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Convention of National Associations of Electrical Engineers of Europe

ELECTRICAL POWER VISION 2040 FOR EUROPE

A DOCUMENT FROM THE EUREL TASK FORCE

ELECTRICAL POWER VISION 2040

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Electrical Power Vision 2040 for Europe

Study by EUREL

Short version

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1. Introduction and motivation

Energy prices are rising from year to year in a speed that is much faster than the rate of price increase. Considering the oil price this increase was over 10% p.a. in the last 15 years while the general rate of price increase was only 1,5% p.a. Experts consider that the ratio of consumption versus exploration of oil and gas is already greater than 1 which mean we consume more than we explore.

Parallel to the resource scenario the climate scenario is also seen as an issue. The meteorologists found out that the average surface temperature of the earth is rising and will have disastrous consequences on our lives if not stopped. It is assumed that the greenhouse gas (GHG) emissions are the cause for the abnormal temperature increase (Figure 1). As consequence of the above mentioned phenomenon the national and international political bodies are discussing the “energy problem” and are working on possible solutions.

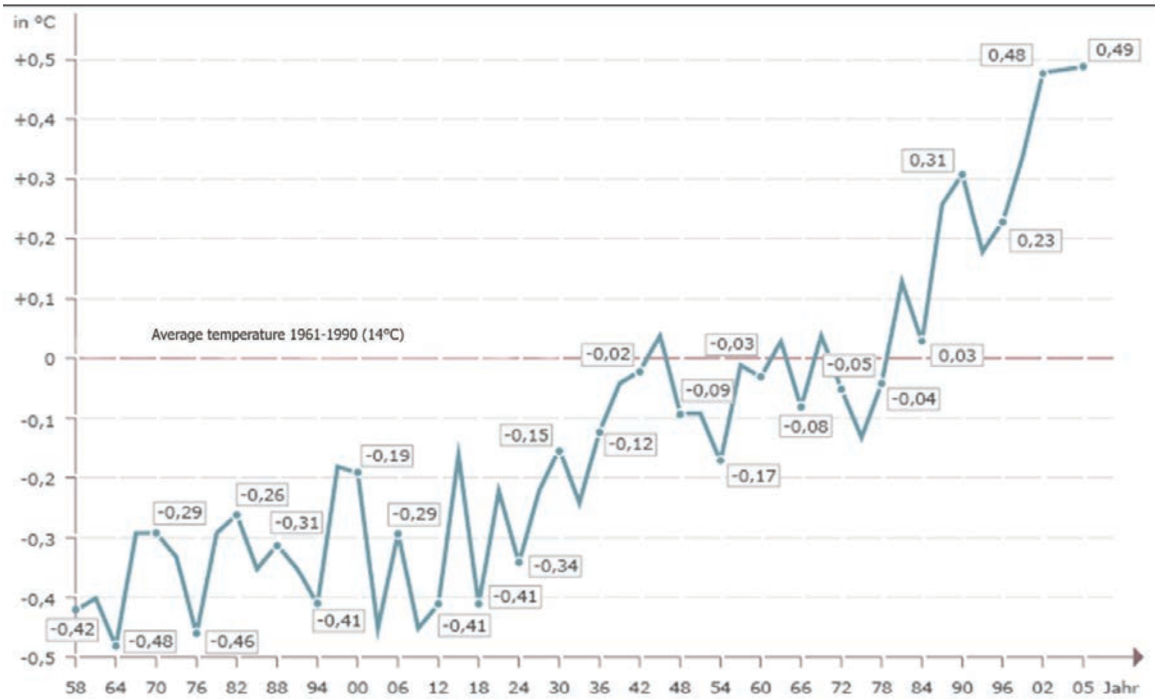

Figure 1: Development of the average surface temperature of the earth

In March 2007 the EU Heads of State and Government set a series of demanding climate and energy targets to be met by 2020, known as the "**20-20-20" targets”**. These are a reduction in the EU greenhouse gas emissions of at least 20% below 1990 levels, 20% of EU energy consumption to come from renewable resources and a 20% reduction in primary energy use compared with projected levels in 2020 to be achieved by improving energy efficiency.

On November 10th, 2010 the European Commission has set up "**Energy 2020 - A strategy for competitive, sustainable and secure energy**". The strategy defines the energy priorities for the next ten years and sets the actions to be taken in order to tackle the challenges of saving energy, achieving a market with competitive prices and secure supplies, boosting technological leadership, and effectively negotiate with our international partners.

And finally on December 15th, 2011, the European Commission communicated the "**Energy Roadmap 2050**". The EU is committed to reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050 in the context of necessary reductions by developed countries as a group. In the Energy Roadmap 2050 the Commission explores the challenges posed by delivering the EU's decarbonisation objective while at the same time ensuring security of energy supply and competitiveness**.** The Energy Roadmap 2050 is the basis for developing a long-term European framework together with all stakeholders.

Having the EU energy strategy and target in mind a task force of EUREL started work in 2010 to develop concepts and scenarios how to implement the European energy goals. EUREL is the Convention of National Associations of Electrical Engineers of Europe. In 2010 the special task force "Power Vision 2040 for Europe" was set up to investigate the future power supply of Europe. The task force´s experts were coming from utilities, industry and universities from various European countries. They have prepared this study on the electrical power supply for Europe for the next decades until 2050.

The study analyses in a first step the electrical power demand in the EU27 countries plus Croatia, Norway and Switzerland (EU27+) until 2050. This forecast includes the expected efficiency improvement potentials in the electrical devices and processes, it considers new applications like e-cars and it incorporates the trend in power demand of the recent years. In a second step the study describes the available technologies to produce electricity with a strong focus on renewable and their integration challenges. But also traditional technologies like water, fossil and nuclear source are investigated. Finally the study shows in three scenarios the possible power generation mix, the resulting CO_2 emissions and the investment costs for the transformation of the electrical power industry until 2050 taking in account the goals of the EU commission. The study gives conclusions and recommendations for the future European power supply system at the end of the document.

2. European power generation in the past

The growth of power generation in Europe followed mainly the demand increase in the residential and service sector as well as the development of the European Industry. Figure 2 reflects the situation in the 27 states of the European Union in 2008 as well as in Norway, Switzerland and Croatia, which is appreviated in the following as EU27+. Croatia is included since it will become a member of the EU in

July 2013. Norway and Switzerland are linked very tightly into the European electricity system. Although the primary energy mix is quite different in the various member states the backbone of the power supply in EU27+ is coal, gas, nuclear and water. Today oil and renewables do not play a significant role. This may differ partly in certain countries – i.e. Germany with regard to the renewables – but it is overall valid. The increase of power generation from 1990 to 2008 was 1,6 % p.a. or 37% overall. While the use of oil decreased by 51%, the gas fired power station output boosted by 311%. Coal contributed nearly the same amount to the energy mix in 1990 as in 2008, nuclear and water increased only slightly by 17%. The renewables (except water) started in 1990 practically with no contribution. The total output of the power stations in EU27+ was 3598 TWh in 2008 coming from 2770 TWh in 1990. While nuclear, coal and gas generated in 2008 approximately a quarter of the

