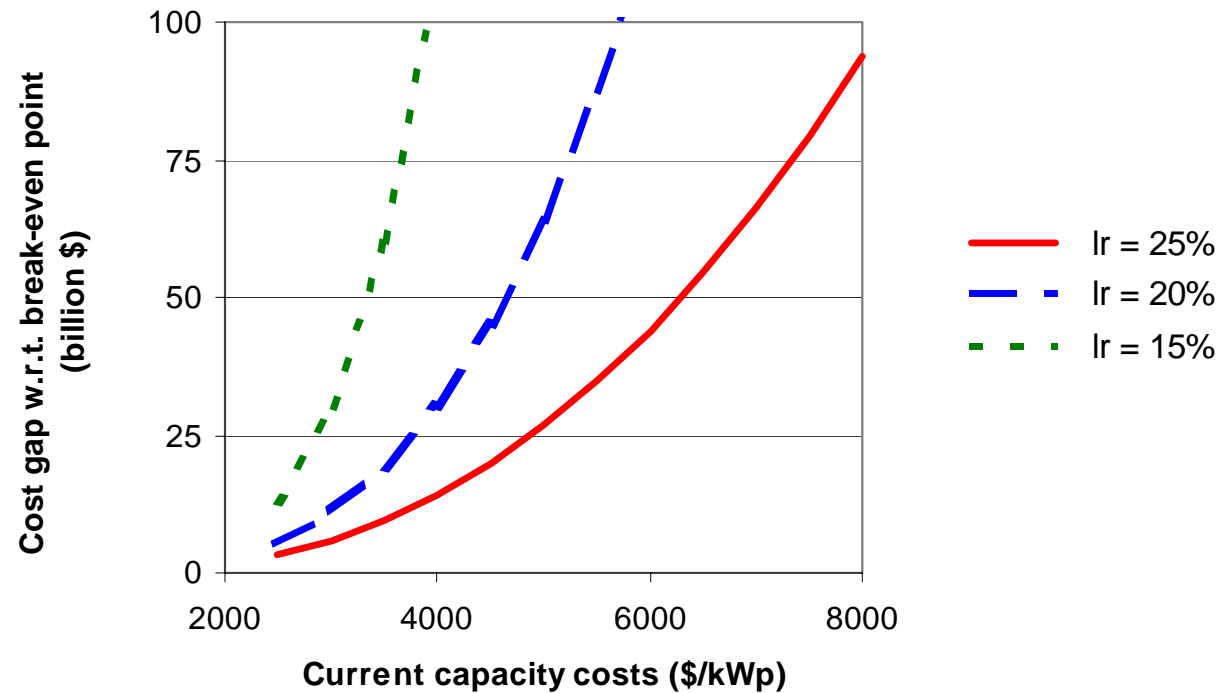
And also:

- Criticizing learning curves;

But nevertheless:

- Continuing learning-curve analysis.

Using learning curves: PV



Cost gap to be bridged for PV to become competitive typically amounts to up to 100 billion \$.

