Perspectives of Renewable Energies

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1 Present structure of global electricity production and demand

The present contribution of renewable energies (RES) to the global energy supply makes up 18 % (Table 1) concentrating on the use of hydro power and biomass. The relatively high share of biomass, however, is mainly caused by the non-sustainable use of fire wood in the poorer developing countries (non-commercial energy) and is thus no basis for a sustainable application of biomass. Only one tenth of the present biomass share can be regarded as ecologically tolerable, including energetical exploitation of residual wood and organic waste (mostly in the industrialised countries) as well as generation of biogas from keeping livestock and from food production. Considering this fact, the value to be taken as a basis for a sustainable growth of RES is about a **5 %** share in the present global final energy consumption[1]. The real "modern" technologies for using energy from solar irradiation and wind as well as geothermal heat, however, only contribute with a mere 0.4 % to the coverage of the present world-wide final energy demand.

This fact especially becomes obvious in the structure of the global electricity production (Figure 1), /IEA 1999, UN 1998, Wind 1999/. Coal (hard coal and lignite) is the most important energy source while hydro power ranges second with about 700 Gw and a share of 18 % in the overall electricity production which amounts to 14,400 TWh/yr (1998).

All the remaining RES, however, only supply 0.7 % of the electricity produced world-wide with 8,000 MW from geothermal power stations, 5,000 MW from biomass power stations and cogeneration plants, 10,000 MW from wind power plants as well as 350 MW from solarthermal power plants and about 900 MW from photovoltaic plants, which is altogether 94 TWh/yr, with solar irradiation contributing the smallest share with 2 TWh/yr. The global electricity production out of RES with its total of 2,700 TWh/yr (98 % of which from hydro power) is all in all higher than that of nuclear energy. At present, wind energy shows extraordinarily high growth rates with about 3,000 MW/yr (i.e. 1,600 MW of which in Germany alone in 1999).

Presently, there are particularly big differences between industrialised and developing countries in their electricity consumption of a factor of 10 (Figure 2), with the industrialised countries consuming almost 75 % of the electricity produced. The average per capita figures are for the OECD 8,600 kWh/yr (USA 14,700; EU 15 7,250), for the CIS and East Europe 3,750 kWh/yr, whereas the average figures for China are only 980 kWh/yr and 750 kWh/yr for the remaining developing countries. Even with great potentials for a more rational use of electricity, which is indeed possible with up-to-date appliances and drives, and further technical progress a considerable demand of the developing countries to catch up in the electricity sector can be expected.

[1] This is 9 % of the global primary energy consumption in 1997 with 395 EJ/yr /IEA 1999/.

Table 1: Annual global potential and approximate technical potential of renewable energy sources (based on: global final energy consumption in 1997 = 1), /TAB 2000/

Energy source	Total physical supply	Technically usable (final energy)[1)]	Presently used (final energy)
Solar irradiation	2,850[2)]	3.80[3)]	0.001
Wind power	200	0.05[4)]	0.0003
Biomass	20	0.40[5)]	0.140[6)]
Geothermyl heat	20	1.00	0.003
Energy of oceans[7)]	10	0.05	0
Hydro power	1	0.15[8)]	0.035
Total	3,100[9)]	5.90	0.180

1) Final energy consumption (1997 = 9.4 billion t coe/yr = 275 EJ/yr; /IEA 1999/)
2) Irradiation on continents (= 15 % of total solar irradiation)
3) 3 million km^2 surface for collection (= 2 % of the global land surface) with 40 % direct heat, 40 % electricity and 20 % hydrogen (as an example)
4) Only land-based; mean value from /WEC 1995, Grubb 1993/
5) Residual material from forestry and agriculture and 1.5 km^2 area fro cultivation (= 1 % of global land surface)
6) Present consumption of fire wood and organic waste
7) Energy from waves, tides temperature gradients
8) "Technically usable" according to /World Atlas 1998/
9) Global annual energy consumption corresponds to 3 hours of physical potential of RES

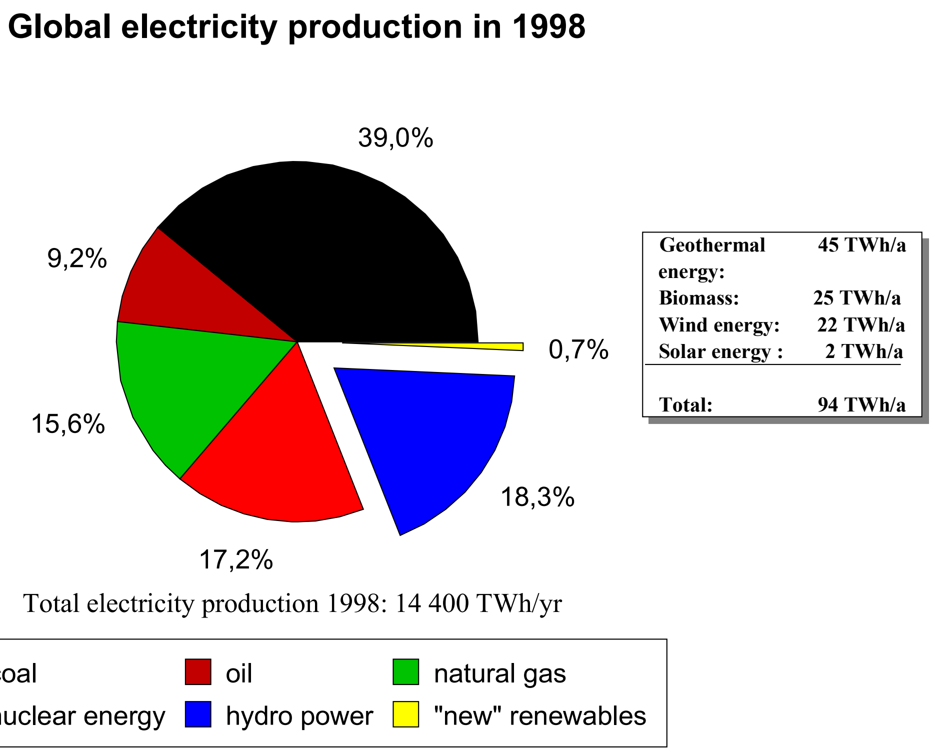

Figure 1: Present global electricity production and share of primary energy sources

