Experience curves as policy tool
The case of PV

Edited by Gerrit Jan Schaeffer, ECN Policy Studies, interim coordinator EU-Photex project

Contributions by Project Partners: GENEC (F), FhG-ISE (D), ISET (D), UU-STS (NL), CESI (I), ECN Solar Energy (NL)

EXCETP-EXTOOL workshop “Experience Curves: A Tool for Energy Policy Analysis and Design”

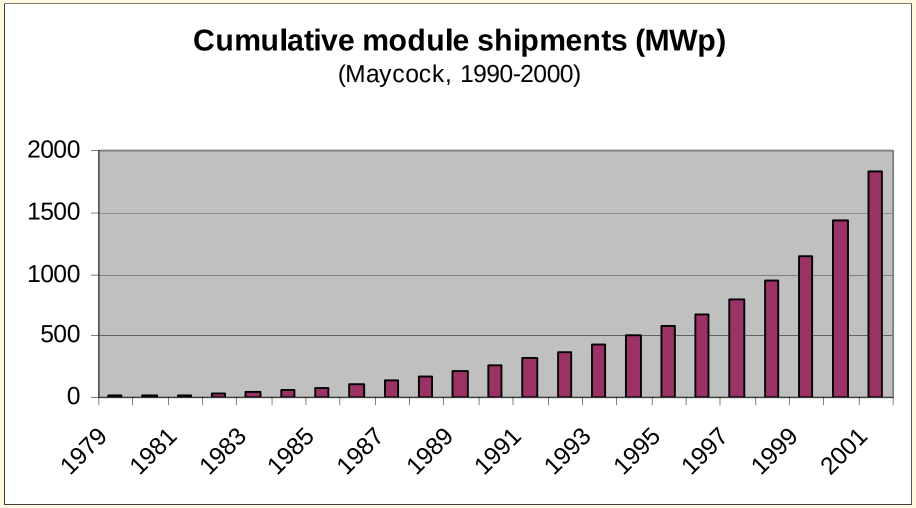
Paris, 23 January 2003

ECN

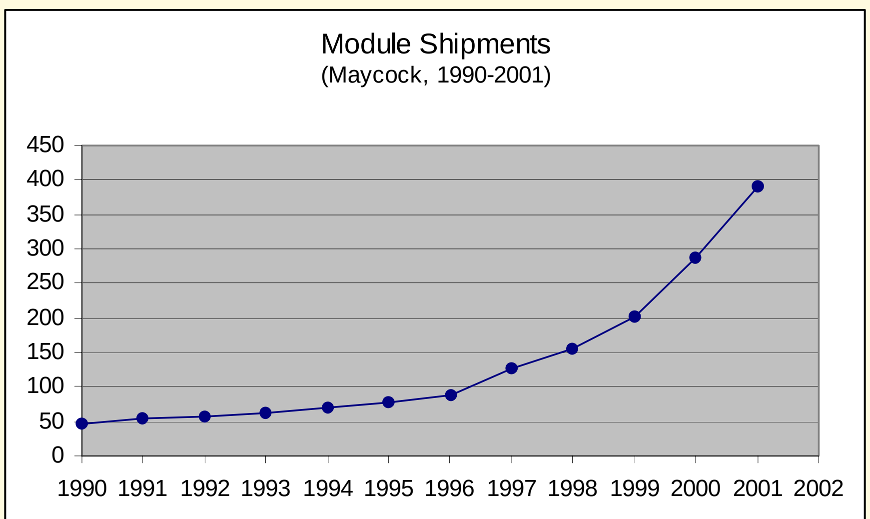
Photex

- General objective
  - to further develop experience curve approach as a policy and analysis design tool
- Specific objectives and characteristics
  - focus on one technology and its components (PV)
  - study the effects of different policy schemes on technology progress
  - advise on a right balance between R&D and D&D spending
  - analyse sources and mechanisms of technology learning

PV has experienced a very fast growth over recent years



Year	Growth rate
1986	35%
1987	27%
1988	24%
1989	23%
1990	22%
1991	21%
1992	18%
1993	16%
1994	16%
1995	15%
1996	15%
1997	19%
1998	20%
1999	21%
2000	25%
2001	27%



1990	
1991	19.1%
1992	4.5%
1993	5.2%
1994	14.0%
1995	11.8%
1996	14.2%
1997	42.0%
1998	23.1%
1999	30.0%
2000	42.9%
2001	35.8%

ECN

What progress ratio do we need?

Effects of different progress ratios on break-even costs and cumulative production (*Van der Zwaan and Rabl, 2002*)

Progress Ratio	Cum. Production [GWp]	Cum. Production [% of 3300 GWp = current world capacity]	Surplus cost of reaching break-even [USD billion]
0.7	23	0.7%	15
0.75	48	1.5%	27
0.8	148	4.5%	64
0.85	957	29%	288
0.9	39700	1200%	7110

Assumptions: Current costs $5/Wp; break-even costs $1/Wp (implies kWh cost of 0.05 – 0.01 $/kWh); initial cumulative production is 1 GWp

Progress ratio should be between 0.75 and 0.8?

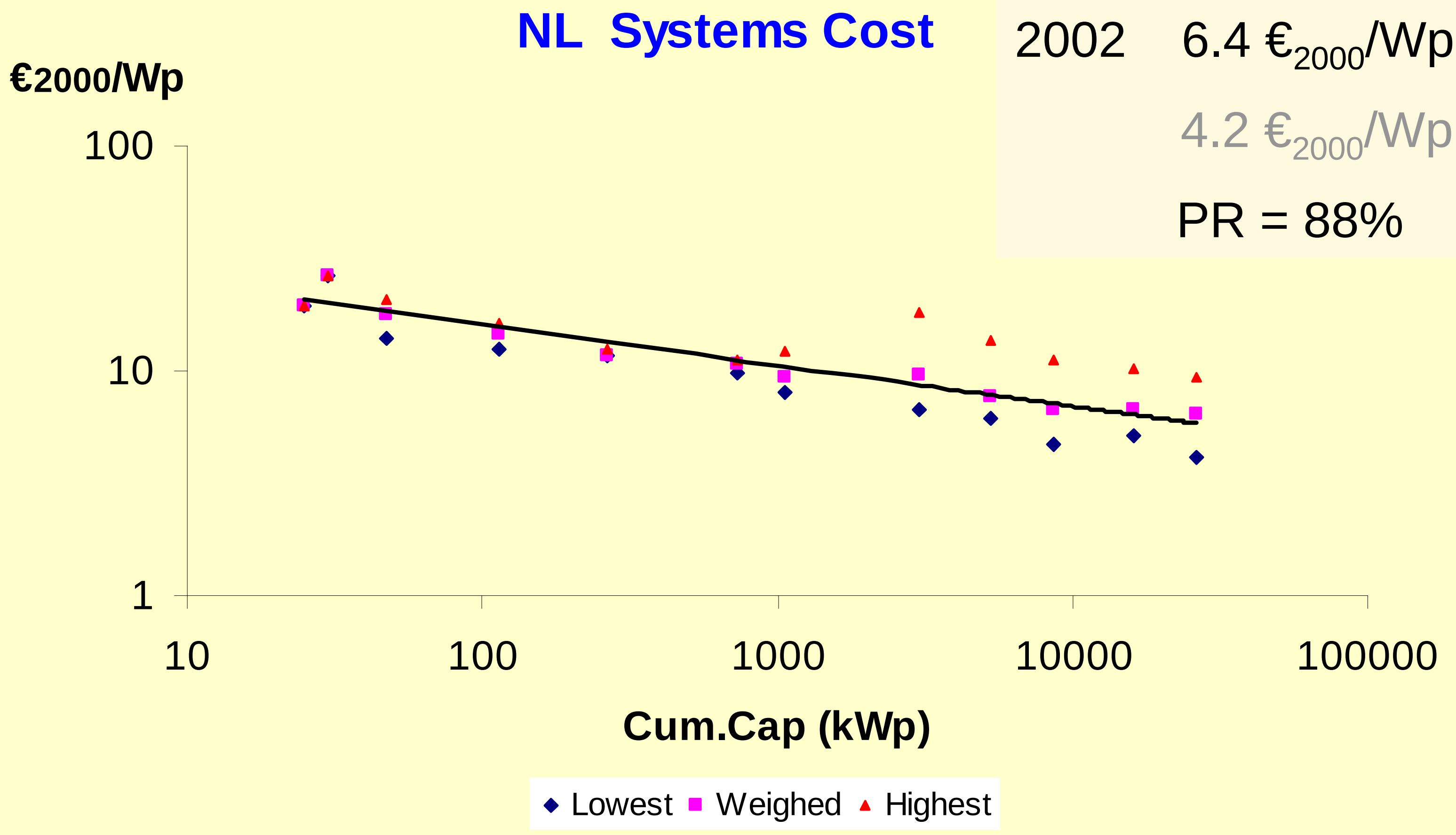
First progress ratio results from Photex

