Federal Ministry for the
Environment, Nature Conservation
and Nuclear Safety

"Lead Study 2007"

Update and reassessment of the "Strategy to increase the use of renewable energies" up until the years 2020 and 2030, plus an outlook to 2050.

Summary

Study commissioned by the
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)

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1. General characteristics of the Lead Scenario

This Lead Study 2007 outlines the **LEAD SCENARIO 2006** formulated during the course of 2006. This is a targeted scenario outlining how the German Government's target of cutting Germany's emissions of climate gases to around 20 % of 1990 levels by 2050 can be achieved in principle. Interim targets aside, it is vital that this long-term target is met (throughout all industrialised countries) if we are to prevent levels of CO_2 concentration in the atmosphere from exceeding the critical level of approx. 450 ppm (corresponding to an average global temperature increase of less than 2°C compared with the period 1980-99). This target is to be met without the use of nuclear power. Earlier studies commissioned by the BMU and the German Environmental Agency (UBA)[1] provided the groundwork for this Lead Scenario.

The reference forecast formulated by the energy industry in Energy Report IV has been used as a basis for reference and comparison purposes. This scenario has been updated to 2050 and is referred to in this document as **REF 2005**. The key demographic and economic data from Energy Report IV used for REF 2005 and LEAD SCENARIO 2006 have only been modified in respect of traffic volume development, drawn from a number of UBA studies in 2006.

The coordinated sub-strategies "Increased utilisation efficiency in all sectors", "Increased conversion efficiency via the significant expansion of cogeneration (CHP) and more efficient power plants" and "Start of the widespread use of renewable energies" were identified as the principal structural elements and implemented with due regard for mutual interactions. We were able to conclude that the conversion of energy supply will occur in several stages, each of which with its own characteristic features and time scales.

The period between now and 2010 will determine whether we are in time to utilise the "window" of opportunity for a promising approach to a sustainable energy supply. During the second phase from 2010 to around 2020, even under favourable framework conditions, it was found that with most of the technologies for the use of renewables, the expansion process will still need to be accompanied by suitable environmental and energy policy instruments. This period will determine whether the stimulated momentum for the expansion of renewables can be sustained in the longer term and lead to self-supporting markets, and whether suitable export markets needed for the further expansion of renewables have been successfully established. Only then will subsequent expansion after 2020 offer prospects of success in accordance with the development outlined in the scenarios.

2. Key data of the Lead scenario

Under the LEAD SCENARIO 2006, by 2020 renewables will contribute 27.3 % to gross electricity generation, and 15.7 % to total primary energy consumption. By 2030, this figure will increase to 25 % of primary energy consumption, rising to just under 50 % of primary energy consumption by 2050 (cf. **Table 1**). By this date, renewables will cover 80 % of electricity consumption, 48 % of heating consumption and 42 % of fuel consumption.

The LEAD SCENARIO 2006 outlines the minimum expansion of renewables needed in the medium term (2015 to 2020) in order to sustain the current expansion momentum. Following a decline in investments in renewable energy plants from currently 10 billion €/a to 8 billion €/a by around 2011, investment levels will then pick up again, rising to 13 billion €/a by 2020 and to 20 billion €/a by 2050. Under the LEAD SCENARIO 2006, the year 2020 will be characterised by significant growth gradients (and is therefore only an interim stage within

[1] For sources refer to the full-length version of this report

the context of a long-term strategy). By this date – with a few exceptions – we can assume that the markets for renewables are well-established and operating at full efficiency. By approximately 2020, the electricity generated from renewables will increase at an annual rate of around 9 – 10 TWh/a or 1.5 percentage points, while the contribution of renewables to primary energy coverage will increase at an annual rate of around 75 – 80 PJ/a or 0.8 percentage points.

Table 1: Key findings of the LEAD SCENARIO 2006, highlighting the contributions of renewable energies

	2000	2005	2010	2020	2030	2040	2050
Primary energy, PJ/a	14402	14238	13492	11903	10425	9057	7899
Primary energy from renewables, PJ/a*)	382	665	1134	1874	2614	3300	3829
Renewables as a share of primary energy consumption; %	2.7	4.7	8.4	15.7	25.1	36.4	48.5
Final energy, PJ/a	9234	9118	8735	7968	7299	6567	5773
Final energy from renewables, PJ/a	346	601	850	1439	2072	2686	3156
Renewables as a share of final energy consumption; %	3.8	6.6	9.7	18.1	28.4	40.9	54.7
Electricity final energy, PJ/a	1779	1829	1799	1746	1699	1629	1573
Electricity final energy from renewables, PJ/a	132	229	299	512	795	1087	1250
Share from renewables, %	7.4	12.5	16.6	29.3	46.8	66.7	79.4
Heat final energy, PJ/a**)	4663	4643	4412	3854	3395	2918	2482
Heat final energy from renewables, PJ/a	205	291	381	537	769	1001	1182
Share from renewables, %	4.4	6.3	8.6	13.9	22.6	34.3	47.6
Fuel final energy, PJ/a***)	2792	2646	2524	2368	2205	2020	1718
Fuel from renewables, PJ/a	9	81	170	390	508	598	724
Share from renewables, %	0.3	3.2	6.9	16.8	23.5	30.1	42.2
Gross electricity generation, TWh/a	571	612	595	570	551	546	564
Generation from renewables, TWh/a	36.7	63.5	92	156	249	352	434
Share from renewables, %	6.0	10.4	15.5	27.3	45.2	64.5	77.0
Primary energy, PJ/a	14402	14238	13492	11903	10425	9057	7899
Renewable energy sources	382	665	1134	1874	2614	3300	3829
Mineral oil	5497	5128	4721	3966	3373	2717	2011
Hard coal, other,	2060	1832	1631	1366	940	537	257
Lignite	1550	1595	1466	1221	764	278	46
Natural gas, petroleum gas, pit gas	3063	3240	3176	3138	2734	2225	1756
Nuclear power	1850	1778	1364	338	0	0	0
Fossil fuels, total	12169	11795	10994	9691	7811	5757	4070
Energy productivity (1990 = 100)	126	129	151	199	258	326	402
Energy-related CO_2 emissions, million t/a	840	816	748	639	486	324	201
CO_2 emissions avoided by renewables, million t/a****)	43	86	117	181	253	324	370