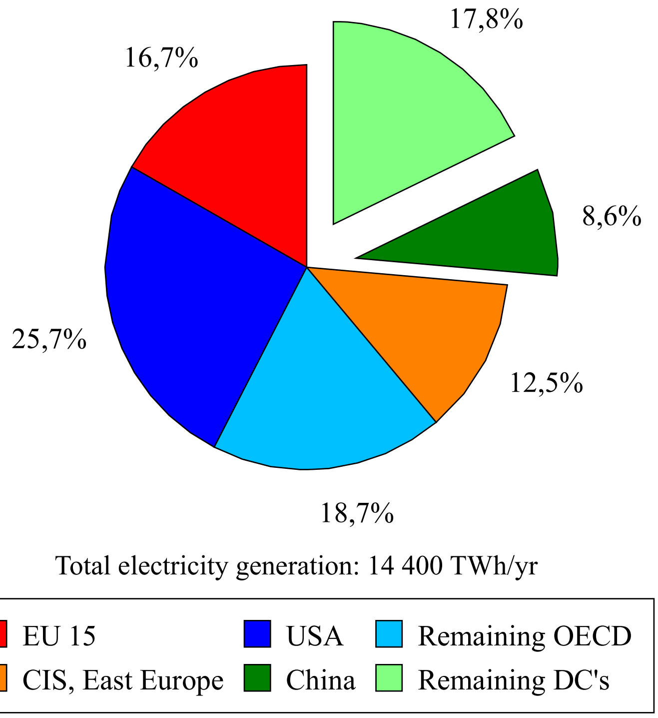

Figure 2: Structure of present (1998) global electricity consumption by regions

2 Potentials of renewable energies

Considerations on using renewable energy sources are based on their extraordinarily great physical potential and the fact that unlimited energy sources which already exist in the eco-sphere can be used for human purposes. Thus the most crucial criteria for ecological sustainability can be fulfilled. The solar irradiation on the continents, the potential energy of water, the kinetic energy of wind, waves and tides, the chemical energy stored in the permanently growing biomass, the thermal energy of the oceans and the geothermal energy annually offer about 3,000 times as much energy in form of unlimited energy flows (Table 1, column 2) as is presently consumed world-wide. Based on these data, the **technical potentials** describe the energy, which can be supplied from the present point of view, in a form the final consumer can make use of, i.e. direct heat of different temperatures, electricity and fuels for heat generation and transportation (e.g. hydrogen) produced with RES. When determining these technical potentials, a number of restrictions have to be considered:

- potentials and limits of technological efficiencies, possible capacity of a plant, technical potentials for development of the technologies for energy conversion and use which are available already or which will be available in the near future

- structural restrictions for exploitation due to the dependency on sites (e.g. geothermal energy), limited transportation radii (e.g. biomass), availability of area or its competitive use (e.g. collectors, solar panels, cultivation of energy crops), limited availability and reliability of energy supply (e.g. electricity from fluctuating sources), discrepancies in demand and supply (e.g. surplus that cannot be used or too high peak loads with wind and solar electricity)

- ecological restrictions with respect to the area required (e.g. wind energy), disturbance of flowing waters (e.g. hydro power), limited possibilities for the use of biomass (e.g. residual material from forestry and agriculture; cultivation of energy crops)

Statements on the technical potentials for the use of renewable energies therefore depend on numerous assumptions and are not to be regarded as some fixed value. If these criteria are taken into consideration, merely a share of **some thousandths** (irradiation, wind, energy of oceans) to **some hundredths** (biomass, geothermal heat) of the physical energy flows mentioned can be used energetically, i.e. in form of usable secondary energy carriers. Hydro power already "concentrated" is an exception where technical exploitation of around 10 % is possible.

Making technical use of the physical energy flows to such an extent, however, would be enough to cover the energy demand of the whole population entirely, in principle, even if requirements still continue to rise (Table 1, column 3), as from the technical pint of view at least **six times** as much energy (final energy) as is presently used could be supplied by energy carriers without any restrictions in principle. For this estimation, the area for making use of solar irradiation has quite restrictively been limited to 2 % of the global land surface, which is about 10 % of the area **not** being covered by settlements, forests and agriculture at present. Obviously, the area could be even larger as well. The potential areas for growing energy crops make up about 5 % of the area used for agriculture.

The following data are to be taken as a further example for the global technical potential of RES only in the field of electricity generation with wind, water and solarthermal power plants /Wind 1999, IEA 1999, World Atlas 1998, Klaiss 1992/:

- wind power, land-based = 53,000 TWh/yr /Wind 1999/

- hydro power = 14,300 TWh/yr electricity /World Atlas 1998/

- potential of solarthermal power plants in suitable areas in the Mediterranean region = 350,000 TWh/yr /Klaiss 1992/

These figures, which together add up to be more than 30 times the global electricity production of 1998, show that supplying the world's population almost entirely with RES is not at all endangered because of limits fixed by their potentials.

3 Basic situation in the developing countries

According to /UN 1998/ the term of "developing countries" comprises 124 countries showing quite different structures, conditions of incomes and accordingly also amounts of energy consumption. Among them there are relatively wealthy countries like Korea or Kuwait as well as extremely poor ones like Mozambique or Ethiopia. Thus the developing countries are divided into three groups according to their ranking in the UN's "Human Development Index (HSI)", i.e. highly developed countries (HDC), medium developed countries (MDC) and less developed countries (LDC), to be able to differentiate better between them. This first group and the subgroup of "GUS and Eastern European states" of the category of industrialised countries overlap with regard to their characteristic data like per-capita income and per capita energy consumption, educational standard, life expectancy, etc.

The data given in Figure 3 clearly show the wide gap between the industrialised and developing countries. 21 % of the world's population in the industrialised countries produce (and use up) more than 80 % of the world-wide goods and services, consume 70 % of the commercial primary energy (73 % of the electricity) and cause 63 % of the global CO_2 emissions.

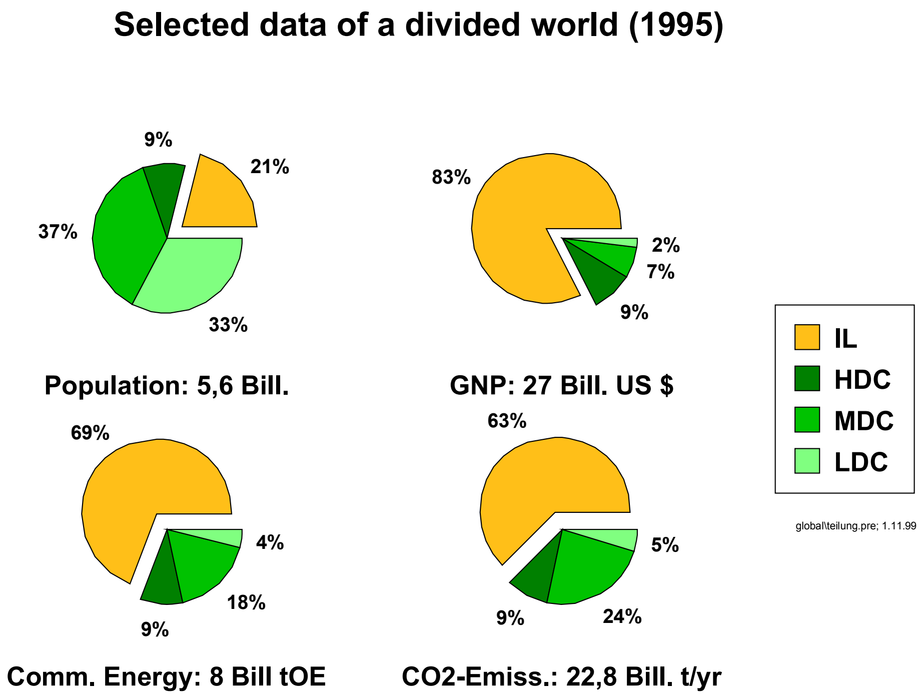

Figure 3: Division of data on industrialised countries and three groups of developing countries

