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A Comprehensive economic evaluation of integrated desalination systems, using fossil fuelled and nuclear energies, and including their environmental costs

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CONTENTS

- Background
- The environmental impact of desalination
- External costs and their internalisation
- Revised economic evaluation with environmental costs

Environmental impact of desalination

- A future desalination strategy, based solely on the use of fossil fuelled systems is not sustainable. In addition to limited reserves, the water demands would continue to increase as population grows and standards of living increase.
- Conservation measures (recycling, modernisation of water distribution networks, education for intelligent use of available water…) would reduce this demand to a certain extent (30 %) but would not be able to halt the dissemination of fossil fuelled plants because….
- But, desalination is an energy intensive process…

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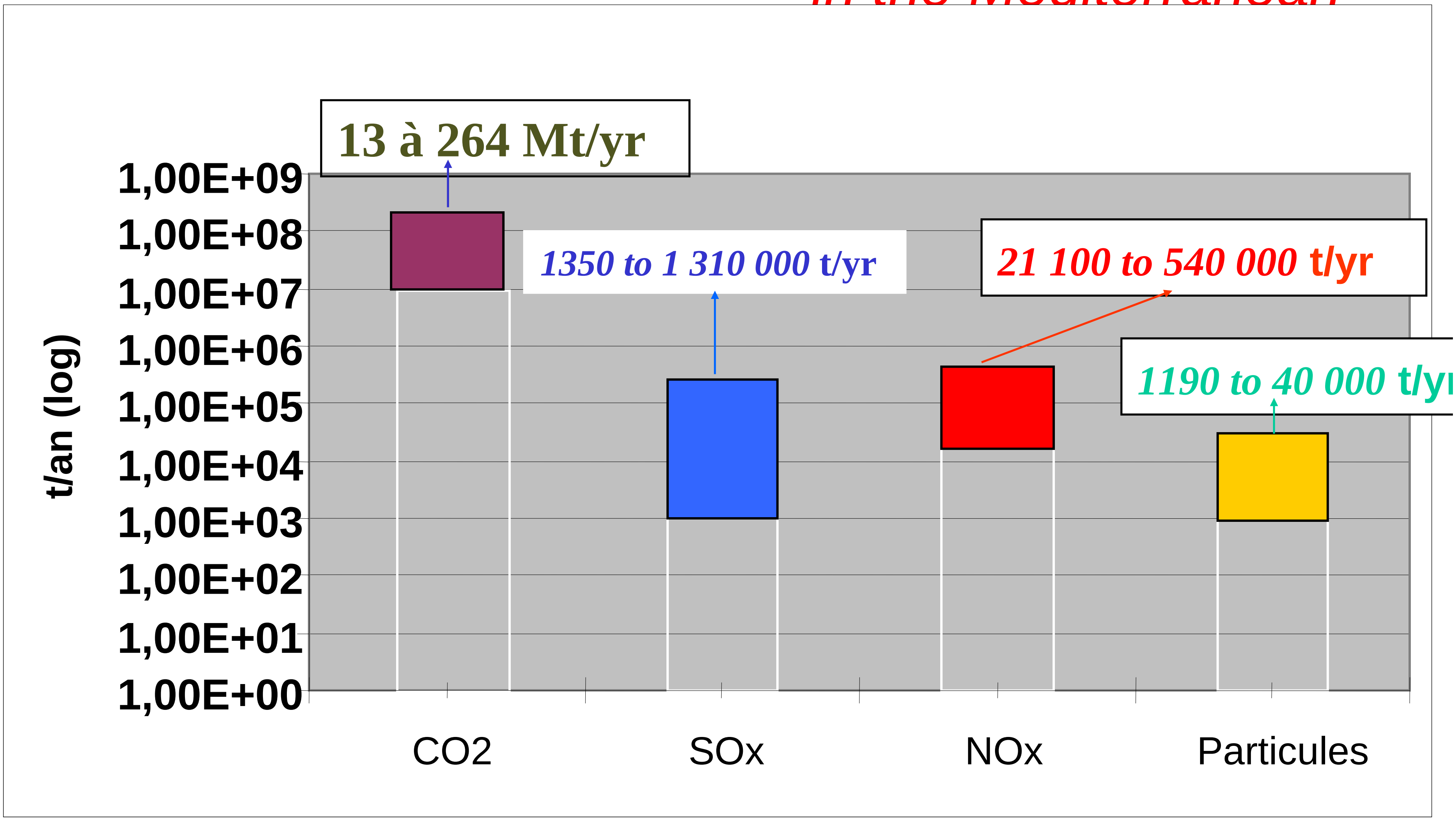
- The most important impact of fossil fuel utilisation for desalination is the production of GHG and other toxic emissions. The exact amounts of these depend upon the type of fuel and the desalination process used.
- It can be shown the for the Mediterranean region alone, one would require an additional desalting capacity of about 20.1 million m^3/day in 2025.
- This is a pessimistic scenario, assuming that only 2.5% of the total needs would be met by desalination. However,…

