Part 5: Investment and Electricity Cost Calculation

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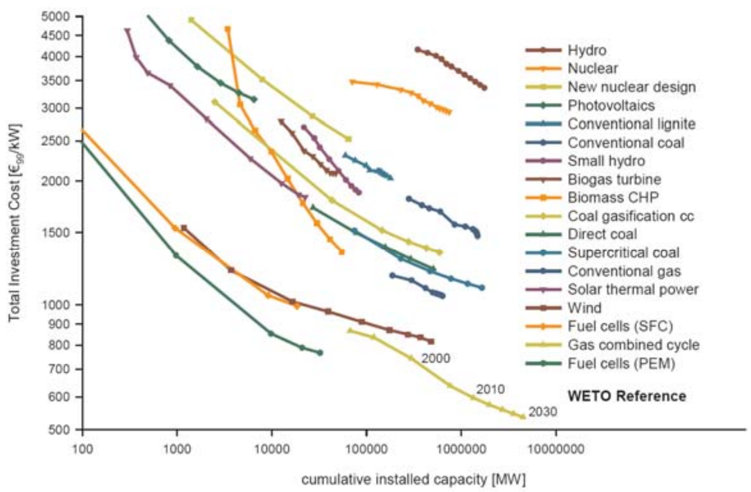
Investment Cost Modelling

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.

