Part 5: Investment and Electricity Cost Calculation

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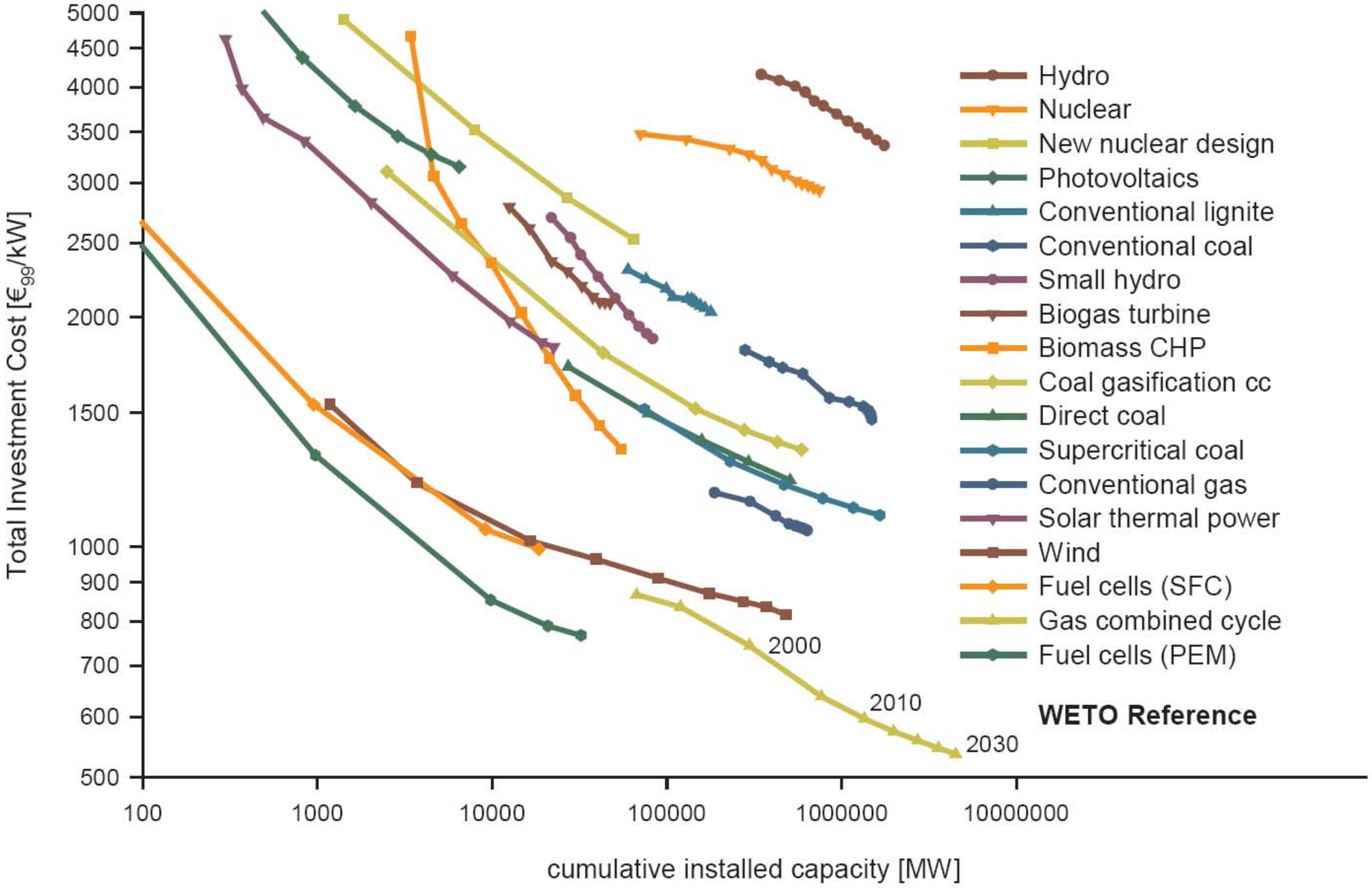
Investment Cost Modelling

Learning Curves Theory

1. Capital goods become cheaper due to mass production, larger units, advances in research & development and increasing competition.
2. There is no scientific model but a lot of experience that lead to an empirical model function.
3. Each time the installed amount of a product doubles, the investment cost goes down by a rate of X% (learning rate).
4. If one assumes an expansion rate of a product with time, one can model the progress of investment cost declination of a product over time.
5. Investments are often given in constant monetary value, inflation has to be added if time scales are introduced.

Neij 2008

Equipment Cost Learning Curves



Cost Learning Curve Function

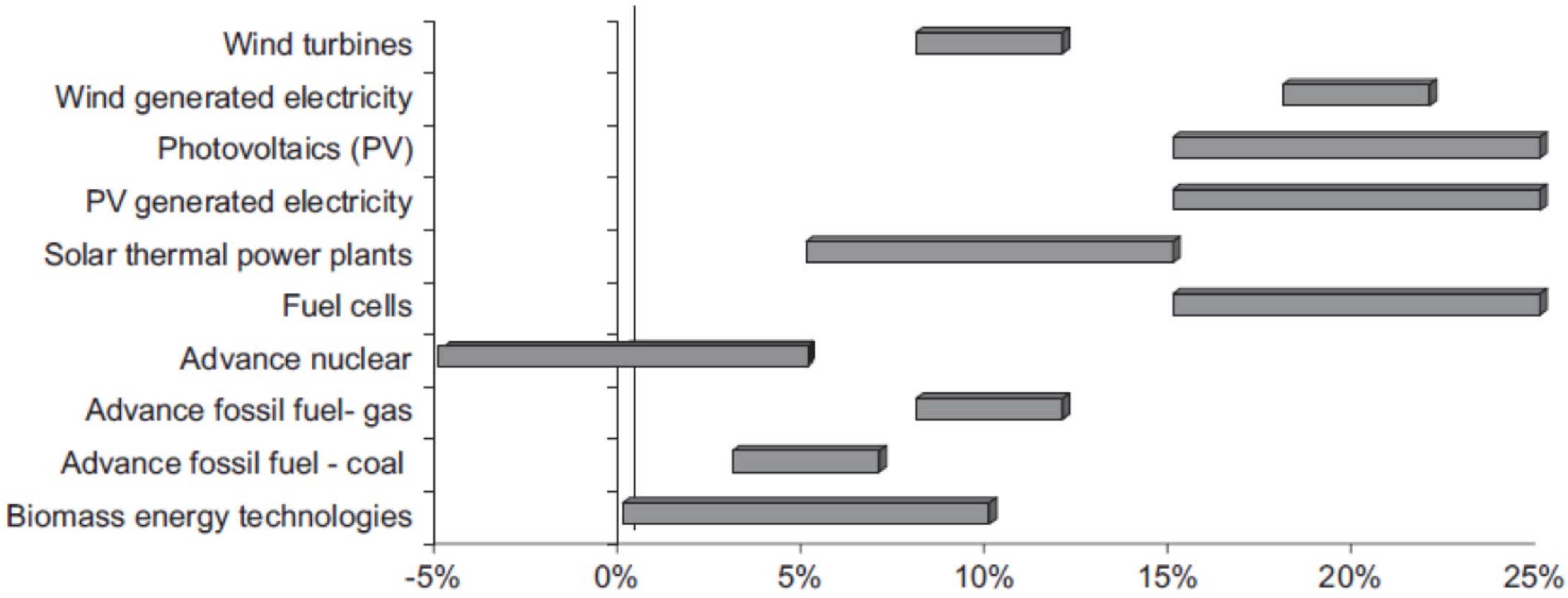
$$C_x = C_0 \left(\frac{P_x}{P_0} \right)^{\frac{\log PR}{\log 2}}$$

PR	progress ratio = (1 – learning rate)
C_x	specific investment at point x
C_0	specific investment at reference point 0
P_x	cumulated capacity at point x
P_0	cumulated capacity at reference point 0

Neij 2003

Learning Rates for Different Technologies

L. Neij / Energy Policy 36 (2008) 2200–2211



Global Capacity Projections

Source: Greenpeace 2009	Installed Capacity (GW)		Reference Scenario			
Year	**2005**	**2010**	**2020**	**2030**	**2040**	**2050**
Photovoltaic	2	10	49	86	120	153
Concentrating Solar	0,35	2	28	150	300	500
Wind Offshore	0	1	35	110	135	160
Wind Onshore	59	124	311	330	390	420
Hydropower	878	989	1215	1400	1560	1710
Biomass Power	21	28	52	72	86	95
Geothermal Power	9	11	17	22	28	33
Ocean Energy	0	0	2	4	7	9

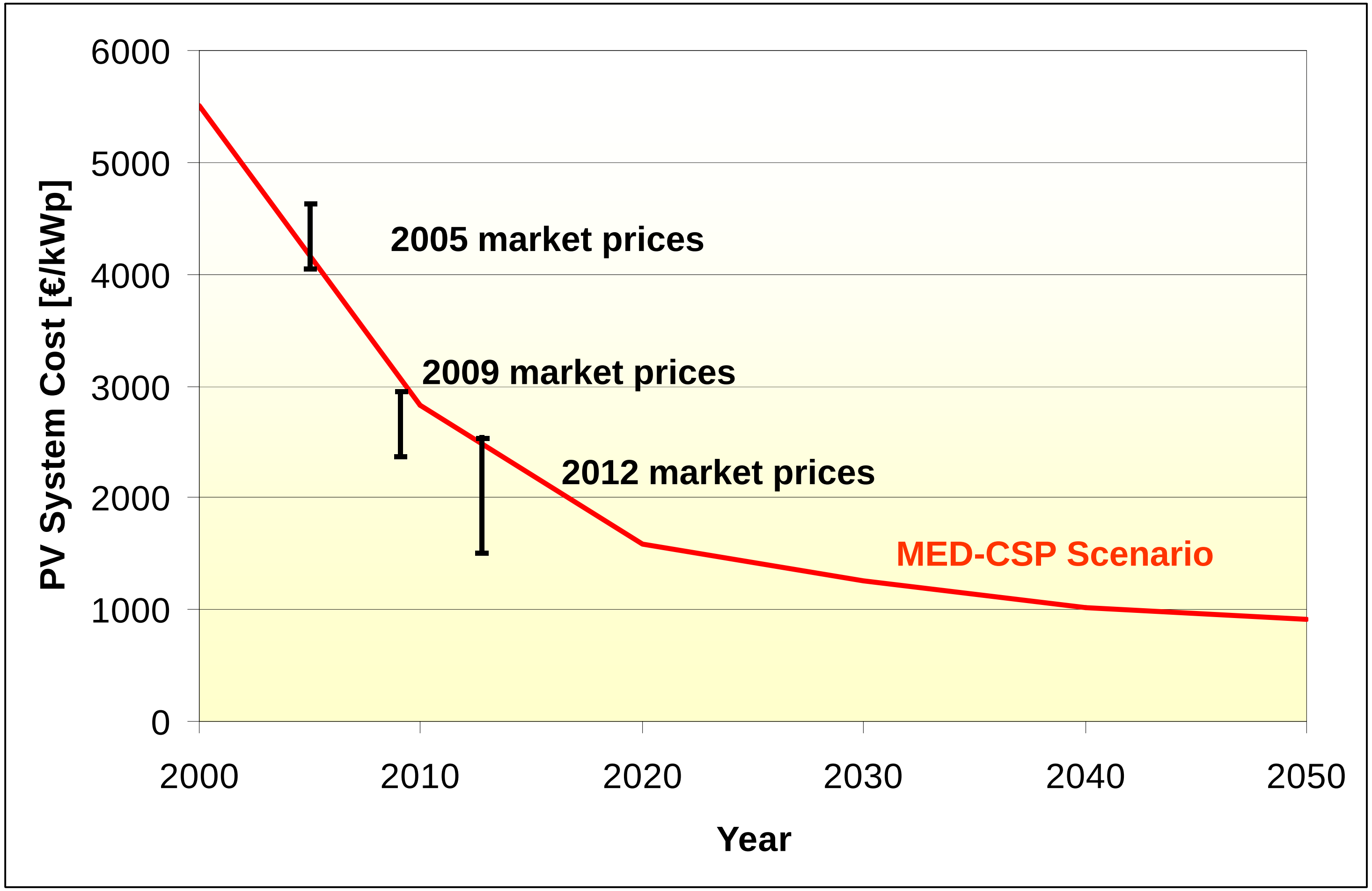
Source: Greenpeace 2009	Installed Capacity (GW)		energy (r)evolution scenario			
Year	**2005**	**2010**	**2020**	**2030**	**2040**	**2050**
Photovoltaic	2	21	269	921	1800	2900
Concentrating Solar	0,35	5	83	200	468	800
Wind Offshore	0	1	35	110	135	160
Wind Onshore	59	164	858	1512	2085	2573
Hydropower	878	978	1178	1300	1443	1565
Biomass Power	21	35	56	65	81	99
Geothermal Power	9	12	33	71	120	152
Ocean Energy	0	1	17	44	98	194