GHG and particle emissions by dessalination in the Mediterranean



At world level, these emisions will be multiplied by a factor of 2.5 or more!!

Influence of externalities on power and desalination costs

- An externality ("external cost") arises when the social and economic activities of one group of persons have an impact on another group and when that impact is not accounted for or paid.
- In the field of power generation, externalities are the cost imposed on the society and the environment by the adverse effect of all power generation systems on human health and the eco-system.

Impact pathways for energy and transport externalities

Impact	Pollutant	Effect
Human Health	PM_{20}, O_3, SO_2, NO_x	Reduction life expectancy
-Mortality	As, Cd, Cr, Ni, Benzene compounds, diesel particles	Cancers
	Noise	Loss of amenity, health
	Accident risk	Fatalities from accidents at work or traffic

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Impact	Pollutant	Effect
Human Health	PM_{20}, O_3, $SO_{2,}$ PM_{10}	Respiratory problems, restricted activity
- morbidity	PM_{10}, CO	Congestive heart failure
	PM_{10}	Chronic bronchitis, respiratory problems
	Hg, Pb	Decreased IQ, neurotoxicity

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Impact	Pollutant	Effect
Building materials	SO_2, Acid deposition	Ageing of steel, zinc, limestone, mortars, paints..
Crops	O_3, SO_2, NO_x, Acid deposition	Crop yields or destruction
Global warming	CO_2, CH_4, N_2O, N, S	Chronic bronchitis, respiratory problems
Eco-systems	N, Acid deposition	Increased acidity, loss of usable land