*) Primary energy according to the efficiency method; **) Fuels only, i.e. excluding electricity used for heat provision, ***) Final energy from traffic less electricity used for mobile purposes, including mineral oil for stationary power generation ****) For electricity, we have only assumed the displacement of fossil fuel plants (emission factors declining from 0.922 kg CO_2/kWh_{el} in 2005 to 0.750 kg CO_2/kWh_{el} in 2020 and 0.560 kg CO_2/kWh_{el} in 2050).

By 2020 at the latest, the more efficient use of energy and the expansion of cogeneration plants must also start to show significant signs of success if we are to achieve the set climate protection target for 2050 with maximum economic efficiency, i.e. with an optimum "division of labour" between efficiency strategies and renewable energy strategies. The LEAD SCENARIO 2006 complies with the Coalition Agreement requirement of doubling energy productivity by 2020 compared with 1990 levels. To this end, energy productivity will increase by an average of 2.9 % per annum between 2005 and 2020, compared with an average increase of just 1.6 % p.a. between 1990 and 2005. According to the LEAD SCENARIO 2006, after 2020, energy productivity will continue to rise but more slowly, reaching quadruple the 1990 level by 2050. The importance of giving equal weighting to both the "efficiency pillar" and the "renewable energies pillar" is indicated by their contributions to reducing CO_2 emissions: 47 % of the additional 177 million tonnes of CO_2/a avoided between 2005 and 2020 is attributable to increased energy efficiency, while the remaining 53 % is attributable to the continued expansion of renewables. Together with the 86 million already avoided in 2005, in the year 2020 renewables will help to cut CO_2 emissions by a total of 181 million tonnes of CO_2/a.

Comparing the LEAD SCENARIO 2006 with reference developments in recent years (the Energy Report IV and the "oil price variant" based on the latter, as well as the scenario formulated by the Enquete Commission in 2002) reveals growing similarities between the reference forecasts and the LEAD SCENARIO 2006 in terms of their key parameters (cf. **Figure 1**). Since the latter, as a targeted scenario, outlines the restructuring and other measures needed in order to meet the German Government's long-term climate protection target, it is also a suitable tool for measuring recent "progress" in energy and environmental policy. Provided the energy policy targets agreed in the Coalition Agreement are implemented in a timely fashion, the differences between associated "reference developments" and key data in the LEAD SCENARIO 2006 will diminish further.

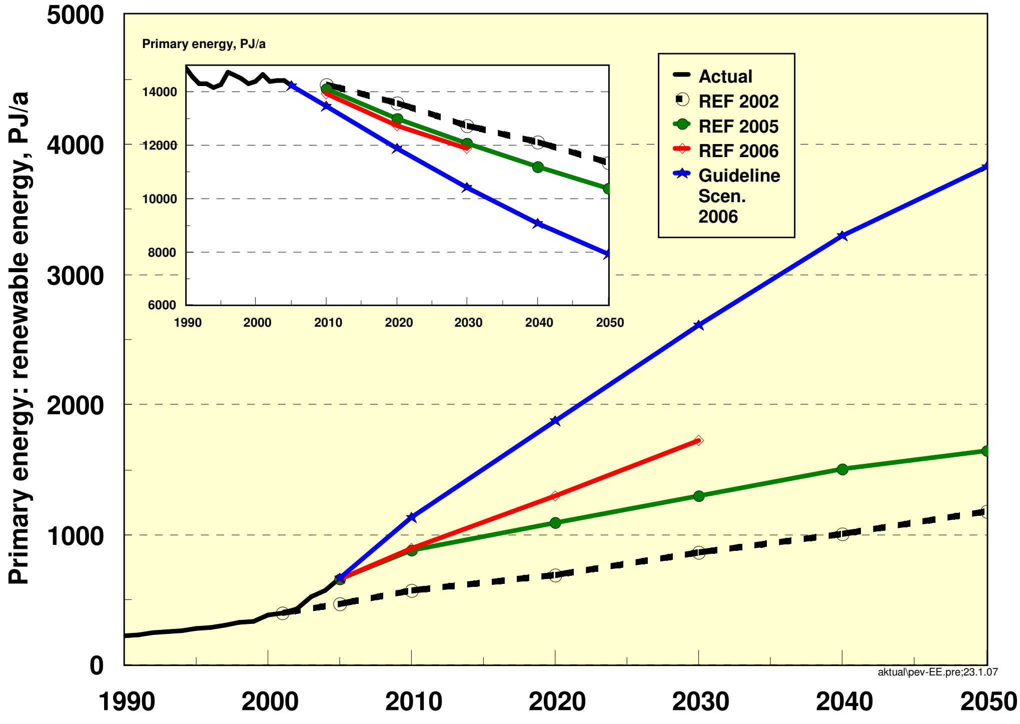

Figure 1: Development in primary energy consumption (small chart) and the contribution of renewable energies to primary energy consumption in reference developments for the years 2002 (Enquete Commission), 2005 (Energy Report IV) and 2006 (oil price variant) and in the LEAD SCENARIO 2006.