In contrast, 33 % of the world's population in the LDC have to get by on 2 % of the total wealth and 4 % of commercial energy, but then they only cause 5 % of the global CO_2 emissions. As the average values are related to groups the extreme differences in the country specific data are smoothed out. A comparison of these data (Figure 4) makes the contrasts even more obvious. Thus the energy consumption of an average American citizen is 25 times higher per capita than that of an average African and is 5 times higher than the global average. The poorest countries (e.g. Ethiopia, Niger, Bangladesh) have to get by on one hundredth of the (commercial) energy used by an American. With his 200 GJ per capita per year, the German citizen as well uses more than three times the average global amount.

Concerning energy supply, the developing countries are usually considered as "decentralised" (i.e. no or hardly any networks) supply structures, which means isolated consumers who have no access to a (rather extensive) electricity grid and who can dispose of (expensive) oil only to a small degree due to bad transportation infrastructures, which indeed applies to about two thirds (almost 3 billion people) of the population of developing countries or half of the world-wide population today. Approximately 2 billion people generally concentrated in MDC and LDC do not have any electricity supply from national or decentralised electricity grids. In these countries there is the highest consumption of non-commercial energy (i.e. fire wood, mainly used for cooking) which is estimated to be about 10 % of the global energy consumption /IEA 1999/. In LDC it is almost as high as the consumption of commercial energy and amounts to still 20-25 % of the total consumption in MDC. Many people there can only survive by time consuming and unproductive gathering of fire wood.

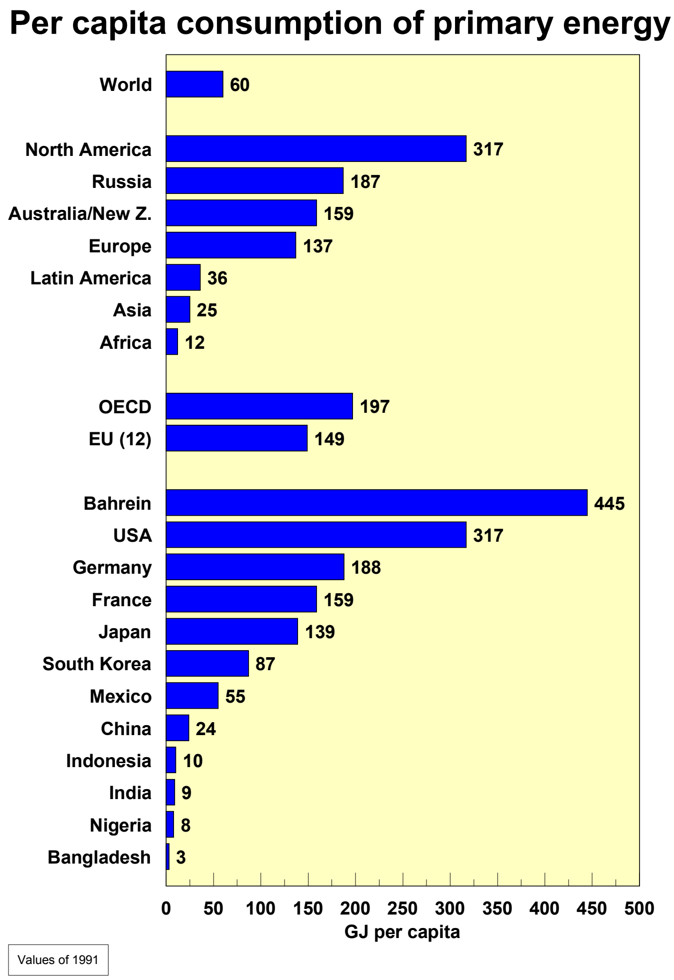

Figure 4: Per capita consumption of commercial primary energy in some groups of countries, continents and individual countries

At the same time the developing countries are in a process of urbanisation that cannot be stopped anymore (Figure 5). In 15 years already, half of their population (a total of 5.9 billion in 2015) will live in cities which are in general considerably bigger than those of the northern hemisphere. Of the 15 cities with more than 10 million inhabitants at present 11 with a total of 140 million inhabitants are situated in developing countries with Mexico City, Sao Paulo and Bombay being the biggest.

This development trend is also of great importance for the determination of the future energy supply which has to offer sustainable solutions for both areas. On the one hand it is important to guarantee satisfying the basic requirements of energy of the rural population on the basis or renewable energies with adequate decentralised technologies like e.g. small water power plants, photovoltaics and efficient exploitation of biogas and biomass as soon as possible thus slowing down the trend towards urbanisation as well, if possible. On the other hand bigger central plants on the basis of EEQ, i.e. also grid connected wind power plants, water power plants of suitable size and solarthermal power plants have to be considered as part of the development strategy with the same intensity. Also improving the efficiency in energy production (combined heat power plants), its distribution and above all its exploitation in densely populated and urban regions, but also in rural areas, are of enormous importance.

To put it precisely, the development strategy for the energy supply of developing countries should be as follows: while in industrialised countries a new optimisation of the energy supply structures towards more decentralisation takes place caused by technological developments (e.g. with gas turbines, fuel cells, wind, new biomass as well as information technologies and thus with control and supervision) and the continuous liberalisation of the energy markets (less capital binding, shorter periods for planning and building, higher flexibility and capability to react), in the developing countries a combination of decentralised and central energy supply technologies as good as possible should be created right from the start. From the point of view of sustainability, i.e. also under the precondition that in the long run a share of EEQ as high as possible can be mobilised, the alternative is not “central” or “decentral” but rather getting the most efficient and most practical grid connection of plants of different sizes and performances. With the help of the industrialised countries, the developing countries could probably reach this aim faster, i.e. make use of an important possibility to make up deficits in development.