Equipment Cost Learning Curves

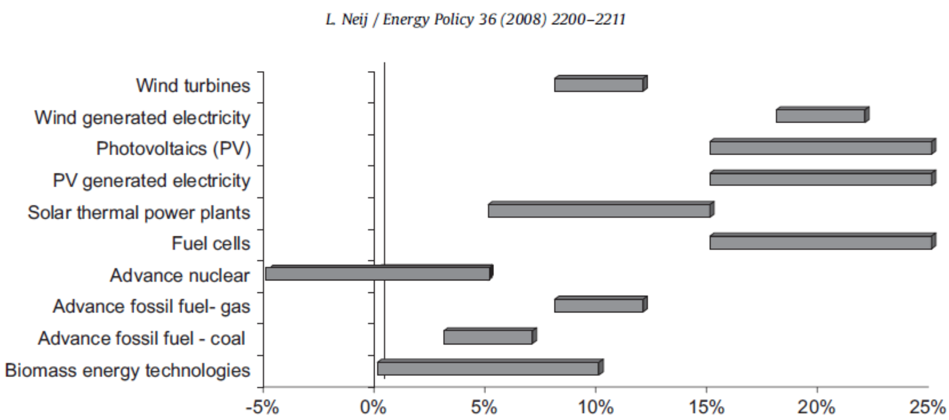


Cost Learning Curve Function

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

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

Learning Rates for Different Technologies

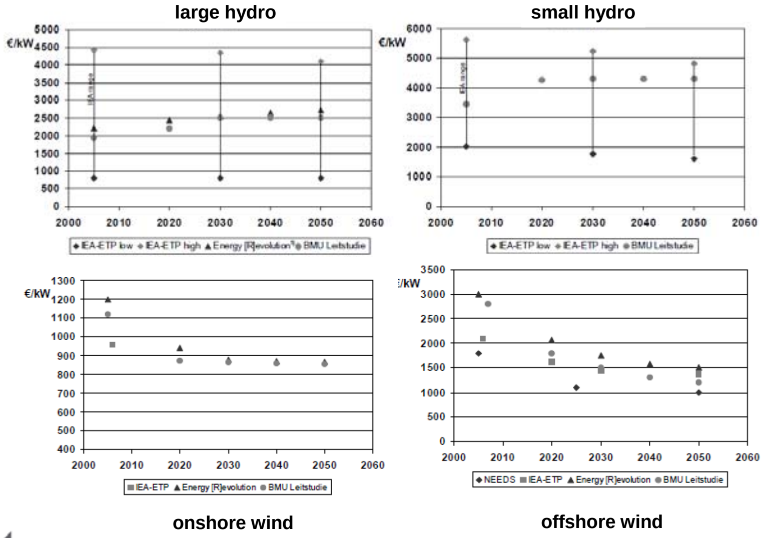


Global Capacity Projections

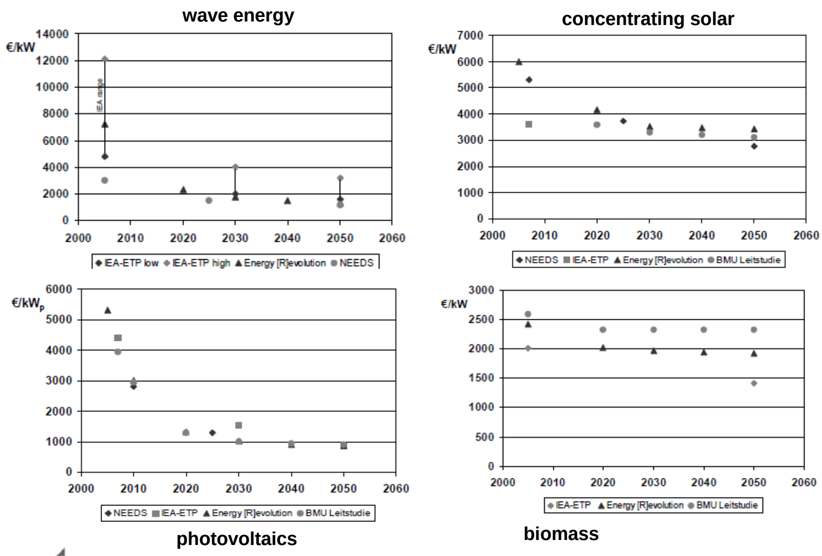
Source: Greenpeace 2009	Installed Capacity (GW)		Reference Scenario			
Year	**2005**	**2010**	**2020**	**2030**	**2040**	**2050**
Photovoltaic	2	10	49	86	120	153
Concentrating Solar	0,35	2	28	150	300	500
Wind Offshore	0	1	35	110	135	160
Wind Onshore	59	124	311	330	390	420
Hydropower	878	989	1215	1400	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

Investment Cost Projections from Different Sources



Investment Cost Projections from Different Sources



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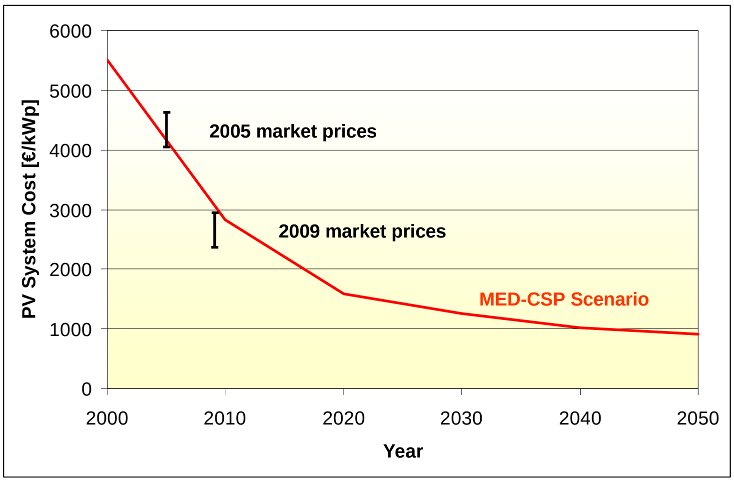
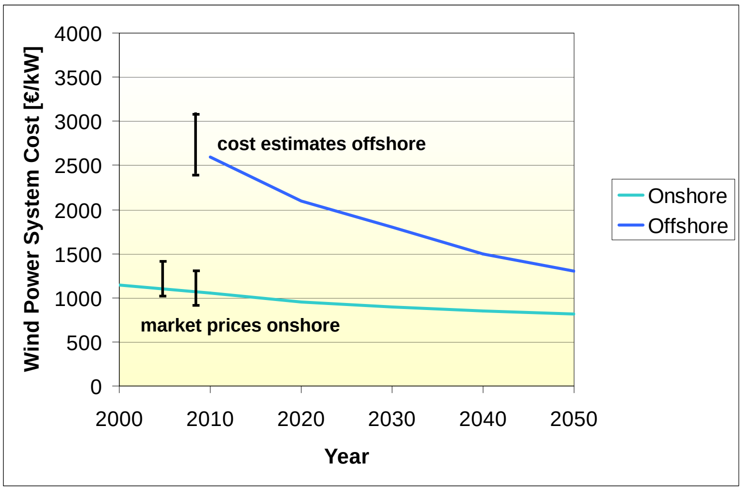
Photovoltaic System Cost Perspectives



MED-CSP 2005, LBBW 2009, ECOFYS 2009

Wind Power Investment Cost Perspectives



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MED-CSP 2005, ECOFYS 2009, Lead Study 2009

