Nuclear power - the energy balance

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Note
In this document the references are coded by Q-numbers (e.g. Q6). Each reference has a unique number in this coding system, which is consistently used throughout all publications by the author. In the list at the back of the document the references are sorted by Q-number. The resulting sequence is not necessarily the same order in which the references appear in the text.

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Part A

Nuclear power in its global context

World energy statistics

In 2006 nuclear power provided 14.8% of the world electricity production, according to the statistics of BP 2007 [Q91], see Table A.1. In this study the figures of BP are used, for they give the most recent data. The statistics of IEA 2006 [Q274] give data up to 2004.

Table A.1
World electricity generated in 2006. Source: BP 2007 [Q91].
1 TWh = 1 terawatt-hour = 1 billion kWh = 0.0036 EJ (exajoules). 1 EJ = 10^{18} joule.

source	TWh	EJ	fraction of world electricity %
nuclear	2808.1	10.109	14.8
hydro	3040.4	10.945	16.0
modern renewables *	527.7	1.9000	2.8
fossil-fueled **	12651.6	45.545	66.5
total electricity	19027.7	68.500	100

* The contribution of the modern renewables is an extrapolation of figures from IEA 2006 [Q274]. See text below. This amount is not given by BP 2007 [Q91].
** The remainder of the world electricity is generated by fossil-fuelled power plants.

The main part of the world electricity is produced by fossil-fueled power plants. A small fraction of the total is generated by 'modern renewables': e.g. wind, solar, geothermic power, biomass. BP 2007 does not mention this fraction, IEA 2006 [Q274] cites 2.1% for the year 2004 (the most recent at the time of writing). A contribution of 2.1% in 2004 means a production of 366 TWh (1.32 EJ). Assuming a growth rate of some 20% per annum, the contribution of modern renewables in 2006 might be some 527 TWh (1.90 EJ), or 2.8% of the world electricity production.

The contribution of nuclear power to the world energy supply is usually presented in an ambiguous way, due to statistical manipulations. In addition the total world energy consumption is not accurately known. A significant part of the world energy (some 10%) is consumed in developing countries and is supplied as 'traditional biomass', such as: wood, straw, dung and peat. The amounts of these combustible fuels are not well known and are approximated in the energy statistics or deleted.

Table A.2
Energy mix of the world energy consumption in 2006.
Source: BP 2007 [Q91]. This table omprises commercially traded fuels only and exclude traditional biomass and modern renewables.
MTOE = million (metric) tonnes oil equivalents, 1 MTOE = 0.042 EJ.
Columns 2 and 3 contain data from [Q91]. In column 4 these data are converted by the author into exajoules (EJ). Columns 2-5 represent the energy units actually generated in 2006. Column 6 represents the world energy consumption in primary energy units, as presented by BP in [Q91]. In column 7 these amounts are converted into exajoules by the author. Column 8 gives the contributions of the listed energy sources, as would follow from the figures of BP [Q91].

	Actually generated energy units				Primary energy units (BP)		
1	2	3	4	5	6	7	8
energy source	TWh	MTOE	EJ	fraction (%)	MTOE	EJ	fraction %
nuclear	2808.1		10.109	2.4	635.5	26.69	5.8
hydro	3040.4		10.956	2.6	688.1	28.90	6.3
oil		3889.8	163.37	38.7	3889.8	163.37	35.8
natural gas		2574.9	108.15	25.6	2574.9	108.15	23.7
coal		3090.1	129.78	30.7	3090.1	129.78	28.4
Total world			422.36	100	10 878.4	456.89	100
Sum fossil		9554.8	401.30		9554.8	401.30	

In the authoritative statistical energy reviews, e.g. BP 2007 [Q91] and IEA 2006 [Q274], electricity generated by nuclear power stations is converted into primary energy equivalents (measured in million tonnes oil equivalents MTOE). Primary energy is discussed in detail in Part C2.
BP converts by multiplying the amount of electricity by a factor of 2.6, which is based on an assumed average conversion efficiency of 38% (heat into electricity) of thermal power plants, in effect fossil-fuelled power plants. The same conversion is applied to hydropower, but not to other renewables.
IEA applies another convention: in case of nuclear power a multiplier of 3 is used. In case of hydropower and modern renewables the multiplier equals 1.

The IEA convention implies that 1 J electricity from a nuclear power plant equals 3 primary energy units and that 1 J electricity from a hydropower plant or a wind turbine equals 1 primary energy unit. Electricity is not labeled: 1 J nuclear electricity has exactly the same work potential as 1 J wind-generated electricity. The reason for the inconstistencies in the statistics of BP and IEA is not clear.