Specific Investment Cost as Function of Time

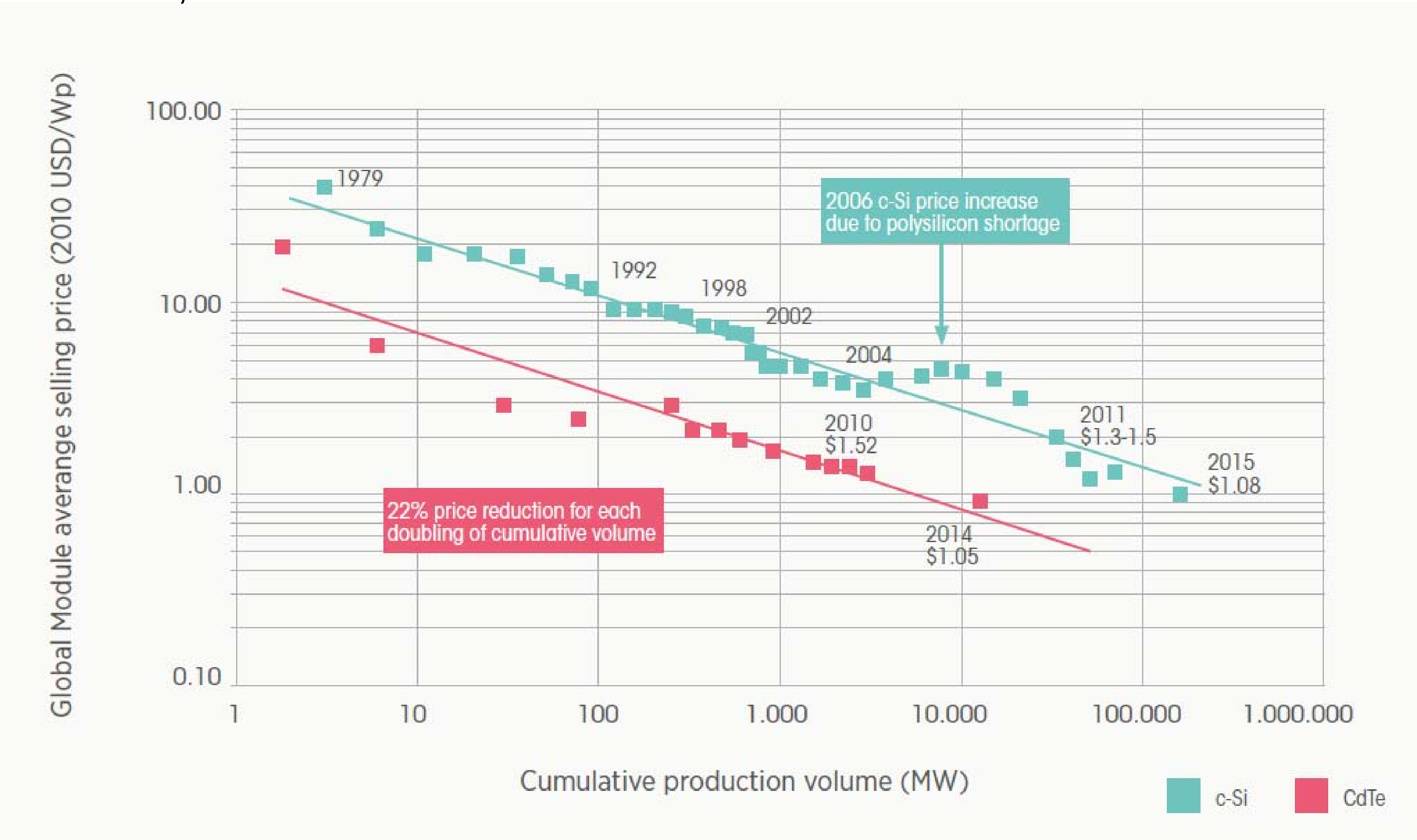
	2000	2010	2020	2030	2040	2050
Offshore Wind		2600	2100	1800	1500	1300
Onshore Wind	1150	1050	950	900	850	820
Photovoltaic	5500	2830	1590	1250	1010	910
Concentrating Solar SM4	10920	8675	6152	4982	4640	4299
Hydrothermal < 2000 m	4000	3000	2300	2100	2050	2000
Hydrothermal 4000 m	5600	4300	3300	2700	2550	2500
Hot Dry Rock 6000 m	14000	10000	7500	6100	5500	5000
Large Hydro	2150	2300	2400	2500	2550	2600
Small Hydro	3600	3900	4050	4100	4150	4200
Large Scale Biomass	2400	2200	2000	1970	1950	1940
Small Scale Biomass	7800	7180	6700	6350	6000	5700
Biogas Plants	2800	2700	2600	2510	2430	2400
Ocean Energy	3000	2500	2250	2100	2050	2000

values in $€_{2005}$/kW

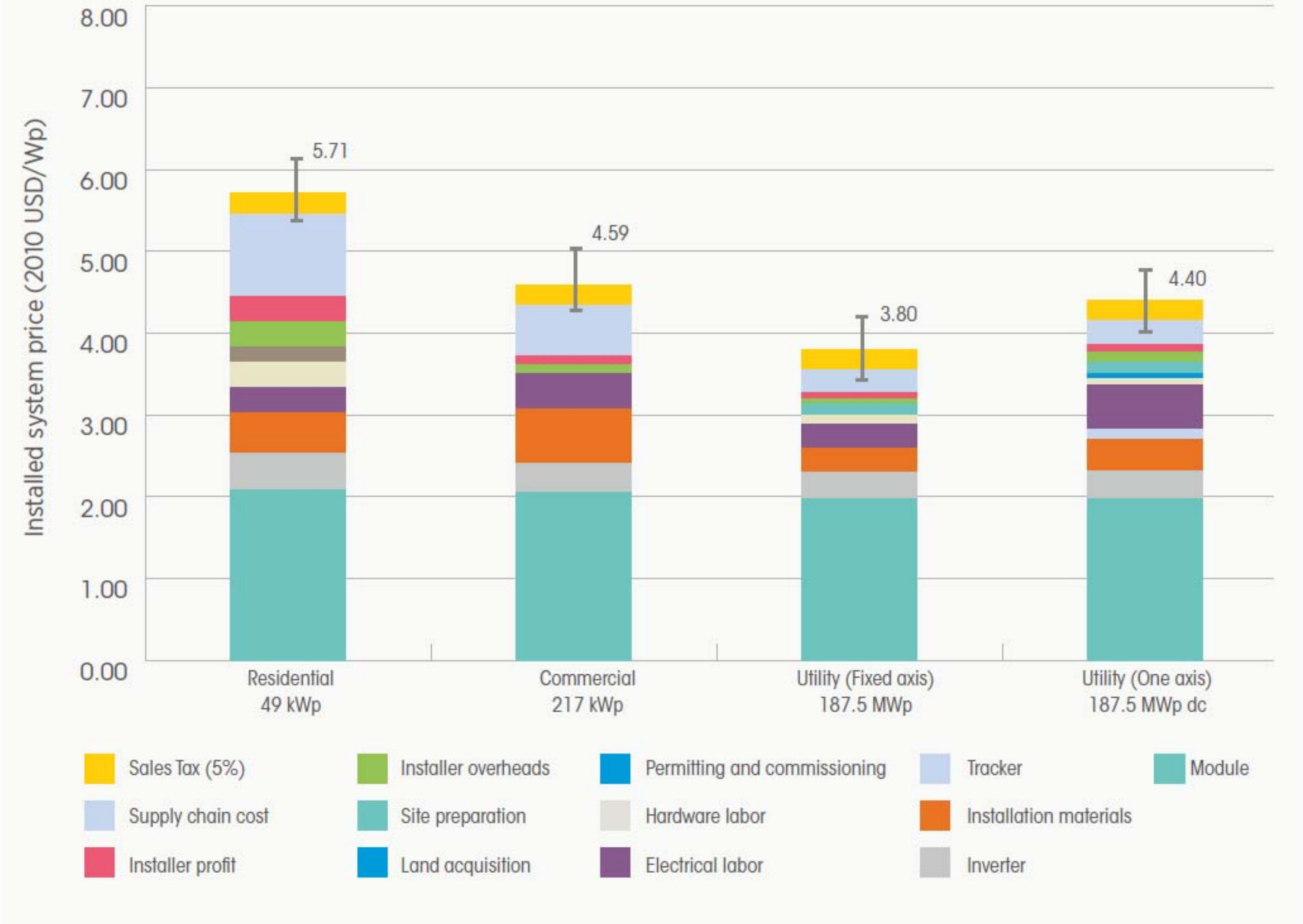
Photovoltaic System Cost Perspectives



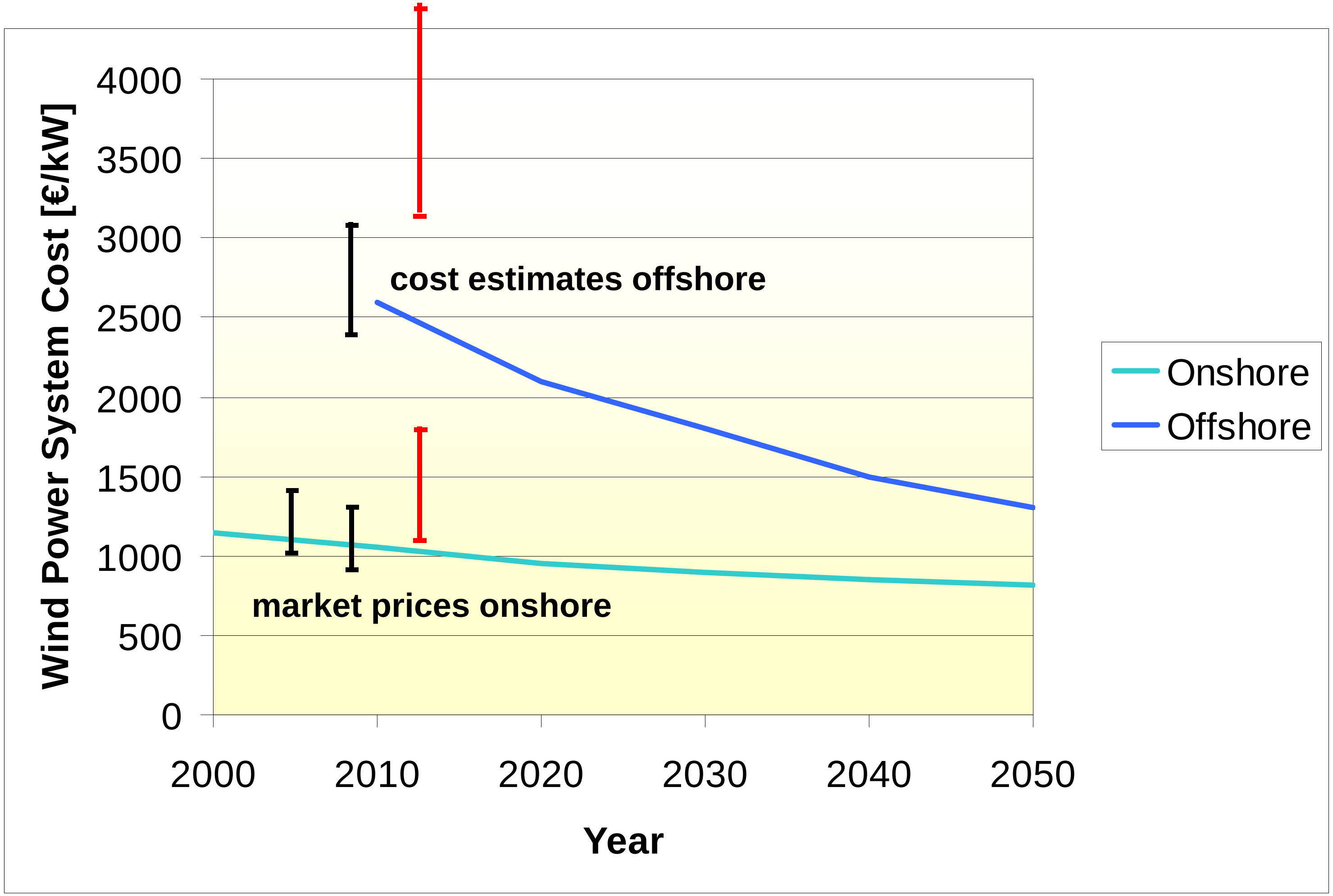
The global pv module price learning curve for c-si wafer-based and cdTe modules, 1979 To 2015