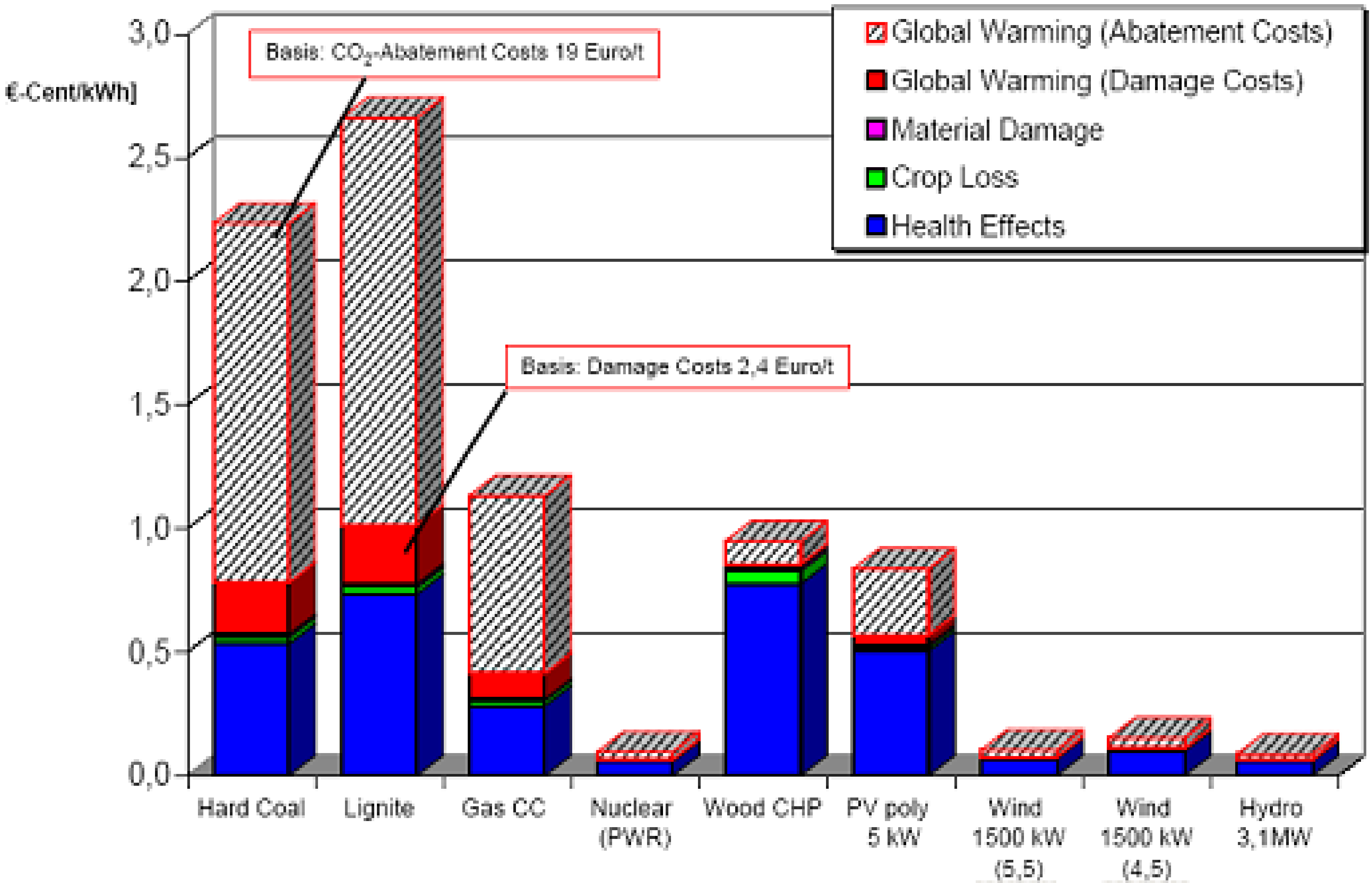
External costs of electricity production in the EU(cents/kW.h)

Coal and lignite	Oil	Gas (CC)	PWR	Biomass	Hydro	S/PV	Wind
2.5 to 19	3.8 to 14	1.3 to 7.6	0.25 to 0.64	0.64 to 6.4	0.038 to 0.89	0.76	0.063 to 0.32