According to the BP statistics the nuclear share in 2006 was about 5.8% of the world energy demand (column 8 in Table A.2) and the contribution of hydropower 6.3%. The IEA [Q274] cites for 2004 a contribution by nuclear of 6.5% and by hydro 2.2%. The large difference between nuclear and hydro is attributable to the conversion convention pointed out above. In fact hydro delivered slightly more usable energy units (2803 TWh) than nuclear (2758 TWh).

However, the nuclear contribution to the actually generated energy units, here expressed in the SI unit joule, worldwide is 2.4%, as summarized in columns 4 and 5 of Table A.2. The contribution of hydropower calculated in this way is 2.6%.

BP 2007 [Q91] gives data on commercially traded energy units only. The reason cited by BP is that the amount of the so called traditional fuels (wood, peat, straw, dung) is not accurately known. WEA 2000 [Q79] and World Energy Assessment Update 2004 [Q79a] confirm this uncertainty, but nevertheless these studies give an approximation.

Table A.3
Energy actually made available in 2006 to society and its economic system. Sources: BP 2007 [Q91] and IEA 2006 [Q274].

energy source	electricity TWh	combustibles MTOE	EJ	fraction (%)
nuclear	2808.1		10.109	2.1
hydro	3040.4		10.956	2.3
oil		3889.8	163.37	34.3
natural gas		2574.9	108.15	22.7
coal		3090.1	129.78	27.2
Total traded energy units	5848.5	9554.8	422.36	
traditional biomass *		1243.6	52.23	11.0
modern renewables **	527.7		1.90	0.4
world total	6376.2	10798.4	476.49	100.0

* Approximate, extrapolation from [Q274], assumed growth rate 3%/a.
** Approximate, extrapolation from [Q274], assumed growth rate 20%/a

IEA 2006 [Q274] gives for combustable biomass in 2004 a figure of 10.6% of 11059 MTOE, corresponding with 1172.3 MTOE or 49.23 EJ. Assuming an annual growth rate of 3%, the consumption of combustable biomass in 2006 would be 1243.6 MTOE or 52.23 EJ. If this value is included in the world energy statistics, we get Table A.3. It should be noted that the amount of energy constituted by tradional biomass has a significant uncertainty, first because it is not accurately measurable and second due to the extrapolation here applied. However, the order of magnitude may be correct.

The nuclear energy contribution

The nuclear contribution to the world electricity generation in 2006 amounted to 14.8% (see Table A.1). During the past decade the nuclear share is slowly declining from a high of some 17% in the early 1990s. due to the growth of nuclear capacity lagging behind the growth in the world electricity generation. The historical development of the nuclear contribution is illustrated by Figure A.1.

