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Long term scenarios for a sustainable energy future in Germany

Research project for the German Umweltbundesamt

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Executive Summary

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1 Challenges for the energy supply

Four essential sustainability deficits in the present energy supply can be derived from the guidelines for a sustainable development.

1. ***Global climate change*** is seen as a problem with a high possibility of occurrence which is linked to the usage of fossil energy fuels. International energy politics certainly show differentiated positions regarding the urgency with which climate change is to be counteracted.
2. The ***scarcity and price increases of crude oil and natural gas*** nowadays are not the main perspective of politics and the public, even though it is largely agreed that the so-called "depletion mid-point" of crude oil – meaning the point at which the maximum of supply is reached – will occur in the next 15–20 years.
3. Varying positions exist in respect of any ***nuclear dangers***, especially with regard to the possibility of accidents and their consequences as well as the dimension and time span of radioactive impact during usage and disposal.
4. The ***strong difference in energy usage between industrial and third world countries*** has virtually not decreased over the last few years.

Analyses of existing scenarios, i.e. consistent descriptions of possible futures of energy systems, show that **only a combination of efficiency and fuel switch strategies and consequently the expansion of renewable energies, allows all sustainability deficits of today's energy supply system to be overcome**. In addition, sufficiency strategies have a supplementary implication for industrialized countries. The following actions which are derived from the scenario analyses result for Germany:

- An increase in the average energy productivity by 3–3.5% for at least two to three decades (compared with approximately 1.7%/year in the last decade). This leads to a lower primary energy consumption of 25% to 30% by the year 2030 compared to status quo conditions.
- An increase in renewable energies in primary energy consumption by 12–15% by the year 2030 and in the generation of electricity by 25%, in comparison with a status quo development of 4 to 5% for primary energy and under 15% for electricity.
- A minimum increase by doubling or trebling the contribution of combined heat and power (CHP) in comparison to now.

2 Benchmarks of the scenarios – with "efficiency" to "sustainability"

The requirements specified so far are not sufficient for achieving the sustainability targets in the long term. Our analyses show that until the middle of the century a substantial requirement for modification is needed, especially if the long-term aim to decrease CO_2 (reduction by 80% by the year 2050, compared to the 1990 level) is to be achieved. Within such a sustainability scenario primary energy consumption must be more than halved in the next 50 years to approximately 46% of today's level (year of reference 1998 – Figure 1). Final energy requirements must be reduced to 54% of today's level. A persistent strategy to economize on electricity should reduce the demand for electricity by the year 2050 by a total of 20%. This comes true if energy-efficient devices and production procedures are implemented during the cycle of typical reinvestments. Those hurdles which today often stand in the way of energy conservation must be decisively diminished through innovative measures and instruments (e.g. energy efficiency funds).