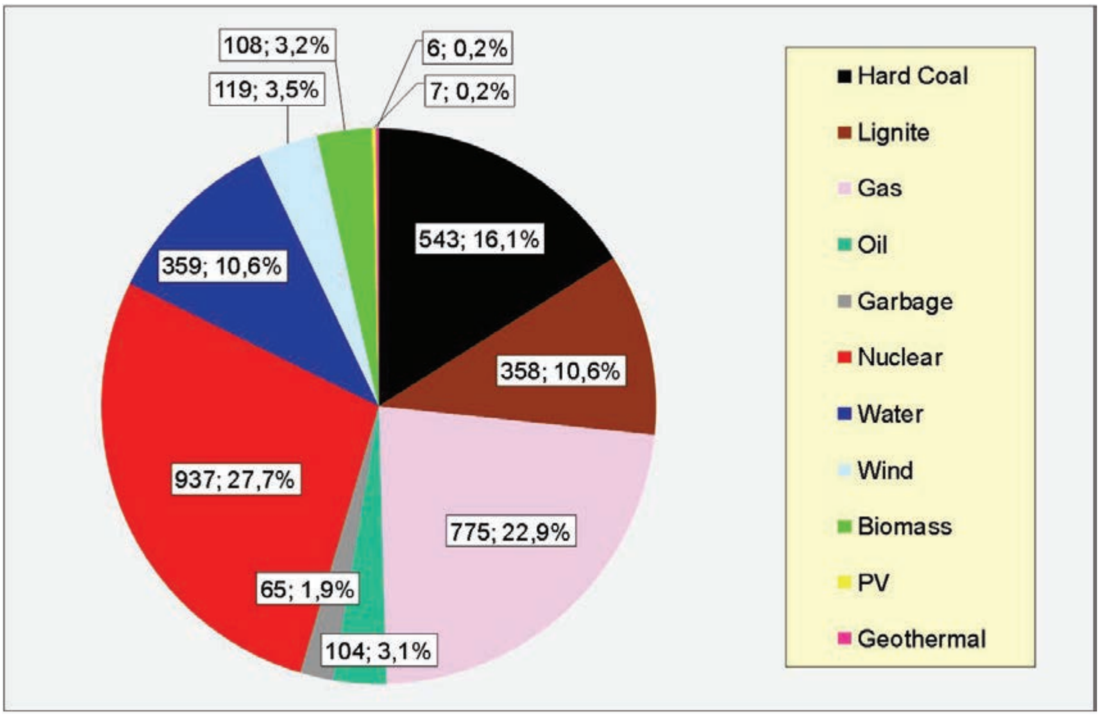

Figure 2: Power generation by primary energy in 2008 in TWh and %

total power supply, water delivered about 10%, all others together summed up to 12%. These overall numbers differ partially very much in the various member states.

Because of the very different operating hours per annum of the various types of power plants, the mix of the power plant capacities shows a different picture than the mix of the generated TWh´s. Nuclear power stations generated 27 % of the total power, but had only a capacity of 16% of the total. These numbers for coal are 27% resp. 17%. The gas based generation and the installed capacities are with 23% nearly identical. The oil power plant fleet shows a very different picture. The generation is only 3%, the installed capacity is16% of the total. Most of the oil power stations are not anymore in operation or are in standby. They are substituted by new, much more efficient gas power stations.

For renewables the situation is principally different. The operating hours depend on the availability of the natural resources water, wind and sunshine and cannot be independently controlled by the demand except for the bio mass. Therefore the full load operating hours are relatively low. An exception is the biomass. The relation of the shares of the total generation to the shares of the total installed power capacities is 11% to 17% for water, 3,5 % to 8% for wind, 0,2% to 1% for photovoltaic power generation while for biomass generation the relation is 3,2% to 2(!). This must be considered when the renewables will be expanded in the future.

Figure 3 shows the fast increase of the renewable power production in the recent years. While in 1990 the generation of electricity by wind, biomass, photovoltaic and geothermal resources was basically negligible, the contribution in 2008 to the total generation was already more than 7% or nearly 250 TWh.

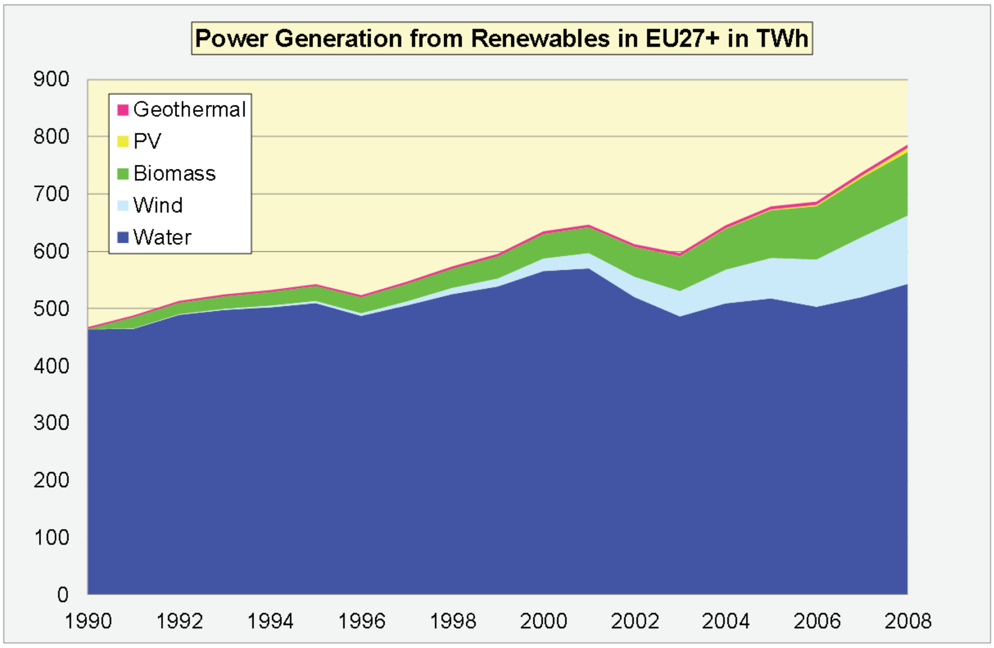

Figure 3: Development of renewables in EU27+ in TWh

3. Changing role of electric power

The main sectors of final energy consumption in EU-27+ in 2008 were in the areas of residential (24.6%), transport (32.6%) and industry (27.9%), while for the electricity consumption the sectors of the industry (40.4%), the households (28.2%) and the services (26.7%) were dominant. The transport sector has only a share of 2.5% on total electricity consumption but 32.6% on total energy use.

Urbanization of the world is in progress and is significant for electricity demand. In developing countries today about 45 % of the population is living in urban areas (Table 1), whereas in industrialized regions like in Europe already 75 % is reached. In the EU 100% of the population is supplied with electricity. In the industrialized countries the electrification rate is about 95 to 99 % in the urban areas but only about 60 to 70 % in the rural areas. One can say, urbanization is linked to electrification.

	1950	1960	1970	1980	1990	2000	2010	2020	2030	2040
D.C.	18.0	21.7	25.3	29.6	35.1	40.2	45.3	50.5	56.0	61.6
I.C.	52.5	58.7	64.6	68.8	71.2	73.1	75.0	77.5	80.6	83.5

Table 1: Urbanization rate in per cent of the total population in developing countries (D.C.) and industrialized countries (I.C.)

Electricity represents clean energy and is the ideal form of supply for densely populated urban areas. The following sectors will show increasing electricity demand in the future:

- End-use in the private sector
- Energy efficient buildings and smart cities
- Urban traffic
- Suburban traffic

Europe will change its generation scheme in the next decade toward at minimum 40% of renewable in energy end-use. Wind energy and photovoltaics will form the sources with the highest growing rates, while the classical fossil und nuclear power stations will keep their absolute value in installed power capacity, but will have lower time of usage which will shrink in some areas with high level of renewable energy sources (RES) to values below 2.000 h/a.

3.1 Changing role of electricity in the transport sector

In the field of transport trains, undergrounds and tramways have switched in history to electricity. Nevertheless the electricity demand of the transport sector has today only a share of about 2%. But electrification of the power train in cars, busses and trucks will show a growing tendency to electrification in the future.