3. Structure of electricity generation up to 2020

The interim target for 2020 (which is highly relevant to the electricity sector) was analysed in considerable depth. Under the terms of the Renewable Energy Sources Act – i.e. sustaining the growth momentum that has arisen since approximately 2000 – renewables could well account for 27.3 % of electricity generation by 2020, and are therefore very likely to exceed the original target of "at least 20 %". This is no guarantee that the set climate protection targets will be met. In view of the imminent renewal of Germany's power plant portfolio, incorporating the agreement to phase out nuclear power by 2020 as well as the replacement of up to 40 GW of outmoded fossil fuel plants, we analysed how this window of opportunity could be utilised in a targeted way in order to pursue a strategy of effectively integrating renewables into electricity supply and expanding the use of cogeneration (cf. **Table 2**). As well as a total of 56 GW output from newly build renewable plants (since 2001), the LEAD SCENARIO 2006 also envisages that a further 42 GW of new fossil fuel plant output could be built by the year 2020. However, under the climate protection path outlined by the LEAD SCENARIO 2006, only 16 GW of this output may be from coal-fired power plants, while 13.5 GW should take the form of combined heat and power generation (CHP), including 4.1 GW in the form of district heating power stations. Together with biomass and biogas plants, which likewise generally take the form of district heating power plants, a total of 10.5 GW of decentralised output will need to be constructed between 2000 and 2020. By the year 2020, cogeneration will account for 19 % of electricity generation (or 110 TWh/a).

Table 2: Structure of new power plant construction from 2001 as required under the LEAD SCENARIO 2006 (cumulative outputs)

Output in GW	2010	2015	2020	2025	2030
Hard coal and lignite, waste, condensation power plants and cogeneration plants	6.5	13.3	15.6	18.4	21.1
Gas, condensation power plants and cogeneration plants	4.2	13.2	22.7	29.0	31.2
Large fossil fuel plants, total	**10.7**	**26.5**	**38.3**	**47.4**	**52.3**
- of which as cogeneration pants	2.6	6.6	9.4	13.3	15.7
- of which as cogeneration plants, coal	1.3	4.3	5.7	7.3	8.4
Decentralised district heating power plants*, fossil	**1.8**	**3.0**	**4.1**	**5.3**	**6.4**
Renewable energy sources	**32.2**	**43.4**	**56.0**	**68.3**	**80.6**
- of which wind power	22.9	29.8	37.3	44.1	51.0
-- of which offshore wind power	0.55	4.25	10.0	15.6	23.0
- of which biomass including biogas	3.9	5.1	6.4	7.1	8.0
- of which photovoltaics	4.7	7.4	10.0	11.8	13.7
Total new output construction	**44.7**	**72.9**	**98.4**	**121.0**	**139.3**

* District heating power plants with < 10 MW_{el}

4. Assumptions regarding the future development of energy prices

The development of future energy prices and climate protection measures (CO_2 certificate prices) will significantly affect the additional costs associated with increasing the use of renewables under the LEAD SCENARIO 2006. Rapid price increases may allow renewable energy technologies to reach cost-effectiveness earlier, leading in turn to larger market shares. A significant portion of the efficiency potential may be implemented in a way which helps to cut costs and keep prices low. The price increase on which the "oil price variant" (EWI/Prognos 2006; referred to here as REF 2006) is based suggests that if energy prices were to rise more sharply, further efficiency success is anticipated, i.e. a lower overall primary energy demand and a higher proportion of renewables than in the reference forecast of Energy Report IV (cf. also Figure 1). The economic assessment used in the LEAD SCENARIO 2006 is therefore based on current energy price increases for conventional energy resources and recent findings on potential short- to medium-term changes in energy prices. In addition to the original price path outlined in the reference forecast in [EWI/Prognos 2005], referred to here as the "low level" (price path A) (32 $\$_{2000}$/bbl in 2020), we also consider two further price paths – price path B: "moderate increase" (60 $\$_{2000}$/bbl in 2020) and price path C: "significant increase" (75 $\$_{2000}$/bbl in 2020) – for analysis purposes, thereby ensuring that the cost sensitivity of the LEAD SCENARIO 2006 covers an adequate bandwidth. The CO_2 certificate prices assumed for the year 2020 vary between 10 €/t CO_2 (price path A) and 20 €/t CO_2 (price path C). Using the price of crude oil as an example, Figure 2 compares these price paths with the historical development of this key indicator. The author anticipates that future oil prices will be somewhere between the corridor of price paths B and C.