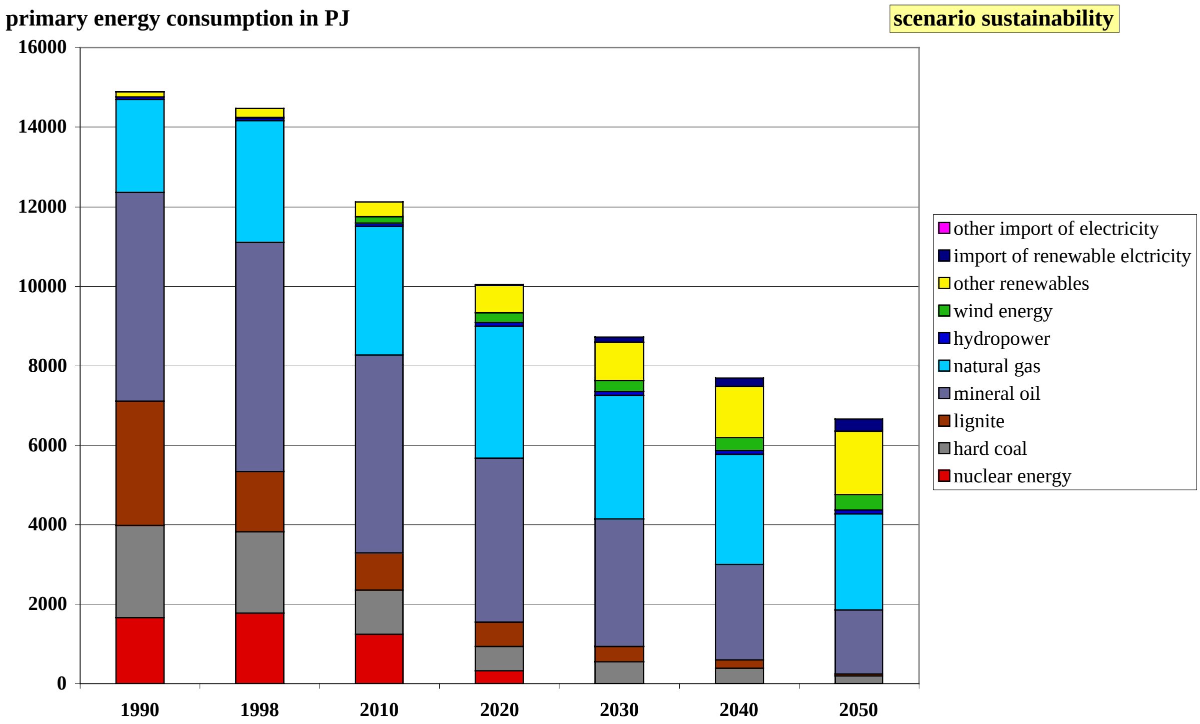

Figure 1: Development of primary energy consumption in the sustainability scenario until the year 2050.

2.1 Electricity supply of the future – efficient, decentralized and widely interconnected

Not only economizing on electricity is needed in such a changed energy world but also its supply has to change drastically. It is just the right time for it. The necessary replacement of German power stations expected within the next two decades due to aging processes (by the year 2020 up to 70% of today's capacities have to be replaced), creates the necessary scope. The increase in generation of electricity from renewable energies and CHP results in a shift in the generation of electricity to the location of electricity applications. Intelligent control systems must ensure that these decentralized electrical power units are coordinated and conveniently fitted into the load management of the consumers (virtual power stations). While natural gas extends his contribution of electricity supply in mid-term, renewable energies will become the dominant factor not later then 2040 (in 2050 their share in generated electricity will amount to approximately 65%, Figure 2), whereby all available options as well as the import of electricity from renewable energies from foreign countries (offshore wind energy from the North Sea countries, electricity from solar thermal power stations in Southern Europe or North Africa) will be of importance. Large condensation power stations, which dominate today's generation of electricity, will only play a subordinate role in 2050. After

2030 sufficient scope for electrolytic hydrogen production will arise on these conditions, whereby the generation of electricity will rise despite the further decline in demand of consumers.