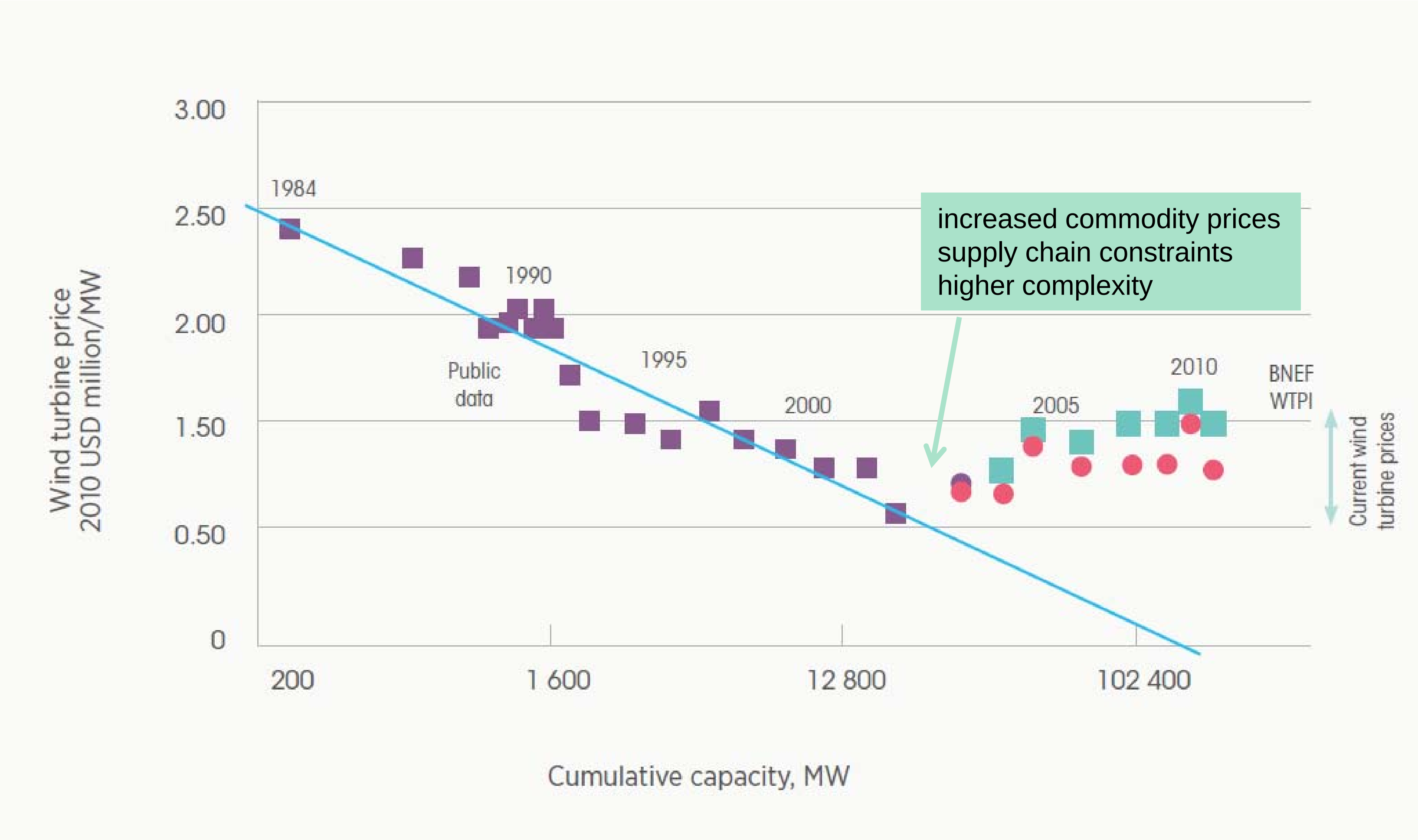
System cost breakdown for residential, commercial and utility-scale c-si pv systems in the United States, 2010



