

## Sustainable Development in Energy: Comparative Assessment of Energy Options

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## Content

- The concept of sustainable development: What does it mean for the energy system and how can it be measured?
- A comparison of various electricity supply options with regard to sustainability

## The Brundtland Commission 's Definition of Sustainable Development

"Sustainable Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

The challenge is to simultaneously help to deliver economic prosperity, to reduce and eliminate poverty, to provide environmental quality and social equity and to maintain the natural foundations of life in spite of a growing global population.

**"Sustainable development": What does it mean for the energy sector**

- Scientific fundamentals
- Sustainability and the use of finite (*non-renewable*) resources
- Sustainability and the economic principle

➤ **Scientific fundamentals**

- Second law of thermodynamics => Life and development of economical and cultural achievements require a permanent input of workable energy and material.
- Growing knowledge (*Gestaltungsfähigkeit*) and the connected possible technological progress create the base for preserving and expanding the abilities of future generations.
- Environmental pollution results from the release of substances into the environment, not from the energy degradation.

➤ **Sustainability and the use of finite (*non-renewable*) resources**

- Can the use of finite resources (e.g. Oil and Coal) be consistent with the principles of sustainability?
- Supply of energy service requires the use of workable energy, but also the use of non-energetic resources and materials.
- Use of finite resources require a compensation  
=> the expansion of resource quantities available technically and economically.
- State of technology determines the technological-economical available base (*potential*) of raw materials and energy.

➤ **Sustainability and the economic principle**

- Prudent use of scarce resources represents a key aspect of sustainability.
- Also the general economic principle targets at minimising the use of resources.  
=> Costs and prices are a measure for usage of resources.
- Costs can only be a measure for relative sustainability of energy systems, if all costs (including the usage of the environment) are considered.  
=> Internalisation of external costs (Getting prices right).

### **Sustainable energy supply: management rules (1/2)**

- Use of renewable resources must not exceed their rate of regeneration.
- Use of non-renewable energy carriers and raw materials requires a compensation for future generations. This compensation requires the extension of the technical-economical accessible resource base.
- Emissions of substances into the environment shall not exceed the absorption capacity respectively the ability for assimilation of the natural environment.
- Hazards and risks for human health and environment from energy provision have to fall below natural hazards and risks avoided by use of energy.

### **Sustainable energy supply: rules for orientation and activities (2/2)**

- The supply of energy services shall be carried out with the possibly lowest total costs (private plus external costs). Total costs represent a useful measure for the usage of scarce resources. Therefore they are an indicator for relative sustainability of technologies and systems for supplying energy services.
- Research and development are the basis for improving efficiencies for usage of resources, for limiting energy caused environmental impacts and for expanding the technical-economical energy-basis for future generations.

**Indicators for sustainability (1/2)**

Dimension	Scope	Indicator	Unit per unit of Energy
Ecological	Usage of resources	Consumption of finite energy resources	J resp. kWh
		Consumption for raw-materials, e.g. copper, bauxite, iron	kg
	Influence on climate	Greenhouse gas potential (GHG)	kg CO <sub>2</sub> – equivalent
	Acidification / Eutrophication	Potential for acidification	kg SO <sub>2</sub> -equ.
		Potential for eutrophication	kg PO <sub>4</sub> <sup>3-</sup> -equ.
	Waste	Waste (non-radio-active)	kg
Radioactive waste		m <sup>3</sup>	

**Indicators for sustainability (2/2)**

Dimension	Scope	Indicator	Unit per unit of Energy
Social	Adverse health effects	Public health-risks	YOLL (years of life lost)
		Occupational health-risks	YOLL
Economical	Costs	Microeconomic costs	
		External costs	
		Total costs	

**Reference Electricity Production Technologies**

		Technology	Power installed	Efficiency	Life
<b>Coal</b>	(43 %)	Pulverised Fuel Firing	600 MW	43.0 %	35 a
<b>Lignite</b>	(40 %)	Pulverised Fuel Firing	800 MW	40.1 %	35 a
<b>Gas CC</b>	(57.6 %)	Combined-cycle	777.5 MW	57.6 %	35 a
<b>Nuclear</b>	(PWR)	PWR	1375 MW	34 %	40 a
<b>PV</b>	(poly)	poly-crystalline	5 kW	9.5 % <sup>1)</sup>	25 a
	(amorphous)	amorphous	5 kW	4.5 % <sup>1)</sup>	25 a
<b>Wind</b>	(4.5 / 5.5 m/s) <sup>2)</sup>	horizontal axis wind energy conv.	1 MW	—	20 a
<b>Hydro</b>	(3.1 MW)	Run-of-River	3.1 MW	90 %	60 a

<sup>1)</sup> System-efficiency  
<sup>2)</sup> Average windspeed p.a.