1991 20   €$_{2000}$/Wp

2002   6.4 €$_{2000}$/Wp

4.2 €$_{2000}$/Wp

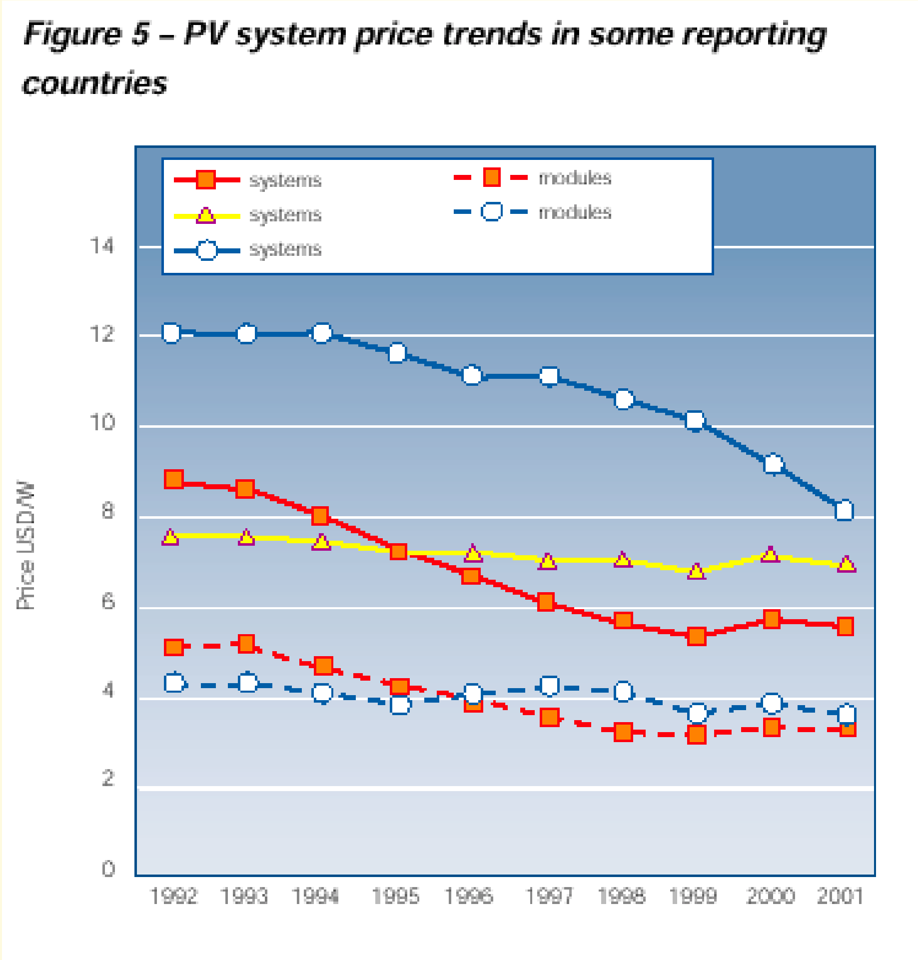
PR = 88%



Systems in Germany
(Source: ISET)

Timeframe	Progress Ratio	Database
1988-2001	94%	Current Photex
1990-2001	91.6%	Photex price + general capacity data
1991-2001	93%	ISET

IEA-PVPS, Task 1



Capacity between 1992 and 2001 grown 5 times;
Prices from about 10 $/kWp to 7 $/Wp;
→ Progress ratio 93%

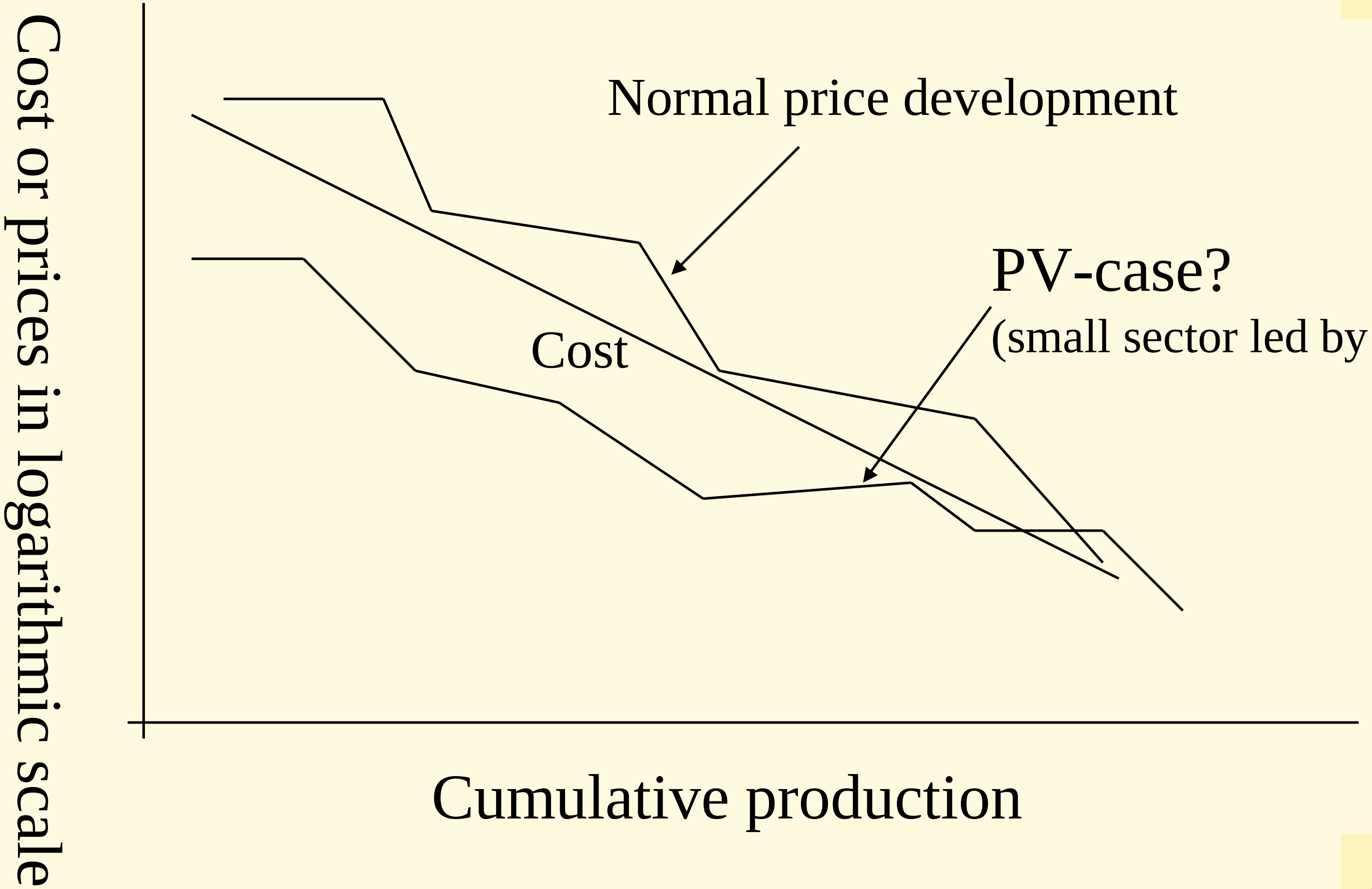
(Preliminary) intermediate conclusion

- To keep costs and deployment efforts to a reasonable level the PV-progress ratio should not be higher than 80%
- Current PV-systems progress ratio seems to be slightly above 90%
- Current progress ratio PV-Systems seems to be too high!
  - if price developments reflect cost developments!