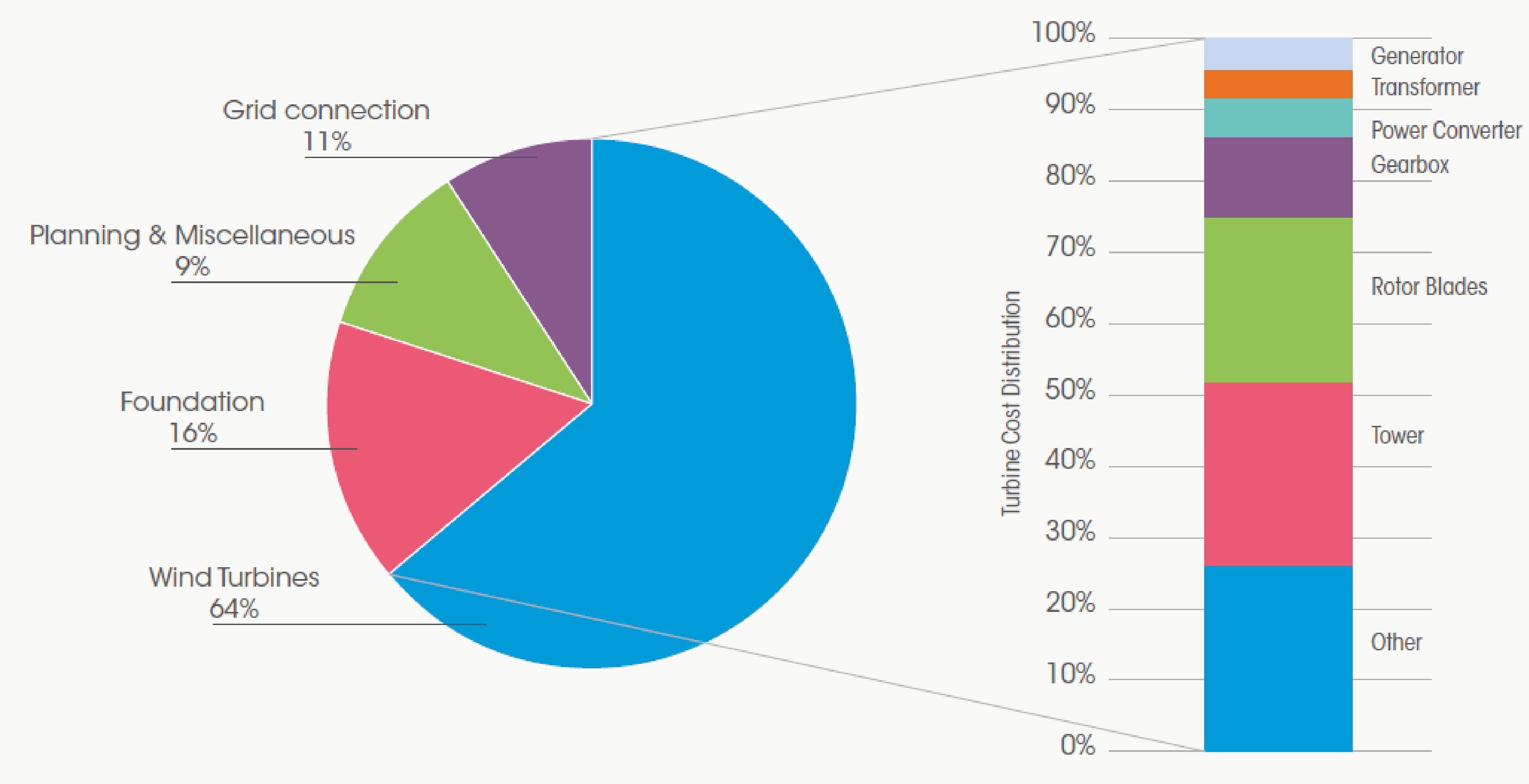
Wind Power Investment Cost Perspectives



Historical learning rate for wind turbines, 1984 to 2010

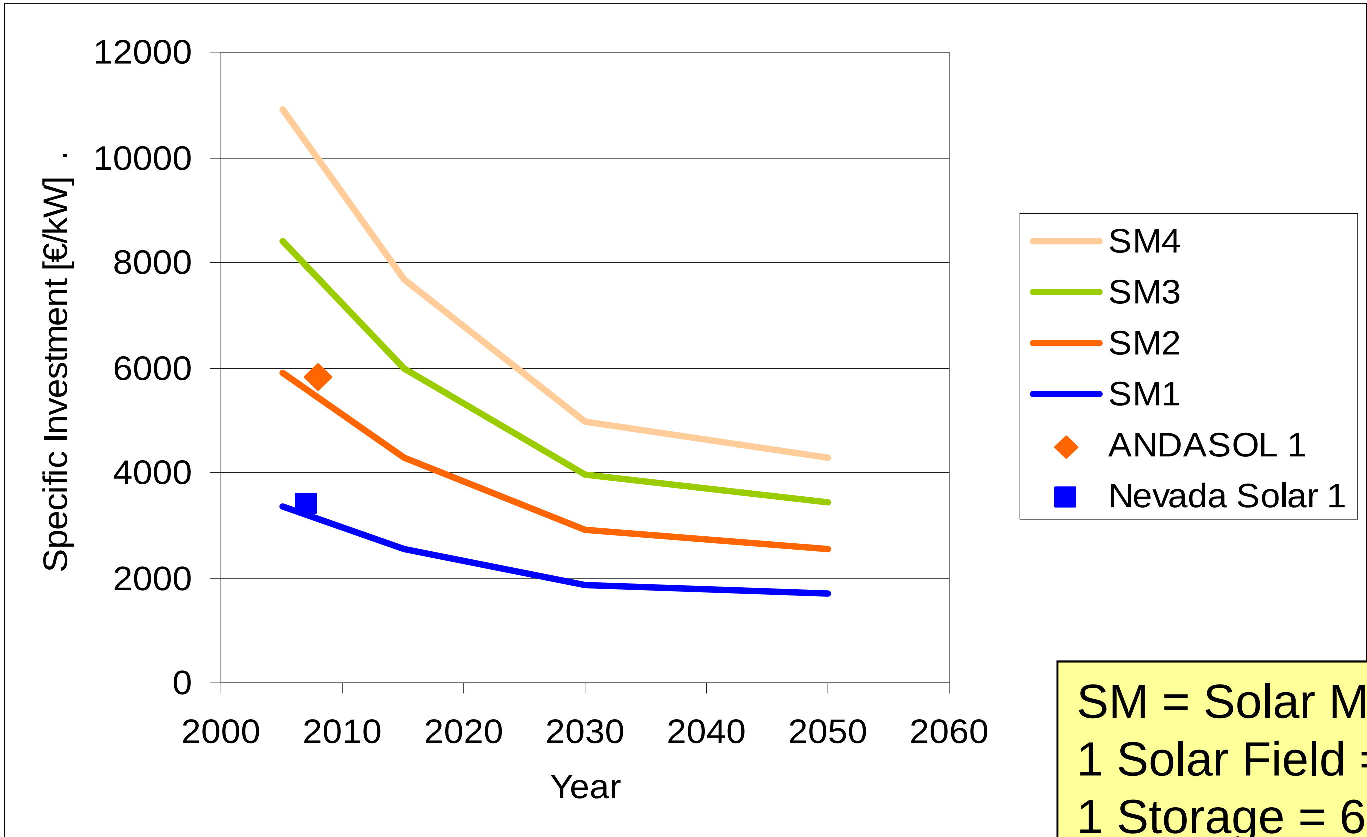


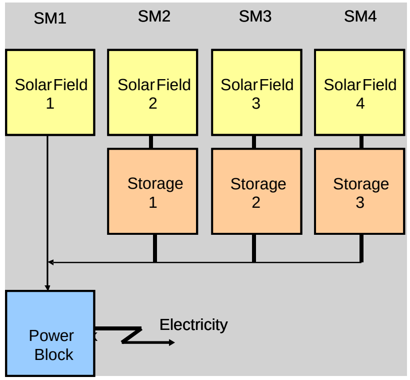
Wind Power Investment Cost Breakdown



CSP Investment Cost Perspectives

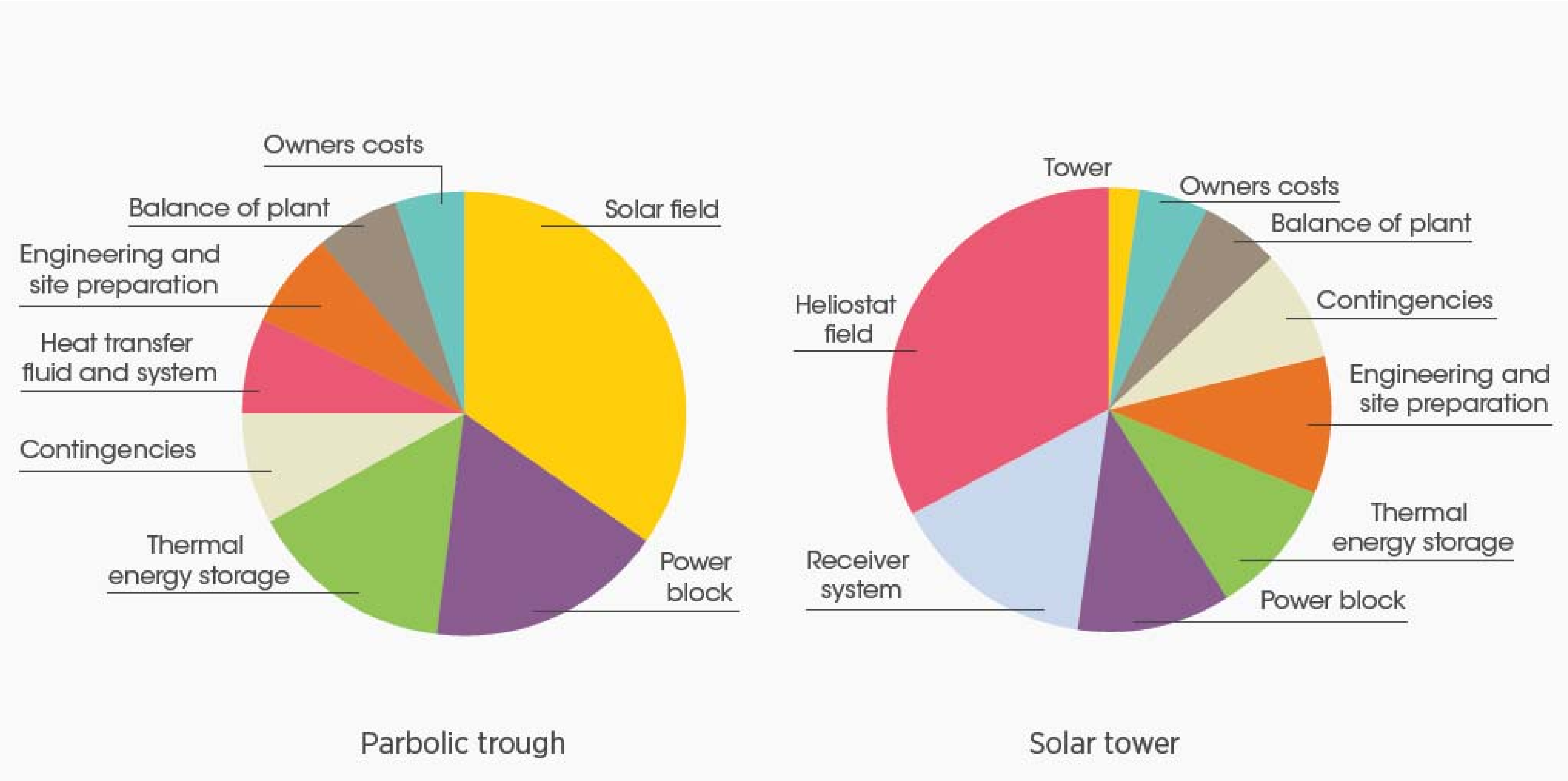
Year	*PR*	2005	2015	2030	2050	Unit
World CSP Capacity		354	5000	150000	500000	MW
Solar Field	90%	360	241	144	120	€/m²
Power Block	98%	1200	1111	1006	971	€/kW
Storage	92%	60	44	29	25	€/kWh





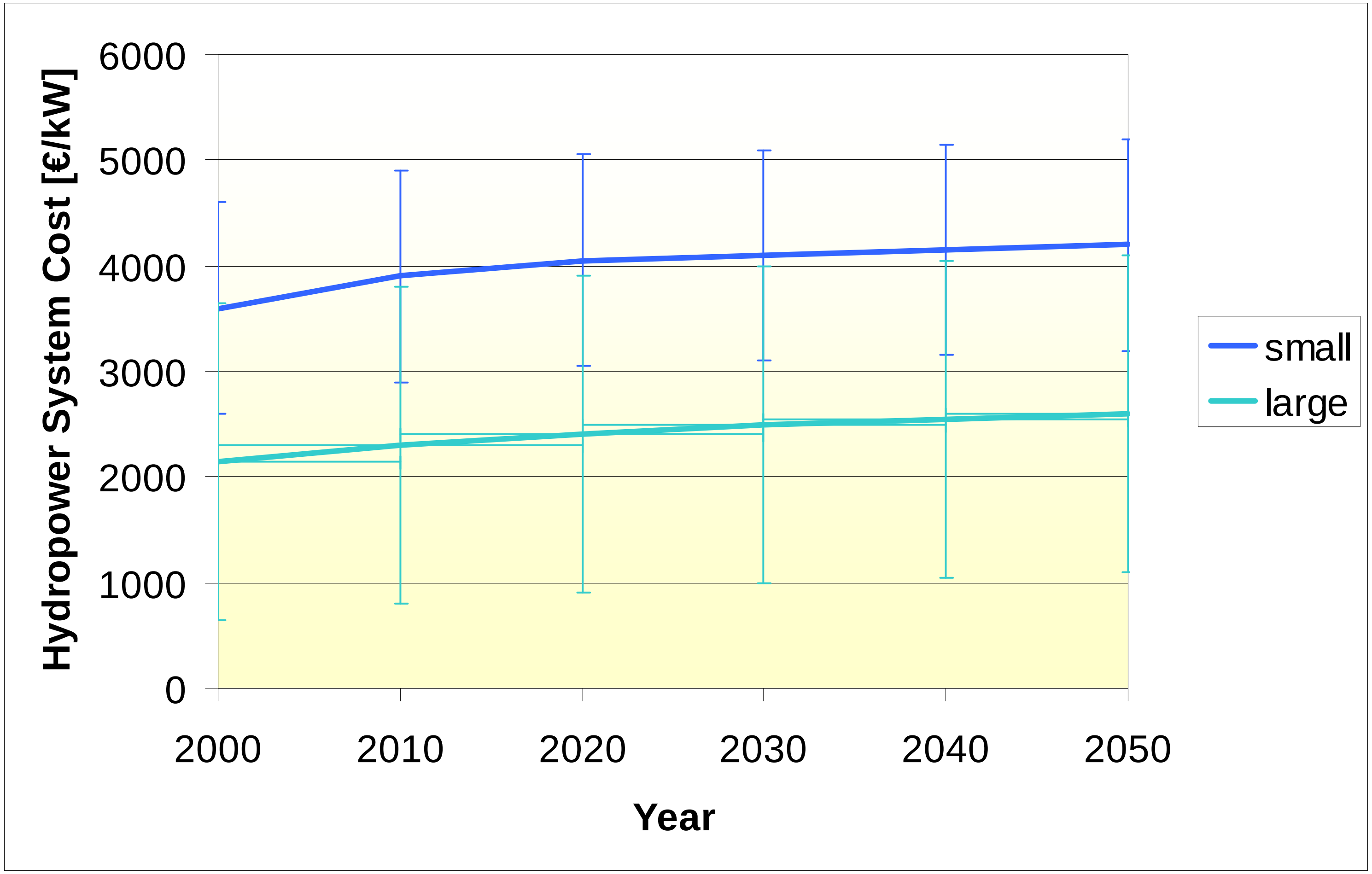
SM = Solar Multiple
1 Solar Field = 6000 m²/MW
1 Storage = 6 hours (full load)

Total installed cost breakdown for 100 MW parabolic trough and solar tower CSP plants in South Africa