Source: Marheineke 2002

**Cumulative energy requirements (CER) and energy payback periods (EPP)**

		CER (without fuel) [kWh <sub>Prim</sub> / kWh <sub>el</sub> ]	EPP [months]
<b>Coal</b>	(43 %)	0.29	3.6
<b>Lignite</b>	(40 %)	0.17	2.7
<b>Gas CC</b>	(57.6 %)	0.17	0.8
<b>Nuclear</b> (PWR, ult.waste dispo.)		0.07	2.9
<b>PV</b> (5 kW)	amorphous	0.62	71
	poly	0.94	107
<b>Wind</b> (1 MW)	5.5 m/s	0.08	7.3
	4.5 m/s	0.18	16.4
<b>Hydro</b>	(3.1 MW)	0.05	13.7

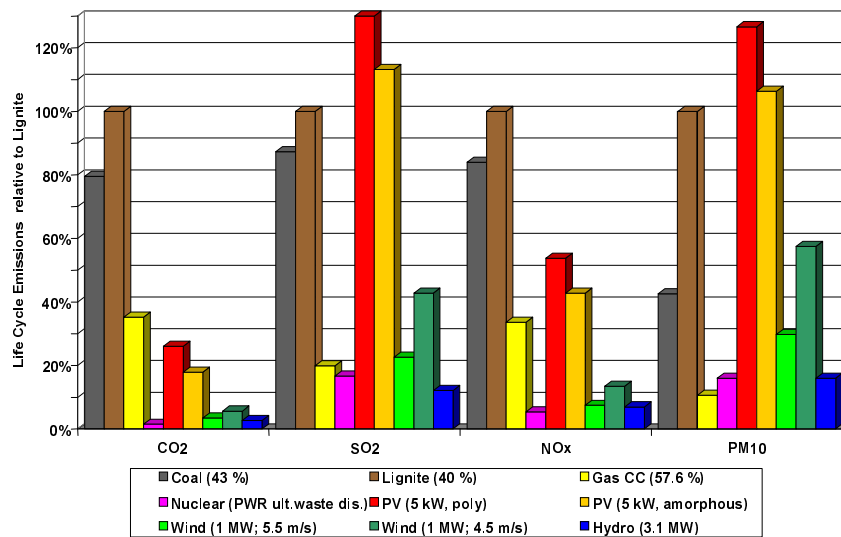
Source: Marheineke 2002

**Total life cycle raw material requirements**

	<b>Iron</b> [kg / GWh <sub>e</sub> ]	<b>Copper</b> [kg / GWh <sub>e</sub> ]	<b>Bauxite</b> [kg / GWh <sub>e</sub> ]
<b>Coal</b> (43 %)	2308	2	20
<b>Lignite</b> (40 %)	2104	8	19
<b>Gas CC</b> (57.6 %)	969	3	15
<b>Nuclear</b> (PWR, ult. waste dispo.)	445	6	27
<b>PV</b> poly	6708	251	2100
(5 kW) amorph	8153	338	2818
<b>Wind</b> 5.5 m/s	5405	66	54
(1 MW) 4.5 m/s	10659	141	110
<b>Hydro</b> (3.1 MW)	2430	5	10