A comparison of different power trains in relation to their specific energy demand in kWh per 100 km show that electricity driven vehicles are much more efficient than fuel driven cars. For the combustion drives the energy demand tank-to-wheel is about 80 kWh/100km while for electric drives supplied by renewable energy this number is about 25 kWh/100km. So the electrification of the cars will bring a reduction of the energy demand plug-to-wheel of about 70%. Furthermore the car batteries can be used as energy storage for renewable energy from photovolaics or wind and thus can save storage capacities in pumped storage hydro plants, which are limited. The electrification of all cars in Europe would need about 15% of the electricity demand but would save about 50% of the oil consumption.

3.2 Changing role of electricity in the residential sector

The “smart cities” initiative of the EU has the aim to bring more efficiency in the private end-use sector. It comprises the energy demand of buildings, households, urban industry and commerce and of the urban and suburban traffic. Two targets have to be brought together in this context: improving efficiency in the end-use and renewable energy development. By these measures the fossil energy demand should be replaced by renewable energy under the condition, that the standard of living should not be significantly affected. Electricity will play a major role in substituting fossil energy by renewables and will increase its portion on the end-use energy demand.

The total energy demand of a household can be reduced by about 65% by new thermal insulated buildings, new appliances, efficient illumination and changing from fossil to electrical cars. The saving of fossil energy is connected with increased electricity demand which will increase from 5400 kWh/a to 8200 kWh/a per household. But in total this will save energy and reduce greenhouse gas emissions. The additional electricity demand will come from applicatons like heat pumps, ventilation systems, home automation and electric car.

3.3 Future role of security of supply

Electricity from wind and PV represents fluctuating generation systems. The security of supply is therefore linked to an energy backup system, consisting of transmission and distribution grid, energy storage capacities and flexible backup power stations.

So in parallel to the renewable energy sources (RES) the traditionally centrally generated electricity has to be reinforced and adapted for the integration of the RES and maintaining the security of supply by flexible thermal and hydraulic power stations to enable system control.

4. Environmental, economic and political requirements on the supply security of electrical power

The following statements summarize the results of the policies of the European Union and the deliberations of the European Parliament until 2012 and take on considerations of national governments. They are not results of this study.

4.1 Green-house gas (GHG) reduction goals

The climate conference in Kyoto in 1997 has decided for the first time internationally binding targets for the reduction of greenhouse gasses like carbon dioxide, methane, nitrous oxide, hydro fluorocarbons and sulfur hexafluoride until 2012 by 5.2% compared to 1990. In 2010 the next to last World Climate Conference in Cancun agreed only to continue the implementation of the Kyoto - agreements without setting new targets for the period after 2012.

However, the EU has committed itself in 2007 under the target triple of “supply, competitiveness, environment", to reduce the CO_2 emissions by 2020 by at least 20% compared to 1990. But this would not be sufficient to limit the heating of the atmosphere within 2°C. Therefore, the bodies of the EU consider to increase the reduction target to 30% by 2020. By 2040, emissions are to be reduced by 60%. With the use of appropriate technologies no CO_2 should be emitted any more by the power generation industry by 2050.

With the "Declaration on the Future Energy Supply" of September 2011, the World Engineers Convention (WEC) together with national engineering associations stepped into the discussion of the international community on the search for an ecological, economic and socially sustainable energy future. Reducing the emissions will increase productivity, will save resources and will make energy affordable.

4.2 Electricity price policy and price control

The cross-border trade in electricity volumes will increasingly take place with the necessary expansion of the internal energy market. Therefore an EU-wide legal framework is needed to ensure transparency in price creation, to provide guidance for necessary investments in energy production systems and networks and to prevent market abuse. This requires that the energy regulatory authorities in the member states of the EU cooperate with the "EU Agency for the Cooperation of Energy Regulators (ACER)”. The collection of data for this work should be done only nationally, but with the mandatory transfer to the EU agency.

The “Regulation on Energy Market Integrity and Transparency (REMIT)” and the “Directive on the Taxation of Energy Products and Electricity “ which are in the process of the parliamentary discussion should be pursued. The market surveillance rules for electricity are to be adjusted to the rules of the EU emissions trading law. Power should be valued on the basis of the energy content and not on the basis of the CO_2 content. This energy content-based taxation will encourage more efficient energy use and energy savings.

4.3 Dependency reduction from suppliers of primary energy from outside the EU 27

The conversion of the centralized power generation structures with the consumption of mostly imported primary energy like coal, oil, gas and uranium to more decentralized renewable power plant systems opens the chance of reducing the import dependence from fossil energy sources. Today we spend per year € 290 billion or about 3% of the GDP of the EU member states for the import of oil, gas and coal. In Germany two recently published concepts for a future carbon-free energy supply with the title "Sustainable Energy System 2050," from the German renewable research network and "Towards 100% Renewable Power" from the Advisory Council on the Environment come to the conclusion that in Europe the potential of renewable energy resources is much higher than the demand for energy. However these statements assume that all EU measures are implemented consequently and in time to restructure the energy supply system.

4.4 Efficiency improvement to reduce costs and to protect resources

Increasing energy efficiency is clearly the most cost-effective part of the energy revolution. According a DENEFF study investments in energy efficiency measures amortize in less than nine years. According to calculations by the EU Commission (COM 2008/772), an average household can save 1000 € per year by energy efficiency measures. Overall, in the EU the possible energy savings by energy efficiency measures and in the energy conversion process of coal, oil, gas and uranium to electricity and heat are twice as much as the energy generation potential of renewables.

The EU “Directive on the Energy Performance of Buildings" from May 2010 provides the guidelines for the reduction of 40% of the total energy consumption in the EU. This is also true for the electricity consumption. The aim of the directive is a “Low-Energy-Building” with a very high energy performance. The energy for those buildings should come from renewable resources.

On June 22nd , 2011, the European Commission published a proposal for a "Directive on Energy Efficiency”. To achieve the 20% saving goal of the EU until 2020, a broad mix of measures are proposed.

As with other finite ressources such as coal, oil, gas and uranium we are dealing already today with the shortage of "rare" metals. The mining of those metals is coupled with the environmental pollution and significant energy consumption. Together with the restructuring of the energy supply system and our behavior on energy and material consumption we have to ensure the recycling of valuable resources after the end of the products´ life cycle This is the most important measure of efficincy improvemnet in the material usage sector.

5. European electrical power demand in the next decades

5.1 Development of power demand from 1990 to 2008

The power demand in the various member states of the EU is a mirror of the industrial, residential and services development state of each country. Electrical power substitutes more and more other forms of energy. This is the reason that the demand of power has continuously risen in the last decades. Figure 4, left side, shows the development of the power demand in EU27+ from 1990 till 2008 (Note: all data are from EUROSTAT). The figure is structured in the sectors industry, transportation (only electrical trains!), residential, services and agriculture.

The overall growth was 1,6 % p.a. over the whole period. The demand was 2290 TWh in 1990 and rose to 3042 TWh in 2008. The industry consumption grew by 0,8 % p.a. It had a share of 46% in 1990 and decreased to 40% in 2008. The residential sector increased with an average growth rate of 1,8 %, the services sector ramped up by 3,2 % p.a. from 465 TWh to 880 TWh. These changes reflect on one hand the switch in the industry sector from heavy power industry to more high tech industry and on the other hand the high investment of the industry sector in energy efficiency measures.

5.2 Estimation of the power demand until 2050

The model for the estimation of the power demand in the future, i.e. until 2050, is based on a combination of a top down and a bottom up model. In any case the demand is individually estimated for industry, transportation, residential, services and agriculture. The estimation is calculated by three basic components: firstly the development of the demand in the past is observed and put forward to the future to some extend, secondly the efficiency potential of the different sectors are taken into account and thirdly new applications powered by electricity (heat pumps, ventilation, e-cars, e-light trucks) are considered. Another important factor for estimating the future demand is the demographic factor. The number of the EU27+ inhabitants will decrease by 5 to 10% until 2050 but the number of households will rise and thus the number of used devices (e.g. refrigerators).