Using learning curves: PV

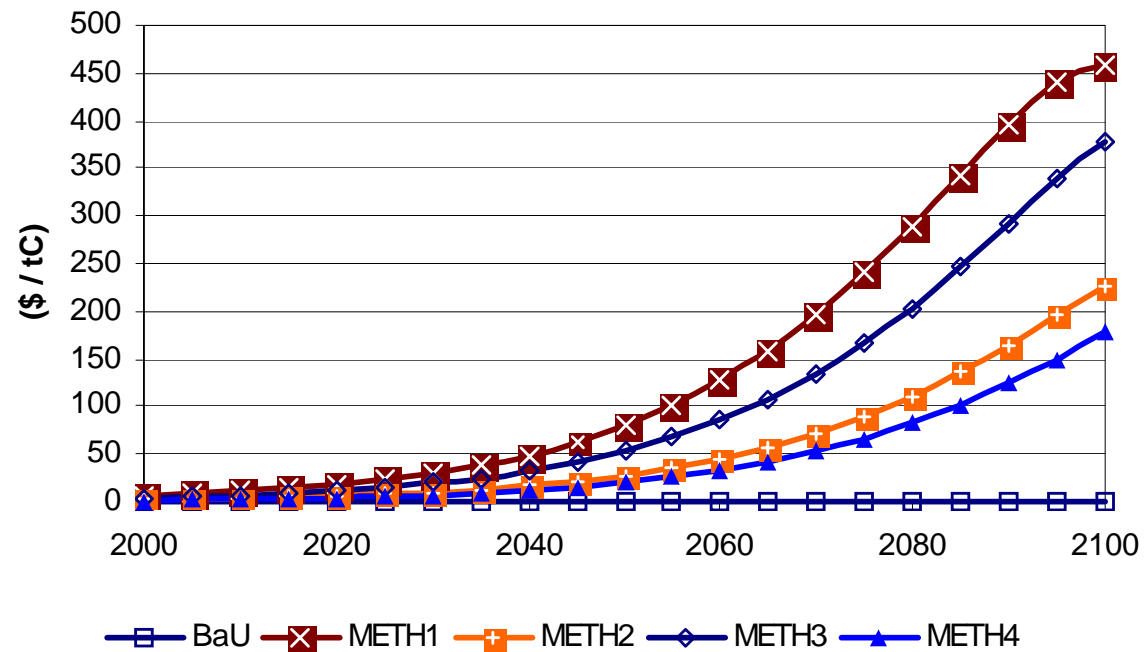
Progress ratio (%)	70%	75%	80%
Break-even production (GWp)	23	48	148
Break-even production (% of world)	0.7%	1.5%	4.5%
Break-even cost (\$ billion)	37	74	211
Conventional cost (\$ billion)	22	47	147
Cost gap (\$ billion)	15	27	64
Cost gap (% of break-even cost)	41%	36%	30%
Avoided damage (\$ billion)	5	12	37
Avoided damage (% of cost-gap)	37%	44%	58%

An important part of the investments can be justified on the basis of the fossil fuel external costs avoided.

Using learning curves: PV

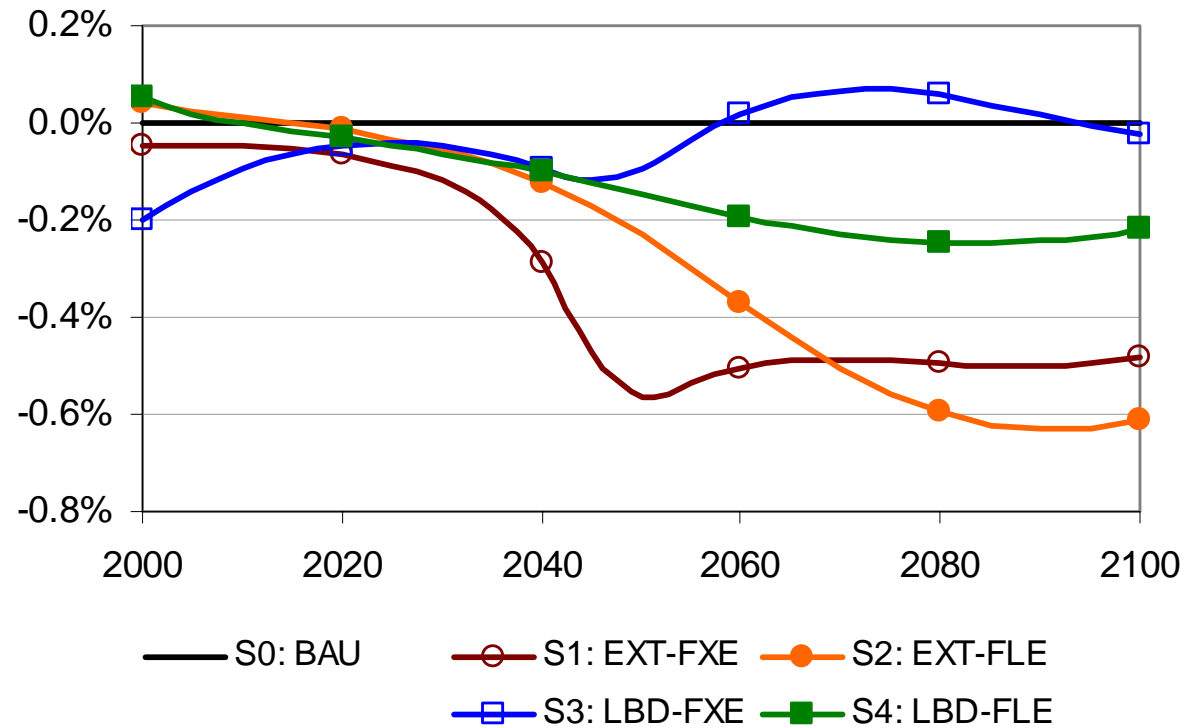
- van der Zwaan, B.C.C. and A. Rabl, “The learning potential of photovoltaics: implications for energy policy”, *Energy Policy*, 32, 13, 2004, pp. 1545-1554.
- van der Zwaan, B.C.C. and A. Rabl, “Prospects for PV: a learning curve analysis”, *Solar Energy*, vol.74, no.1, 19-31, 2003.