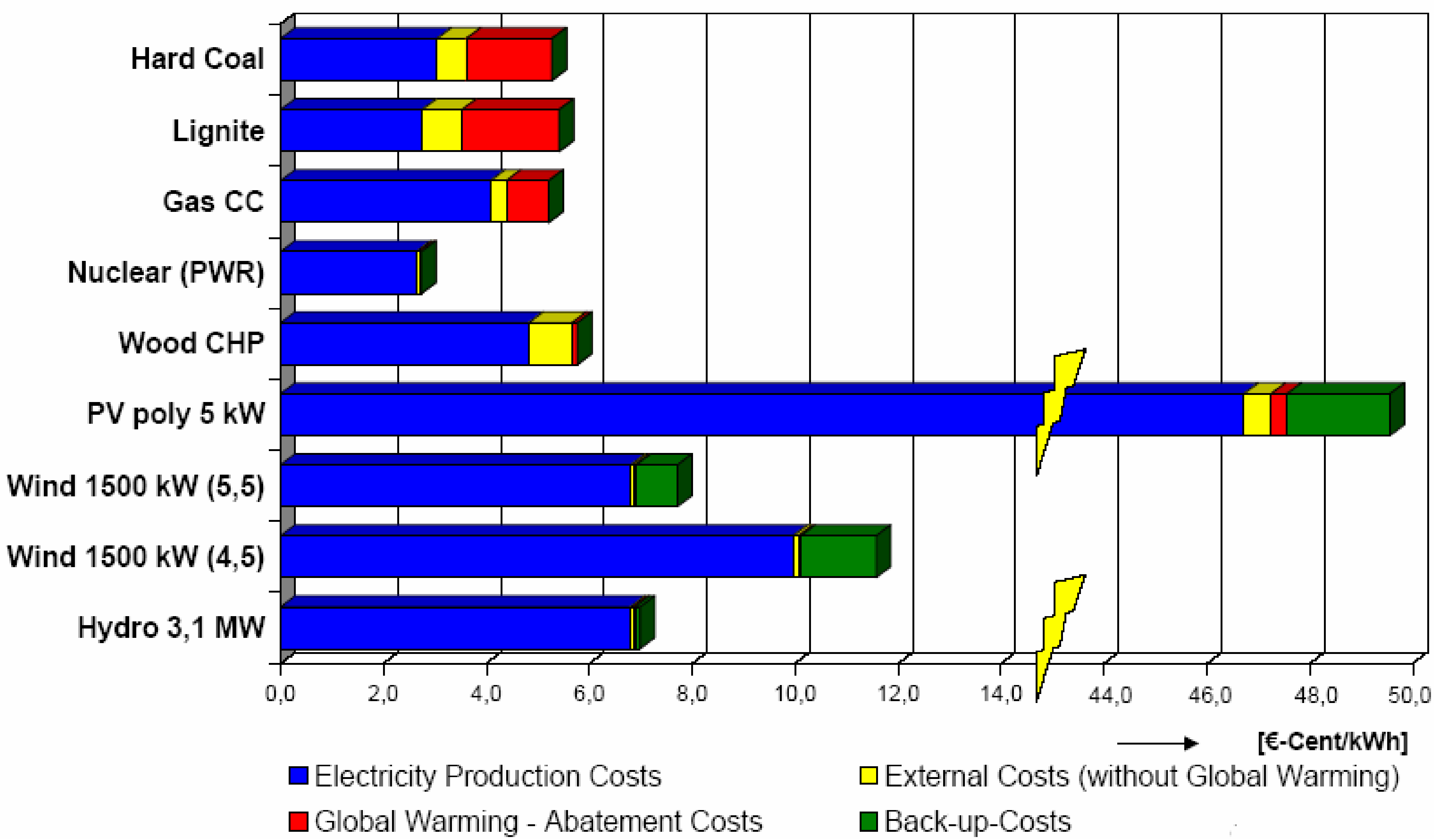
Eco tax of 19 €/t CO_2; 1€ = 1.2695 $; now 34€/t

1 year of life lost = 50 000 €

External costs in Germany



Internalisation in Germany



Economic Evaluation

- 4 Nuclear reactors : PWR900, AP600, GT-MHR, PBMR
- 3 Fossil energy based systems: Coal (CFB-900), CC-900, OIL-500; with performances foreseen for 2015
- Two desalination processes; MED, RO with nominal capacities of 120 000 m^3/day.
- DEEP-3, with relevant modifications by CEA
- Costs from reliable sources except for the HTRs (from the developers); all updated to 2006 US $
- Comparison with renewable energies later. (Oarai)

Basic assumptions of calculation

- See table 1

Power costs with/without internalisation of externalities in France and Germany (8% disc rate)

	Units	CFB-900	CC-900	Oil-500	PWR-900	AP-600	GT-MHR	PBMR
Fuel price	$/bbl ($/t)	(65)	60 (11 Mbtu)	60				
Total	Cent/ kW.h	5.922	11.806	14.107	4.003	4.446	3.099	3.237
Total with E1	Cent/ kW.h	9.722	13.106	20.507	4.253	4.696	3.349	3.487
Total with E2	Cent/ kW.h	18.622	16.906	28.107	4.383	4.826	3.479	3.617

Current fossil fuel prices; E1, E2: lowest and highest calculated external costs in France and Germany

MED water costs with/without internalisation of externalities in France and Germany; 8 % discount rate