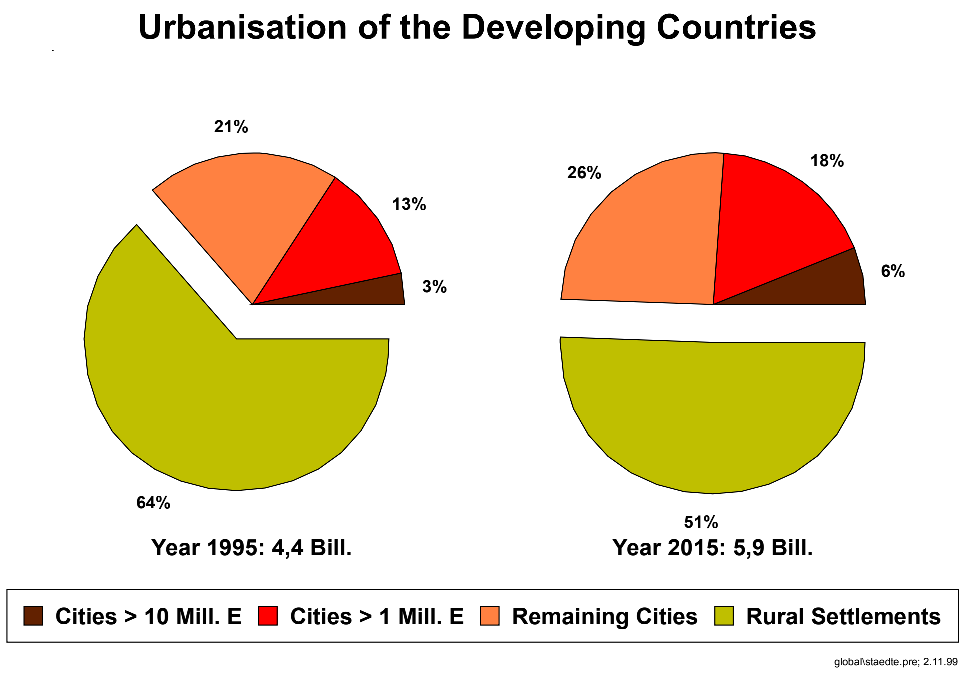

Figure 5: Distribution of the population in developing countries on rural areas and cities of different sizes in 1995 and 2015

4 Scenarios of future global energy demand and generation

Numerous studies on the world-wide future energy consumption assume that RES will contribute considerably by the middle of the next century (Figure 6 /Shell 1995, WEC 1995, WEC 1998, Johansson 1993, Lovins 1999, Nitsch 1999/, regardless of the other assumptions made in these studies on the effect of a more rational use of energy and the contribution of nuclear energy. The probable contributions of RES will reach up to 20 billion t coe/yr (Shell scenario, which is more than the world-wide total energy consumption at present, and will make up 25-75 %[2] of the total supply. In view of their potential, RES can quite well be imagined to make such contributions according to the above considerations. From the present point of view, however, it is not clear how the necessary global growth dynamics of RES shall be set off as punctually and extensively as would be required to have the assumed contributions realised by the middle of the next century already.

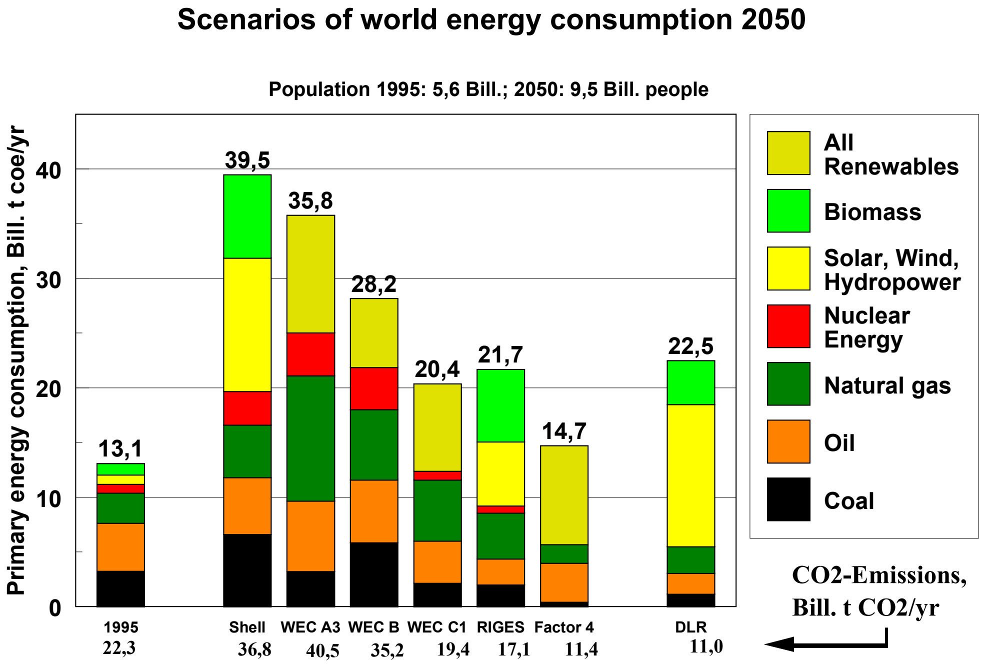

Figure 6: Different scenarios of global energy consumption 2050 and comparison with present primary energy consumption; Shell = "Sustainable development" scenario /Shell 1995/; WEC = World Energy Conferences 1995 and 1998; RIGES = "Renewable-intensive global energy scenario /Johansson 1993/; Factor 4 = Scenario from /Lovins 1999/; DLR = Own calculations /Nitsch 1999/; 1 billion t coe/yr = 29.3 EJ/yr

The probably most extensive analyses in this respect have been made by the World Energy Council (WEC) and were last discussed in Houston in 1998 /WEC 1998/. In general, the WEC sets up several energy scenarios in certain groups (as a rule each group always contains several scenarios): group A describes a process which is strongly orientated towards

[2] Despite high RES contributions and increasing contributions of nuclear energy, scenarios assuming traditional growth rates in the industrialised countries and transferring it to developing countries as well **do not reach any reduction** of the global CO_2 emissions (Shell, WEC A, WEC B). This stresses the enormous importance of a world-wide energy use to be much more rational as is assumed in the WEC C, RIGES and DLR scenarios and especially in the „Factor 4" scenario.

strong economic growth and plenty of energy available. Group B id often taken as trend scenario ("business as usual") whereas group C describes so-called "ecologically driven" scenarios. In the more recent studies on scenarios /WEC 1998/ the WEC has clearly corrected former misjudgements with respect to an enormously increasing world-wide consumption of primary energy. The values assumed on energy consumptions are now considerably lower and thus put the possibilities of substituting fossil energies by RES quite differently. Thus also scenarios with intensive rational energy use, as shown in the right-hand section of the figure (RIGES, Factor 4; DLR), become a point to be considered together with the WEC studies.

The future importance of RES within the global energy system becomes clear especially from the description of the future electricity generation and the mix of energy sources used for electricity generation (Figure 7). Apart from "Factor 4" with very high rational use of energy, all the scenarios assume strong increases in electricity consumption particularly in the developing countries. The differences in the increases are generally due to differing assumptions on rational use of electricity in the industrialised countries with already high per-capita consumption. There is a very strong increase also still in the industrialised countries assumed in the prognosis of the IEA /IEA 1998/ where electricity consumption by 2020 is therefore supposed to have reached almost twice the amount of 1998 with the share of RES decreasing at the same time. In the other scenarios, however, the absolute contribution of electricity generation with RES by 2020 is supposed to be twice (scenario B1, C1) or three times (scenario A1; DLR) the amount of 1998, which leads to shares in the total production of 25-35 %. According to the WEC scenarios of 2050 electricity supply with RES will then be four times (scenario B) to six times (scenarios A1, C1) the present amount. In the scenarios with high electricity consumption, such an increase brings about RES shares of about 35 %, and 58 % in scenario C1.