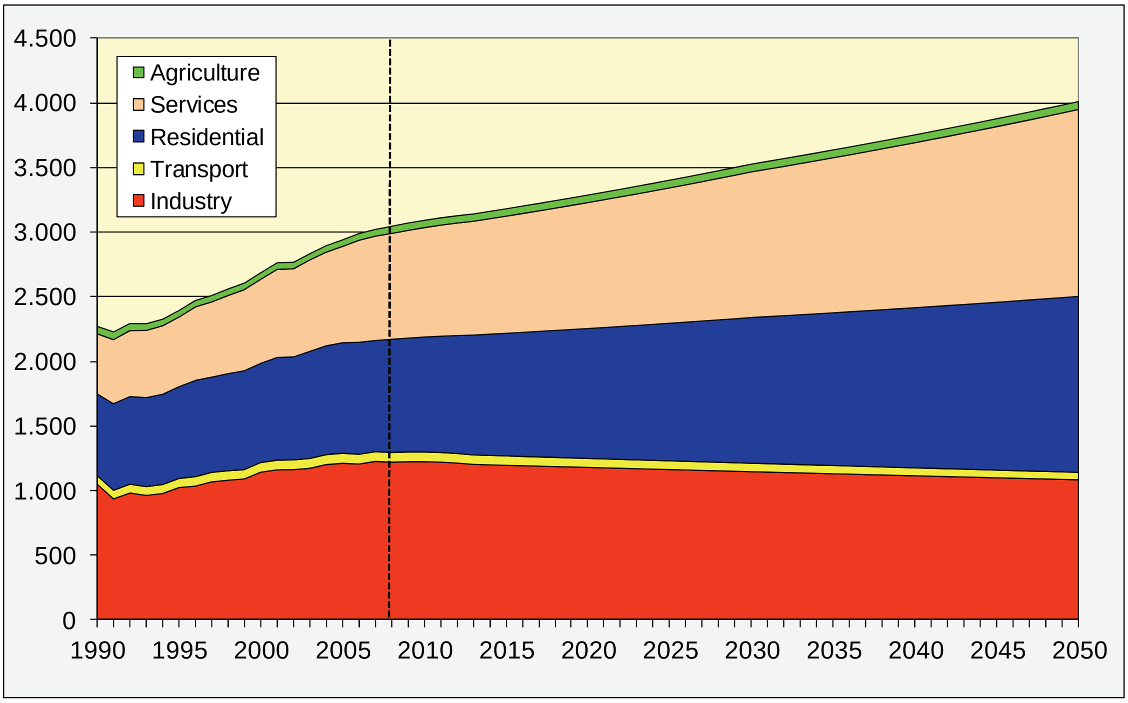

Figure 4: Power consumption in TWh in EU27+ until 2050 (conservative scenario)

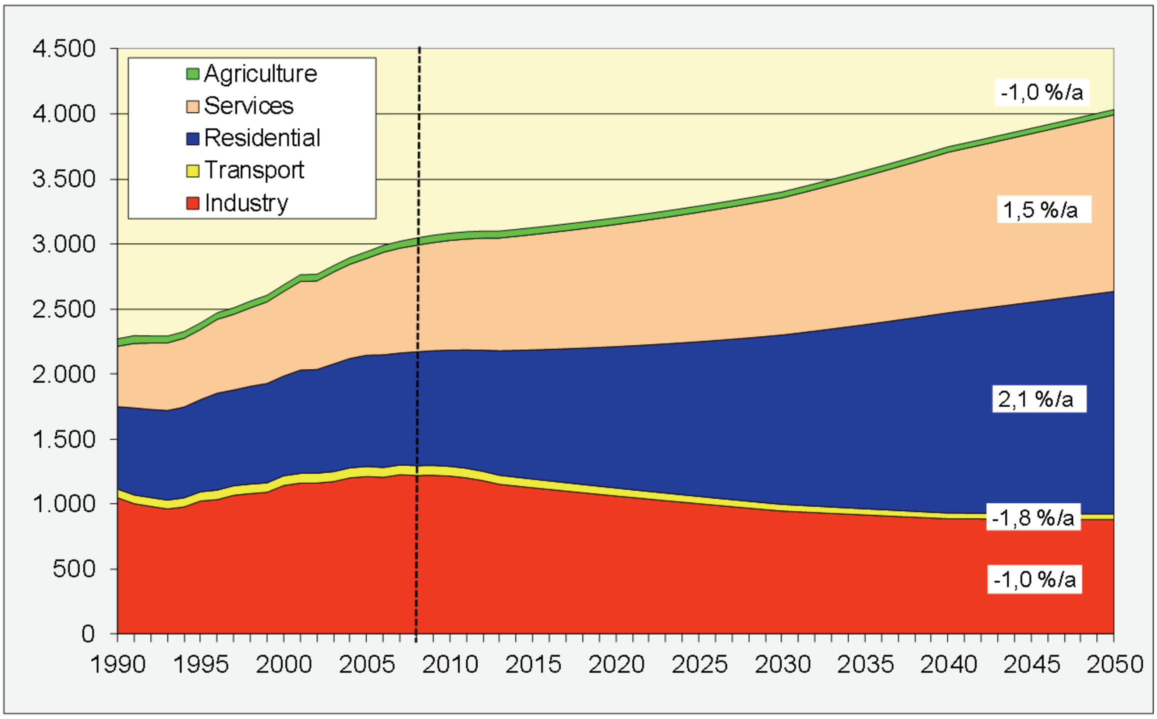

Figure 5: Power consumption in TWh in EU27+ until 2050 (progressive scenario)

The forecast is split into a conservative and a progressive scenario (figures 4 and 5). The conservative approach considers an efficiency improvement of 0,5% p.a. in industry and transportation and 1% in the residential and services sector, while the progressive approach is based on 1% yearly efficiency improvement in industry and transport and 1,5% in the other two sectors. In the conservative model it is assumed that in 2050 30% of all cars are e-cars and of all light trucks only 10% are e-trucks, in the progressive approach there will be 50% e-cars and 30% light e-trucks. These assumptions are the best with our today´s knowledge. The power consumption in 2008 was in the EU27+ 3043 TWh. On the basis of the above described estimation model the demand will rise until 2050 to approximately 4300 TWh. This is an increase of 1,2 % p.a.

6. Options for future bulk power transport and supply security of power

The value creation chain in electricity markets comprises three constituents: the production side (generation of electricity), the demand side ("consumption" of electricity) interlinked by transmission and distribution grids. The latter play a crucial role as they "transport" electrical energy from the power plants to the customer. The transmission system operates with high voltage levels over long distance. From the transmission level the power "flows" into the sub-transmission grid and eventually into the distribution grid. Transmission and distribution of electrical energy can be seen as different functions having different technical characteristics, i.e. in terms of voltage level, grid topology and used assets. This chapter only deals with the transmission system targeting questions of bulk power transport, i.e. the transmission of "massive amounts" of electricity.

6.1 The transmission grid in Europe – current situation and challenges

The existing power grid in Europe is a highly-interconnected system, spanning the whole of Continental Europe with connections to neighboring systems e.g. in Scandinavia (Nordel), the United Kingdom and Russia. The current structure of this meshed, supra-national system was largely influenced by available generation technologies. In the 1950's efforts started to couple the different national networks to a supra-national system of networks. This was achieved through the foundation of the UCTE. In 1958 the transmission grids of Switzerland, France and Germany were coupled. During the following decades other national networks joined the UCTE. In 2008 the UCTE was replaced by its successor organization ENTSO-E with 41 members. Technically this means that all transmission systems of the member countries are operated together as one so-called synchronous zone.