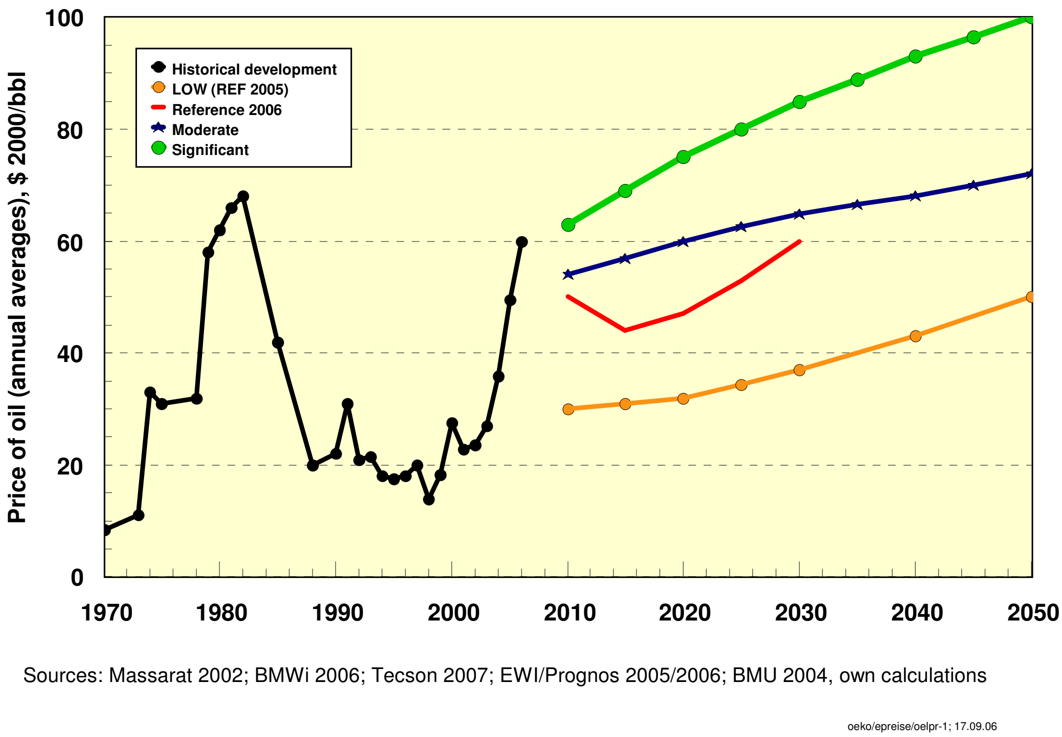

Figure 2: Comparison of the three energy price paths as illustrated by the real price of oil ($\$_{2000}$/bbl), including the oil price variant (REF 2006) according to EWI/Prognos 2006.

5. Future cost of renewable energies

Increasing the use of renewable energies under the LEAD SCENARIO 2006 leads to further cost cuts among the affected technologies, particularly those which are still in the early stages of their market launch as far as the energy industry is concerned (cf. Figure 3). Photovoltaic power, offshore wind power and geothermal energy all indicate further significant cost degressions. In the case of the geothermal energy, as with CHP technologies for the utilisation of biomass, the cost of electricity generation is additionally influenced by rising heat credits. In the case of biomass, importance is also attached to the development of fuel costs, which are generally likely to exhibit a rising trend.

For all technologies, electricity generation costs will stabilise at between 4 and 6 ct/kWh$_{el}$ in the longer term, with the exception of photovoltaic power, which will be in the region of 10 ct/kWh$_{el}$ in Central European latitudes. The mean cost for new plants under the LEAD SCENARIO 2006 was 10 ct/kWh$_{el}$ in 2005 (the figure excluding photovoltaics is 8.1 ct/kWh$_{el}$). In the short term (until approximately 2010), cost levels will indicate a rising trend, due to the significant growth in photovoltaics and biogas plants as well as the forthcoming construction of offshore wind farms. Between 2010 and 2030 it will then decrease continuously to 6 ct/kWh$_{el}$, falling further to 5.4 ct/kWh$_{el}$ by 2050. In this respect, it is crucial that cost levels will remain stable and calculable in the long term, as they are only influenced by technological developments and associated investments, but not by the growing scarcity of resources or critical geopolitical developments. There will be no sudden, unpredictable price increases, such as those which typically occur with a raw materials-based energy supply in the event of shortages.