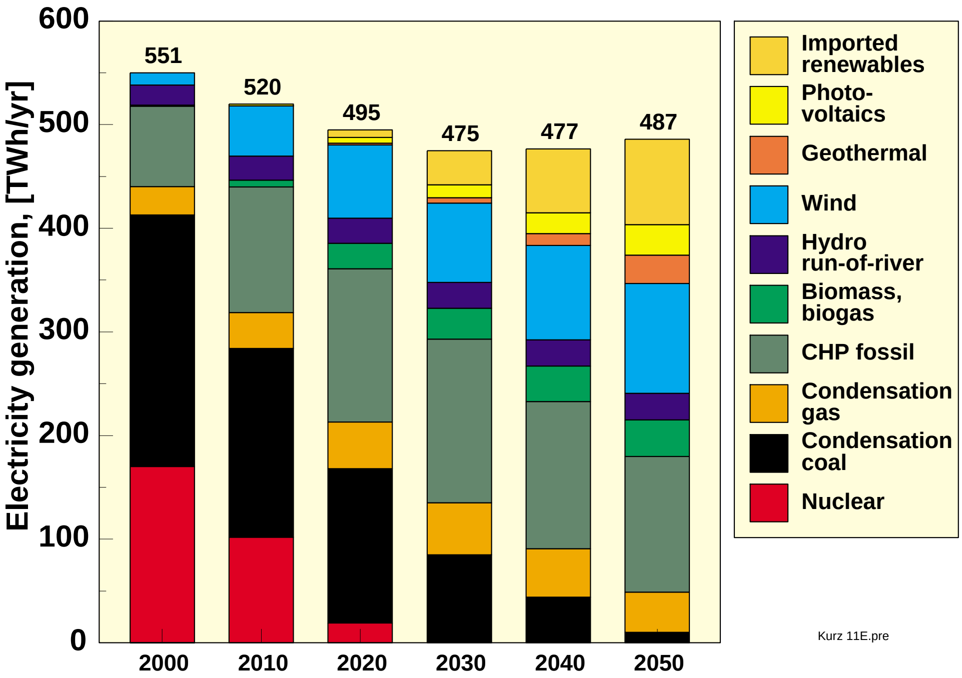

Figure 2: Structural changes during electricity generation in the sustainability scenario by the year 2050. From the year 2030 electricity requirements for hydrogen production by electrolysis due to an increase of electricity demand, in 2050 this will amount 57 TWh/a.

2.2 Renovation of old buildings and district heat concepts – Characteristics of an efficient fossil-regenerative power supply

Apart from the improvement in insulation standards of buildings, the sustainability scenario requires primarily a drastic increase in the energetic renovation rate. Although 2.5% of all existing buildings are being renovated on a yearly basis (e.g. façade renewal), only in every fifth case is an energetic renovation completed at the same time. The specific reduction possibilities of 50 to 70% can only be attained when there is a constant increase in the number of buildings which are also energetically renovated.

Comparable to the interconnection of smaller and medium-sized generators of electricity to virtual power stations the sustainability scenario requires the expansion of intelligently linked heating systems. This permits a number of efficient techniques with their individual advantages being combined in the best possible way. In the first step, efficient cogeneration systems with fossil fuels can be the foundation for introducing gradual renewable energies to a larger extent later on.

For the structural changes assumed in the sustainability scenario, it is necessary to distribute about two thirds of the heat requirement reduced by 45% over district and central heating systems (Figure 3) by 2050. The restructuring of the heat sector causes the number of individual heating systems supplied on the basis of crude oil to disappear completely and also a strong decrease in those supplied with natural gas can be expected. The German settlement structure, with closed communities and relatively small properties, represents in principle a good starting point for the development of district heating systems. Nevertheless, the necessary measures will take decades to be implemented and will have to be introduced as fast as possible.

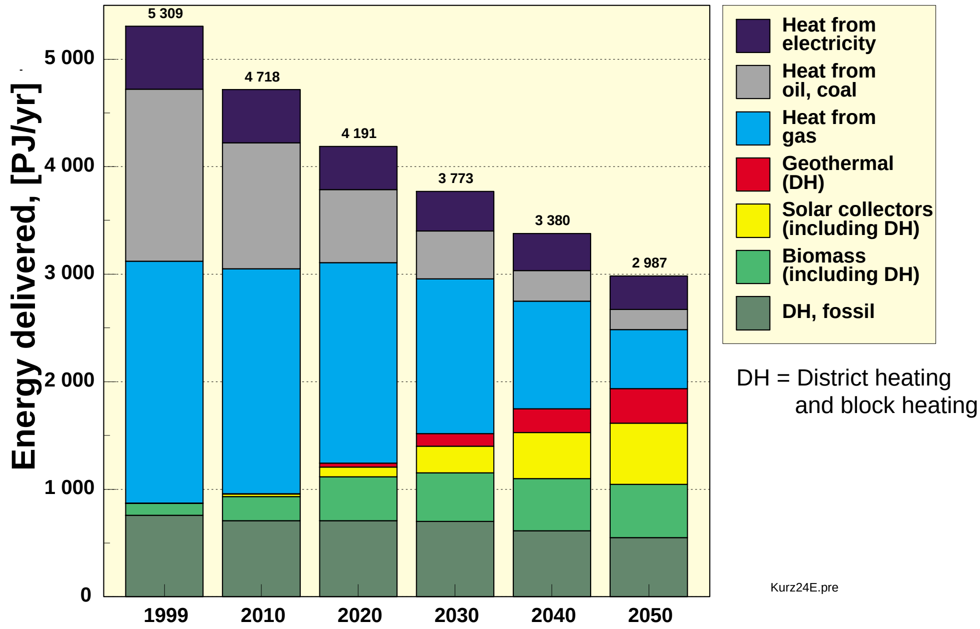

Figure 3: Development of the energy demand and change in the energy supply structure (space heat, hot-water supply, process heat) in the sustainability scenario through district and central heating supply systems based on fossil fuels, biomass, as well as solarthermal and geothermal energy, with the remaining energy demand being covered by conventional solutions.