The national liberalization processes were supported by legislation from the EU targeting the creation of a single European electricity market. Generally, the liberalization efforts led to a significant increase of cross-border trading activities, and in turn, to an increase of cross-border power flows. Another challenge is the infeed of fluctuating electricity like wind and photovoltaic energy. As in a power system supply and demand always have to be balanced, appropriate measures must be deployed in order to react to variations on the generation as well as on the load side. The change of the production mix towards higher shares of infeed from fluctuating renewable sources leads also to an increased demand for reserve power. Investments into off-shore and on-shore wind farms lead to substantial infeeds away from the existing load centers. The deployment of small decentralized and renewable generation technologies has changed the infeed from higher to lower voltage levels. Infeed from lower voltage level are becoming increasingly common.

6.2 Market options for the facilitation of future bulk power transport

It is expected that large scale integration of renewable sources puts congestions on power balancing mechanisms even in large systems. For the efficient integration of renewable sources, new market structures are required. One of the new approaches is to combine the different national market places in order to use trading and balancing procedures across borders.

Another step forward is the coupling of balancing markets for real-time operation to deploy balancing resources (secondary reserves) from other control areas. When a certain control area monitors an area control error (ACE), balancing services could be deployed from TSOs across the border.

6.3 Technological options for the facilitation of future bulk power transport

When it comes to network investments different technological choices exist that depend on the specific project. Generally, a cross-border interconnector can be regarded as a coupling between two neighbouring grids. The network parameters and the method of operation of either system influence to a large extend the final investment decision. Most networks around the world are based on alternating current (AC). Thus, if there are no specific reasons of technical or economic nature, these networks will be coupled AC synchronously.

In some cases, synchronous coupling is impossible or economically not desirable, namely with coupling between systems with different nominal frequency or a different mode of frequency and voltage regulation, with long cable connections (distances greater than 30-40 km) or with a weak coupling between two grids because of stability problems. In these cases, instead of using AC, energy may be transmitted by high voltage direct current (HVDC) using an overhead line, an underground or submarine cable, or a combination of these. Converter stations to switch between alternating and direct currents are needed at both ends of an HVDC connection

6.4 Case Study

The following case study is intended to give an indication of how network investments will influence total generation costs in Europe. The results were computed for a scenario in 2050 with high-infeed from renewable sources, such as wind and photovoltaics. The network investment costs for such a scenario amount to 61 billion €

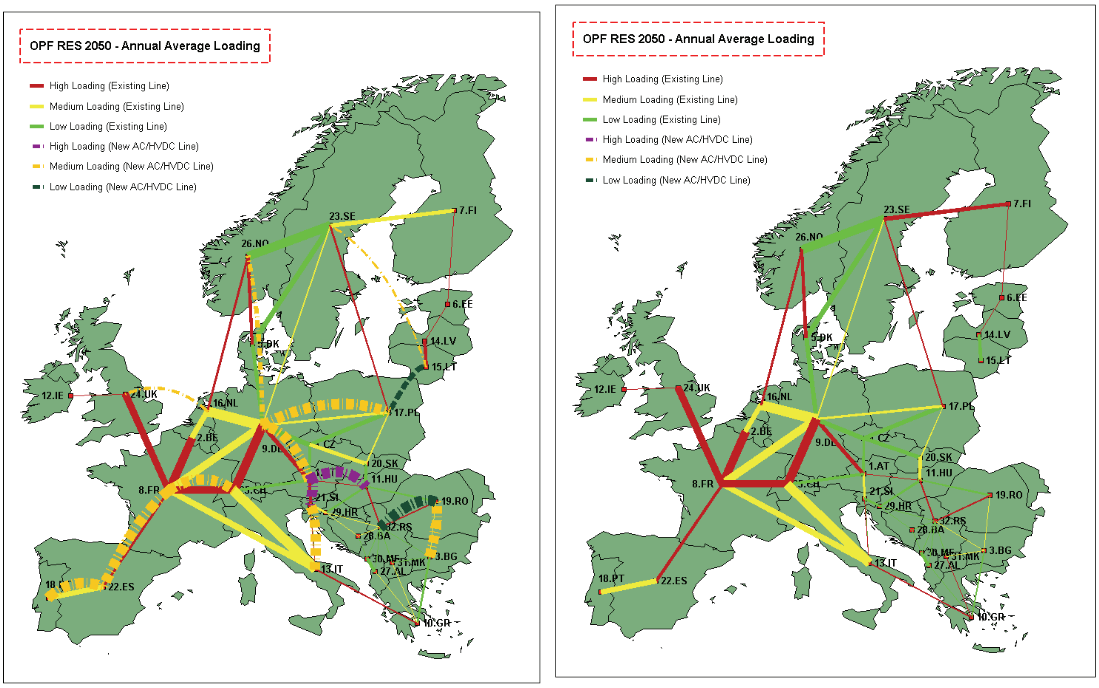

Figure 6, right side: Annual Average Line Loading in 2050 (Base Case); left side Annual Average Line Loading in 2050 (HVDC Expansion).

7. Options for future power production

7.1 Fossil with CCS

Notwithstanding the desired long-term reductions of energy-related CO_2 emissions, it seems unlikely that fossil fuels will be entirely phased out by the mid-century, simply because of the substantial resources of coal and natural gas (both conventional and unconventional) worldwide. It is therefore important to look for ways to develop technologies that permit fossil-fueled plants to operate as (nearly) zero-emission power plants (ZEPPs). There are typically three sorts of concepts that are applied to “capture” the CO_2 from fossil-fueled power plants:

1. Post combustion concept: Capturing CO_2 from exhaust gas
2. Pre combustion concept : CO_2 will be extract from the synfuel
3. Oxyfuel concept : Combustion with pure oxygen

After capture, the CO_2 may be stored and disposed of permanently in distant geological storage site. For geological storage, several possibilities exist. But there seems to be considerable public and political opposition against geological storage sites on land in several European countries. It has also to be considered, that the CCS process costs about 10 to 14 % of the production efficiency of a fossil-fuel plant.

7.2 Nuclear

Energy generation by nuclear fission is a vital field of industrial activity as well as an area of multiple diversified research and development efforts worldwide. Political decisions, phase-out decisions in some countries, are confronted with new building projects in others, and numerous, quite promising mid- and long-term development programs are on-going. The state-of-the-art is characterized by generation III systems,