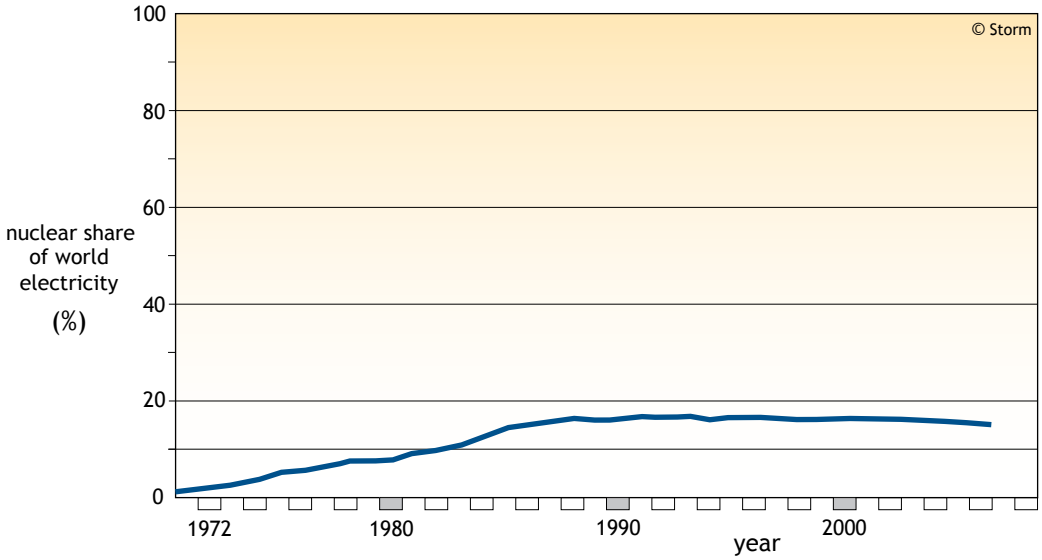
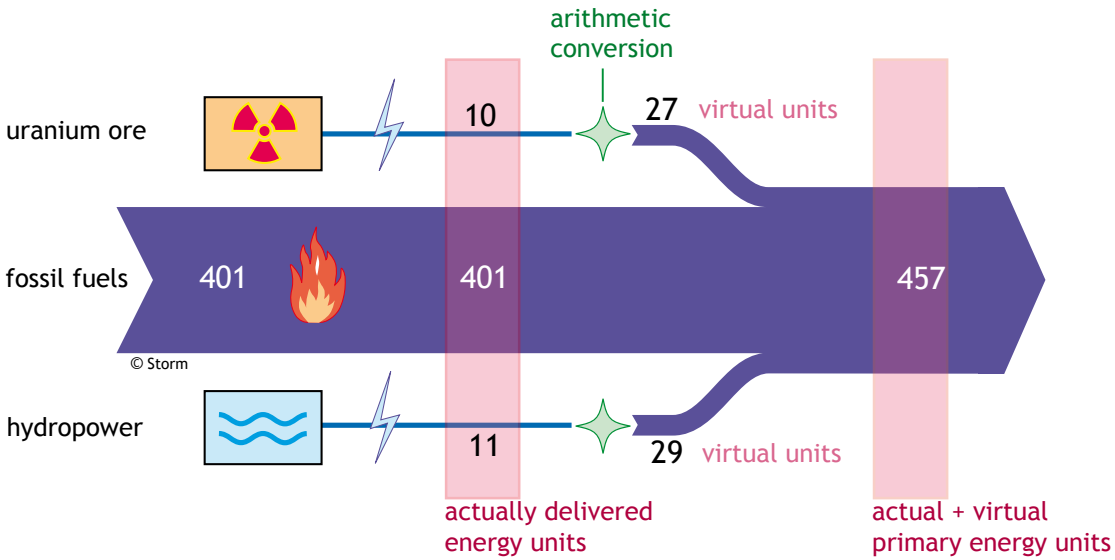


Figure A.1
Nuclear share of the world electricity production.
The nuclear contribution has been stable for about a decade, but now it is slightly declining, because the growth of nuclear capacity is lagging behind the growth in the world electricity consumption.
Sources: Flin 2002 [Q232] and BP Statistical Review of World Energy 2004 - 2007 [Q91].

In the energy statistics of BP Statistical Review of World Energy 2007 [Q91], only commercially traded energy flows are listed.
Electricity from nuclear and hydro are converted into 'primary energy units' (in MTOE: million tonnes oil equivalents) by multiplying the produced electric energy units with a factor 2.6. The resulting figure is the virtual amount of fossil fuel needed to generate the same amount of electricity in a world-averaged fossil fuel power plant. The virtual energy units are added to the actually produced energy units, as present in the traded fossil fuels. This results in Table A.2 column 6.

In Figure A.2 the BP statistical view is illustrated by a diagram. As pointed out above, the IEA uses another convention to present nuclear-generated in the world energy statistics.



World energy 2006, statistical view BP

Figure A.2
World energy production in 2006, a statistical approach from BP 2007 [Q91]. The unit of energy is the exajoule EJ (1 EJ = 10^{18} joule). This diagram comprises only traded energy flows. The electricity produced by nuclear power and hydro power is converted into virtual energy units, called 'primary energy' units. The virtual energy units are added to the actually delivered energy units. The numbers are rounded. Excluded are wind, solar, geothermal power, (modern) biofuels and traditional biomass (wood, peat, dung, etc.).