With the C1 scenario the WEC has for the first time presented a path for development which proves that a risk minimising and sustainable energy strategy is possible world-wide. According to this scenario it is possible both to reach in the 21st century decisive goals for climate protection (limiting the increase in CO_2 concentration to less than 450 ppm and the global increase in temperature to less than 2 °C compared to the pre-industrial status) and to do without nuclear energy world-wide in the long term (i.e. according to WEC by 2100). However, a sufficient reduction of CO_2 (by 2/3 compared with 1999) will only be achieved quite some time after 2050, while the German climate enquête commission and the Intergovernmental Panel on Climate Change (IPCC) call for a world-wide reduction of CO_2 by 50 % /Enquête 1995/ to be effected by 2050 already.

All the given paths for development are considered possible by the WEC. Especially with the C-group scenarios it is a fact that the developments will not set off as a matter of course but that there is considerable urge for action in energy politics. The WEC, however, has shown that risk minimising and climate protection are possible and can surely be financed, but the authors stress that in spite of the long period considered, decisions on the kind of future energy development to be pursued have to be made right now as the strategies depicted in the scenarios will rule each other out within a couple of decades. Also the periods for capital binding in the energy system are usually several decades. A scenario which fulfils the claims of the IPCC for 2050 with regard to CO_2 emissions and at the same time considers the need of the developing countries to catch up in energy was described in /Nitsch 1999/ (see Figure 6, right-hand bar). The total contribution of RES to the global consumption of primary energy will be 75 % in 2050, but with its 17 billion t coe/yr it is lower in absolute terms than the contribution of almost 20 billion t coe/yr in the Shell scenario (Figure 6, left-hand bar). The scenario describes the goals of sustainable energy supply for the next century, which are protecting the climate , minimising risk and bringing into line the global living conditions in an ideal way. It shows a possible transition from the present status towards this goal and can therefore be regarded as an orientation for the necessary steps to be taken in politics, economy and science in order to solve the problems that have arisen.

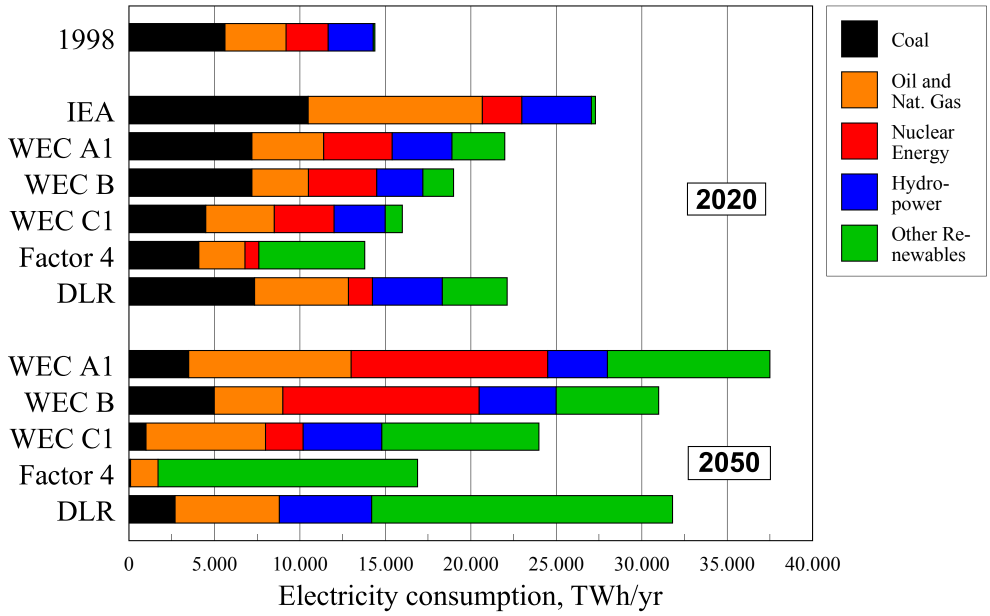

Figure 7: Scenarios of global electricity consumption 2010 to 2050 from /IEA 1998, WEC 1998, Lovins 1999/ (Factor 4) and /Nitsch 1999/ (DLR) and structure of primary energy sources

The corresponding scenario of the global electricity supply (Table 2, Figure 8) assumes a very efficient use of electricity in the OECD countries with a reduction in the per-capita electricity consumption by 30 % by 2050 and a considerable increase in fast-developing and developing countries with the per-capita electricity consumption to have tripled by 2050. With its total electricity production of 31,800 TWh/yr assumed in 2050, i.e. 2.2 times the value of 1998, the scenario is approximately in line with the WEC's B-scenario in Figure 7 with respect to consumption, but as far as the structure of electricity generation is concerned it is quite similar to the WEC's C1-scenario. At present, coal is the most important energy carrier for electricity generation with a share of 40 %, which in itself causes about 25 % of the global CO_2 emissions (and 85 % of the total emissions caused by electricity generation). Coal will still play this part in the next 30 years also in spite of great efforts to mobilise the use of RES. Producing electricity with gas will become more important and will on the longer term replace coal as the leading fossil energy carrier. The goal of risk minimising leads in the scenario to a steady decrease of nuclear energy and to its application running out by 2040.

The demands made on the RES contributions to the future global electricity supply and the resulting growth rates can be derived from the above goals of the scenario. Due to the high increases in consumption in developing countries and the assumed decrease of nuclear energy use, these demands are very strict. Thus in the following these demands are taken to deduce an upper value for the potential contribution of photovoltaics and for the market growth required in this respect. For a punctual and adequate mobilisation of RES (without hydro power) in the sense of this scenario, their share has to increase by 2020 with high growth rates of an average 16-17 %/yr. RES will then cover one third of the electricity demand. Then growth rates of less than 10 %/yr dropping down to 3 %/yr between 2040 and 2050 will be enough to make RES the dominant energy source of the next century with a share of about 70 % in 2050.