	CFB-900	CC-900 (Oil-500)	PWR-900	AP-600	GT-MHR	PBMR
Water costs ($\$/m^3$)	0.9487	1.3777 (1.5713)	0.84505	0.8795	0.6418	0.6942
Δ (%)		**+45 (+66)**	**-10**	**-7**	**-32***	**-27***
Water costs E1	1.2378	1.4766 (2.0581)	0.86447	0.8989	0.6490	0.7021
Δ E1(%)		**+19 (+66)**	**-30**	**-27**	**-48**	**-43**
Water costs E2	1.9147	1.7656 (2.6361)	0.87458	0.9090	0.6528	0.7062
Δ E2(%)		**-7.8 (+38)**	**-54**	**-52**	**-65**	**-63**

RO water costs with/without Internalisation of externalities in France and Germany;8 % discount rate

	CFB-900	CC-900 (Oil-500)	PWR-900	AP-600	GT-MHR	PBMR
Water costs ($/m^3)	0.6928	0.8893 (0.9539)	0.63084	0.6451		
Δ (%)		**+28 (+38)**	**-8.9**	**-6.9**		
Water costs E1	0.8140	0.93276 (1.1581)	0.63891	0.6532		
Δ E1(%)		**+14.6 (+42)**	**-22**	**-20**		
Water costs E2	1.0979	1.05976 (1.4005)	0.6431	0.6574		
Δ E2(%)		**-3 (+28)**	**-41**	**-40**		

Comparison of MED and RO water costs ($/m³)

	CFB-900	CC-900 (Oil-500)	PWR-900	AP-600	GT-MHR	PBMR
MED	0.9487	1.3777 (1.5713)	0.84505	0.8795	0.6418	0.6942
RO	0.6928	0.8893 (0.9593)	0.63084	0.6451	-	-
Δ (%)	-27	-35 (-39)	-25	-27		
MED/E2	1.9147	1.7656 (2.6361)	0.87458	0.9090	0.6528	0.7062
RO/E2	1.0979	1.05976 (1.4005)	0.6431	0.6574		
Δ E2(%)	-42	-40 (-47)	-26	-28		

BUT…..

- Residual salinity of water from MED (MSF) ≤ 25 ppm
- Residual salinity of water from RO ~ 300 à 500 ppm
- Salinity of 25 ppm can also be achieved by a two-stage RO process (Ashkelon), but the cost would be higher

- Modern tendancy is : hybrid MED/RO; MSF/RO systems.
  – Their cost would be intermediate between MED and RO

Conclusions

- Integrated seawater desalination systems are likely to be deployed intensively in the future in view of the large water and electricity shortages in many regions of the world
- A future desalination strategy, based on the utilisation of fossil fuelled systems is not sustainable because of the considerable amounts of GHG rejected. At the moment, the only solutions would appear to be nuclear energy and wind energy.
- For large scale desalination, only nuclear energy is competitive

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- For a discount rate of 8%, current fossil fuel prices, <u>without external costs:</u>
  - Compared to the CFB-900 +MED plant, the desalination costs by PWR+ MED and AP-600 +MED system are 7 to 10 % lower.
  - Those with the CC-600 +MED and Oil-500 +MED are 45 and 66 % higher.
  - In the same conditions, the next generation HTRs such as the PBMR and GT-MHR, utilising "free" waste heat with MED, lead 27 to 32 % lower desalination cost.

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- Desalination costs with RO, for all systems, show the same trends. They are in general 25 to 40% lower than corresponding MED costs. But..

- Internalising externalities for all systems further reduces nuclear desalination costs by 27 to 65 %.

Monetary evaluation methodology

Health end-point	Recommended central unit values in € price year 2000
Value of a prevented Fatality	1,000,000
Year of Life Lost	50,000 / year lost
Hospital admissions	2,000 / admission
Emergency Room Visit for respiratory illness	670 / visit
General Practicioner visits:	
Asthma	53 / consultation
Lower respiratory symptoms	75 / consultation
Respiratory symptoms in asthmatics:	
Adults	130 / event
Children	280 / event
Respiratory medication use – adults and children	1 / day
Restricted activity days	130 / day
Cough day	38 / day
Symptom day	38 / day
Work loss day	82 / day
Minor restricted activity day	38 / day
Chronic bronchitis	190,000 / case