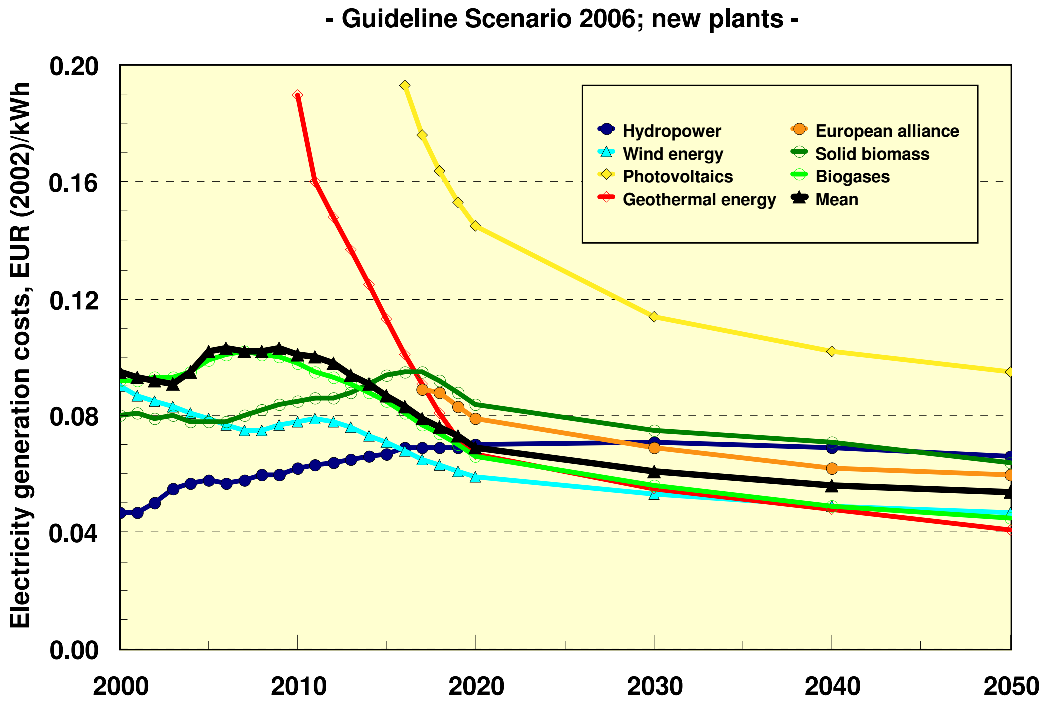

Figure 3: Future development of the cost of technologies to produce electricity from renewables until 2050 and mean of the overall renewable energies mix under the LEAD SCENARIO 2006 (equivalent value 2002; real interest rate 6 % p.a.; mean figures are given for several individual technologies)

We should not underestimate the importance of this factor for the successful development of economies, particularly those which are still in the development phase, such as newly industrialising and developing countries. From an energy policy viewpoint, it is also important to note that the majority of cost cuts will have been implemented by around 2020 (mean cost will then be 6.9 ct/kWh$_{el}$, excluding photovoltaics 6.4 ct/kWh$_{el}$). This will also be the approximate date after which additional support of renewables will no longer be necessary.

Figure 4 shows the development of the cost of heat generation alone (i.e. excluding CHP heat) from renewables. Heat from collectors, which remains expensive at present, could become far more cost-effective in future if greater market opportunities are given to large plants in particular, in conjunction with district heating networks and seasonal accumulators.

Geothermal energy, particularly hydrothermal plants, likewise has the potential to become even more cost-effective, while biomass heating systems offer little remaining potential for cost cuts. On-going technological progress will be largely balanced out by rising fuel costs. Heating plants including network distribution are rather more cost-effective than individual heaters. The long-term cost of heat from renewables will be in the magnitude of 7 to 9 ct/kWh$_{th}$.

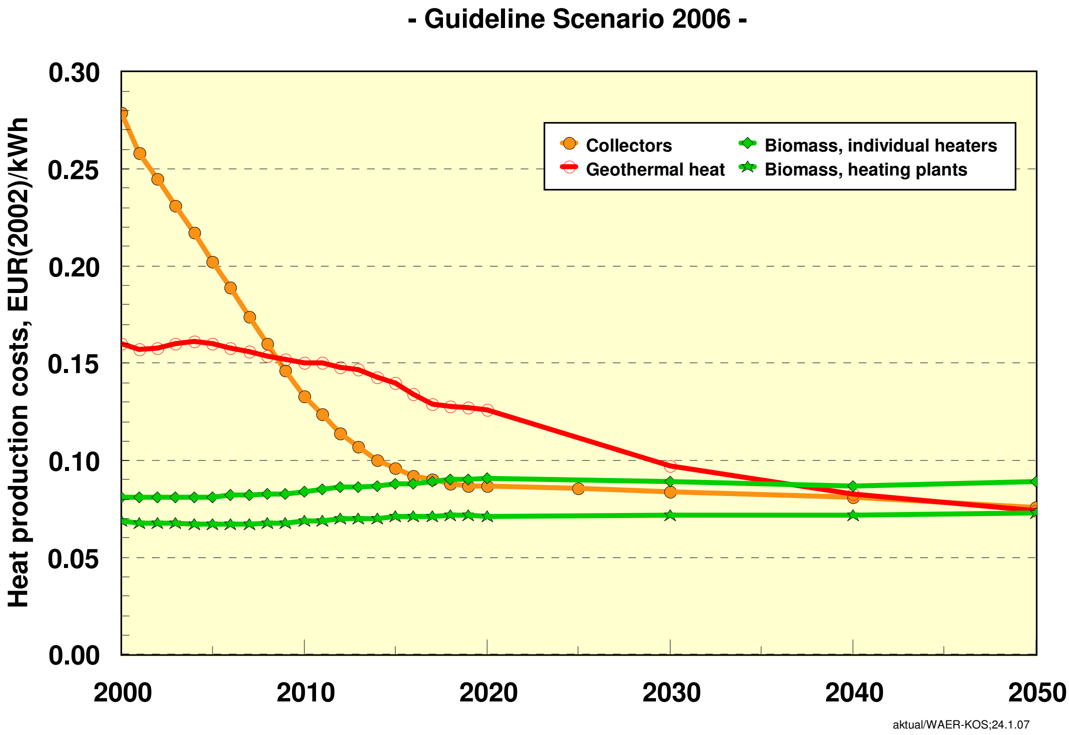

Figure 4: Future cost development of collectors, geothermal heat, individual biomass heaters and biomass heating plants (in each case, mean figures are given for several individual technologies).

6. Electricity production costs under the LEAD SCENARIO 2006

While the cost development of renewables is only dependent on technological parameters and the assumed learning curves (and assumed marked volumes), the future costs of electricity from fossil fuel plants will be determined to a large extent by fuel price developments and the intensity of climate policy (CO_2 prices). The total cost of electricity under the LEAD SCENARIO 2006 will therefore also depend on the price paths presented in section 3. **Figure 5** shows the future development of electricity costs for price path C. The medium voltage level is used here as a reference basis, since some of the power plants (decentralised CHP, some renewables) feed into this level. Given the on-going construction of new renewable plant output, the average electricity generation costs are initially higher than those of electricity production from fossil fuels only.