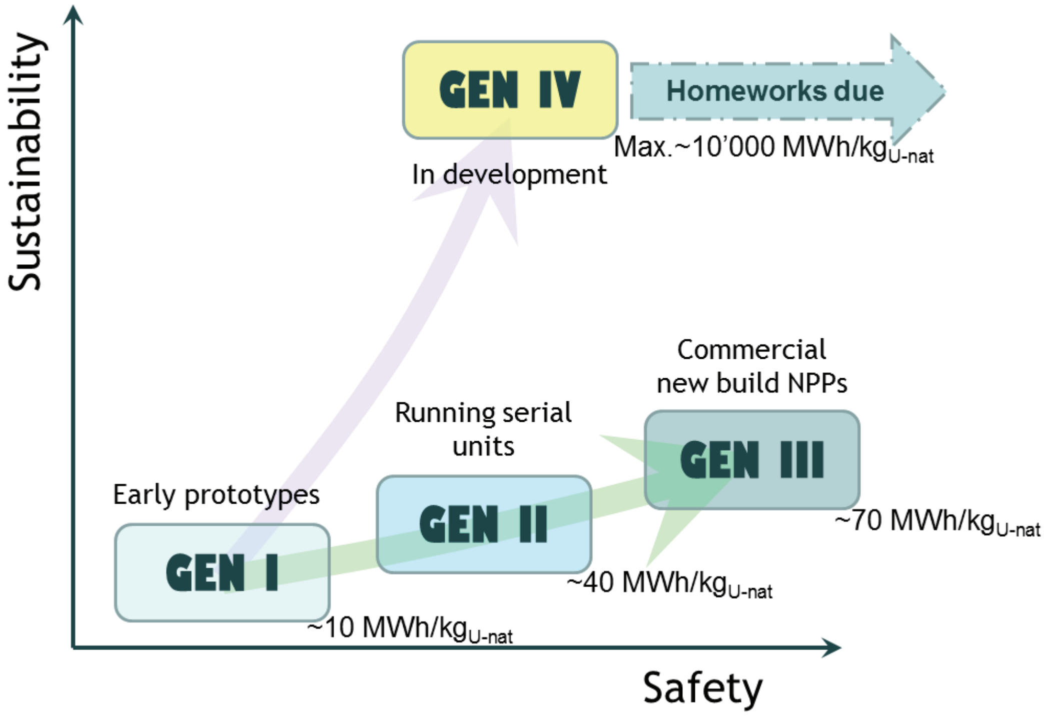

Figure 7 Generations of nuclear power plants

which were developed with the goal to abandon the necessity for measures of external emergency response by deterministically excluding either the core damage or the release of large amounts of radioactive substances in case of such an event, whereas the core damage frequency was drastically reduced by strengthening the protection and emergency systems of the reactor. In the end, newly built projects offer a very high degree of safety, but it is not possible for fundamental reasons to eliminate a residual risk completely. However, major accidents such as those of Chernobyl and Fukushima, happened on plants of generation II that were not sufficiently upgraded with regard to the current knowledge on severe accidents and external events initiating an accident. In Chernobyl and Fukushima, it was therefore not the corresponding current state-of-the-art that failed, but the way the state-of-the-art was taken into account by the utilities and the regulator.

Nuclear technology offers solutions that can provide an outstanding gain in sustainability, both at the front and the back end of the fuel cycle. Generation IV systems are not just subjects of purely theoretical considerations – the general feasibility of most of the reactor concepts has already been experimentally proven in considerable scales, which are sometimes very close to installed electrical power rates interesting from the point of view of a commercial use. Still, the development has to continue, mainly to solve open issues concerning safety and reliability.

7.3 Wind

The expansion of the wind energy use for power generation in the EU has a 25 year old history. In 1990 the installed wind capacity was approx. 500 MW. With a total installed wind fleet capacity of 94.000 MW by the end of 2011, the EU has approx. 40% of the current worldwide installed fleet of 238.000 MW. Beyond the ongoing development of the new onshore green-fields with good wind conditions we expect additional two growth trends

1. Wind use in regions with poor wind conditions supported by partial replacement of the wind plants of the first generation (repowering). The increase of the hub height and reduction of the specific power per rotor surface will enable a significant improvement of the energy yield in region with low wind speed.

2. Wind use of offshore – plants, preferred in shallow waters with excellent wind speed conditions and high load factors from about 40%.

One of the main challenges of the grid-integration of offshore wind plants concerning system operation with significant contribution from wind generation is the balance between production and consumption in the presence of wind variability. The improvement of weather forecasting and implementation of flexible thermal plants to cover the residual load are promising mitigations, which are perceived to address these challenges. Moreover, further capacity increase and strengthening of the European network is anticipated to be needed in order to integrate large and quickly increasing amounts of wind capacities. Therefore, the accelerated construction of the offshore grid and a further expansion of the onshore grid are of high importance.

Over a relatively short life time of the modern wind technology many technology trends have already emerged. The average size of new installed turbines has increased from 180 kW in 1990 to 6 MW in 2012.

7.4 Geothermal

Geothermal energy is an indigenous, environmentally friendly and virtually inexhaustible, renewable energy which can be used in every country on earth. 99% of the Earth's mass is hotter than 1000 °C, 0.1% colder than 100 °C. Additionally, a radioactive decay of uranium, thorium and other fission products is active within the earth and constantly generates new heat. Some of this heat is radiated into space. These losses are marginal compared to the energy content of the Earth's mass and to the energy that is constantly generated. A model calculation has shown that the earth has cooled only about 300 - 350 °C over the last 3 billion years.

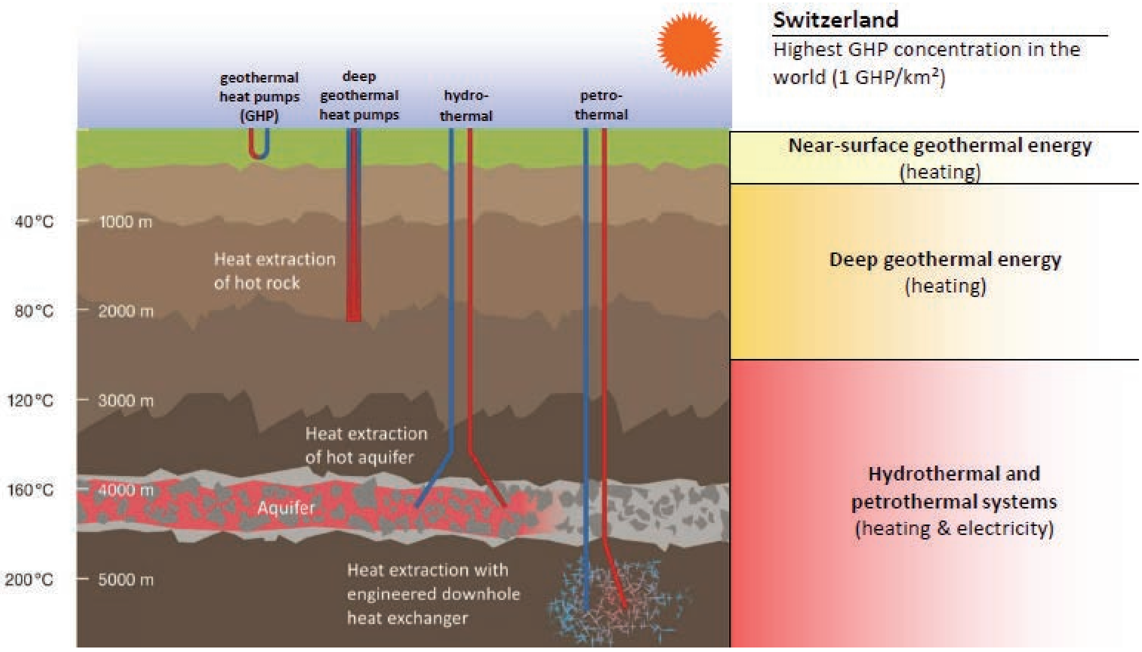

Figure 8: Geothermal energy use [ETHZ]

If the entire global energy consumption was generated by geothermal energy today, it would only be a fraction of the heat generated in the earth's interior or the daily energy radiated into space. Knowing this, one can say that terrestrial heat is a virtually inexhaustible energy source, available 24 hours a day, 365 days a year. With today's investments, one can only use geothermal energy in the Earth's crust, which is between 20 and 65 km thick, under the Oceans 5 to 6 km. The average thermal gradient is 2.5 - 4 °C per hundred meters depth. Geothermal energy – in the form of hot springs – has been used by our ancestors. Today, the worldwide installed electrical capacity of the geothermal power plants is about 11 GW electric power and 50 GW heat.

Today we can differentiate between 4 systems:

- Surface geothermal energy in layers between 150 and 600 m, mainly used for home heating or cooling.

- Deeper geothermal energy for heating purposes going down to 2000 m

- Hydrothermal systems using hot waters (aquifers) in deep water-bearing layers between 2500 and 4000 m (utilisation for heat and electricity)

- Petrothermal systems using at least 2 holes which are drilled into the basement (granite or gneiss) down to 5000 m or more. Water with high pressure is pressed into the rock. This opens up naturally occurring rock cracks (fracturing). So one can realise a natural heat exchanger. Such a heat exchanger with an edge length of 1 km, i.e. a cube of 1 km^3 at a temperature of 200 °C may produce 10 MW of electric power for 20 years.