2.3 Transportation – first efficient, then renewable

In the transportation sector the interconnection of efficiency and fuel switch strategies plays a substantial role, whereby initially efficiency improvements are at the forefront of attention here. Since the capacity of passenger transportation according to assumptions will grow by 10% by the year 2050 and the capacity of goods transportation is to more than double, effective efficiency improvements for vehicles have the highest priority. A focused strategy to reduce the consumption of the vehicle fleet by technical measures, accompanied by a voluntary switch to more economical vehicles as a result of increased energy awareness, leads to an evident reduction in fuel consumption. This applies in particular to individual traffic (average fleet consumption in the year 2030 approx. 4.5 l/100km, in the year 2050 approx. 2 l/100km). The introduction of alternative fuels will take place over time, and will gain significance around 2020 (Figure 4). While to begin the amount of diesel will increase in proportion to the relatively growing significance of goods transportation, petrol respectively will lose its significance, Furthermore the share of natural gas will increase to 2.5% in the year 2020 and to 12% in the year 2050. Natural gas will be given the role of forerunner in the launch of hydrogen gas, because hydrogen gas will already contribute 17% of the demand for fuel in the year 2050. Many technologies developed for the use of natural gas can be easily adapted for hydrogen applications. Biodiesel will play a moderate role due to the competition between the cultivation of energy providing crops and the desired expansion of ecological agriculture for sustainability reasons.

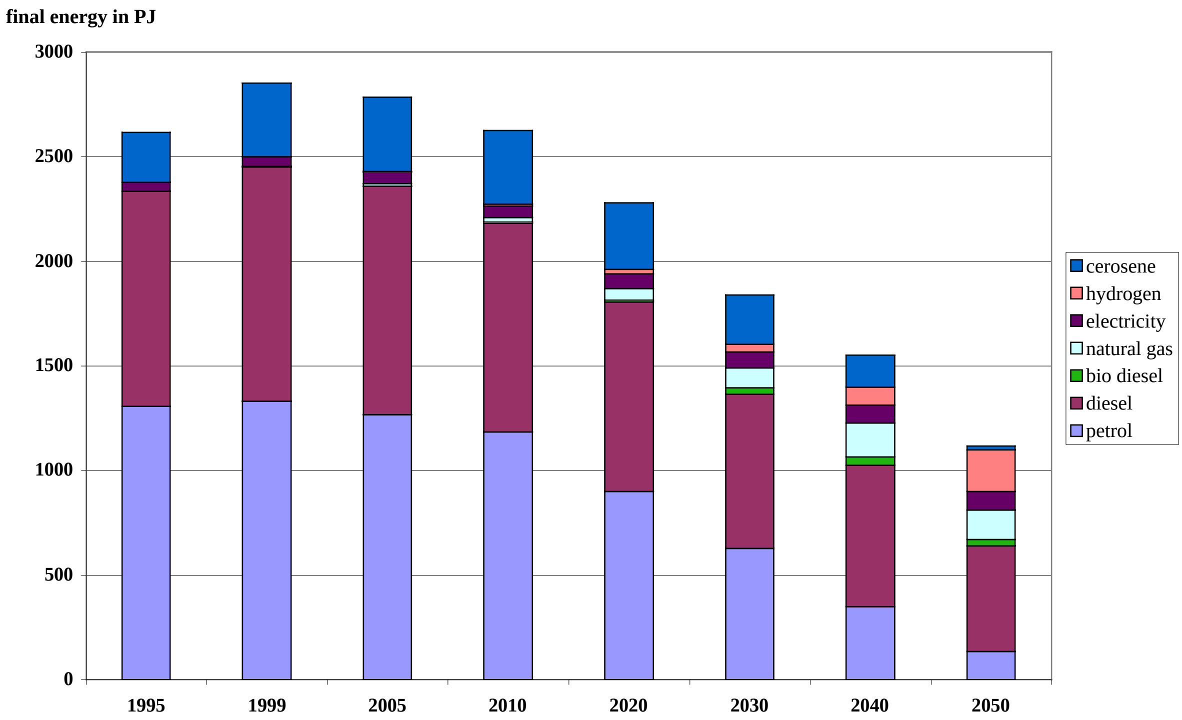

Figure 4: Development of final energy demand for transportation and its structure in the sustainability scenario until the year 2050.