The maximum difference is 0.7 ct/kWh$_{el}$ and will occur in around the year 2010, after which time it will decline continuously. After 2025, the renewables mix assumed in the LEAD SCENARIO 2006 will become more cost efficient than the generation of electricity from fossil fuels (disregarding the construction of new photovoltaic plants, this date is brought forward to around 2020). While the cost of the latter will continue to rise steadily, the further expansion of renewables will effect a stabilisation in electricity costs at the medium voltage level at around 7.4 ct/kWh$_{el}$, with a trend towards further reduction in the longer term. At the same time, an increasingly climate-friendly and reliable electricity supply will emerge. The example shown in Figure 5 illustrates the fact that energy scenarios must consider development over at least three decades, and that this must be maintained via suitable energy policy framework conditions and protected throughout several legislative periods, in order for the full benefit of the combined efficiency and renewables strategy to be accurately assessed.

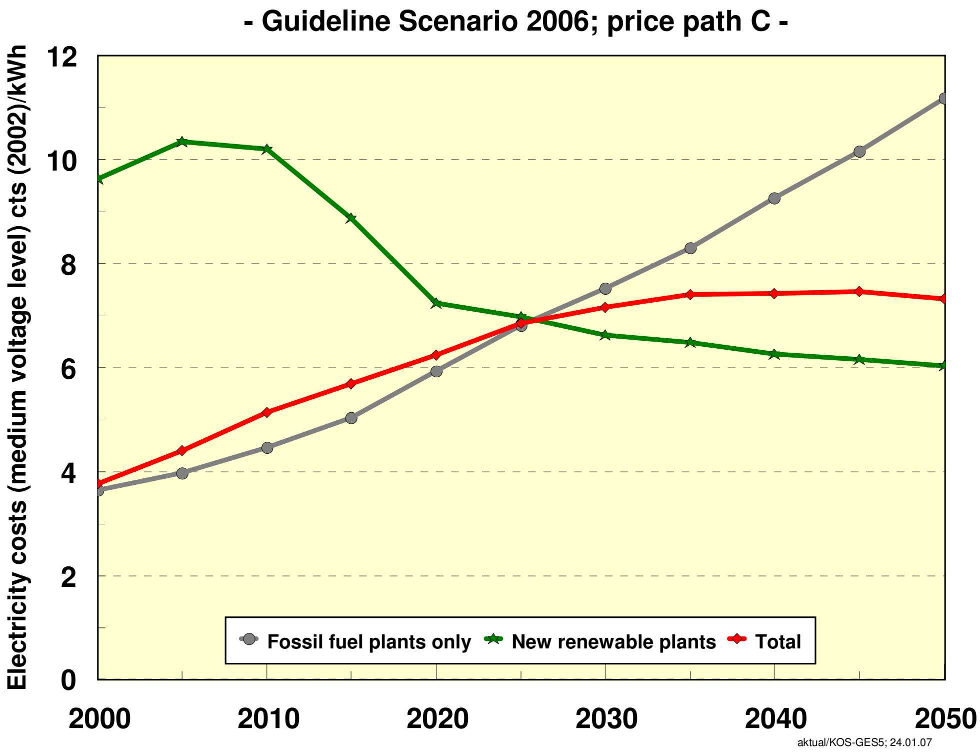

Figure 5: Average electricity production costs under the LEAD SCENARIO 2006 (price path C) at the medium voltage level versus the average costs of the new renewable plants mix and the remaining fossil fuel plants mix (OLD + NEW).

Although we can generally assume that energy and CO_2 prices will rise in future, the level of this price increase is uncertain and in some cases controversial. The fundamental assertion that an electricity supply based on renewables will be economically advantageous in the longer term remains valid if price paths B and A are used for analysis. However, the dates on which the power plant mix of the LEAD SCENARIO 2006 becomes more cost-effective than power supply from fossil fuels alone will vary according to the price path chosen. For price path B, the intersection point will occur in around 2030; at 0.71 ct/kWh$_{el}$, the maximum difference is slightly higher in 2015 than for price path C, while the long-term electricity price level is 7.0 ct/kWh$_{el}$. Even in the very unlikely case of energy price levels remaining more or less constant (price path A), the intersection point will only occur one decade later than in the upper price path C, with a maximum difference in total costs to the fossil mix of 0.75 ct/kWh$_{el}$. Hence, even if one were to assume lower energy (and CO_2) prices, this does not alter the need for a fundamental restructuring of the energy supply in accordance with the LEAD SCENARIO 2006; however, given the long time scale before economic benefits are felt, this would make implementation of the restructuring process more difficult from a political and social viewpoint.

7. Differential costs of increasing the use of renewable energies

In 2006, the differential costs of renewable energies in the electricity sector[2] totalled 3 billion €/a (cf. **Figure 6**; black curve). Wind power dominates with around 1.7 bn €/a. Its differential costs have already peaked and are set to fall in future, passing the zero line in around 2020. Including the expansion of offshore wind power, by 2020 windpower will provide around 85 TWh/a of electricity – three times the current amount – at average costs of 6 ct/kWh$_{el}$ (high voltage level). The differential costs of electricity generated from biomass, currently around 0.5 bn €/a, will peak in around 2017 at approximately 0.8 bn €/a. These costs will only be reduced slowly, as rising biomass prices will offset the technological cost reductions. In the overall balance sheet, hydropower has rising "negative" differential costs, as the expense of modernising existing plants and constructing new ones will be minimal compared with the benefits obtained from existing hydropower. The differential costs of electricity generated from geothermal energy are minimal and will remain below 0.15 bn €/a. The differential costs of importing electricity generated from renewables in other European countries (occurring after 2015 according to the current scenario) are very low, at a maximum of 0.05 bn €/a.