Surface geothermal energy can be used to generate heat (and cold) using heat pumps practically all over the world. Hydrothermal systems are quite difficult to locate, except in cases where hot water escapes or hot springs exit the surface (Larderello in Italy).

Basically, petrothermal systems can be used worldwide. Because of the higher temperatures needed, these systems are mainly suited for electricity production. To date, there are pilot or research projects (Soulz sur Forret). A considerable research effort is still needed to make such systems widely useable. If this breakthrough takes place – which no doubt will happen one day – this technology can substantially contribute to the substitution of electricity production by fossil sources.

7.5 Photovoltaics

The energy of solar radiation can be used directly in the form of heat or converted to electricity using solar cells. It is assumed that solar radiation has a constant value since ancient times. On the edge of the Earth's atmosphere it is 1,*367* kW/m². A part of this radiation is reflected from the atmosphere, a part absorbed and converted into heat and most of the radiation reaches the earth's surface. The intensity of the radiation does not only depend on the time of day, but also on meteorological conditions as well as altitude and latitude.

The sun is the largest energy source that can easily be used on earth. The annual solar energy quantity that reaches the earth is 1.5×10^{15} MWh. This represents more than 10.000 times the total energy consumption of humanity in 2010.

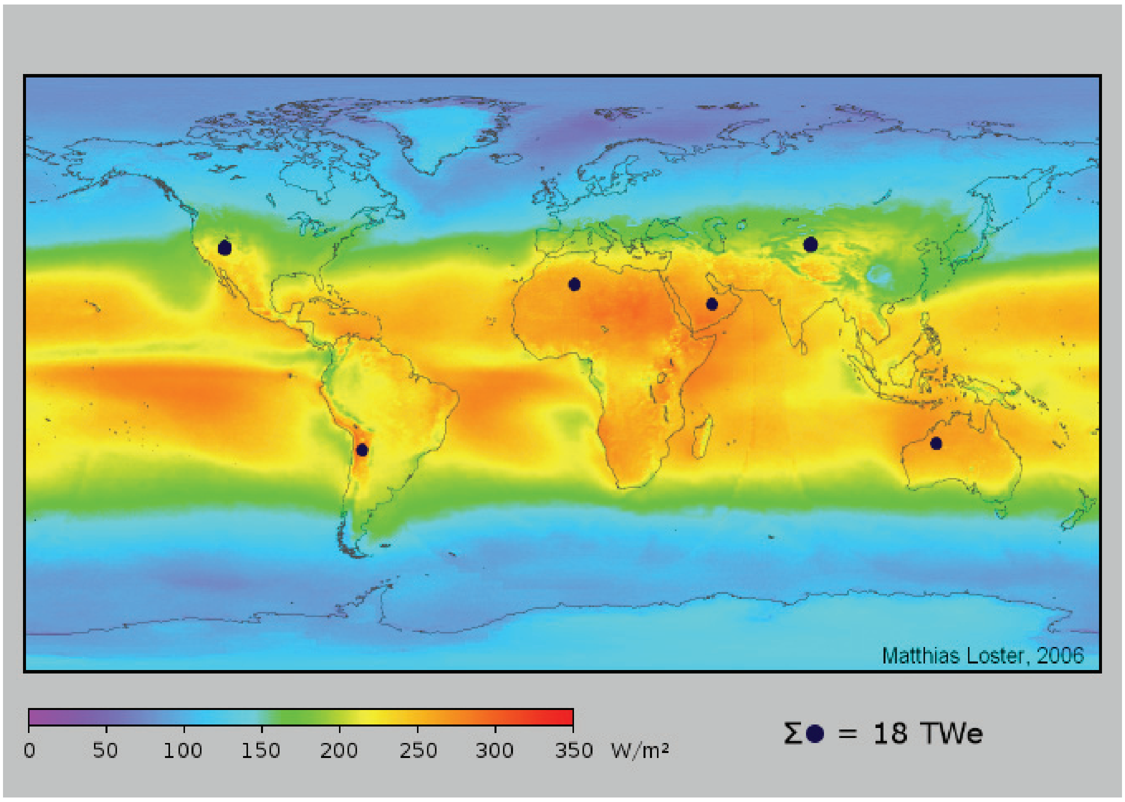

Figure 9: Average solar irradiance

Depending on the time of day and season and on altitude and latitude, the irradiated solar energy is about 1000 W/m² in central Europe and 2500 W/m² in the Sahara desert. If the current efficiency of industrially manufactured photovoltaic modules is considered to be 14-20 %, an area of around 6 – 8 m² is needed to install a power of 1 kW. The time in which the solar radiation is sufficiently strong for electricity production with solar cells is 800 hours in Germany, in northern Italy 1100 hours. For comparison purposes: a year has 8760 hours. Photovoltaic is a stochastic energy. To compensate the fluctuations conventional power plants are necessary, but also tin case when the sun is not shining as on cloudy days or in the night.

7.6 Concentrated Solar Power

In addition to the direct conversion of solar irradiation to electricity by means of photovoltaic cells, an interesting indirect conversion technology, usually designated as “concentrated solar power” (CSP) is often advocated. In the CSP technology, solar irradiation is focused onto a focal point where it heats up a particular liquid substance with the eventual goal to drive a thermodynamic cycle to produce electric power. In contrast to PV, which is mostly utilized as a distributed or decentralized electricity-generation source, CSP is usually considered for large-scale applications. CSP has the advantage over PV that it can incorporate large-scale (thermal) storage to deliver a “more constant” electrical output, if so desired. As a corollary, it is a generation technology that is dispatchable, clearly augmenting its value. A drawback for

Europe is that the technology is only economically sensible in areas with ample direct solar radiation; southern Europe may be appropriate if the technology manages to become cheaper, otherwise northern Africa and the Middle East will have to be considered, which requires cautious reflections concerning security of supply when electric power is transmitted across the Mediterranean Sea.

7.7 Biomass technologies for power plants

Current energy supplies in the world are dominated by fossil fuels. Nevertheless, about 10–15% of the demand is covered by biomass resources, making biomass by far the most important renewable energy source used to date. On average, in the industrialized countries biomass contributes some 9–13% to the total energy supplies, but in developing countries the proportion is as high as a fifth to one third. In quite a number of countries biomass covers even over 50–90% of the total energy demand. A large part of this biomass use is however non-commercial and used for cooking and space heating, generally by the poorer part of the population.

The major applications of biomass fuels for electricity generation are:

- Co-firing of biomass with coal in power plants and coal-fired district heating plants
- Biomass-fuelled district heating combined with small-scale electricity production
- Gasification in a combined cycle for electricity production
- Electricity production from waste biomass (waste incineration, landfill gas recovery, anaerobic digestion).

7.8 Hydro Power

Water powered scoop wheels for irrigation purposes had already been known in Mesopotamia in the 5th Century BC. They are probably the oldest machines used by mankind. The first documented water powered grinding mills were used in Asia in the 3rd Century BC. At the beginning of industrialization, water power was used to drive the newly developped machines such as lathes, drilling machines, etc. Hydroelectric power plants currently produce approx. 3400 TWh electric energy worldwide. This corresponds to around 16.5 % of global electricity production.

Hydroelectric power plants located in rivers are called “run-of-the-river” power plants. They use the large flow rate of the river with a low gradient and are also called low-pressure power plants, with a drop height of up to 15 meters. Storage power plants use the water accumulated by a dam. Generally, the water falls from a great height into the turbine and produces large quantities of energy with smaller amounts of water. They have a drop height of 25m up to 400m. Pumped storage power plants feature a lower elevation reservoir where water can be stored. This water is mainly pumped up to the higher reservoir with excess energy (e.g. wind energy). When pumping, around 20% more energy is needed than is gained from production.