3 Economic and social impacts

In the course of 50 years the sustainability scenario will show distinct changes in the energy system, which presuppose considerable investments in techniques, in the more rational use of energy and energy conversion, and the employment of renewable energies. Therefore, if the principles specified below are considered, then changes can be made also in an economically attractive way.

1 **The energy supply system is to be temporally optimised as a priority and to be organised more efficiently:** In most cases a more rational use of energy or the avoidance of unnecessary energy use is more economical than the supply of renewable energies in the short and medium term. Appropriate investments are partly even combined with economic advantages in comparison to a status quo development. They are therefore a

substantial condition for limiting the additional costs of the sustainability scenario. These technological options should therefore be rapidly applied in all consumption sectors so that renewable energies can then cover significant shares of this reduced energy demand.

2 **The costs during the entire period of building up renewable energies are to be minimized:** The use of potential renewable energies should occur at locations where yields are as high as possible with well-adapted plants to achieve a high utilization of the installed plants. The expansion should place as few adjustment demands as possible on the network to achieve low costs for the expansion of grids and to limit the necessary reserve capacity for power plants operating with fossil fuels. This means that the adjustment of energy demand and energy supply should be as optimal as possible timewise for achieving a balanced mix of energy sources.

3 **The mobilization of all relevant technologies is to be well timed and in the right order:** In consideration of point 2, more technologies which today are still expensive (photovoltaics) or yet to be demonstrated (HDR: hot dry rock concept for the generation of electricity), should be brought into the market so that they can take over the market dynamics required at a later time. On the other hand, they should not dominate the markets too rapidly since otherwise the average energy production costs will become unnecessarily high.

If one balances the annual additional investments which arise within the framework of the sustainability scenario in comparison to the status quo development (additional investments in energy saving measures and renewable energies) and compares them to the avoided expenditures (saved fuel costs and avoided investments in conventional facilities), the sustainability scenario (until the end of the viewed period) results in a difference in costs of approx. 200 billion EUR (cumulated and for the year 1998 discounted this adds up to a difference in costs of round about 40 billion EUR). The average additional costs for the national economy therefore amount to an average of 3.8 billion EUR/a (or 48 EUR/person and year) which equals about 0.14% of the average GDP (gross domestic product) in this time period. Costs like this are not very unusual, but for example expenditures like this have occurred for hard coal subsidies in the last two decades. In contrast to the status quo development, even negative costs can be shown for the first two decades due to economic saving measures being carried out. If the economic investments in saving measures are gradually being exhausted and, at the same time, the increasing investments in renewable energies take effect, then the difference in costs will increase accordingly (Figure 5).