Table 2: Energy shares of global electricity generation within the long-term scenario "Solar Energy Economy" from 2010 to 2050 (TWh/yr)

Energy source	1998	2010	2020	2030	2040	2050
Coal	5,621	7,310	7,350	6,450	4,800	2,700
Oil, natural gas	3,570	4,883	5,500	5,800	6,000	6,100
Nuclear	2,480	2,100	1,460	770	0	0
Hydro	2,635	3,555	4,100	4,500	4,900	5,400
Other renewables	94	752	3,740	7,980	12,900	17,600
Total generation	14,400	18,600	22,150	25,500	28,600	31,800
Total renewables	2,729	4,307	7,840	12,480	17,800	23,000
Share of RES, %	19	23	35	49	62	72
Share of RES without hydro, %	0.7	4	17	31	45	55
RES growth rate (without hydro), %/yr		17	16	7.5	4.8	3.1

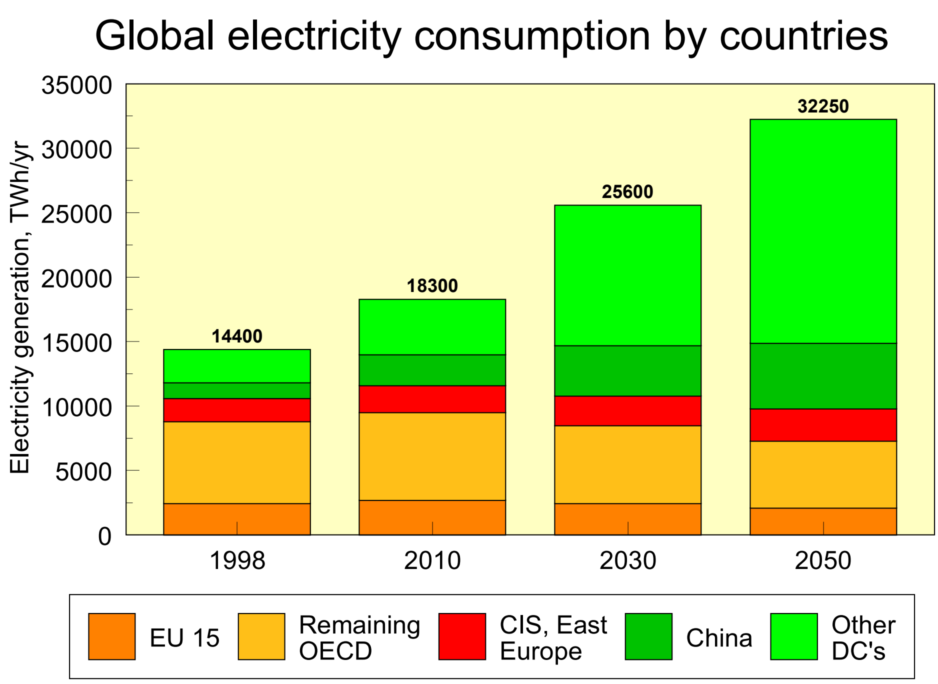

Figure 8: Global electricity generation by regions within the long-term scenario "Solar Energy Economy" from 2010 to 2050 /Nitsch 1999/

5 Global contribution of renewables in the future

In order to exploit RES capacities for electricity generation successfully, it is of prime importance to mobilise **all the RES technologies** in a way coordinating time and economy. Contributions of importance for energy supply can on the short term (i.e. by 2010 only be made by technologies which are near to competitiveness and already supply considerable shares at present. Apart from hydro power, this applies to especially wind energy and biomass on both national and global scale. There is also the necessity of introducing all the other RES technologies into the market to a degree that enables their contributing to cover the future energy supply after 2010 with relevant shares. In the case of geothermal and solarthermal electricity production it is therefore necessary to build a sufficiently large number of power plants within the next decade and to assure their contributing to the world-wide power plant market for granted from 2010 on at the latest. The market for photovoltaics has to increase in a way that after 2010 a share of 1 % of the electricity production can be achieved without any further delay. Only then can a sufficiently quick exploitation of the potential be secured in order to maintain the above growth rates of RES for several decades.

A coordinated use of RES is also necessary to be able to guarantee the availability of RES electricity with high shares in electricity supply in a way as economical as possible and to be able to keep the capacity for reserve and power balance as low as possible. Unusable surplus of wind and solar electricity or extensive measures for storage should also be avoided, which can be managed by combining all the RES technologies with their quite different characteristics and by linking up the numerous plants as extensively as possible, e.g. within a European electricity network. This network should include extensive decentralised feeding in as well as electricity transport from areas with big and very steady supply (e.g. off-shore wind power, hydro power from Scandinavia; solar electricity from South Europe/North Africa) /TAB 2000/. Taking into account these criteria and the considerations of other global scenarios, the dissemination of RES in the above global scenario can adopt the structure shown in Figure 9. Until 2020 the further dissemination of hydro power follows along the considerations of the IEA /IEA 1998/, afterwards it will slow down due to reasons of its limited potentials. All in all, its share will have doubled by 2050 compared with its present 2,635 TWh/yr. Hydro power will therefore remain the most important renewable energy source for electricity production until almost the middle of this century and will then supply 17 % of the global electricity produced (presently 18.3 %).

Wind power is an energy technology which is developing in an extremely dynamical way with world-wide growth rates of around 3,000 MW/yr at present. In the scenario its increase is orientated towards the goal of a 10 % share in the global electricity supply of 2020 of the European Wind Energy Association /Wind 1999/. Including off-shore plants there is presently a capacity of 900 GW installed, which is an average growth rate of 20 %/yr. If this growth dynamic is continued, wind power will have caught up with hydro power by 2040 at decreasing growth rates and will exceed it in 2050 with a share of 5,800 TWh/yr or 2,200 GW. Wind power will then contribute with 18 % to the global electricity production.

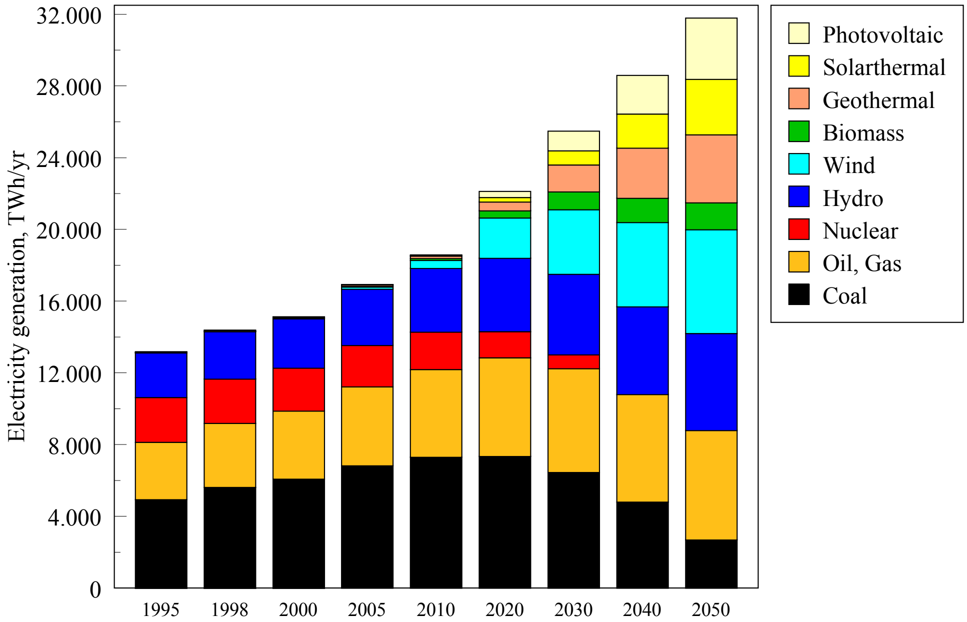

Figure 9: Growth of renewable energy technologies for electricity generation within the scenario "Solar Energy Economy" until 2050