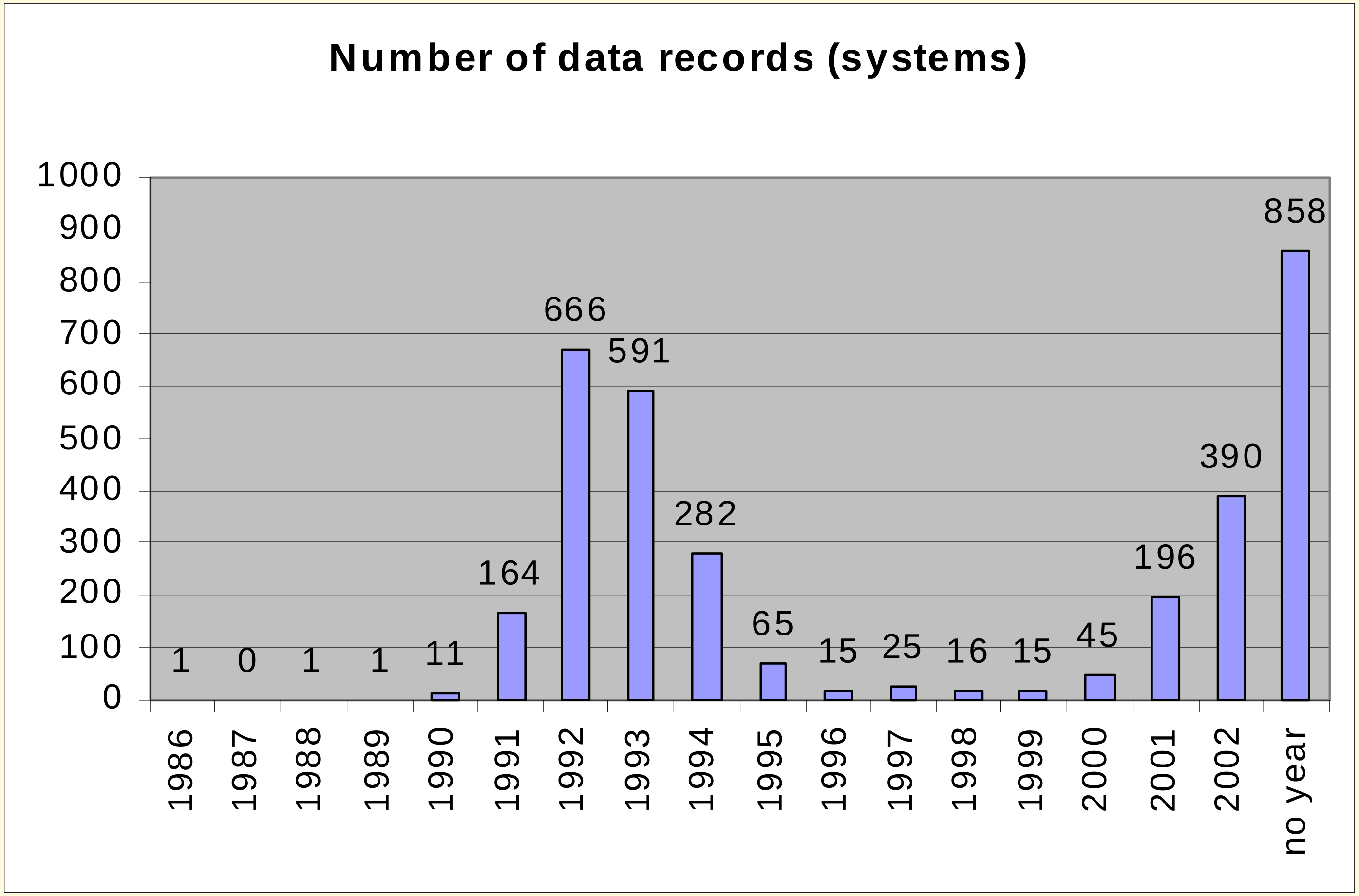
Precautions to the conclusion

- Do price developments reflect cost developments?
- It has been difficult to gather a substantial amount of reliable data. Monitoring activities such as done in IEA-PVPS is therefore essential and should be intensified!

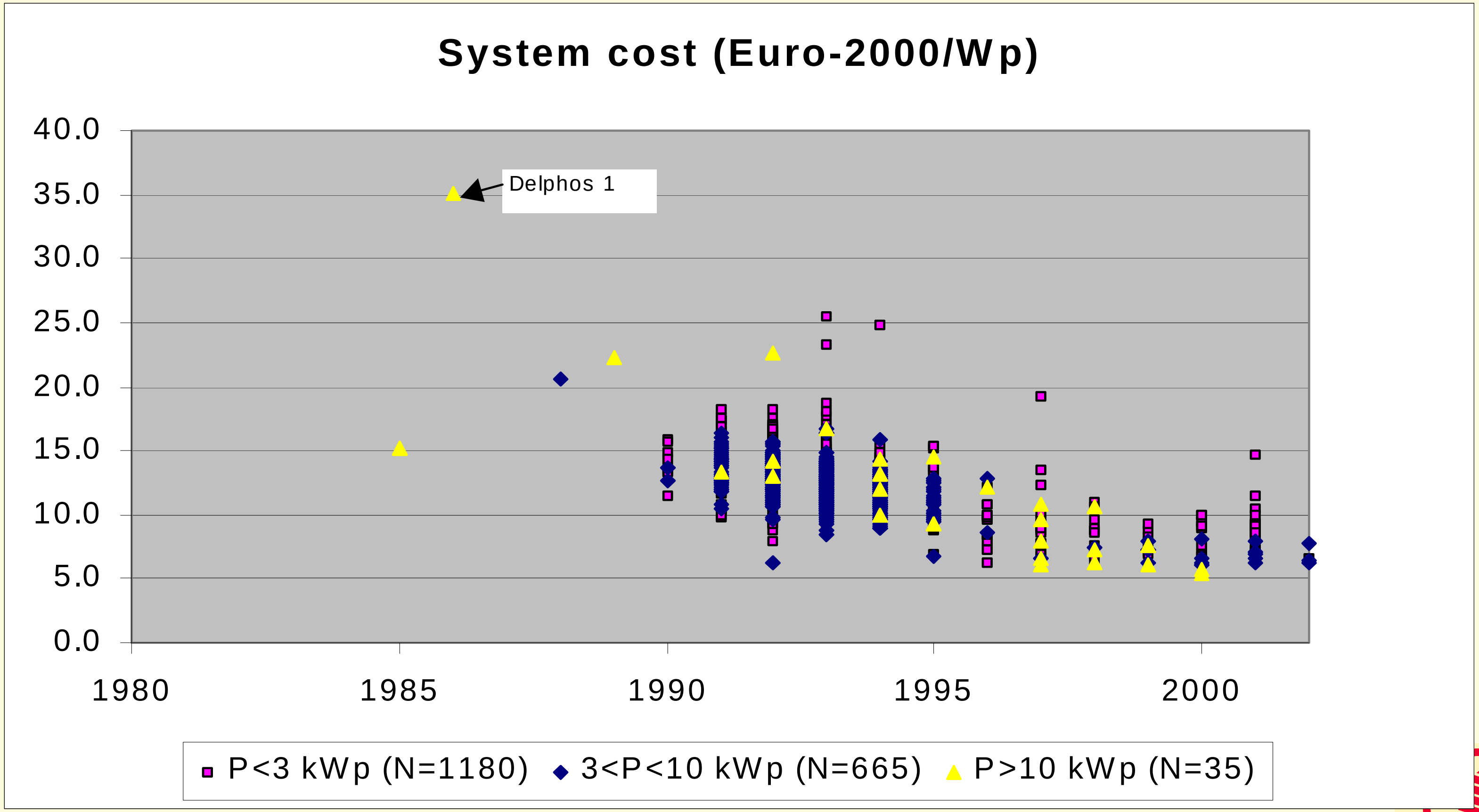
Do costs reflect prices?