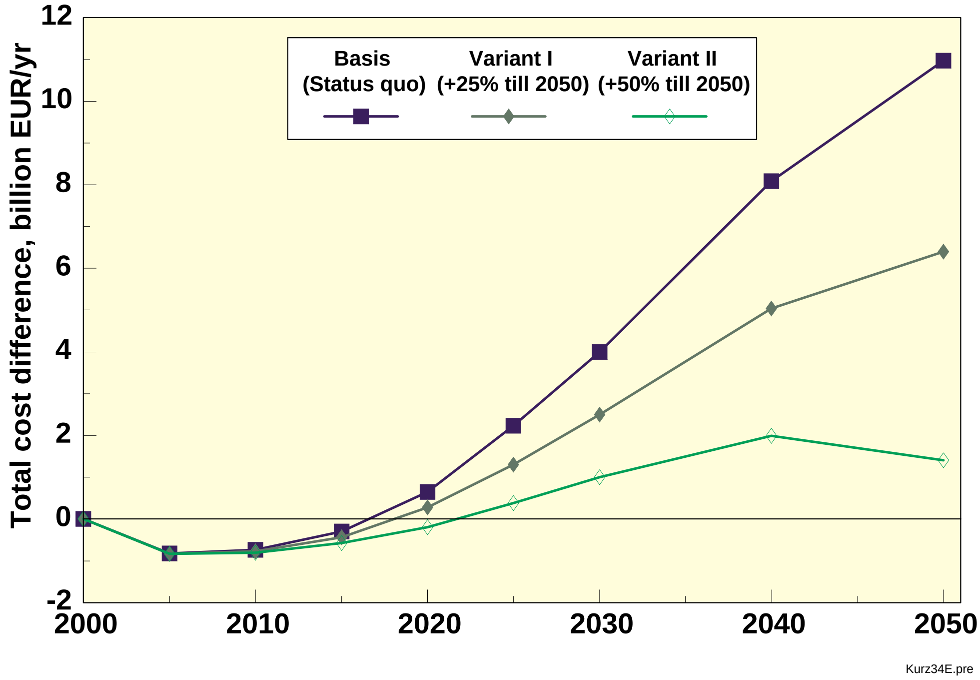

Figure 5: Course of the difference in costs between the sustainability and status quo scenario for three different alternatives of future prices of fossil energy sources.

Which course the difference in costs will take after the year 2030 depends on the anticipated cost development of the relevant energy carriers. If there is a sharper increase in energy cost than in the predicted status quo development – which due to the moderate increase in the status quo development is not unlikely – or if the external costs with the aid of suitable instruments are largely included in the market prices of energy, so the difference in costs of even more expensive energy saving options and a number of technologies from the area of renewable energies will drop in the course of time towards zero or will even become negative. Towards the year 2050 the sustainability scenario could be cost neutral even in comparison with the higher price alternatives of the status quo development.

The domestic energy sources of hard coal and lignite are particularly strongly reduced in the sustainability scenario. This however represents no endangerment to the security of our supply. The **sustainability scenario** can, on the contrary, be understood as an **active crisis safety device** because due to the absolute decrease in primary energy consumption and the strengthened development of renewable energies, the demand for imported energy fuels can decrease absolutely. Also, the relative share of domestic energy carrier lies above the appropriate values of the status quo development. In the sustainability scenario already in 2020 approximately 2,700 PJ less energy is imported from other countries to Germany than under status quo conditions. This is nearly 20% of today's entire primary energy consumption and more than 25% of today's energy imports. At the same time, renewable energies and the saving of energy fulfil also an important contribution to the diversification of the energy supply. Thereby they supplement the domestic coal base and the import of natural gas and oil from abroad, and are still compatible with climate protection requirements.

While the import of fossil energies to Germany decreases, the purchase of electricity from renewable energies from foreign countries is intended from the year 2030. Formally, this means that import dependency rises, but more importantly its potential contribution to peace and the crisis safety device outweighs. In countries now with high fossil energy exports, the development of renewable energies (and their later export) can be a fundamental basis for a peaceful and economically profitable transition. For other countries of the worlds sun belt now with high import shares, in principle however a high supply of renewable energies delivers still unknown options. New business fields and additional options for the provision of foreign currencies thereby arise, providing that their own energy problems are solved first of all. In addition, indirect solutions to other urgent problems (e.g. seawater desalination) can also be carried out at the same time.

Also **no negative effects are tendentiously expected for the labour market**. During the implementation of the various measures necessary for carrying out the sustainability scenario, there will be both winning and losing branches of industry. While in the building industry an additional 85,000 to 200,000 jobs can be created or conserved through the renovation of existing buildings, employment potential in the area of renewable energies could be created for 250,000 to 350,000 persons in the long term. The decrease in employment already noticeable under the status quo development for the coal and mineral oil industry will accelerate. This process however will proceed so slowly that a socially compatible conversion of jobs is possible.

4 Further perspective of a sustainable energy supply

Without doubt, the development outlined is to be seen as very ambitious and requires a particularly dedicated energy policy for many decades. Renewable energies have to be moved more into the centre of efforts and energy efficiency politics have to become the new main focus. The question arises whether the future path demonstrated describes the boundaries of feasibility or whether extensive scope remains. It must first be discussed whether renewable energies could be developed even faster, or in what time frame the entire energy supply could be converted to renewable energies.