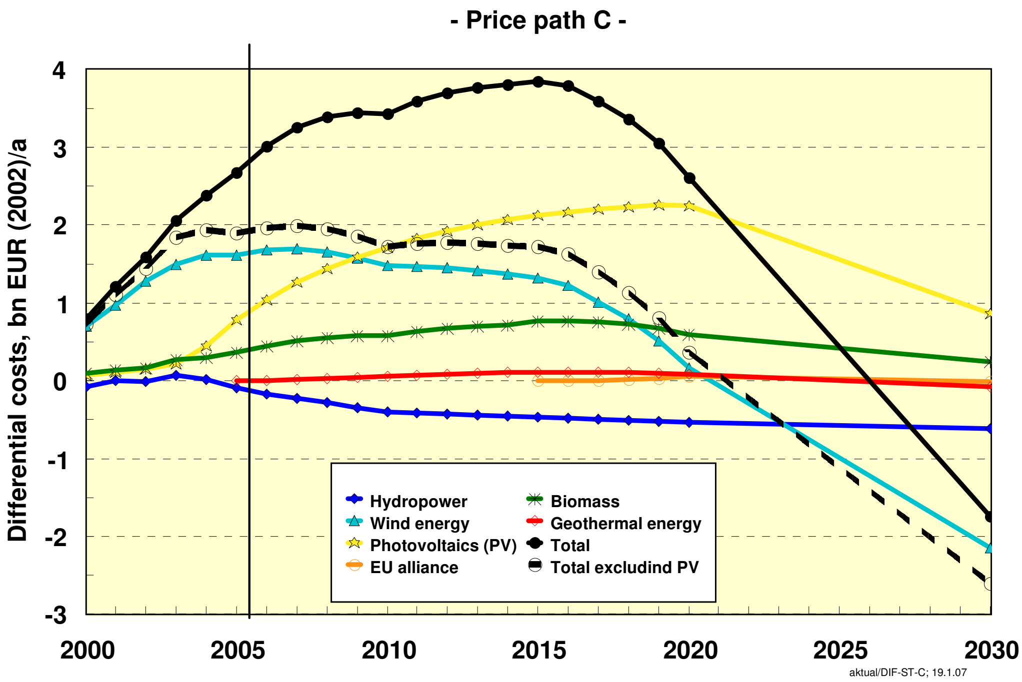

Figure 6: Differential costs of increasing the use of renewable energies in the electricity sector (on a cost basis, equivalent value 2002; price path C) for selected energy technologies and overall development with and without photovoltaics.

In total, the differential costs of electricity from renewables, disregarding photovoltaics, under energy price path C (dotted black line in Figure 6) will not rise above 2 bn €/a (corresponding to a maximum charge of 0.4 ct/kWh). These costs will become negative as early as 2021. From this date onwards, these renewable technologies will effect a stabilisation in electricity generation costs and will contribute 165 TWh/a to electricity generation.

[2] The differential costs of renewables have been calculated on a cost basis and incorporate all plants that utilise renewables. This is therefore different from the differential costs calculated on the basis of fees under the Renewable Energy Sources Act (EEG).

The differential costs of photovoltaics are highly significant. Recent strong growth in this sector has already led to differential costs of approx. 1 bn €/a in 2006. In our assumed expansion scenario (cumulative output rising to 10 GW_p by 2020, 6 times the current level), further cost degressions will limit these costs to 2.2 bn €/a. From 2010, the differential costs of photovoltaics will exceed those of all other renewable technologies. Subject to further expansion, they will then drop to below 1 bn €/a by 2030. PV electricity, like all other decentralised renewable energy technologies, is compared with conventional electricity at the medium voltage level, which in price path C is valued at 7.2 ct/kWh in 2020. By the year 2015, the sum total of differential costs including photovoltaics will peak at 3.8 bn €/a (corresponding to a charge of 0.8 ct/kWh), after which they will rapidly descend towards zero, which they will reach in 2026.

If we assume that energy and CO_2 prices will increase less sharply in future, the date at which electricity from renewables is expected to develop its full macroeconomic potential will change, as will (to a lesser extent) the overall level of differential costs. In an extreme case, with energy prices roughly constant in real terms and comparatively low prices for CO_2 certificates (price path A), the differential costs in the electricity sector would only rise to approximately 4.6 bn €/a (or excluding PV, to 2.4 bn €/a), but would not cross the zero line until after 2040.

From a macroeconomic viewpoint, however, the low price path A also lends itself to comparison with the ideal case whereby the external costs of electricity generation from fossil fuels are largely included. If we take the mean of 70 €/t CO_2 proposed in [Krewitt 2006] as a representative indicator for calculating the actual costs of generating electricity from fossil fuel, the applicable electricity price is approximately 10 ct/kWh_{el}. Compared with these "full costs" of producing electricity from fossil fuels, renewable electricity generation already "produces" "negative" differential costs of 1 bn €/a, or avoids consequential damage costs to an equivalent amount. These "avoided" costs will rise to 4 bn €/a by 2020. This result impressively confirms the macroeconomic benefits of a rapid and long-lasting increase in the use of renewable energies.