Photex data: Database overview: status December 2002 (*Source UU-STS*)



Photex data: System cost data
(*Source UU-STS*)



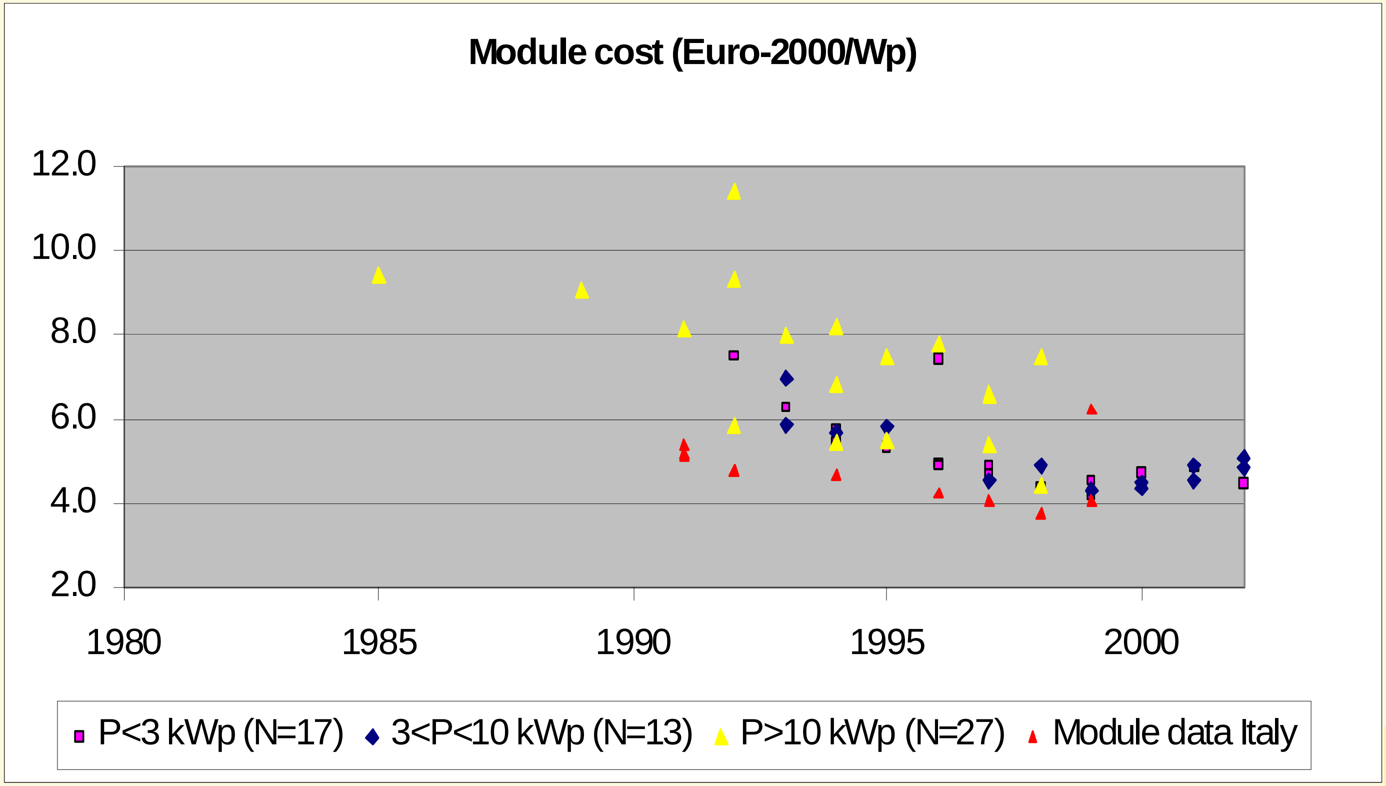
Photex data: increasing the database

- Projects before 1990 (possibly via EU-DGTREN)
- Module data: Strategies Unlimited report
- Incorporating IEA-PVPS Task 2 data

Differences in BOS and module learning in past decade

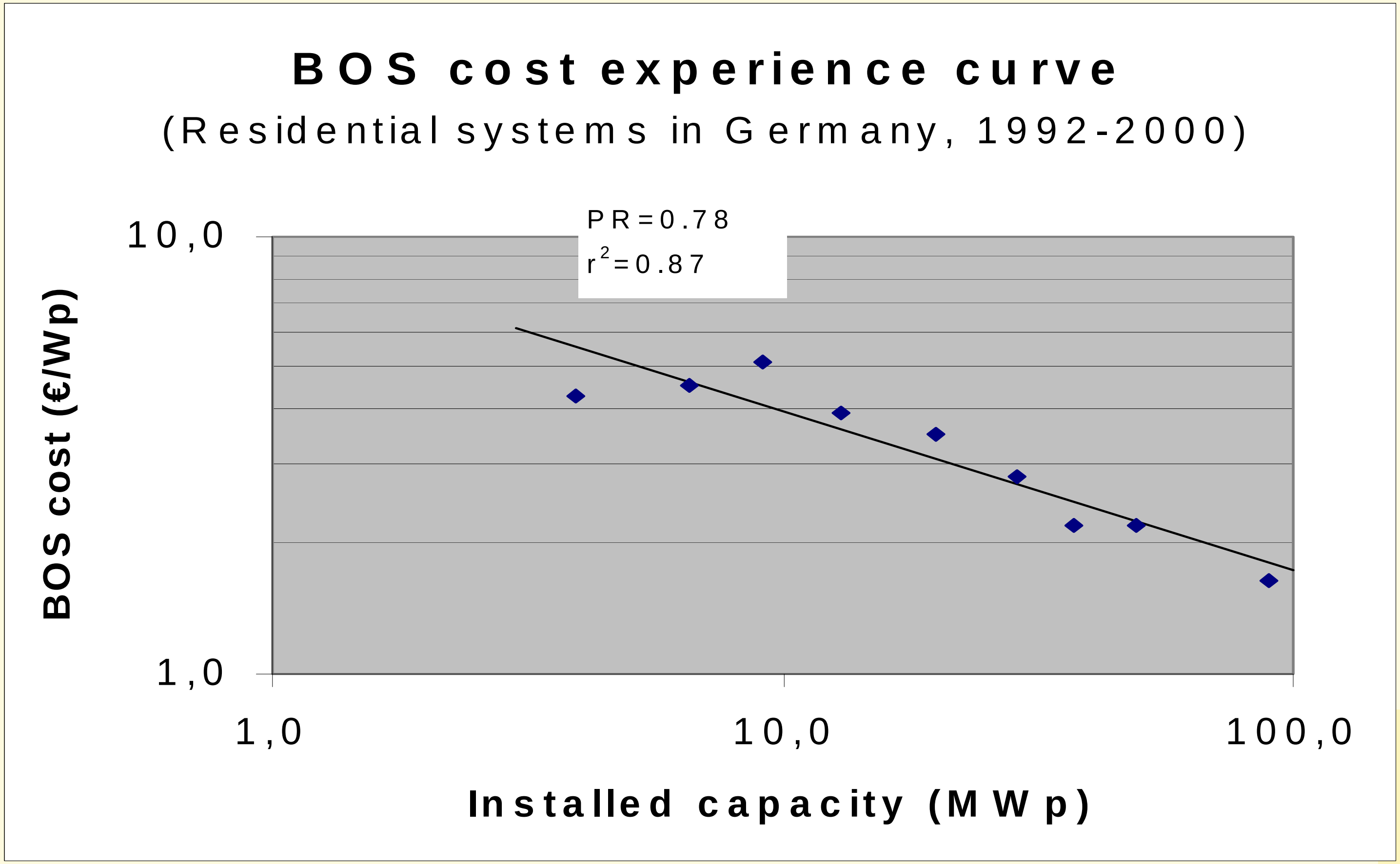
- Module prices have come down slightly
- BOS prices have come down substantially