The application of renewable energies can only be increased if substantial basic conditions such as a progressive European and international climate protection policy, energy-conscious behaviour of power suppliers and consumers, as well as farsighted investments in large production plants for renewable energies, are interlinked in an optimal way. In this case also the transport sector could be transformed to renewables quicker than is assumed in the sustainability scenario, and there could be a further increase in renewable energies in electricity and heat generation,

This expansion only makes sense to a great extent from 2030 on, because only then at the earliest can a sufficiently efficient car fleet be assumed as a decisive basic condition for the introduction of “expensive” alternative fuels. Moreover, the CO_2 reduction effect of the direct employment of renewable energy in electricity generation will be higher at that time. The resulting effect of the clear increase in the contribution of renewable energy to transportation is described in Figure 6 in a “**maximum variation**” for the share of final energy delivered by renewable energies. It assumes sufficient availability of very reasonable electricity generation potentials from renewable energies at around 5 cent/kWh electricity generation costs, where mainly bigger wind-offshore-parks as well as solarthermal power stations are taken into consideration. This additional electricity generation is a source for electrolytic hydrogen generation (in combination with extended demand management, the electrolysis serves as a flexible consumer) and therefore essential for the wide introduction of hydrogen as an alternative fuel. With additional electricity generation from renewable energies of 238 TWh (at this moment this corresponds to about 60% of the demand from the end user sector), round about 70% of the clearly reduced fuel requirements by 2050 will be provided in the form of hydrogen in the “maximum version”. Furthermore approx. 65% of total final energy demand will be delivered by renewable energies.

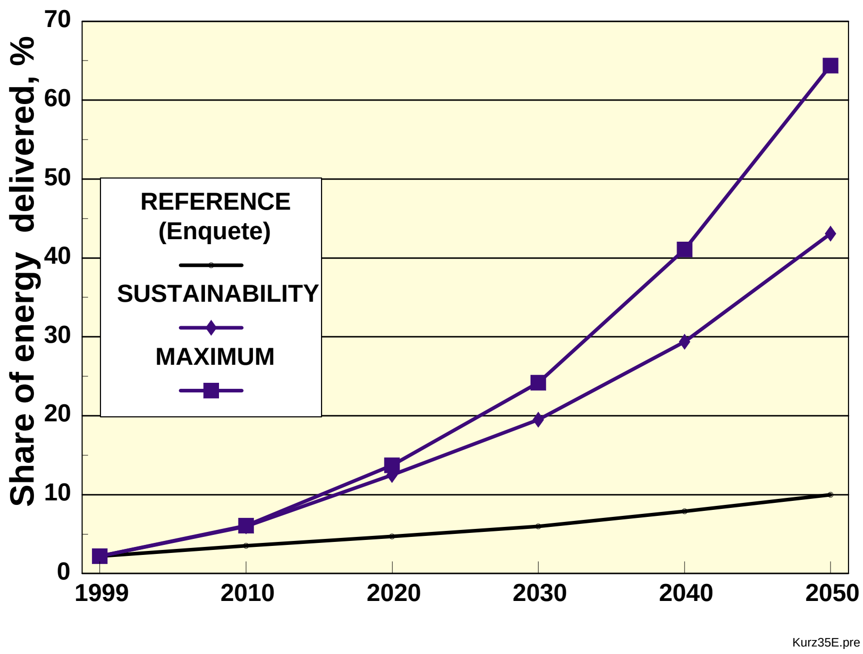

Figure 6: Development of the renewable energy segments of final energy consumption in the “sustainability” scenario in comparison to a “maximum version” and the reference scenario of the Enquete Commission.

After all, this outlined development should only be understood as a step on the way to a totally CO_2-free energy supply. Thus an extrapolation of the maximum variation leads to the **almost entire avoidance of energetically caused CO_2** with a share of hydrogen from renewable energies of around 30-35% of final energy consumption; the transportation sector will be supplied at 85% and the heating sector at around 30% with hydrogen. In the electricity sector the remaining condensation power stations will also operate with hydrogen to cover the necessary reserve power.