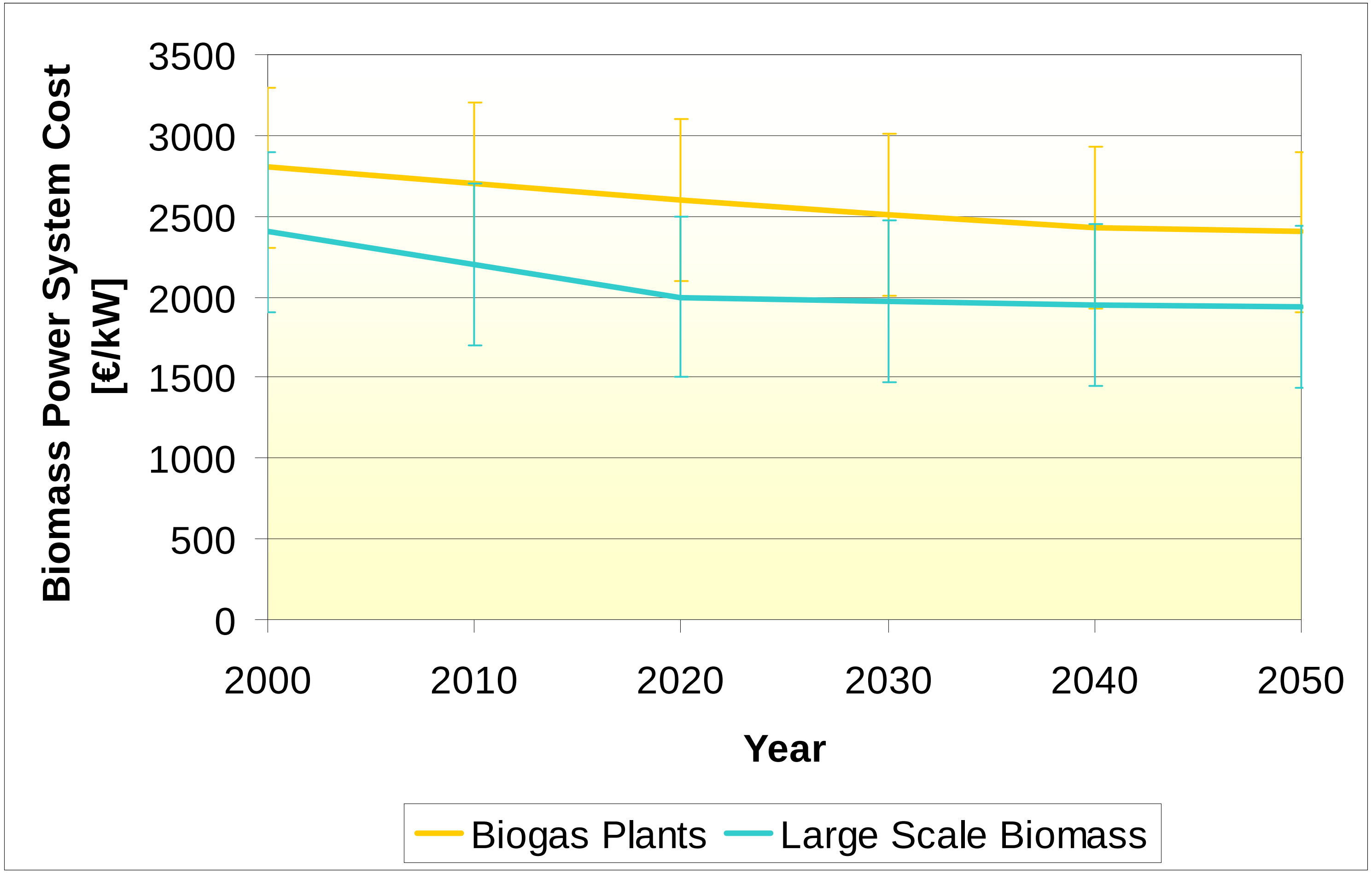


Note: The parabolic trough system has 13.4 hours of thermal energy storage and the solar tower system 15 hours

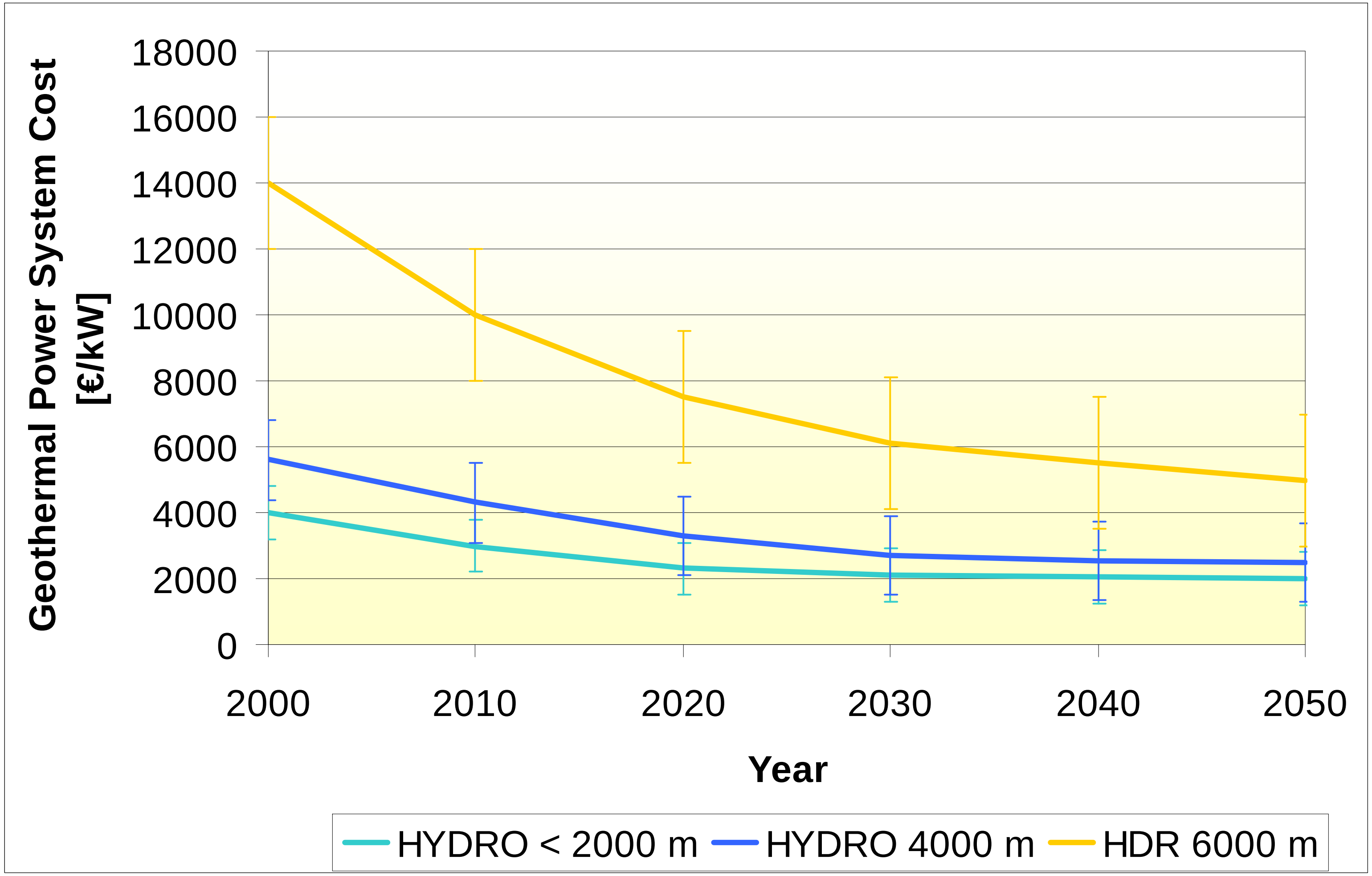
Hydropower Investment Cost Perspectives



Biomass Investment Cost Perspectives



Geothermal Power Investment Cost Perspectives



Electricity Cost Modelling

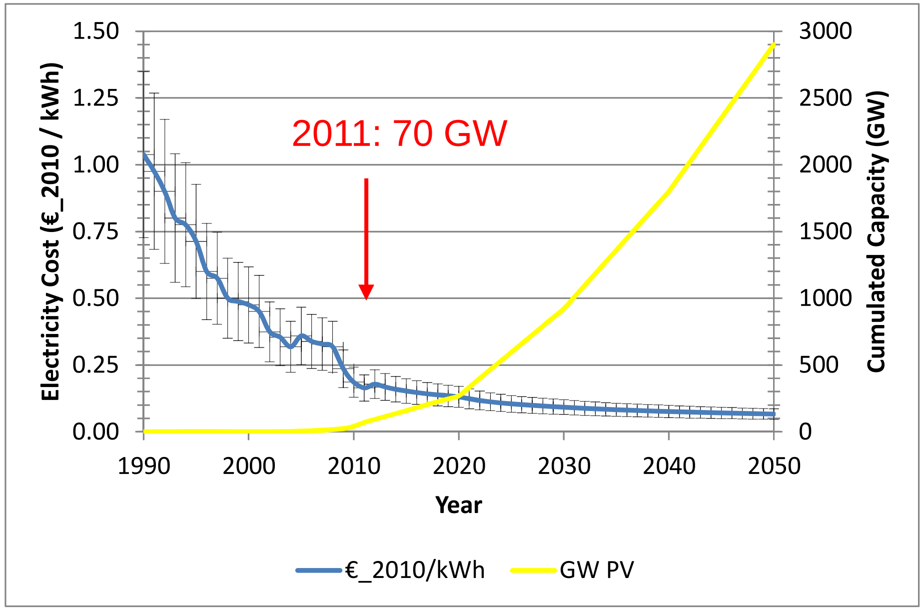
Levelised Electricity Cost Model

$$C_{el} = \frac{Inv \cdot FCR + O\,\&\,M + F}{E_{year}} \qquad FCR = \frac{(1+i)^n \cdot i}{(1+i)^n - 1}$$

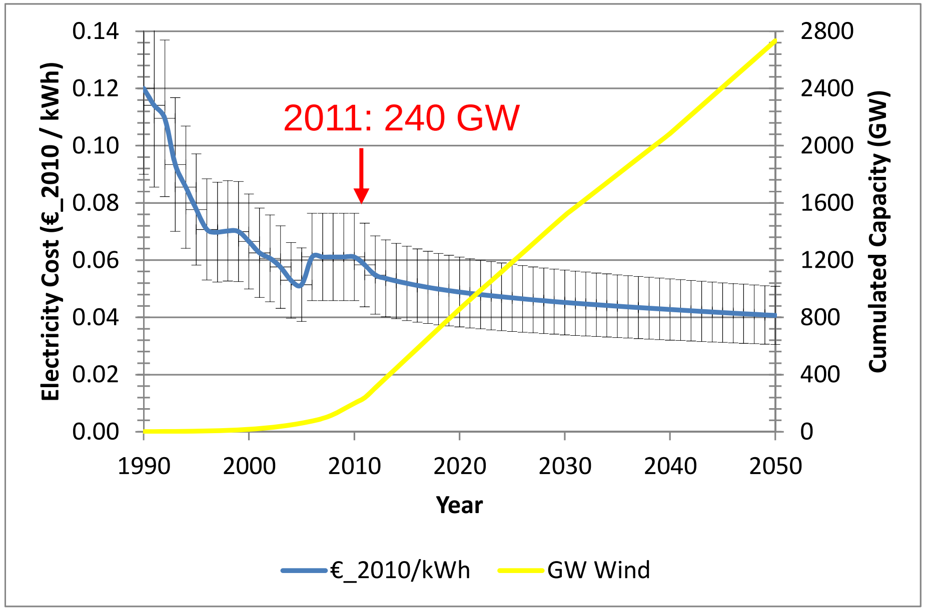
C_{el}	levelised cost of electricity in €/kWh in constant present monetary value
Inv	investment cost in €
FCR	fix charge rate as function of interest rate (i) and economic lifetime (n) in %/y
$O\&M$	net present value of annual operation, maintenance and insurance in €/y
F	net present value of annual fuel cost in €/y
E_{year}	electricity generated per year = installed capacity (kW) · annual full load hours (h/y)

To tap renewable energy sources means to invest in their expansion until they become competitive:

Photovoltaics

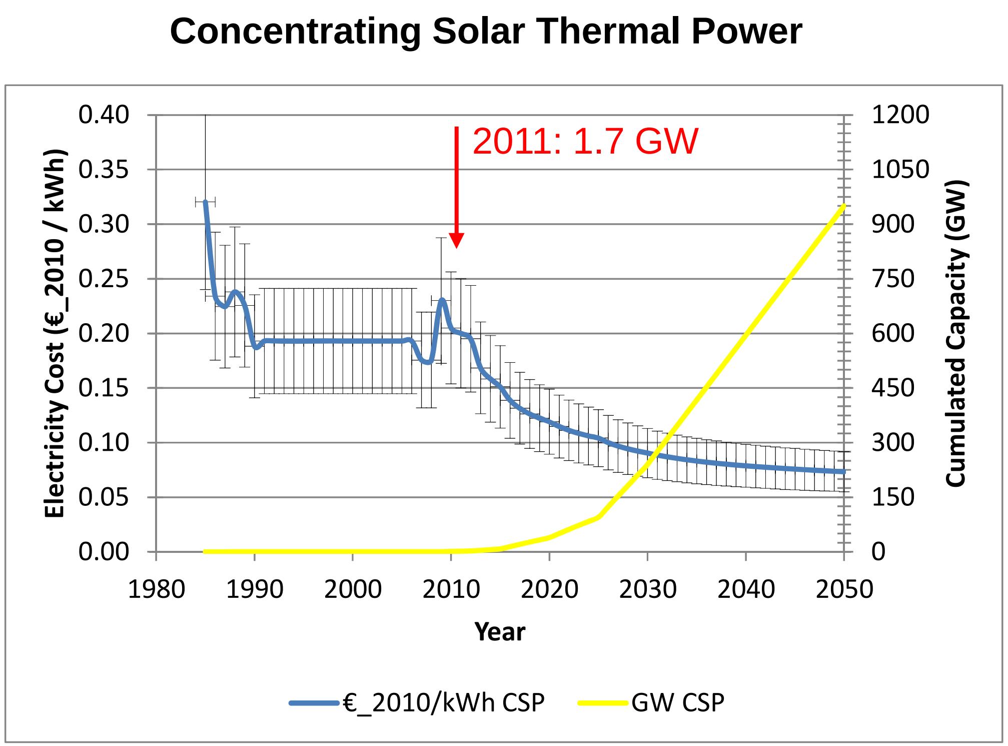


Wind Power (on-shore)



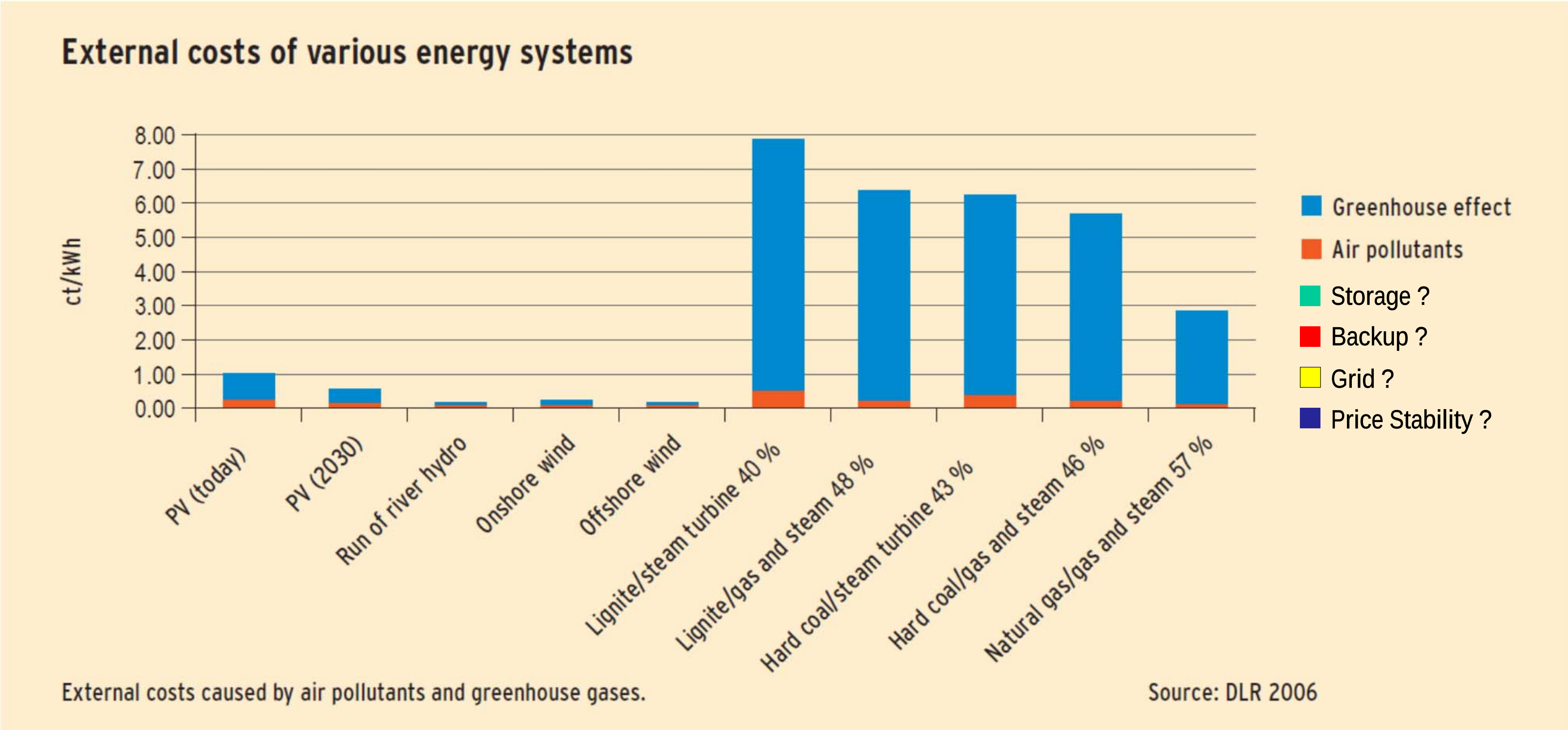
Sources: IER, RISO,WWEA, own calculations
Global expansion according to Energy (R)evolution Scenario, Greenpeace 2010
Learning rates: PV 18%, Wind 10%

To tap renewable energy sources means to invest in their expansion until they become competitive:



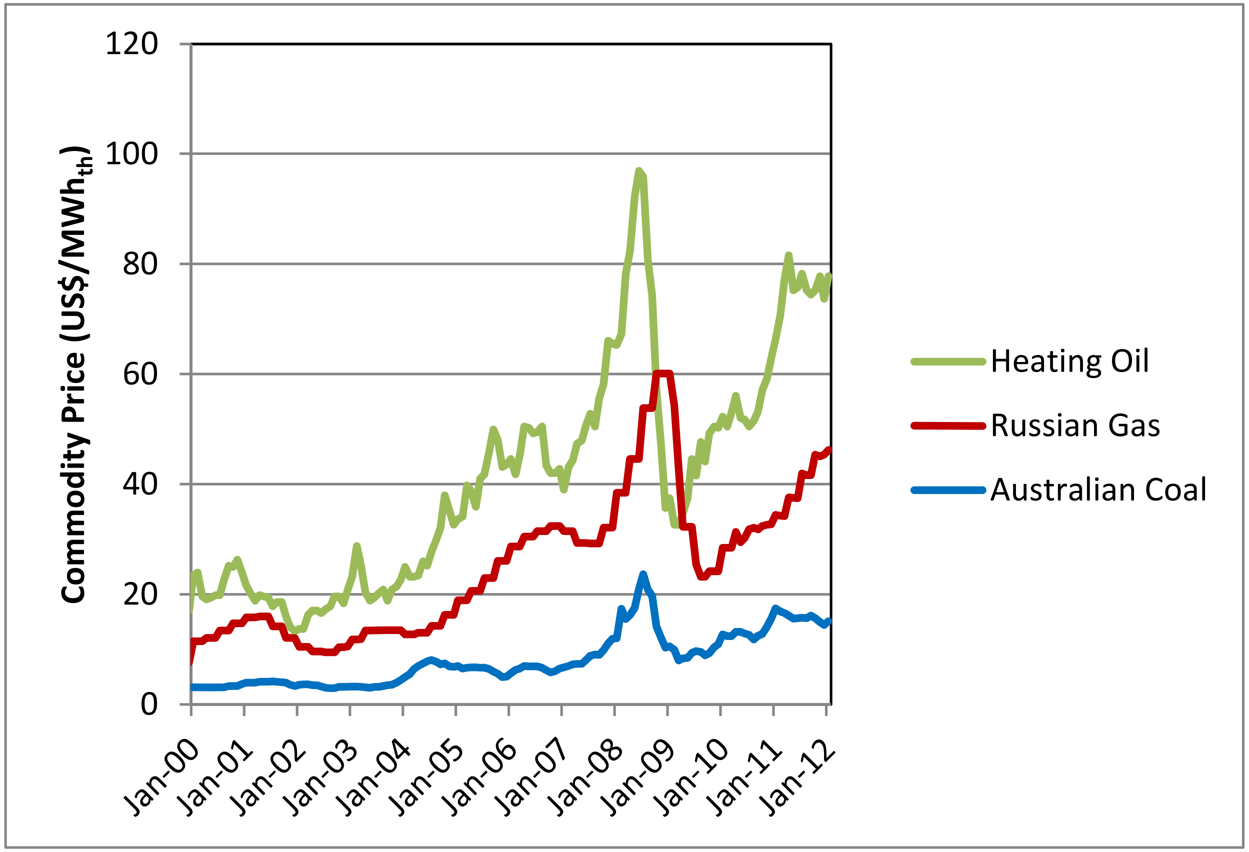
Sources: KJC, Pilkington, DLR, AT Kearney, NREL, IEA, Greenpeace, own calculations
Global expansion according to Trieb et al. 2011
Learning rate: CSP 9%

External costs are also paid by somebody.



http://www.erneuerbare-energien.de/english/renewable_energy/downloads/doc/44744.php

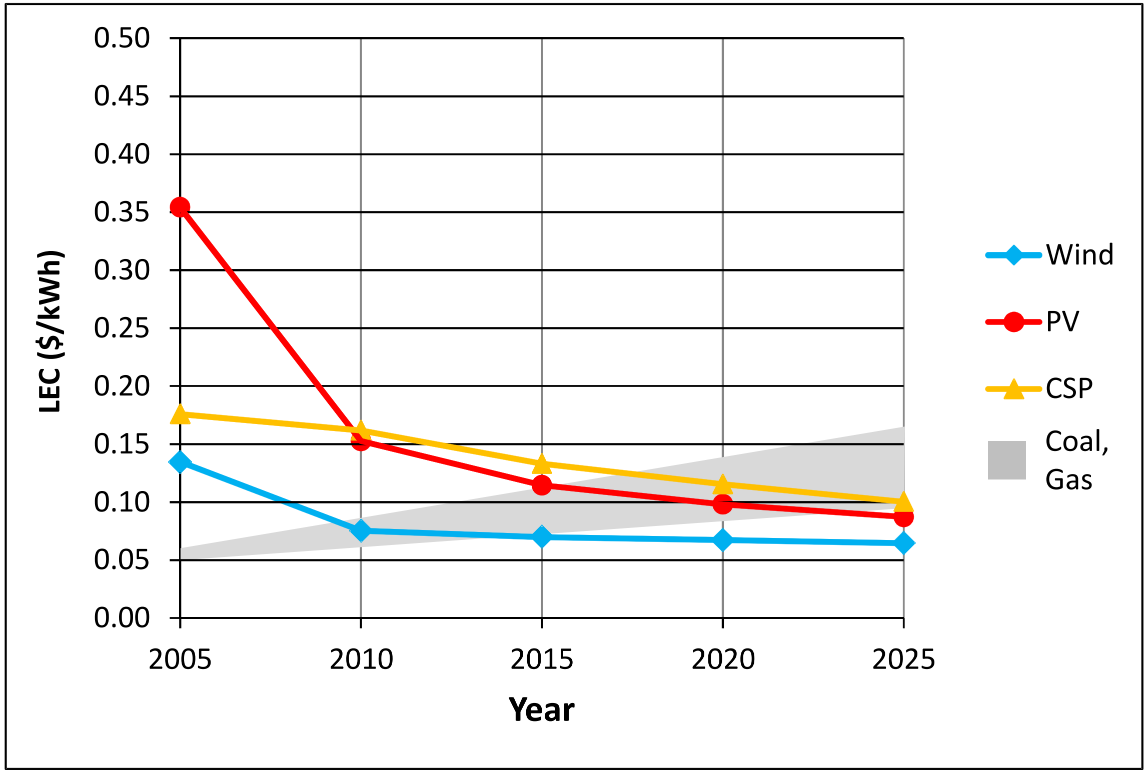
Global fuel cost development since the year 2000