Module prices
(*Source UU-STS*)



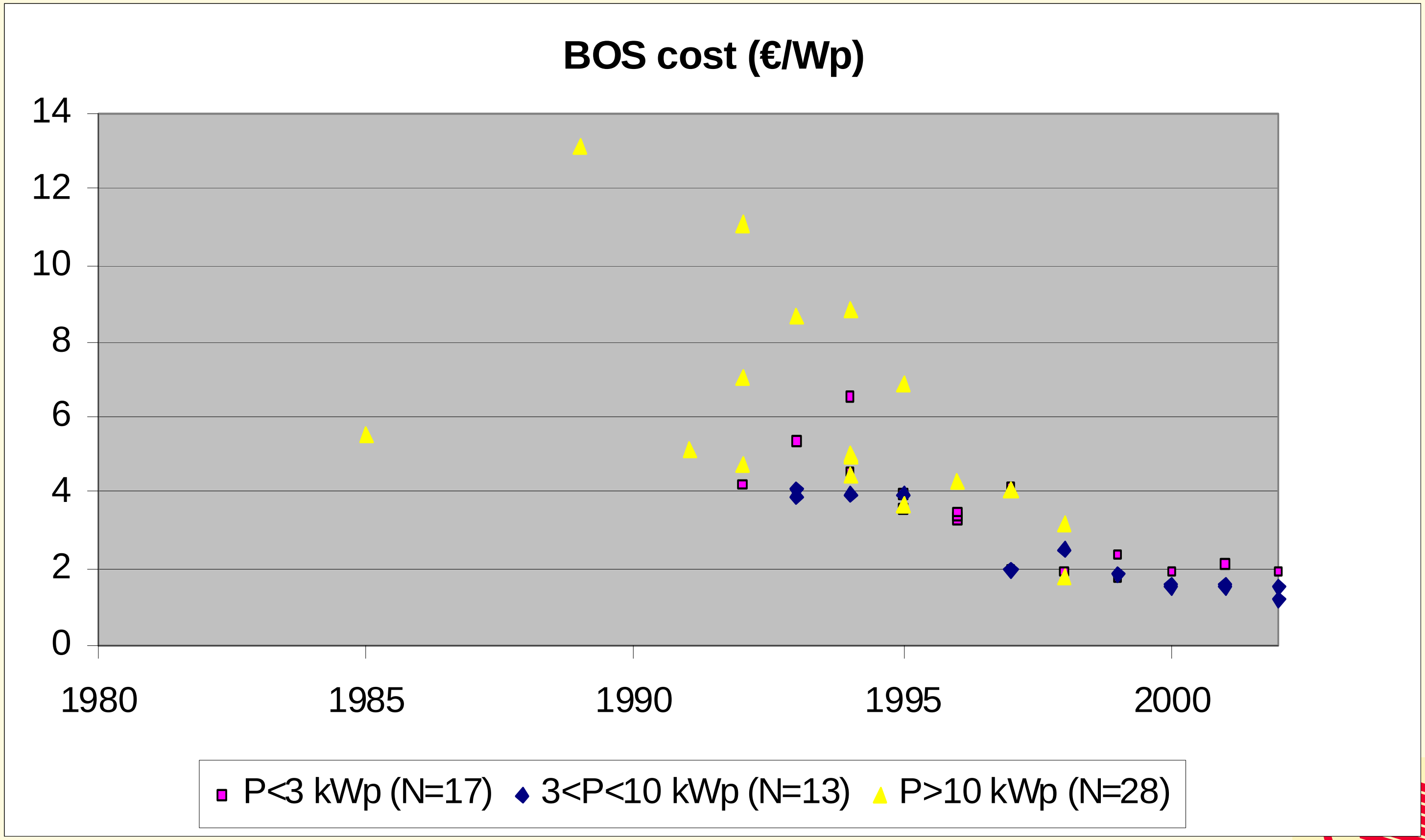
An increase since 1999

BOS prices in Germany
(*Source ISET*)



BOS prices Photex database

(*Source UU-STS*)



BOS is learning fast, especially in Germany (*Source: FhG-ISE*)

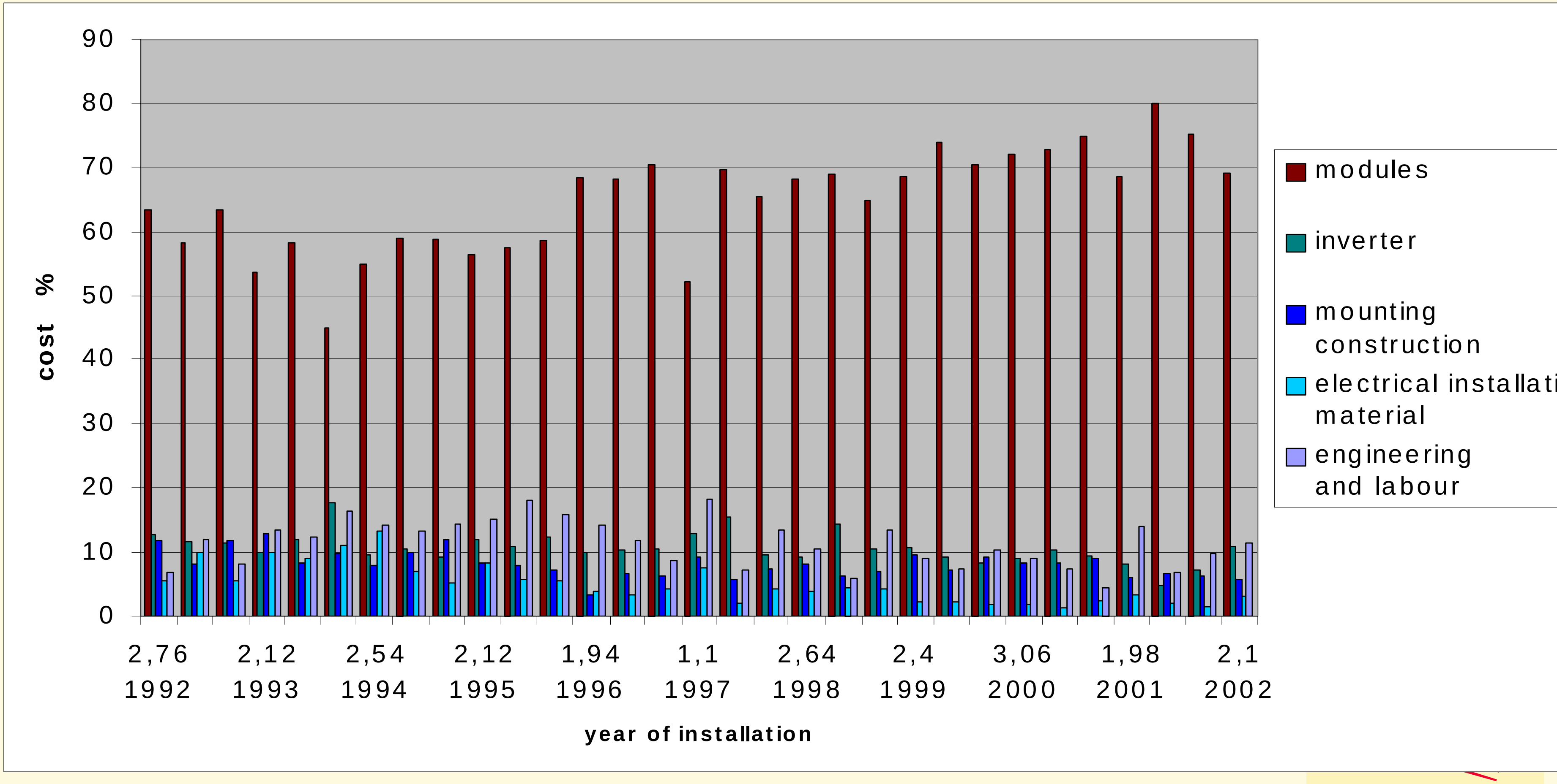
Cost distribution of residential PV systems (1999/2002)

System size	1 kWp		5 kWp		2 kWp		3 kWp	5 kWp	50 kWp
year	1999		1999		2002		2002	2002	2002
	Euro	%	Euro	%	Euro	%	%	%	%
modules	4000	48	3800	56	4100	68	> 70		
inverter	1100	13	900	13	650	11			
mounting structure, installation material	1400	17	1100	16	500	8			
installation labour	1270	15	780	11	650	11			
planning, documentation	500	6	250	4	100	2			
Total [Euro]	**8270**		**6830**		**6000**		**5800**	**5500**	**< 5000**

- Similar trends e.g. in NL and US: the result of reaching a critical mass in volume sales!