A further and intensified establishing of biomass and geothermal energy as energetically relevant technologies for electricity generation requires growth rates of about 10 %/yr until 2010, which will be achieved quite easily with regard to their favourable economic data and their technological maturity, if appropriate priorities are established in energy politics. In the case of biomass it is on the one hand burning it in existing coal power plants and on the other hand intensified building of decentralised cogeneration plants on the basis of (mostly) wood and biogas. Apart from a further tapping of favourable geological resources (particularly USA; in Europe: Italy and Iceland), the dissemination of geothermal energy calls for rapidly entering into electricity generation based on the hot-dry-rock (HDR) technology. Electricity generation with biomass and geothermal energy is extremely important for an effective development of the electricity market with big shares of RES due to its guaranteed availability, its possible high annual availability (biomass in cogeneration plants about 4,000 h/yr, geothermal energy about 7,000 h/yr) and its low costs. Concerning biomass, a decrease in growth is assumed after 2030 because of its limited potential, which will lead to a maximum share in electricity supply of 1,500 TWh/yr (almost 5 %) or 375 GW in 2050. In contrast to this development of biomass, in the case of geothermal energy a further increase can be assumed due to the considerable large potential of HDR electricity production. If once established, geothermal energy with 3,800 TWh/yr (600 GW) in 2050 will play an important part in an electricity supply based on RES.

Solar irradiation merely contributes to the global energy supply with approximately 2 TWh/yr at present. On the long term, however, it will have to become the main contributor to a global renewable energy supply because of its virtually "unlimited" potentials. The technologies for using solar irradiation therefore have to be developed with extreme intensity to enable them to play an adequate role within RES within the next few decades. Both technologies, i.e. solarthermal and photovoltaic electricity generation, are necessary should large-scale substitution of the required fossil energy generation in view of climate protection and resources be successful with the high growth rates in electricity consumption in the developing countries. Points which favour solarthermal electricity production are (solar) electricity generation costs of less than 10 cents/kWh which are very favourable at present already as well as the possibilities of combining it with existing power plants by means of hybrid operation and incorporating it into grid structures. In the longer term, the remarkable potentials for cost reduction due to increasing markets and technological progress will be of growing importance.

Both technologies thus complement one another in a very favourable way in the necessary exploitation of the potentials of solar irradiation /TAB 2000/. Therefore comparable growth rates are assumed in the scenario for both technologies. For solarthermal power plants there are concrete concepts for further development until 2010 /Trieb 2000/ which are used as a basis and claim that with average growth rates of the market by 25 %/yr a share of 1 % will be exceeded in 2020 with 250 TWh/yr (or 70 GW). Further continuing growth of approximately 10 %/yr will lead to a contribution of this technology of 3,100 TWh/yr or 600 GW in 2050. Solarthermal power plants will then contribute by 10 % to the global electricity supply.

Comparable goals, i.e. a share exceeding 1 % in 2020 and 10 % in 2050, can be fixed in the framework of this scenario for the market development of photovoltaics, which requires an average global market growth of 30 %/yr until 2010, of 15 %/yr from 2010 to 2020 and a further 4 %/yr on a high level in the following 30 years.

6 Markets and chances for establishing sustainable energy supply

Maintaining and extending energy supply alone requires considerable efforts even without considering the above mentioned ambitious aims for climate protection and sufficient supply for the developing countries. Annually, about 4-5 % of the global gross national product, i.e. approx. 1,000 billion US$/yr, are used for this purpose. In order to introduce EEQ more intensively, additional funds will be necessary in the beginning to overcome the cost barriers which are presently low prices in conventional energy supply and too high costs of EEQ due to markets of insufficient size and technical potentials still unused.

There are still considerable potentials for decreasing costs for most of the EEQ technologies (Figure 10, /Nitsch 1998/). By 2010, for example, the costs for wind power could be 75-80 % of the present value, taking approximately steady annual sales of plants for granted. All the remaining technologies require considerably increasing market volumes. Reducing the PV costs by 50 % is possible with an annual market volume 15-20 times higher, collectors (on the basis of medium an big plants) can become by 40-50 % more favourably priced with 10 times the market volume. To be able to exploit their potentials for cost reduction, solarthermal power plants, which have favourable electricity generating costs at present already, require a initial monetary support to push their market volume up to approx. 800 MW_{el}/a (e.g. according to the suggested dissemination of the DLR's Synthesis programme /Trieb 1998/ with 7,000 MW of total capacity by 2010). Even the conventional plant technology of biomass exploitation makes cost reductions possible.

Wind power is an example for considerable cost reductions reached already (Figure 11). The specific investment costs of wind converters decreased from their initial 4,000-5,000 DM/kW to about 1,600-1,800 DM/kW (ex works) while the cumulated production increased by a factor of 1,000. The derived learning factor f, which characterises the cost reduction when doubling the cumulated production, is between 0.87 and 0.91 for wind energy for different evaluations. The cost reduction of 20-25 % mentioned may thus be reached with a cumulated performance of 8,000-10,000 MW, which means for Germany approximately in 1005 if the present growth keeps going on. Evaluations for other EEQ technologies lead to similar results with photovoltaics showing the most favourable learning factor of f = 0.78; for collectors it is 0,85-0,88 and for biomass 0.95.

Possible cost reductions of renewables in the future

	Wind-energy	Photo-voltaic	Solarthermal power plan	Collectors	Biomass
Mean energy-cost 1999 (c/kWh; 6% interest rate)	9 *)	80 **)	9	20 - 25	Electricity: 10 - 25 Heat: 5 - 15
about 2010***)	0,65 - 0,70	0,50 - 0,60	0,65 - 0,70	0,50 - 0,60	0,85 - 0,90
2020 - 2030 ***)	0,50 - 0,55	0,25 - 0,35	0,55 - 0,60	0,35 - 0,45	0,80 - 0,85
Market volume necessary in 2010	constant	20 - 30 fold	800 MW(el)/yr	10-fold	10fold

*) location on coast, **) mean Europa: 830 kWh/kWp, ***) 1999 = 1.00

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Figure 10: Present generating costs of renewable energies in Germany (solar power plants in the Mediterranean region) and cost levels to be reached in the medium term with an establishing of bigger market volumes

If the further market development stabilises on a high level after the important start-up phase by 2010, which would be guaranteed in any case by a realisation of the above scenarios for example, cost levels will possibly be reached in the longer term (i.e. 2020 to 2030) which will be clearly lower than the present costs of EEQ exploitation. As in the medium term prices for conventional energy supply will quite probably increase at the same time, EEQ could then indeed be competitive on a liberalised energy market. As a precondition there has to be an accordingly far-sighted energy policy which at present already gives the necessary support for EEQ by adequate **market incentive programmes for the domestic market and by supporting a creation of export markets**. Successful export markets can only be created, if there are technical progress and cost reductions in domestic markets and if it is shown that EEQ are useful for satisfying the demanding energy supply of a highly developed industrialised country and that they are used by those countries themselves. However, it is not always necessary to use all the systems within the specific country directly, which is only to some degree possible with photovoltaic systems and makes no sense with solarthermal power plants. However, with these systems, too, it is necessary to work in research, development and demonstration in order to be able to participate in their components production, design of the plants, their building and operation.