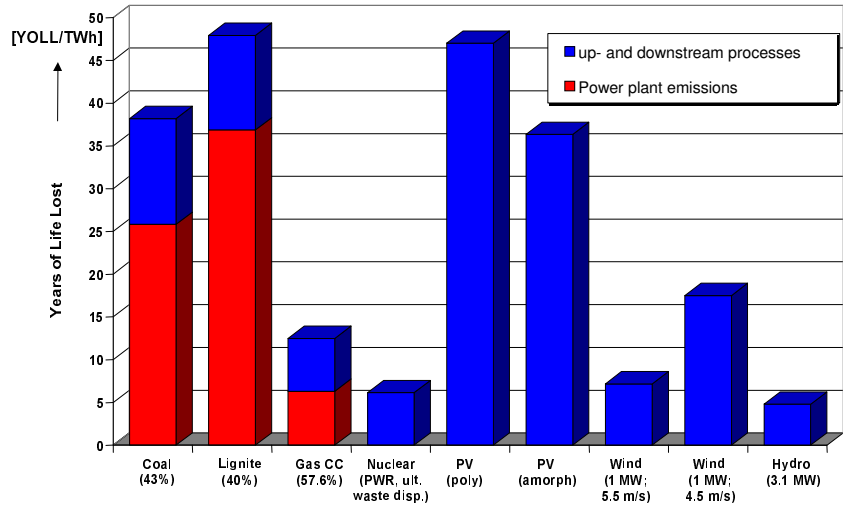
Source: Marheineke 2002

**Life Cycle Emissions**





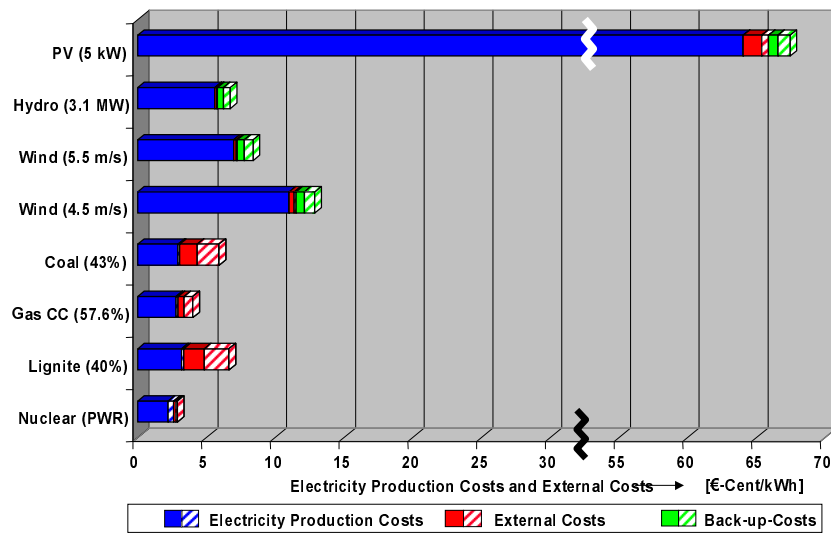
### Health Risks



### External Costs

[€-Cent/kWh]	Coal (43%)	Lignite (40%)	Gas CC (57.6%)	Nuclear (PWR)	PV (5 kW; amorph - poly)	Wind (1 MW; 5.5 - 4.5 m/s)	Hydro (3,1 MW)
<b>Damage Costs<sup>1)</sup></b>							
Health Effects	0,53	0,66	0,17	0,1 - 0,17 <sup>3)</sup>	0,52 - 0,66	0,11 - 0,20	0,07
Agriculture	0,031	0,032	0,015	0,004	0,025 - 0,028	0,004 - 0,008	0,003
Material	0,013	0,015	0,004	0,001	0,010 - 0,014	0,002 - 0,004	0,001
Glob. Warming	0,23	0,257	0,091	0,004	0,050 - 0,072	0,01 - 0,016	0,008
<b>Abatement Costs<sup>2)</sup></b>							
Acid., Eutroph.	0,47	0,55	0,15	0,06	0,42 - 0,56	0,08 - 0,15	0,05
Glob. Warming	1,82	2,04	0,72	0,03	0,40 - 0,57	0,08 - 0,13	0,06
<b>Total</b>	<b>1,27 - 2,87</b>	<b>1,51 - 3,29</b>	<b>0,43 - 1,06</b>	<b>0,17 - 0,27</b>	<b>1,02 - 1,83</b>	<b>0,20 - 0,49</b>	<b>0,13 - 0,19</b>
<sup>1)</sup> Rate of Social Time Preference 3%/a, except radiological risks of nuclear energy (0%/a) <sup>2)</sup> according to standard-price-approach <sup>3)</sup> ultimate waste disposal compared to nuclear fuel reprocessing							

**Costs of Electricity Production and External Costs**



We must consider our planet to be on loan from our children, rather than being a gift from our ancestors. (...) As caretakers of our common future, we have the responsibility to seek scientifically sound policies, nationally as well as internationally. If the long-term viability of humanity is to be ensured, we have no other choice.

Go Harlem Brundtland