Relative cost distribution of residential PV systems- installer in Germany

(Source: FhG-ISE)



ECN

Sources of BOS cost reduction in Germany (***Source: FhG-ISE***)

- Standardisation
  - 2 kW standard mounted roof system has lowest installation costs in Germany
    - standardised planning procedures
    - standardised mounting procedures
    - standardised material
    - installation knowledge widespread also to low-cost personnel
- Further reduction in BOS possible, expected and needed
  - inverters (volume)
  - DIY-kit for installation
  - further (small) innovations and learning

Questions with regard to BOS-costs

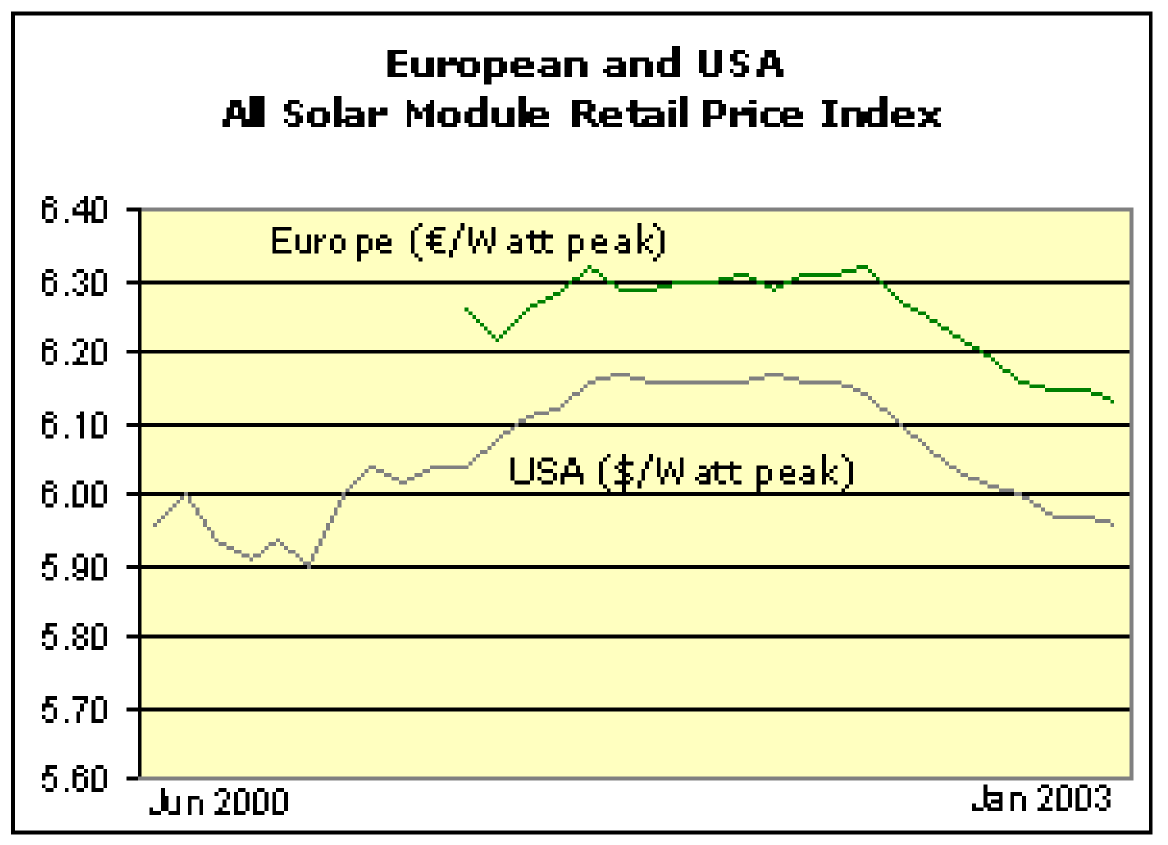
- Is BOS-learning local or global in character?
  - Inverter part is at least (partially) international market
    - Several manufacturers deliver inverters to several countries in Europe
    - Different national standards for dealing with islanding
    - Different national standards for connectors
  - Differences in building norms and practices and policy result in non-ideal spill-over effects between countries
    - e.g. mounted roof systems versus building integrated PV
- Positive effect on costs expected from more EU-wide harmonisation on standards and policy

How to reduce module prices?

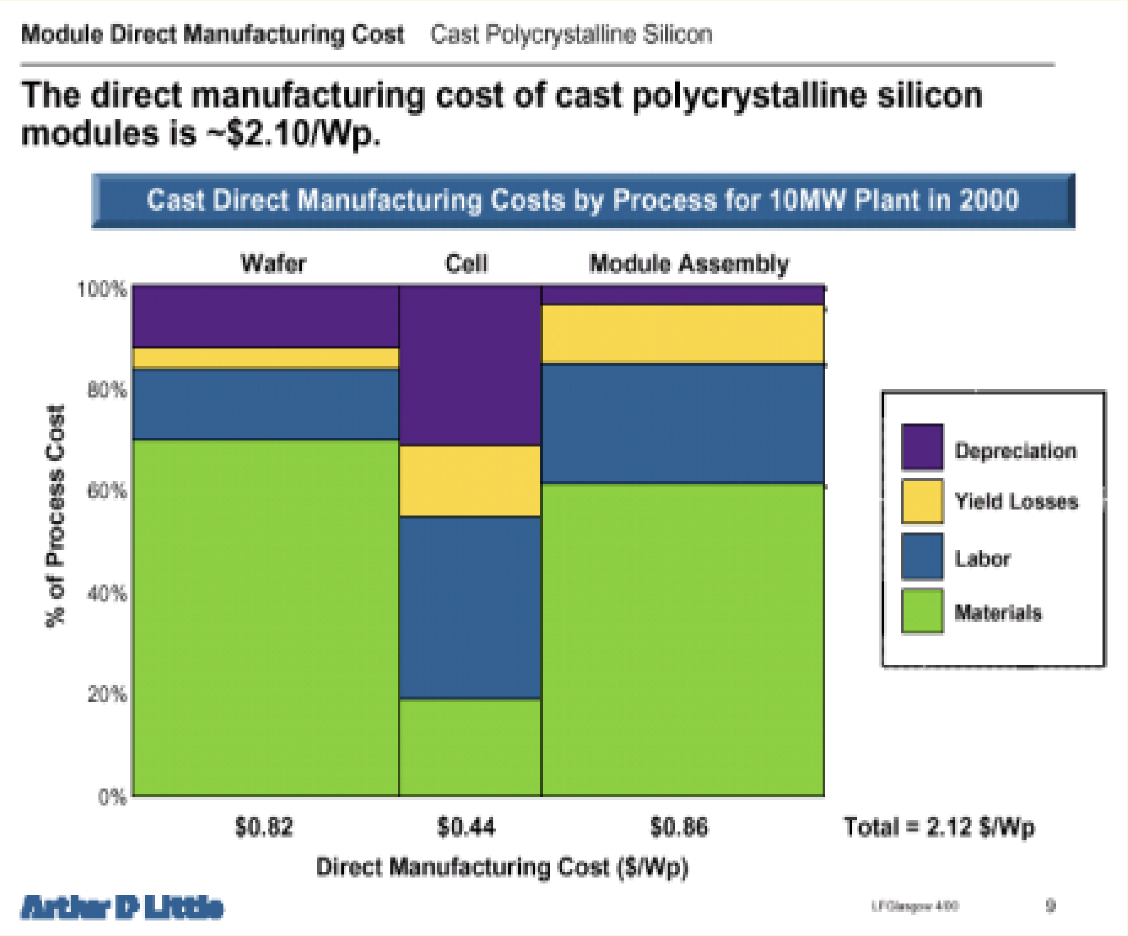
- Observations
  - Module prices have come down barely during the last 5 years
  - Module prices constitute 70%-80% of system prices
- Uncertainties
  - Have module *costs* come down?
  - Are module producers still not making a profit?