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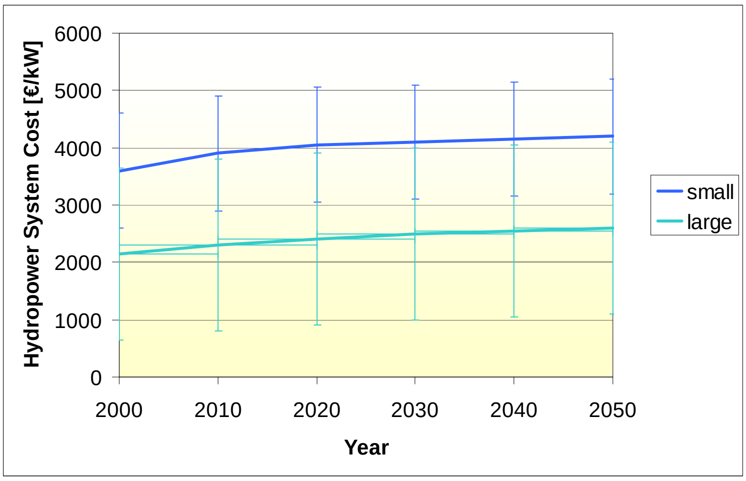
Hydropower Investment Cost Perspectives



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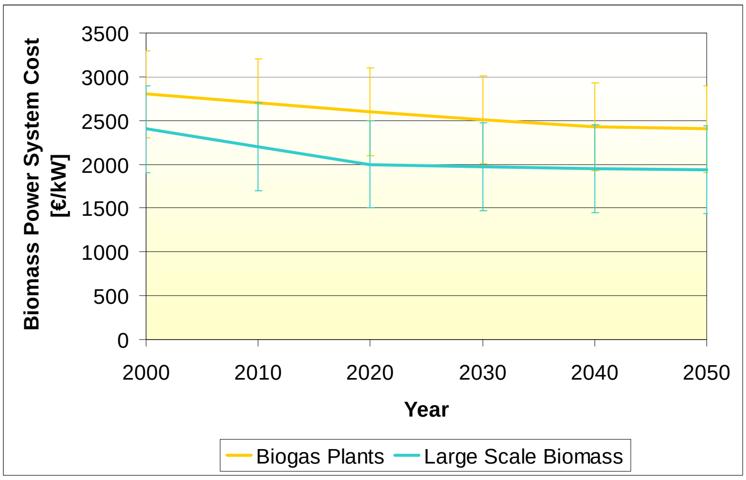
Biomass Investment Cost Perspectives



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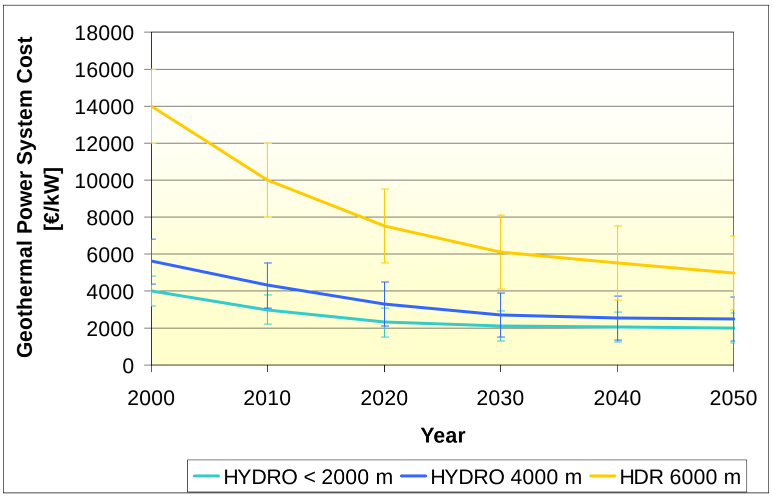
Geothermal Power Investment Cost Perspectives



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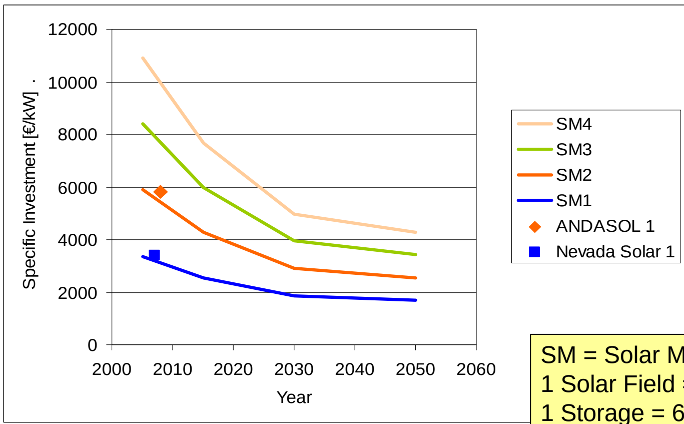
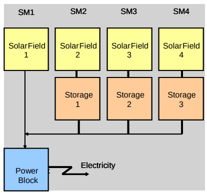
ECOFYS 2009, own estimates

