Introduction

Renewable energy has the greatest energy and technical potential of all known sources of energy. It is environmentally- and climate-friendly, it can be used worldwide, in a few years time it will be the cheapest source of energy, and it enjoys an extraordinarily high social acceptance. Renewable energy is a domestic source of energy and can gradually reduce the use of coal, oil, natural gas and nuclear energy in the power and heat market, and in the long term it can replace these completely and permanently. For this reason it reduces dependence on energy imports, increases the country's energy added value, and creates jobs.

In the last two decades, technological achievements in research and development, based on an energy policy framework which ensures a high degree of investment security for the market introduction of new technologies, has made the use of renewable energy in Germany more efficient and more sustainable.

While transforming the current energy system into a sustainable energy service economy based on renewable energy, electricity, as the central component of this economy, is becoming more and more "green". This is linked to a paradigm shift in power plant operation and the market, integrating renewable energy into the network and the system: away from the previous base load philosophy, based on large centralised fossil and nuclear power plants, to an increasingly large share for decentralised, fluctuating energy from renewable sources, which can be supported by a variety of measures: gas-fired power stations that can react quickly, combined heat and power plants linked to virtual power stations, load and generating management processes linked to smart grids, and efficient storage technologies.

Efficiency technologies become much more important when linked to renewable energy. This is because the goal of a high share of renewable energy in the overall energy supply can only be achieved if in the medium-term more of the existing technical and economic efficiency potential is developed. In the area of space heating, this includes the construction of low-, passive or even energy-plus houses.

In the transport sector, in the medium- and long-term, electromobility will become an important element in climate-friendly mobility, if the electricity for this is completely supplied by renewable energy. If car batteries are integrated bi-directionally into the power network, these can be used to increase security of supply. Electromobility is supplemented by using hydrogen and methane, and fuel for cars and planes which is derived from this.

These developments are happening because politics gives climate protection a high priority. In particular, the targets and requirements set by the EU and the Federal Government have significantly improved opportunities to develop renewable energy and energy efficiency technologies.

In the last 20 years, the consistent policy of market introduction in Germany, together with a long-term research and development policy, has led to a quicker than expected market and technological developments. This remarkable progress shows that if the innovation dynamic is sustained, by 2050 an energy system can already be realised in Germany which is 100% based on renewable energy and energy efficiency.

Examples of technological advances in recent years

- **Energy efficient construction:** significant reduction in demand for heating, cooling, ventilation and lighting in buildings by increasing efficiency in civil and systems engineering (low energy, 3-litre and passive house).
- **Combined Heat and Power:** Increase in efficient energy supply and use by the possible combination of renewable energy technology with combined heat and power (CHP), or with heat pumps.
- **Photovoltaics:** Continuous cost reduction by an average of 7% per year in the last 10 years by increasing efficiency, the more efficient use of materials and new production technologies [1].
- **Solar thermal power plants:** Development and construction of solar thermal power plants with large energy storage [2].
- **Electromobility:** Developing electromobility and the related opportunity to be able to also use renewable energy efficiently in transport.
- **Biomass:** Development of the polygeneration process to use energy from biomass, to produce electricity, heat, cooling and fuel.
- **Hydrogen:** hydrogen production by high temperature electrolysis with efficiencies of up to 80% [3].
- **Fuel cells:** fuel cells are being tested in large-scale field tests for use in energy supply in buildings, in private transport and in local public transport.
- **Renewable methane:** New conversion technology, to produce renewable methane from renewable electricity and CO_2. The gas network can thus be used directly as a large store for renewable energy. (see Chapter 1.2.3.3).
- **Combined cycle renewable power plant:** the development of combined cycle renewable power plants for the coordinated interaction of different RE technologies.
- **Offshore wind power plants:** the development of the use of offshore wind energy with a new generation of installations and improved forecasts of wind power output based on energy and meteorological methods.
- **Network integration:** the development of inverters, which will increasingly take over system services for network stabilisation. Accurate forecasts for predicting the output from wind and solar power plants.
- **Smart Grids:** The development of smart grids in conjunction with smart metering: Intelligent distribution grids for power linked to time-of-use tariffs for load management [4].
- **Solar heating and cooling:** increase in the efficiency of solar thermal collectors and systems for supporting space heating. Development of the use of process heating and solar thermal cooling.
- **The solar active house:** development of a solar active house, which is 50% to 100% heated by thermal solar collectors [5])

The successes of innovative technological development have contributed towards constant advances in the energy policy objectives of the Federal Government, EU member states and the European Commission.