ECN

Latest news on module price developments (Source: solarbuzz.com)



Cost Break Down x-Si (90% of market)



Silicon wafer

Cell Efficiency

Module materials

Labour

(Note: *Direct manufacturing cost do not include overhead such as R&D, Sales, Maintenance and Staff Departments)*

Analysis of cost reduction x-Si

Wafer cost

Feedstock 30%   Scrap from IC Indusry

20 - 30 €/kg   Fluctuating

Independent supply needed

=> 15 - 20 €/kg Si (mg Si 2 $/kg)

Silicon content   2000 17 g/Wp

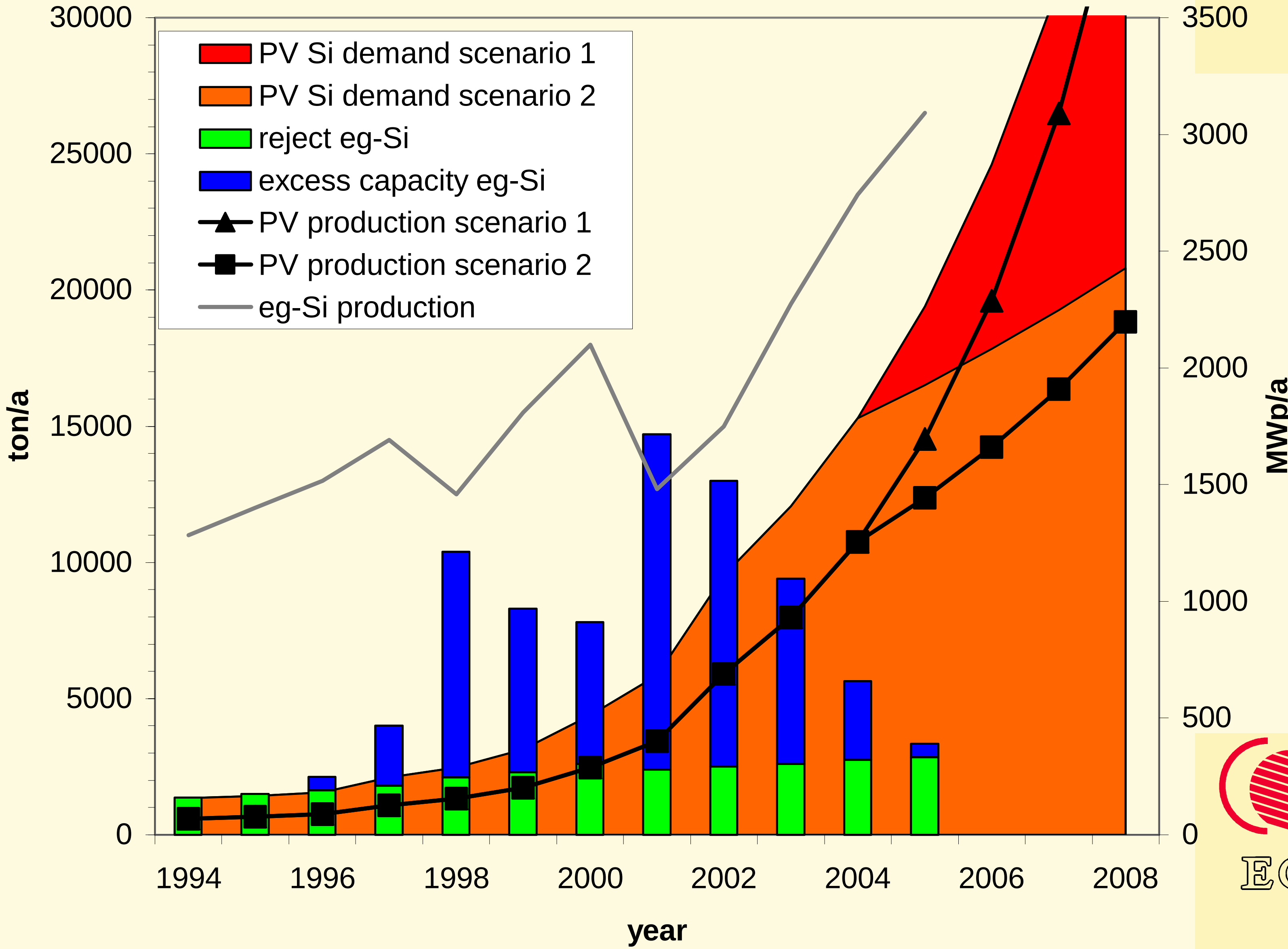
2010 10 g/Wp

sheets (EFG, RGS), wafer thickness

Crystallisation   cast, sheets

Wafering

Si feedstock for PV: supply and demand
(*Source: ECN Solar Energy*)



Analysis of cost reduction x-Si

Cell Processing

Labour, Equipment

Efficiency, (yield, uptime)