CSP Investment Cost Perspectives

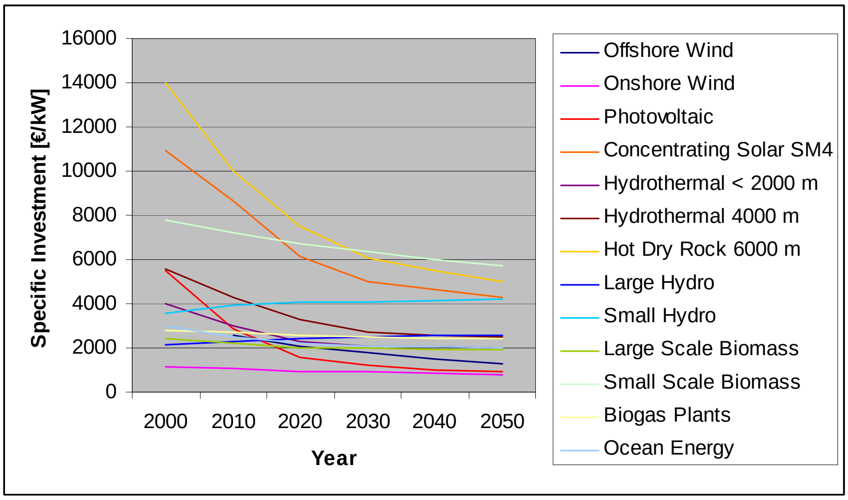
Year	PR	2005	2015	2030	2050	Unit
World CSP Capacity		354	5000	150000	500000	MW
Solar Field	90%	360	241	144	120	€/m²
Power Block	98%	1200	1111	1006	971	€/kW
Storage	92%	60	44	29	25	€/kWh





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

Specific Investment Cost as Function of Time



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

Electricity Cost Modelling

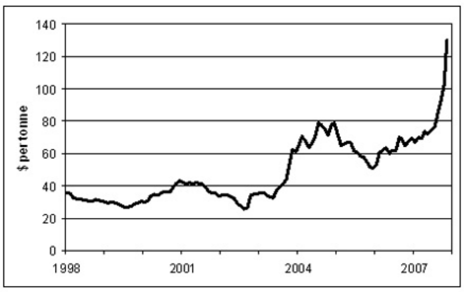
Levelised Electricity Cost Model

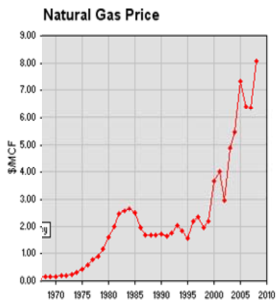
$$C_{el} = \frac{Inv \cdot FCR + O\&M + F}{E_{year}} \qquad FCR = \frac{(1+i)^n \cdot i}{(1+i)^n - 1}$$

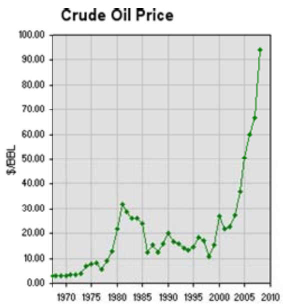
C_{el}	levelised cost of electricity in €/kWh in constant present monetary value
Inv	investment cost in €
FCR	fix charge rate as function of interest rate (i) and economic lifetime (n) in %/y
$O\&M$	net present value of annual operation, maintenance and insurance in €/y
F	net present value of annual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

Fuel Cost Perspectives?