Examples of economic and political advances in recent years

- As mentioned above, costs fell more quickly and there was a more rapid market introduction than expected for renewable energy for power generation.
- Enactment of the EU directives with the 20-20-20 targets, which make it economically worthwhile to think of a European interconnected electricity network.
- The social acceptance of renewable energy has developed quickly and favourably. Survey results show 80%-90% approval.
- The EEG [Renewable Energy Act] was supplemented in Germany by a Renewable Energy Heat Act (EEWärmeG).
- The BMU [Federal Environment Ministry] has currently set a target of completely converting energy supply in Germany to renewable energy by 2050.
- The BMWi [Federral Ministry of Economics and Technology] has set a target of reducing CO_2 emissions by 80%-95%, compared with 1990 levels.

Similarities and differences in existing energy scenarios and reports

a) WBGU [German Advisory Council on Climate Change] report

In its basic structure, the outline of how the energy supply system 2050 will function (see Chap. 1.3) is similar to the WBGU report "Transformation", which is currently being prepared [6]. In the WBGU 2008 report "A world in transition – future bioenergy and sustainable land use" [7], the potential for saving primary energy by changing to energy supply using renewable energy is convincingly described. For this reason this publication, whose technical aspect was covered by the Fraunhofer IWES [Institute for Wind Energy and Energy System Technology] (Schmid, Sterner), was the basis for the diagrams for transforming the current energy system to that of 2050. In addition, in the Energy Concept 2050, reference was made to the ambivalence towards using biomass for energy use, as is also discussed in the WBGU 2008 report: on the one hand, bioenergy has a significant sustainable potential, on the other hand, the risks for food security, biological diversity and climate protection cannot be ignored.

b) DLR [German Aerospace Centre] lead scenarios

2008 and 2009

The Energy Concept 2050 has a productive relationship with the BMU's 2008 and 2009 lead scenarios [8], [9], and with the preliminary work carried out by the DLR and the Fraunhofer IWES on the 2010 lead scenario. For many, these scenarios provide evidence for a system-analytical basis of the Energy Concept 2050 on transformation (Chap. 2), and above all for an economic consideration of this (Chap. 2.5). Until 2020, the papers are very similar in their most important assertions. However, the following differences should be pointed out:

- The Energy Concept 2050 takes into account the BMU's request to devise a concept for energy supply with 100% renewable energy to 2050. In contrast, the last lead scenario to be published, in 2009, only had a target of 50% renewable energy for the year 2050, but in the 2010 lead scenario, which is currently being prepared, for the first time two 100% targets are also being analysed: one version with hydrogen and one version with methane as long-term storage.
- The 2009 lead scenario was not yet able to take account of the new potential of renewable energy - as listed above – and the significant expansion in PV.
- In contrast to the lead scenarios, the Energy Concept 2050 does not take into account the short-term pragmatic implications, but sees its task as to draw up a coherent Energy System 2050 on the basis of new technolo-

gical knowledge, and to specify the energy and research policy requirements that are associated with this.

c) SRU [Advisory Council on the Environment]-May 2010 report

The Advisory Council on the Environment (SRU) has published a report with the title "100% renewable energy power supply to 2050: climate-friendly, secure, affordable" [10], which largely agrees with the views of the FVEE's group of authors on electricity. However, the Energy Concept 2050 expects higher electricity demand, as it includes the expanded use of heat pumps and electromobility. As much of the information in the SRU report is presented in a more detailed, analytical way, the concept refers to this report in some chapters, with the agreement of the SRU and colleagues in the DLR.

d) WWF study of October 2009

The study "Blueprint Germany – a strategy for a climate safe 2050." [11] is a study which covers all energy demand sectors. It relates to the Energy Concept 2050, as it also derives from the question of how an energy supply that is completely based on renewable energy could look in 2050.

When calculating the volume scenario for energy demand in 2050, the Energy Concept is particularly oriented towards energy demand in the transport sector, which is analysed in the WWF study. However, the difference is that as far as possible, the Energy Concept 2050 abandons the use of biomass as a fuel.