Under positive circumstances – which means a reduction in energy consumption corresponding to the sustainability scenario with the simultaneous growth of renewable energy corresponding to the maximum version – the resulting energy demand could actually be completely covered by renewable energies by around 2070; with an extension of renewable energies at a lower speed, the substitution of fossil energies could extend as far as 2100 (Figure 7).

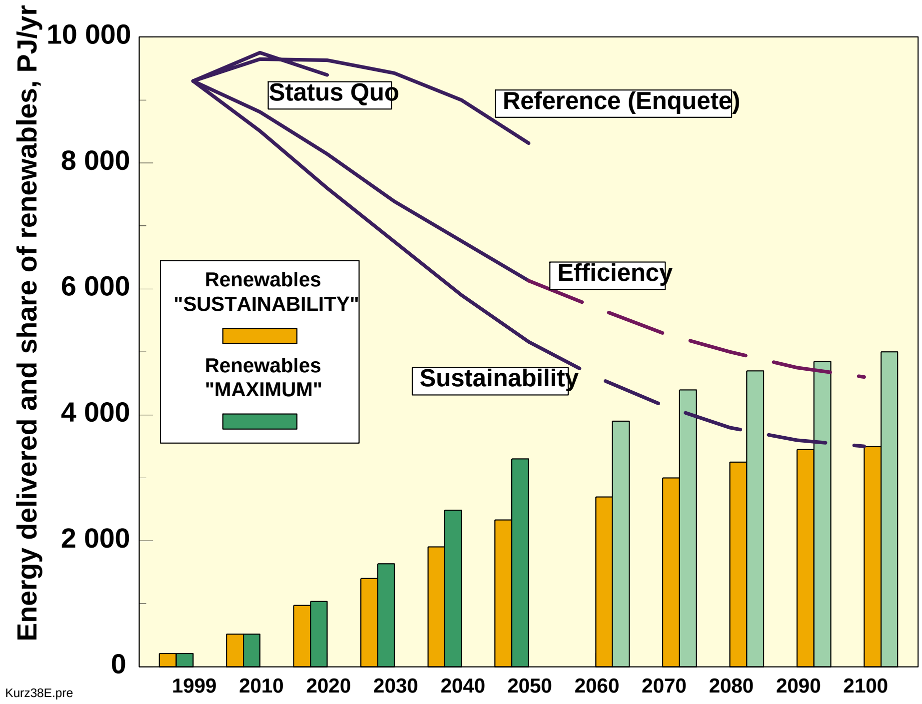

Figure 7: Interaction of energy efficiency and the extension of renewable energies, and possible further development derived of the most important scenario variables in the course of this century.

Reaching the target is definitely only possible when the extension of renewable energies and saving energy by the use of energy-efficient appliances and production processes are closely interwoven. Only by the comprehensive introduction of renewable energies together with an energy saving offensive can the present sustainability deficits in the energy supply be expected to clearly diminish without simultaneously causing new types of problems. Right from the start, attention should be paid to an economic and ecologically optimised extension of renewable energies. This applies to the use of wind energy potentials (onshore as well as offshore), the retrofit of hydroelectric power plants (especially the big plants in the south of Germany) as well as the further extended use of biomass, geothermal energy and photovoltaic.

At the beginning the effects of relief from the new technologies appear slow because of their relatively high costs and their still small contribution to energy supply. For this reason sufficiently high and long-lasting preliminary work is required. That is precisely why the coupling with a strategy for the highly profitable and rational use of energy is essential. The energy policy must face both tasks if it wants to reach its targets. This is necessary not only against the background of national development perspectives, but also as a part of global responsibility. If the technologies necessary for a global sustainable energy supply in the industrialized countries are not developed and their introduction to the market is not advanced, the world-wide problems are not to be solved. In contrast to former times, it does not solely depend on developing individual technologies. Rather, it is necessary to have an interlaced thinking and to integrate the single technologies into intelligent approaches (e.g. decentralized power supply and heat networks). This also requires new co-operation forms among the participants (e.g. energy industry, equipment construction, banks).

A sustainable energy world differs in many points to the world we know today. As shown in the context of the scenarios in which the change processes for the participants involved can be described, this does not give any cause for concern. Changes cannot be avoided to reach the aims of sustainability, and for the persons involved this represents both a challenge and an opportunity.