Using learning curves: DEMETER



CO2 taxes to reach a stringent climate change target can be significantly reduced when including learning curves.

Using learning curves: DEMETER



Climate constraint related consumption / welfare loss is significantly reduced when including learning curves.

Using learning curves: DEMETER

- Gerlagh, R. and B.C.C. van der Zwaan, “Options and Instruments for a Deep Cut in CO₂ Emissions: Carbon Capture or Renewables, Taxes or Subsidies?”, *The Energy Journal*, 27, 3, 2006, pp.25-48.
- Gerlagh, R. and B.C.C. van der Zwaan, “A sensitivity analysis of timing and costs of greenhouse gas emission reductions under learning effects and niche markets”, *Climatic Change*, 65, 2004, pp.39-71.
- Gerlagh, R. and B.C.C. van der Zwaan, “Gross world product and consumption in a global warming model with endogenous technological change”, *Resource and Energy Economics*, 25, 35-57, 2003.
- van der Zwaan, B.C.C., R. Gerlagh, G. Klaassen and L. Schrattenholzer, “Endogenous Technological Change in Climate Change Modelling”, *Energy Economics*, 24, 1, 2002.

Using learning curves: MARKAL

Since long:

- Learning curves for a large range of technologies;
- 'Cluster learning' for options that share components;

Recently also:

- Learning curves for CCS;

Results on internalization of environmental externalities:

- CCS is deployed extensively if climate damages are at least some 100 €/tCO₂ or CCS damages at most a few €/tCO₂.

Using learning curves: MARKAL

- Smekens, K. and B.C.C. van der Zwaan, “Atmospheric and Geological CO₂ Damage Costs in Energy Scenarios”, *Environmental Science and Policy*, 9, 2006, pp.217-227.

Developing learning curves: PV

EU PHOTEX project investigated learning curves for PV:

- Developed learning curves for PV components;
- Observed time-dependence of learning rates;
- Analyzed relation between learning and growth rates.

Developing learning curves: PV

- Schaeffer, G.J. *et al.*, “Learning from the Sun”, PHOTEX project report, ECN-C—04-035, August 2004.

Criticizing learning curves: extrapolability

Learning curves should be handled with great care:

- Sample of observed learning technologies is biased;
- Extrapolability of learning curves cannot be certain;
- Initial data points have high leverage;
- R&D vs. learning cost reductions are intertwined;
- Too often learning fits do not include error margins;
- Technology boundaries matter a lot.

Criticizing learning curves: extrapolability

- Sagar, A. and B.C.C. van der Zwaan, “Technological Innovation in the Energy Sector: R&D, Deployment, and Learning-by-Doing”, *Energy Policy*, 34, 17, 2006, pp.2601-2608.

Continuing learning-curve analysis: unpacking

Learning-by-doing: known result, unknown mechanism.

R&D: known mechanism, unknown result.

- Given their uncertainties, R&D and learning through deployment should almost always work in tandem;
- While both are needed, the fundamental question relates to their relative share in funding.

Aim: unpack learning curves / open the black box.

- Distinguish between e.g. learning-by-manufacturing, learning-by-copying, learning-by-operating, learning-by-implementing, etc.

Continuing learning-curve analysis: hydrogen / fuel cells

For H₂ / FC technologies, learning curves are important:

- Their costs are exceedingly high.

Yet the learning methodology challenges are large:

- Little deployment for many H₂ / FC technologies;

For H₂ production (SMR, electrolysis):

- Part of production well before 1970s (cost data).

Continuing learning-curve analysis

Lots still left to be researched on this important subject.