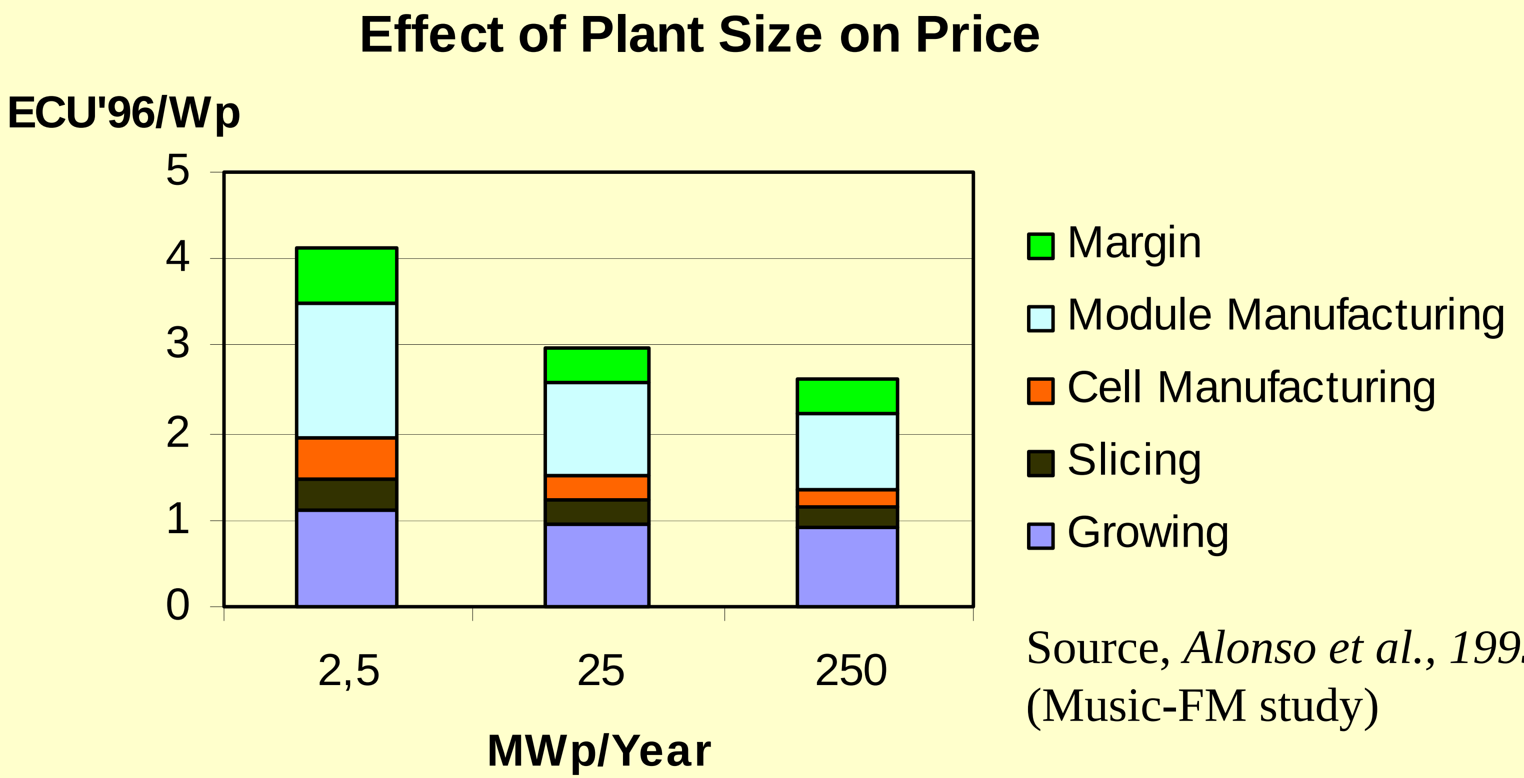
Plant size

Efficiency 12-14% → 15-18%

2000 2010

Plant Size	1990	1 - 5 MWp	50 MWpa
	2000	10 - 25 MWp	300 MWpa
	2010	25 - 100 MWp	2 GWpa

Analysis of cost reduction x-Si



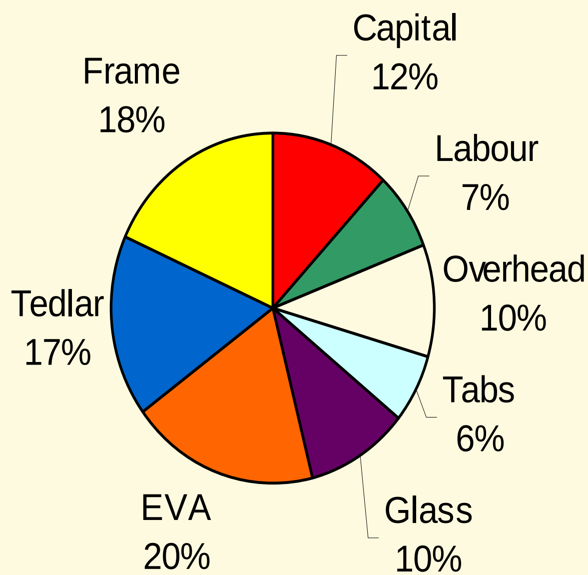
Source, *Alonso et al., 1995*
(Music-FM study)

Analysis of cost reduction x-Si

Module Assembly

Materials, Labour

Yield



Scale-up

Laminates

New encapsulants

Back contact cells

Maycock 2000

Some conclusions

- PV-systems prices do not go down fast enough
- PV-BOS prices have come down very fast, especially in high volume markets
- PV-BOS prices still need to come down further
- Module prices make up 70%-80% of systems and need most focus for cost reduction efforts
- Material costs most important part of module costs
- Building up an own feedstock production is absolutely necessary for PV-industry
- Insecure relationship with ICT-industry will remain: needs more analysis

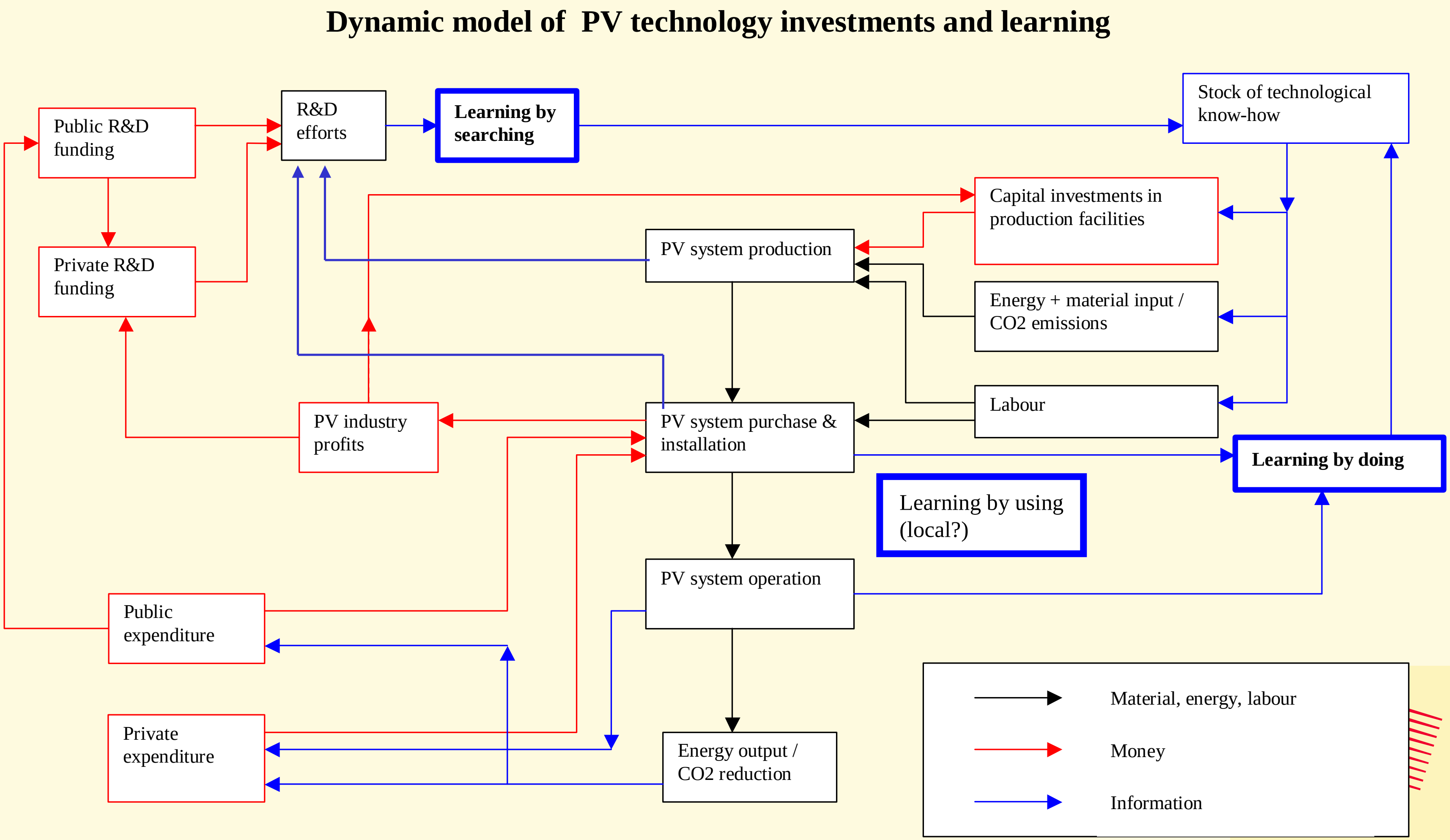
ECN

Implications for policy: how to get progress ratio back on track?

- Progress ratio is a statistical correlation between costs (prices) and cumulative production as a result of a learning process
- Progress ratio can be enhanced by
  - Establishing a better balance between R&D and deployment efforts
    - Enhancing R&D-efforts on PV
    - Ensuring a healthy growth rate of PV
      - Too fast: what is learned cannot be implemented timely in practices of production and use, resulting in prohibitive progress ratio
      - Too slow: learning process stops or reverses (e.g. BOS-learning experience shows learning needs minimum critical mass)
  - Improvement of the learning process itself
    - analyse the learning process
    - improve learning feed-back loops and geographical spill-over

ECN

Improving the learning cycle for PV: a first try to describe it (Source: *UU-STS*; with a few additions from ECN PS)



In conclusion

- The case of PV demonstrates the importance of an experience curve approach to policy analysis and design
  - shows need for ***combined*** RD&DD efforts
    - most substantial cost reduction in BOS by learning by doing induced by aggressive deployment strategies
  - shows need for ***balanced*** RD&DD efforts
    - If DD gets over R&D too much, it effects progress ratio negatively, to an extent cumulative costs become prohibitive.

ECN