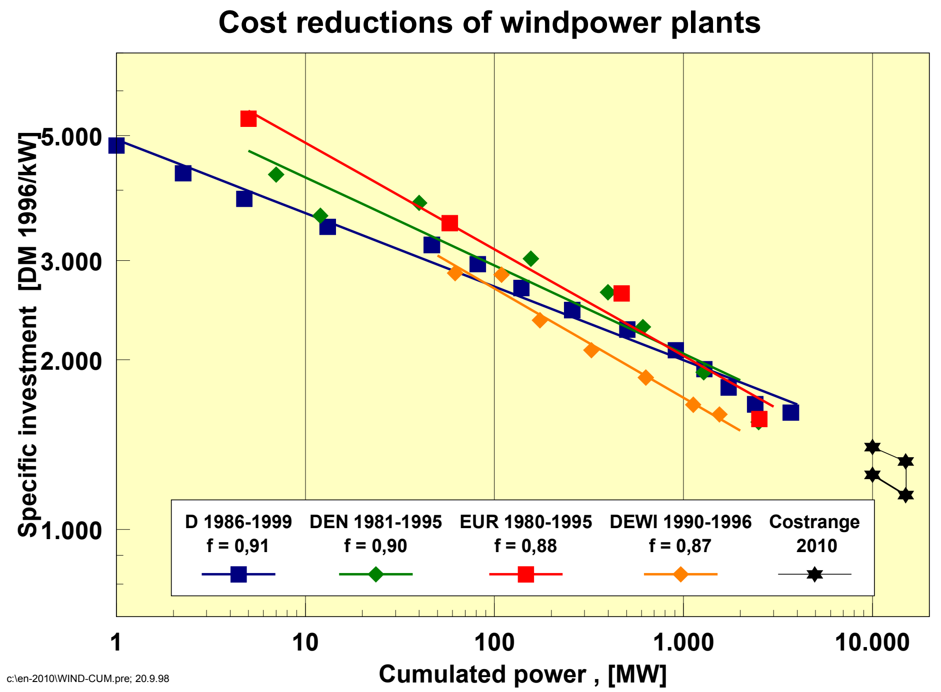

Figure 11: Development of costs for wind power plants in different time periods and reference regions and learning factors derived

A future export market for EEQ is extremely diverse as far as technology is concerned and it covers plants and components of quite different performance and size. It ranges from already established components or plants like water turbines of very different performance, small photovoltaic systems and efficient cookers and stoves via small gas turbines and engines (e.g. for biogas or gasified biomass, collectors and collector plants, biomass heating plants and biogas plants to wind power plants and wind parks of increasing performance and components for solarthermal power plants. This wide variety offers on the one hand good opportunities especially to medium-sized companies to enter into a growing EEQ export market, on the other hand the unclear and confusing variety and the split up market segments make establishing effective export structures difficult. Here, too, support by politics is required with respect to giving advice on export, taking on risk security and making EEQ part of all the relevant bilateral and international discussions in economy.

Supporting an establishment of EEQ export markets as early as possible – with the appropriate lead for domestic markets – and participating in them intensively can be regarded as **efforts paying off in many ways**. Not only does it help protecting the environment and climate, but can also contribute to decrease the gap between the rich and the poor in the world and thus help to avoid conflicts in the present and in the future. Furthermore, the EEQ techniques themselves are tradable without any dangers and risks for misuse. Especially, production and trade in this booming market also offer possibilities for creating safe and promising jobs in the respective country and with progressing technology transfer and division of labour in the developing countries themselves, too. Last but not least, contributing to the establishment of energy supply structures in developing countries with big EEQ potentials can make them popular trade partners in future energy supply. On the longer term, the big potentials of EEQ offer sufficient possibilities of a diversified import of electricity or solar chemical energy carriers to Central Europe. Thus from an early cooperation based on partnership considerable synergetic potentials could arise ready for the partner who takes these cooperation opportunities first. Figure 12 shows these possible synergies with a cooperation between Germany and Morocco as an example where wind and solar power are used for the benefit of the economy and energy supply of both countries.

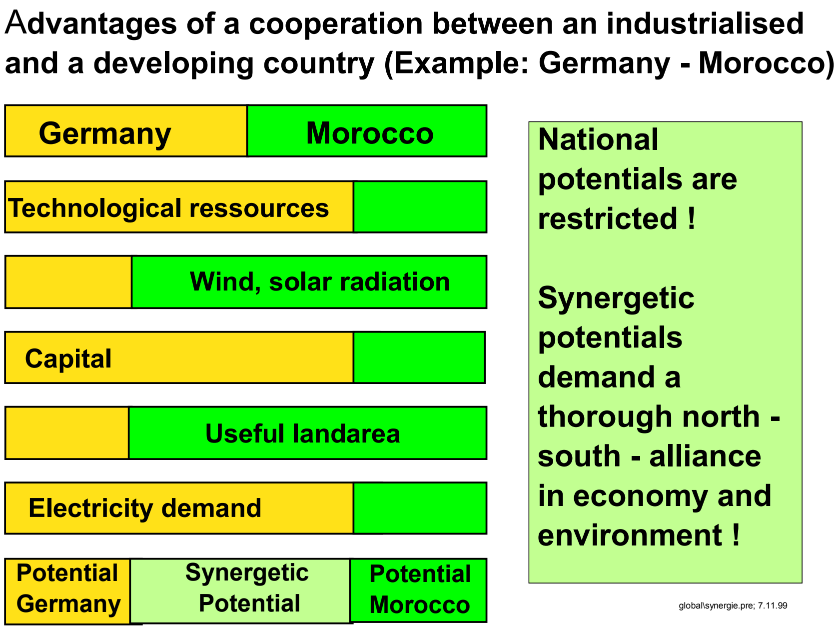

Figure 12: Symbolic presentation of the advantages of an environmental and economic alliance between an industrialised and a developing country with the synergetic potential /Klimaschutz 1999/

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