Coal Price





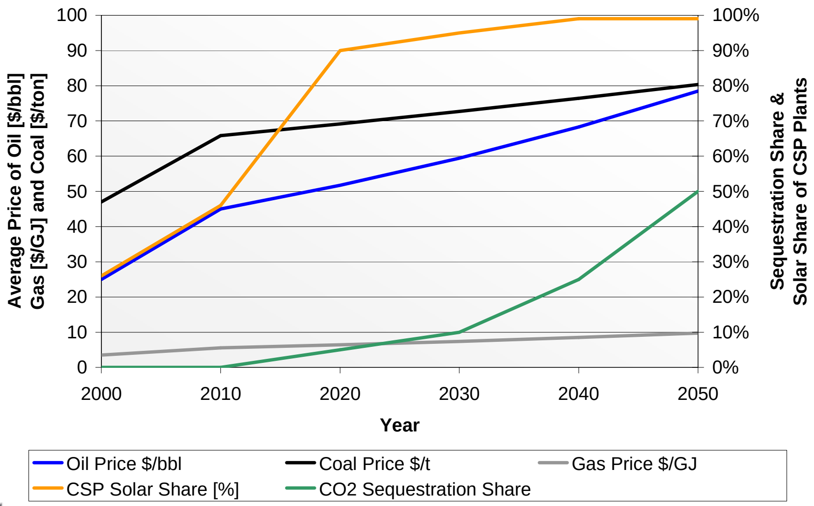


Parameters for Levelised Electricity Cost Model

	Economic Life years	Efficiency % *	Fuel Price Escalation %	Operation & Maintenance % of Inv./y	Annual Full Load Hours hours/year*
Steam Coal Plants	40	40%	1.0%	3.5%	5000
Steam Oil Plants	30	40%	1.0%	2.5%	5000
Combined Cycle Natural Gas	30	48%	1.0%	2.5%	5000
Wind Power	15			1.5%	2000
Solar Thermal Power	40	37%	1.0%	3.0%	8000
Hydropower	50	75%		3.0%	2600
Photovoltaics	20	10%		1.5%	1800
Geothermal Power	30	13.5%		4.0%	7500
Biomass Power	30	35%		3.5%	3700

* vary for different countries and sites

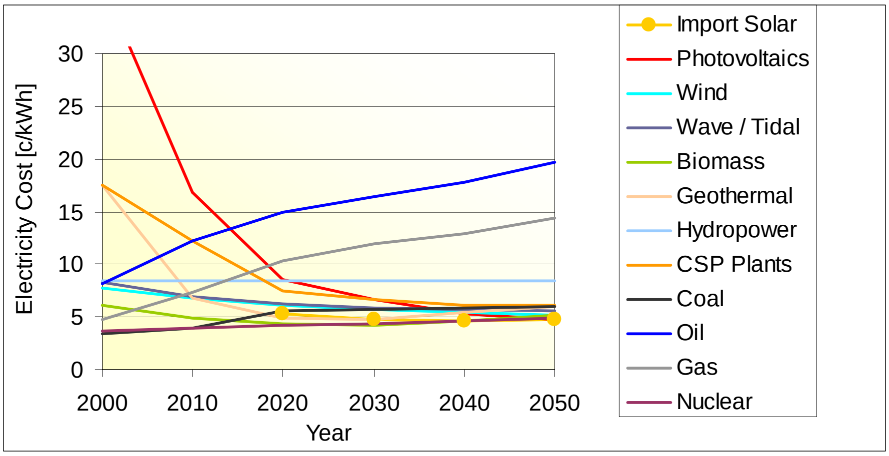
Further Parameters for Levelised Electricity Cost Model



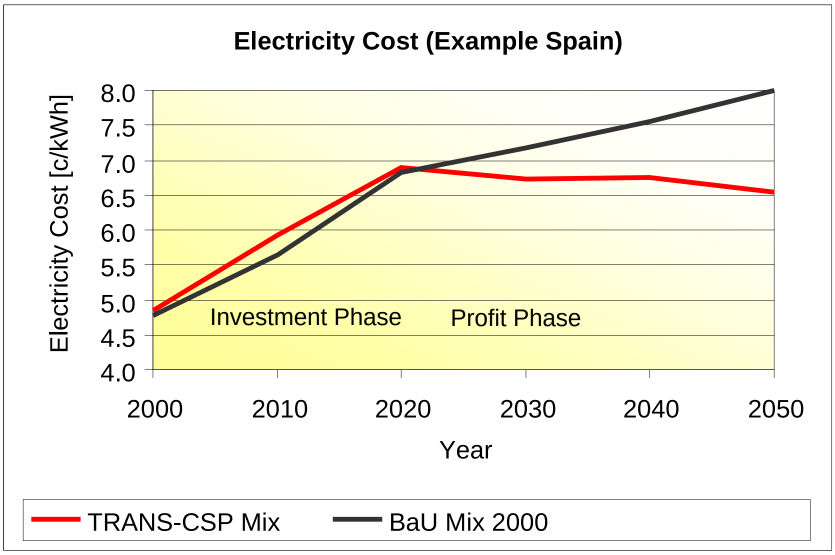
Performance Parameter: Representative Full Load Hours