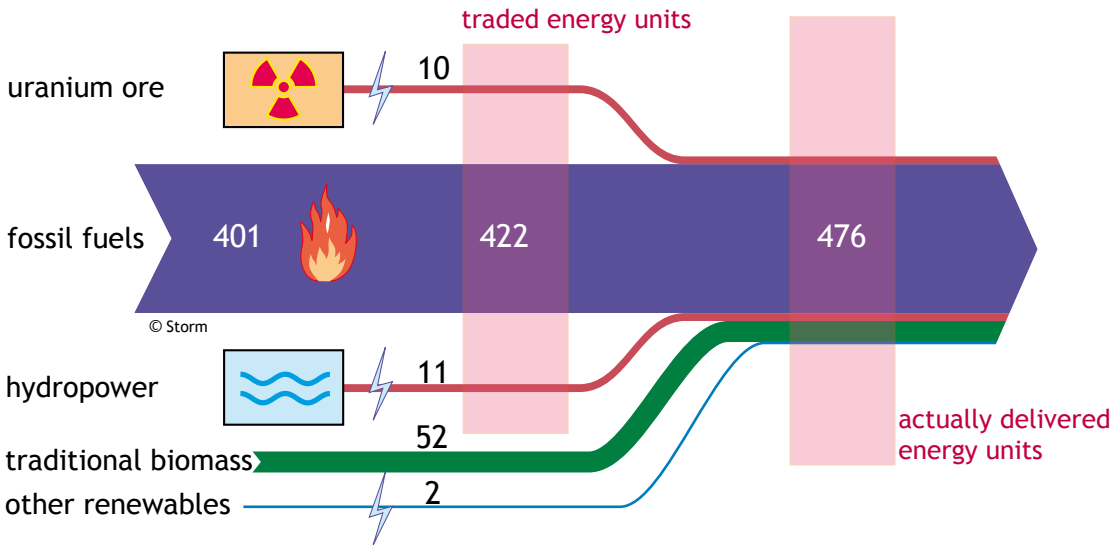
This way of presenting data introduces large and needless ambiguities, due to the fact that the factor 2.6 depends on year, place and implicit assumptions with regard to application and generating technology.
Conversion backwards of all energy quantities into fossil fuel equivalents points to a fossil paradigm.

More serious is the fact that this way of manipulating energy data conflicts with the First Law of Thermodynamics: energy cannot be produced, nor destroyed. Energy can only be converted from one kind to another. A simple example will explain this. The 27 virtual energy units from nuclear cannot be reconverted into electricity via fuel cells (efficiency 60%), producing 16 units electricity. In this way 6 units (16 – 10) electricity would be created out of nothing, in conflict with the First Law.
One joule of electricity, from whatever source, can be converted into exactly 1 joule of heat, not a fraction more.

In the above presentator of world energy flows with rounded numbers the nuclear contribution seems to be 27/457 = 5.9% in 2006, the actual value being 5.8% (see Table A.2). This figure is cited by the nuclear industry.

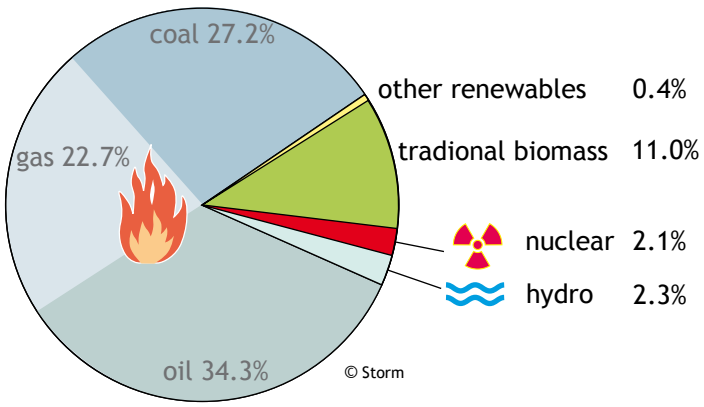
The physical flows of usable energy actually made available to society are listed in Table A.3 and illustrated by Figure A.3. In addition to the traded energy flows of Figure A.2 estimates of the traditional biomass and 'modern' renewables are included. None of the energy flows are converted into virtual energy units.

Based on this picture, the nuclear share of the total world energy supply equals 10/476 = 2.1%.



World energy 2006, physical flows (EJ)

Figure A.3
Actually delivered usable energy (in exajoules) to the world economy in 2006. This diagram is based on Table A.3. The numbers are rounded. Source of traded energy figures: BP 2007 [Q91]. The figure of 52 EJ of traditional biomass is not accurately known and is an estimate by extrapolation of figures in IEA 2006 [Q274], as is the figure 2 EJ of other renewables: solar, wind, small hydro geothermal and 'modern' biomass.



world energy consumption in 2006: ~476 EJ
traded energy: 422 EJ

Figure A.4
World energy generation in 2006. Data from Table A.3.

Nuclear contribution to the CO_2 mitigation

In Figure A.3 all energy units are considered equivalent and no assumptions are made regarding end use. Actually 2.1 usable energy units out of 100 delivered to society are generated by nuclear power.

To approximate the upper limit of the nuclear contribution to the mitigation of CO_2 emissions, we suppose that 1 unit of fossil fuel or biomass produces, on the average, 1 unit CO_2. Assuming nuclear power is carbon free (which it is not), the total carbon emission is 2.1 units less due to nuclear power. So the nuclear contribution to the CO_2 mitigation would be no more than 2.1%. In fact the current contribution is certainly less than 2.1%, for nuclear power is not carbon-free.

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