<u>Calculated from original data</u>:
8.14 MWh_{th}/t Steam Coal
9.6 MWh_{th}/1000 m³ Natural Gas
0.0392 MWh_{th}/gal Fuel Oil

www.indexmundi.com

CSP, PV, Wind, Fuels: cost of generation



Installed capacity: 100 MW

Site: North Africa

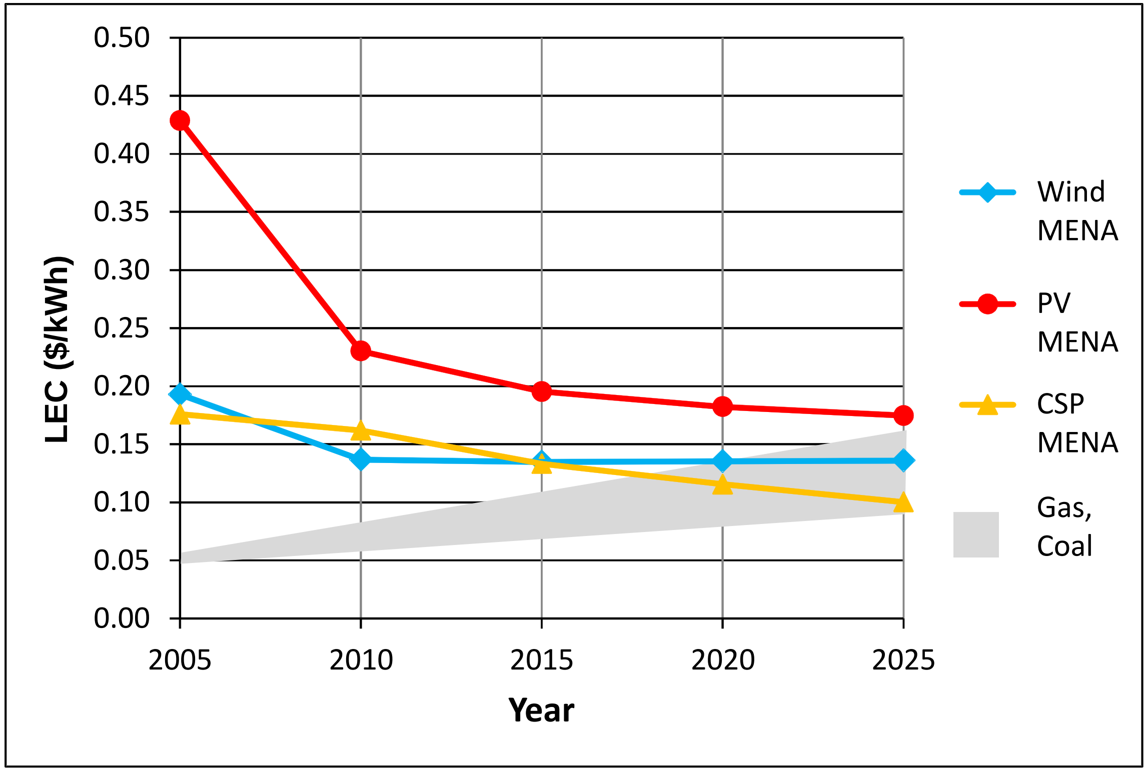
Linear fuel cost escalation
as in 2000-2010, market prices

PV 2000 h/yr, 30 yr
Wind 2500 h/yr, 20 yr
no storage, no backup

CSP 5500 h/yr, 40 yr
incl. thermal energy storage
and 10% hybrid operation with
natural gas

LEC = levelized electricity cost

CSP, PV, Wind, Fuels: cost of flexible power on demand



Load: 100 MW, 5500 h/y, 40 yr

Site: North Africa

Linear fuel cost escalation
as in 2000-2010, market prices

PV, Wind incl. pump storage;
10% backup by natural gas
combined cycle

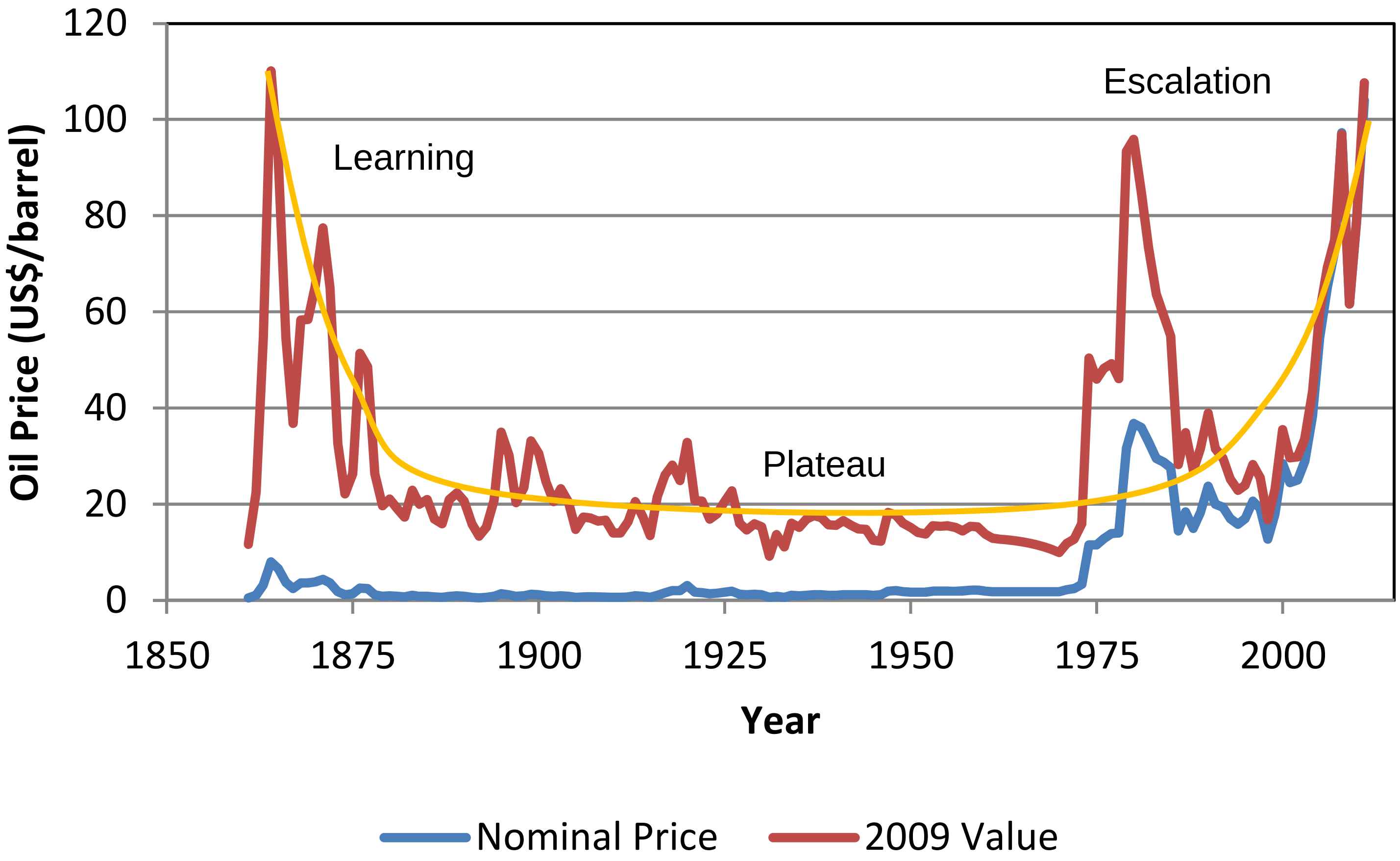
CSP incl. thermal energy
storage and 10% hybrid
operation with natural gas

LEC = levelized electricity cost

Exercise:

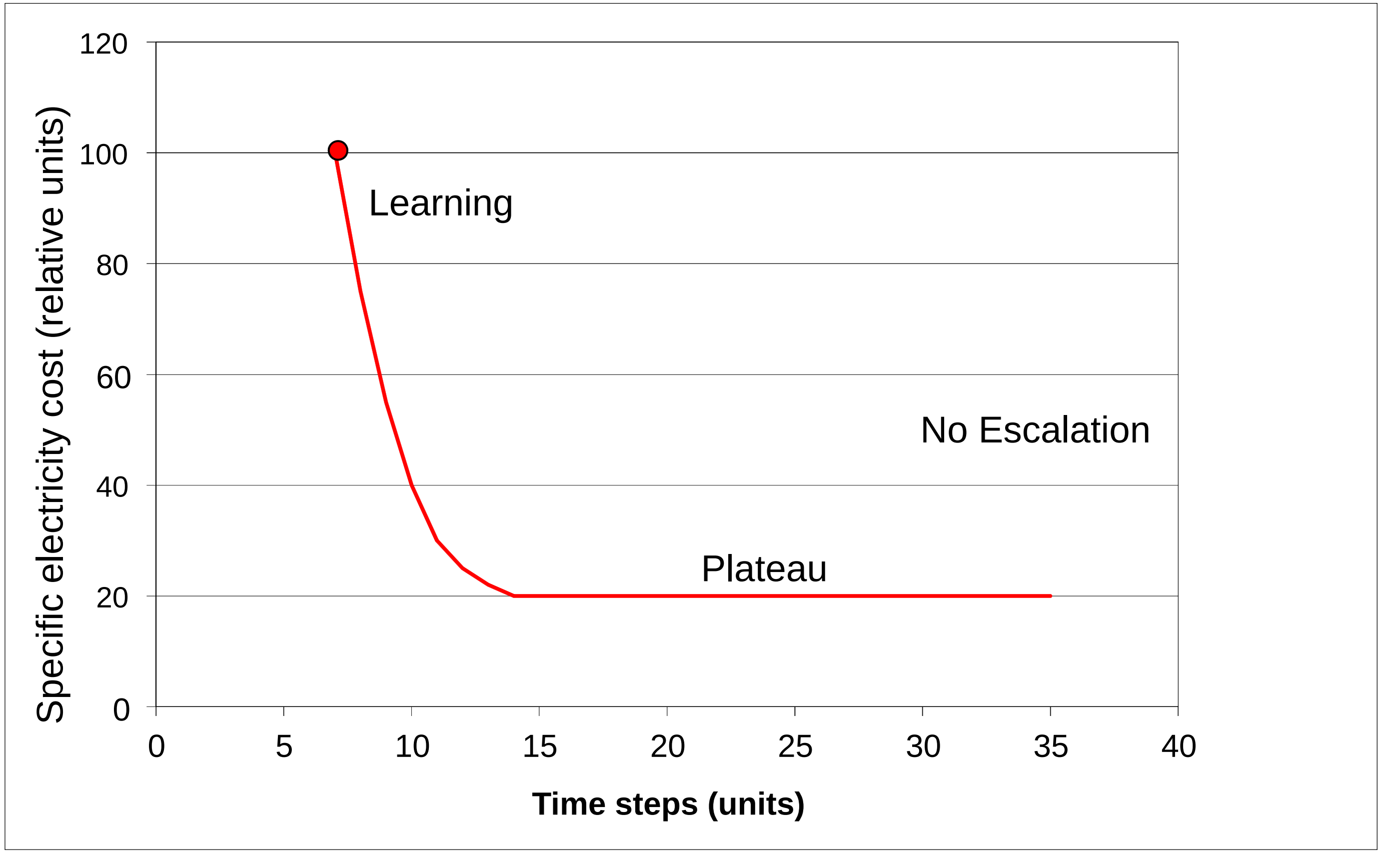
A simple thought experiment

Oil Price History: from 100 $/bbl to 20 $/bbl to 100 $/bbl



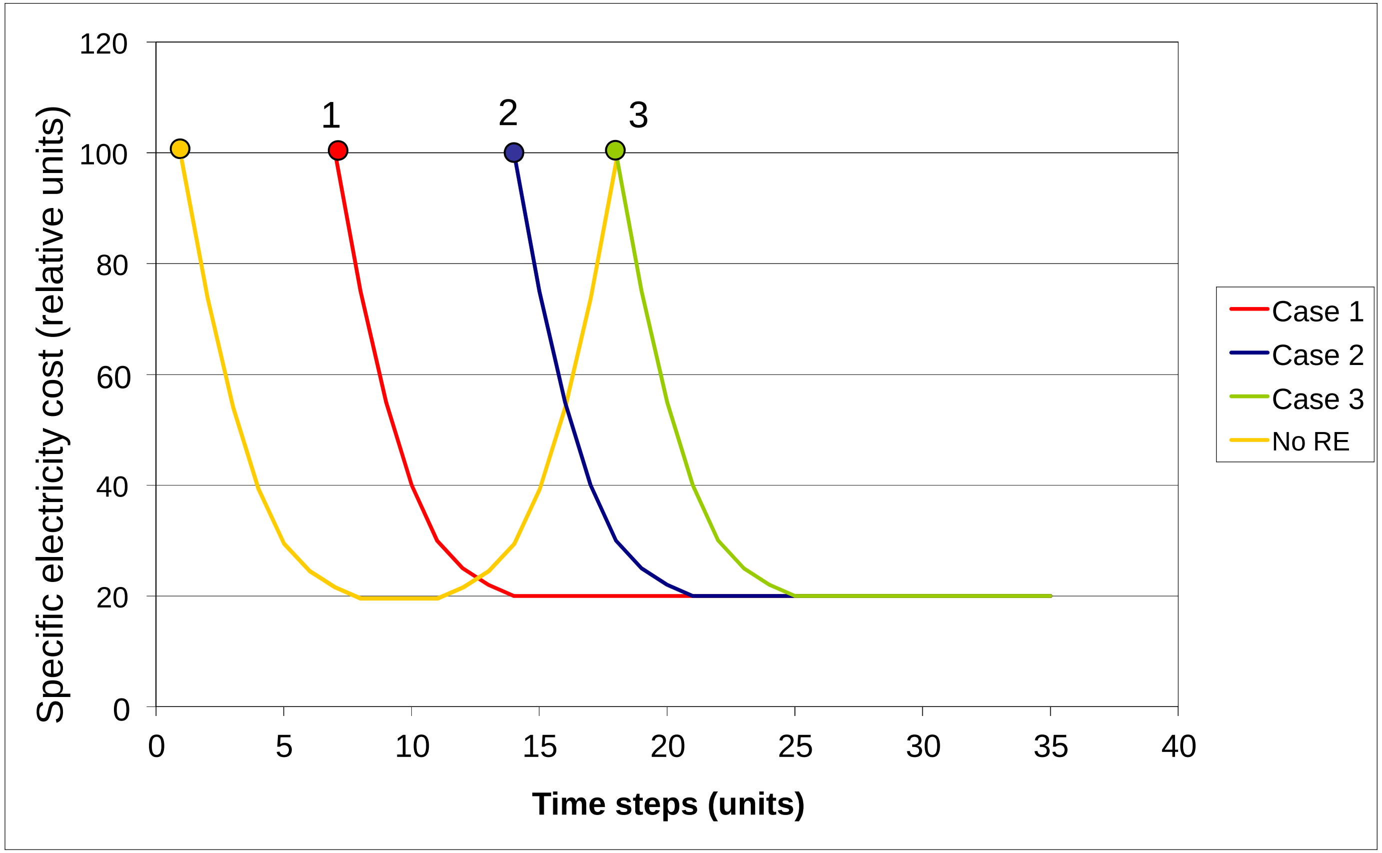
http://chartsbin.com/view/oau

Renewable Energy Learning Curve: from 100% to 20%



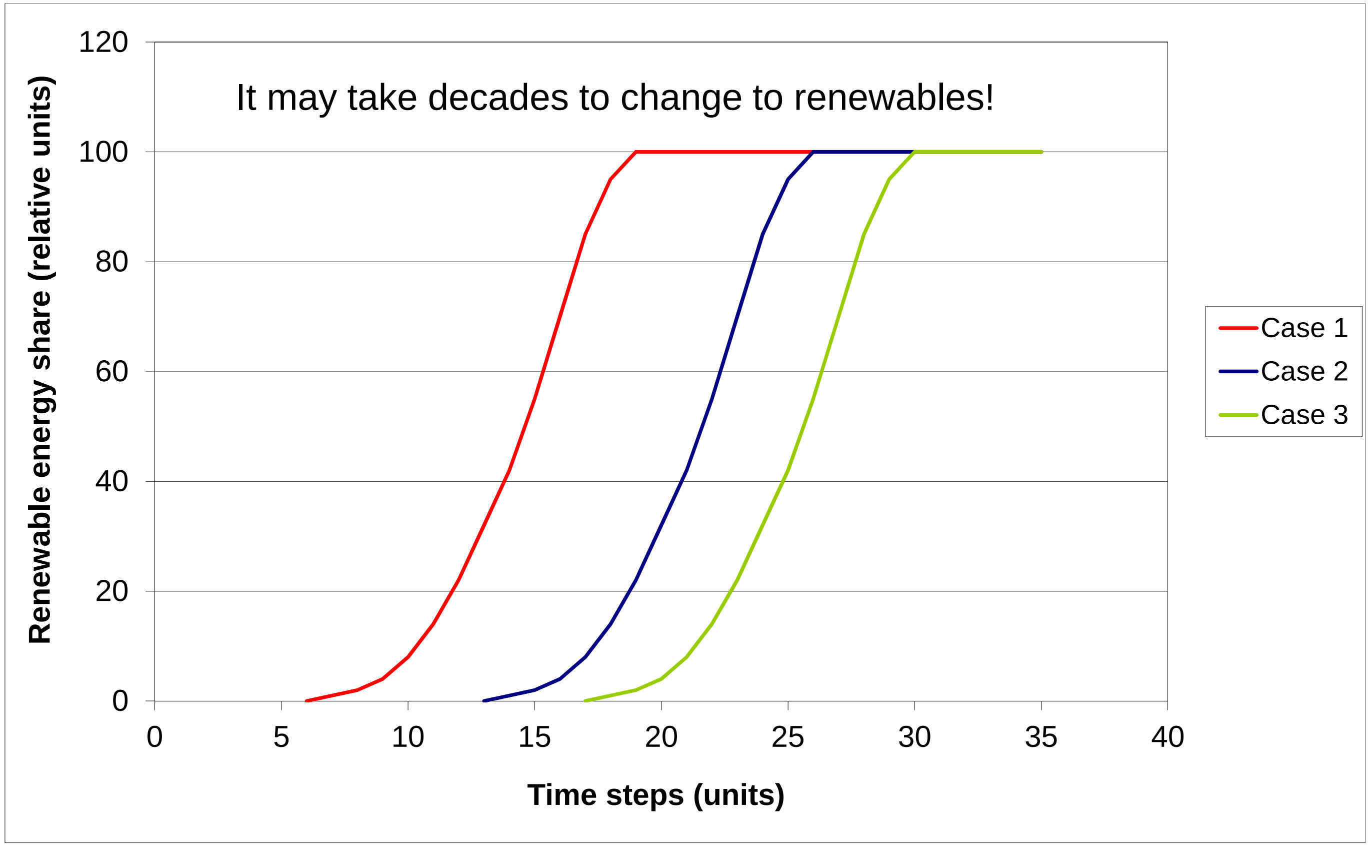
A fundamental difference between fossil energy resources and RE capital goods: after the learning phase the cost stays down if the RE potential is large enough

When is the best moment to start investing in RE?



1. at once the RE learning curve can be started and as fast as possible?
2. when fuel prices obviously exceed the expected long-term renewable energy cost?
3. as soon as renewable energy becomes competitive?

When is the best moment to start investing in RE?



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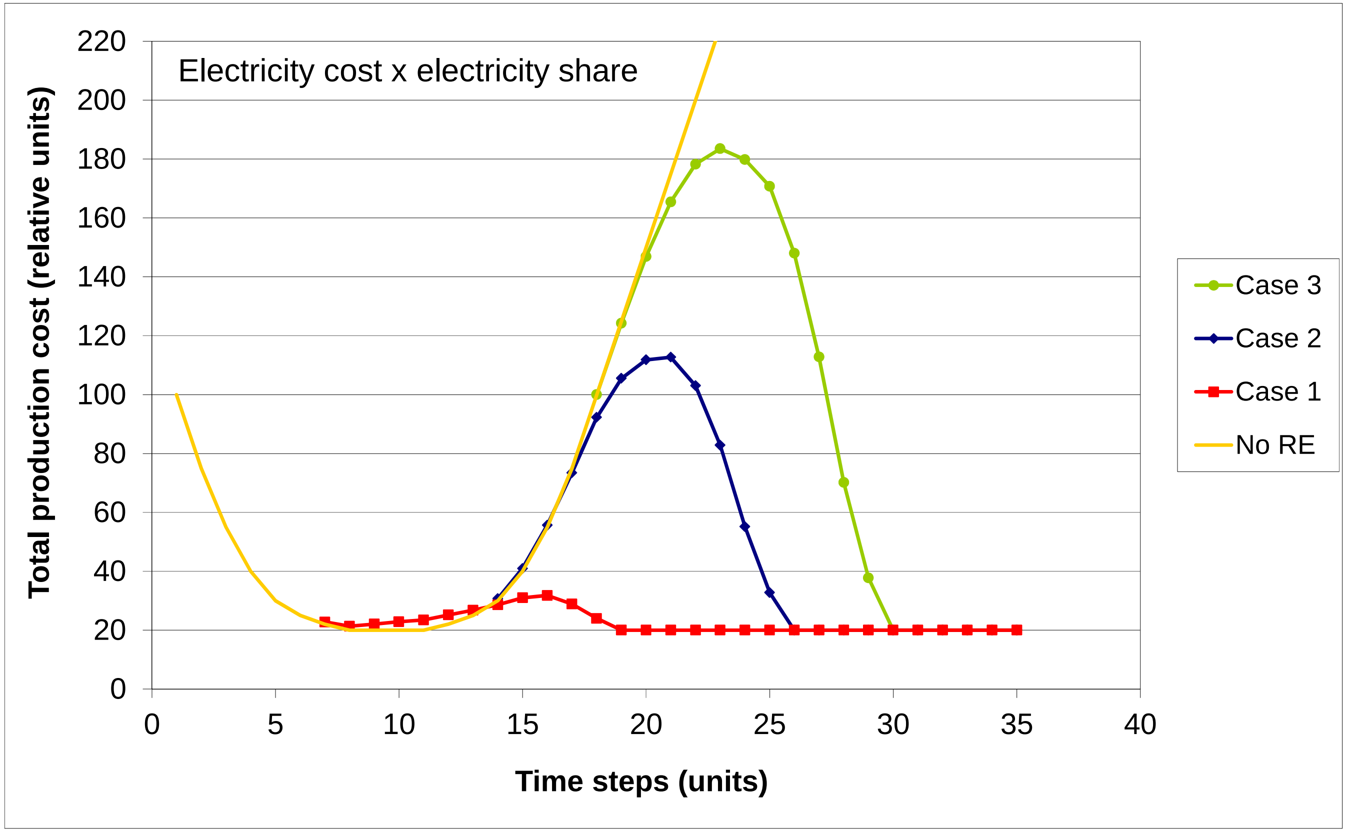

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