Full Load Hours h/a	2000	2010	2020	2030	2040	2050
Load	6005	6005	6005	6005	6005	6005
Wind	2325	2359	2393	2427	2460	2494
Photovoltaics	1353	1515	1677	1697	1707	1717
Geothermal	7500	7500	7500	7500	7500	7500
Biomass	2800	2800	2800	2800	4000	3500
CSP Plants	1900	3500	4500	5000	5000	5000
Wave / Tidal	4000	4000	4000	4000	4000	4000
Hydropower	1705	1705	1705	1705	1705	1705
Oil / Gas	3261	2533	2240	1787	1517	1225
Oil	2458	2185	2427	1537	686	686
Gas	4805	2707	2173	1856	1707	1225
Coal	6202	6202	6202	6202	6202	6202
Nuclear	8367	8367	8367	8367	8367	8367
Import Other (incl. Sol	4920	4667	3500	2800	1333	533
Import Solar HVDC)	0	0	6000	6250	7000	5625

Electricity Cost Learning Curves (example Spain)



discount rate 5%/y at constant monetary value



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€2000, Fuel Cost: IEA / WEO 2005, after 2020 CCS

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Allowable Cost of Different Power Segments

Segment	Source / Technology	Min. Rev. ct/kWh	Max. Rev. ct/kWh
Peak Power	Pump Hydro Storage	10	25
	Fuel Oil		
	Gas Turbine		
	Biomass		
	Geothermal		
	CSP		
Intermediate Power	Coal	5	12
	Gas Combined Cycle		
	CSP		
	Biomass		
	Geothermal		
Base Load	Coal	3	6
	Lignite		
	Nuclear		
	River Run-Off		
	Gas Combined Cycle		
	Co-generation		
	Wind		
	Photovoltaics		
	CSP		
	Geothermal		

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DLR 2006

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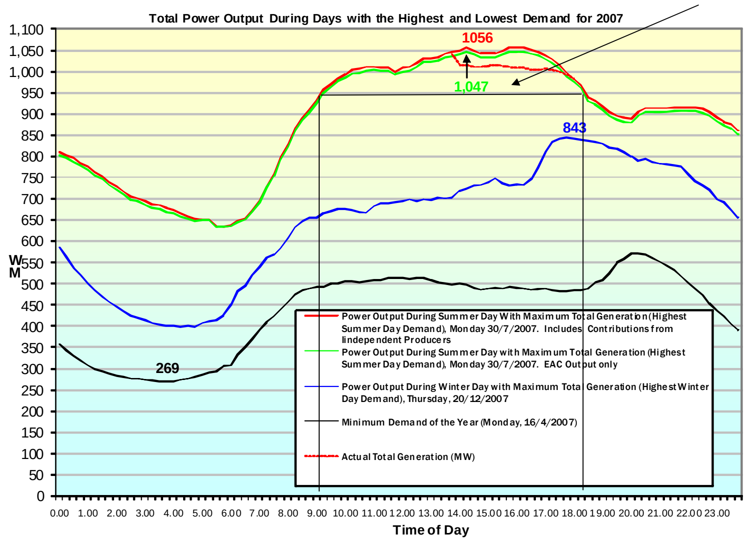
Example: Load Curve in Cyprus 2007

Gas Turbines fired with Diesel



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The Real Cost of Peak Electricity

Present Cost of Crude Oil	80 \$/bbl
Cost of Heat from Crude Oil	50 \$/MWh_{th}
Cost of Heat from Diesel	55 \$/MWh_{th}
Efficiency of Peaking Gas Turbines	15-20%
Cost of Peak Electricity (Fuel Only)	275 - 365 \$/MWh_{el}
Cost of Nevada Solar 1 CSP Plant:	150 - 170 \$/MWh_{el}

Similar Cases exist in many „Solar“ Countries

A Solar Plant can be an Insurance against further Cost Escalation.

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Conclusions

The Old Paradigm

Renewable sources of electricity are very expensive, most countries are too poor to afford their market introduction.

What has been overlooked:

Renewable sources of electricity become cheaper the more they are used, while fossil fuels become more expensive the more they are used.

The New Paradigm

A fast introduction of renewable sources of energy for power generation is the only way to stabilize the future cost of electricity at a relatively low level.

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