The differential costs for the provision of heat from renewables currently total 1.1 bn €/a (**Figure 7**). In relation to the total quantity of final energy for heat, this is the equivalent of just 0.085 ct/kWh_{th}. Adding these "additional costs", which are currently produced primarily by the market incentive programme, onto heating prices would therefore go virtually unnoticed. In future, the falling differential costs of biomass will largely compensate for the continuing rise in the differential costs of collectors and geothermal heat, so that the total differential costs will remain constant for the time being, and will then fall significantly after 2015 if price path C is taken as the basis for comparison. After 2022, overall differential costs will pass the zero line, while the differential costs of collectors and geothermal heat will not approach zero until around 2030. Up until this date, the contribution of renewables to heat supply will have risen approximately 2.6 times compared with current levels, and will then cover around 23 % of the total heating demand.

The resultant differential costs in the fuel sector are likewise comparatively low. For 2005, they total 0.7 bn €/a by comparing biofuels with fuel prices carriage paid to the petrol station but excluding taxes (Figure 7). The current rapid growth in this area will lead to a maximum increase to 2 bn €/a by 2015, after which time these differential costs will descend steadily towards zero. Overall, the differential costs of all consumption sectors currently total 4.5 bn €/a. In a comparison with price path C, they will rise to a maximum of 6.75 bn €/a by 2015, primarily as a result of the current strong growth in photovoltaics and biofuels.

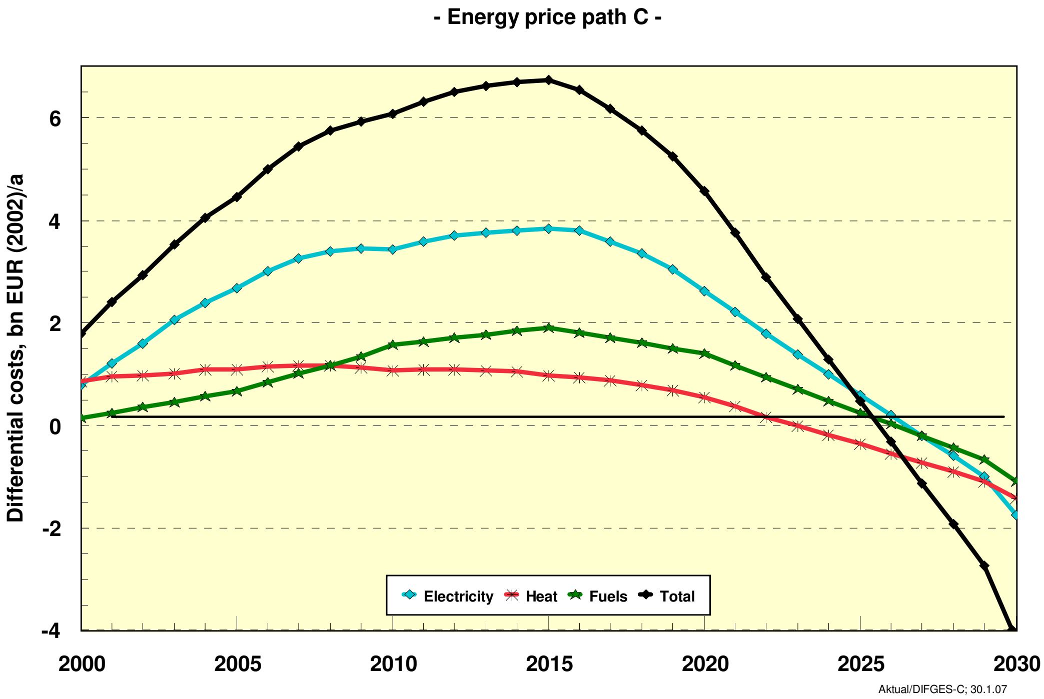

Figure 7: Differential costs of increasing the use of renewable energies in all sectors with price increases for fossil energies corresponding to price path C.

Under price path C, differential costs will be eliminated from around 2025. By that date, renewable energies will cover 23 % of total final energy consumption, thereby avoiding 220 million tonnes of CO_2/a. The negative differential costs which then come into play mean that after this date, renewables will stabilise the energy price level, which would otherwise continue to rise steadily according to the price path assumptions without renewables.

The cumulative figures for differential costs allow us to quantify the cost damping effects of the expansion of renewables after 2025. By 2025, differential costs will rise to around 117 bn €. As early as shortly prior to 2040, the additional funds devoted to the expansion of renewables – measured in terms of the applicable prices under price path C – would be offset by the "negative" differential costs incurred. By 2040, spending will already be 21 bn € lower compared with an energy supply based on fossil fuels. By 2050, this "saving" will have increased to around 330 bn €.

The results indicate that any assessment of the benefits of a significant expansion in renewable energies depends to a large extent on the estimated future price effects of a shortage of fossil resources plus effective climate protection measures. Pinning one's hopes on continuing low energy prices, as currently exemplified by a number of key energy industry studies and as symbolised here by energy price path A, could have fatal consequences for the much-needed (from a climate protection viewpoint) substantial increase in the use of renewable energies. By contrast, an expectation of significant energy price increases coupled with effective monetary effects from climate protection policy, as expressed in price path C and also, in a diluted form, in price path B, are adequate responses to the evident problems associated with our current energy supply.