8. Options for storage technologies

In the past, energy storage has not been an important issue as all the fossil fuels could very easily be stored, e.g. in tanks, caverns or piles. Today's storage systems, mainly pumped hydro power plants, have been used in order to optimise the operation of the thermal power plants. However, most renewable energy sources (RES) have no inherent storage capabilities and thus the power generation directly follows the actual conditions (wind speed, solar radiation intensity, water flow of rivers).

Energy storage capacity will be needed for balancing the fluctuations of the power generation by RES at different time-scales for which adequate control schemes must apply. The provision of control power has been appointed to the grid operator, whereas the provision of scheduled power lies in the responsibility of the energy providing companies. When the day-ahead forecast indicates a lack of power from renewables, the energy provider has to call for corresponding reserve power. Such predictable unavailability can be short term, e.g. intra-day or day/night for PV, but can last also for several days or weeks, e.g. stable weather conditions in Central Europe are the cause for long-lasting periods with almost no wind over a wide area. Furthermore the availability of wind and solar energy can highly vary from one year to the other. Especially in future power systems with high penetration of renewables this has to be taken into account and corresponding reserve capacities have to be provided. Storage systems able to cope with such situations would need huge storage capacities, e.g. for Germany up to some tens of TWh could be necessary.

8.1 Storage technologies

Storage technologies can be distinguished according to table 2 into three major groups with different features.

	X-Large Scale	Large Scale	Medium Scale
Response time	> 15 min	< 15 min	1 s -30 s [1]/ 15 min [2]
Typical discharge times	several days up to weeks	several hours up to 1 day	minutes up to a few hours
Typical storage capacity	100 GWh and more	10 GWh	< 100 MWh
Typical power	1 GW	1 GW	10 MW
Typical cycle frequency	few cycles/year	1 cycle/day	1 cycle/day or more
Storage technologies	Hydrogen based storage systems	Compressed air storage (CAES)	Batteries (Li-Ion, lead-acid, NiCd)
		Hydrogen storage systems	High-temperature batteries
		Pumped hydro	Zinc-bromine batteries
			Redox-flow batteries
Suited applications	reserve power compensating for long-lasting unavailability of wind energy	secondary reserve	primary reserve [1]
		minute reserve	secondary & minute reserve [2]
		load levelling	load levelling, peak shaving

Table 2: Overview on storage applications and suited storage technologies

As indicated in table 2 the most important storage technologies – ranked by their capacity – are the folowing:

- Hydrogen storage
- Pumped hydro storage
- Compressed air storage CAES
- Redox flow batteries
- Batteries based on lead acid, nickel-cadmium, lithium ions and high temperature batteries

8.2 Economic assessment

When evaluating most suited storage technologies, it is necessary to define the boundary conditions in terms of power, energy, response time and capital costs precisely to achieve comparable results. As an example for long-term storage (e.g. 500 MW, 100 GWh, 200 h full load, ~1.5 cycle per month) figure 10 shows a cost comparison of the appropriate storage systems.

The width can be interpreted as “state of the art” (high value) and “achievable costs” expected in 5 to 10 years (low value). Hydrogen storage can benefit from low volume related costs due to its very high energy density compared to CAES. Pumped hydro storage systems could be used as long term storage at lower costs, but the technical potential for appropriate sites with large storage capacities is very limited whereas salt cavern for hydrogen storage could be made available in sufficient quantity in suited regions.

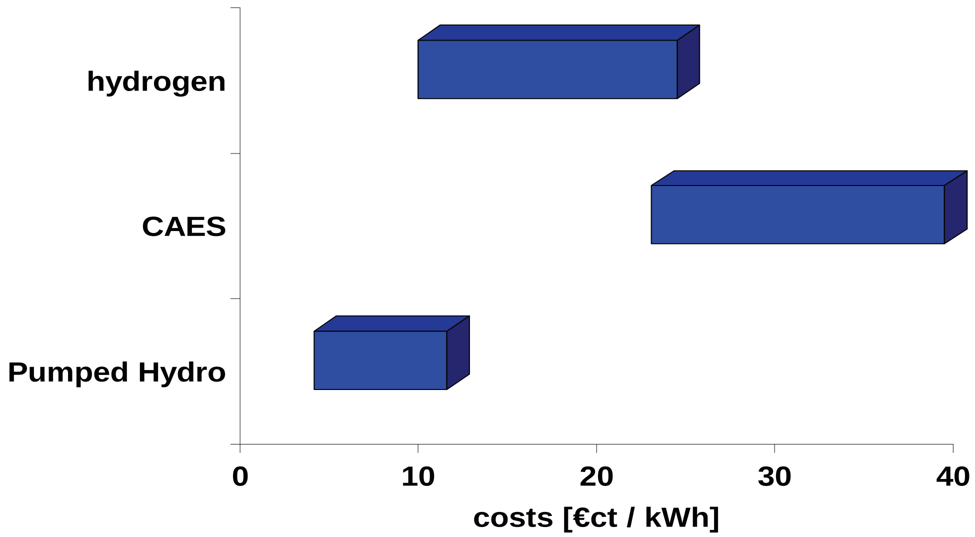

Figure 10: Comparison of storage systems for long-term storage

9. Option for future decentralized micro grid energy structures

According to the initiatives of the European Commission and the Strategic Energy Technology Plan (SET-Plan) until the year 2020 about 20% of the European electricity demand should come from wind energy and about 15 % from photovoltaics, so RES will be good for providing 40% of the needed electricity.

The energy strategy of the future should be to consume as much renewable energy as possible where it is generated but not to transport it in ultra high voltage grid over long distances and not to store long term in very voluminous reservoirs. The micro grid technology seems to be the favorable technology to support this strategy.

9.1 Micro grid management

The decentralized generation in energy settlements should be linked to a micro grid management. The micro Grid management must have the following functionalities:

- Demand Side Management (DSM) to synchronize local demand to local generation
- Energy Storage Management (ESM) to store as much electricity as possible locally for mobility in electrical vehicles or for end-use in local batteries for small scale energy applications as there are illumination and ICT.
- Supply Side Management (SSM) to use as much of balance supply as possible if demand and storage abilities are exceeded and no additional

energy applications (e.g. resistive heating, heat pumps, synchronized clothing or dish washing) are available. In case of over generation temporary switching off is necessary.

- Grid control under insulated operation and black start ability form further management functions. Herewith the micro grid can overcome emergency or blackout situations in the superposed transmission grid.

9.2 Strategic analysis of micro grids

Micro grid technology can be linked in the future with efficiency in end-use, local renewable generation, electrical mobility with grid balancing grid-to-vehicle (G2V) and vehicle-to-grid (V2G) and grid management for improvement of supply security and blackout resistivity. It can thus reduce to some extend the need for very big grid and storage extensions and balance the micro grid in a way, that the existing and available grid and storage capacities, which are the limiting factor of the renewable energy system, can be used without significant emergency situations.

The micro grid technology itself forms a valuable complement to the existing transmission and distribution system and the thermal power stations, which are still necessary because of the fluctuating characteristic of the RES like wind and PV. The existing transmission and distribution system forms in future a security barrier for uninterrupted supply, system control and ancillary services. In the long range it must be converted to a highly flexible generation and transmission system, which supports RES development.

10. Integration of renewables, need for the enhancement of system flexibility

During the transformation phase into predominant renewable energy supply the European electricity sector faces many challenges. One of them is the integration of a quickly increasing share of renewable energy in the electricity generation-mix. The volatile feed-in from the solar and wind power plants impacts the stability and reliability of the grid operation and could develop to a serious issue of a secure European energy supply. For the reason that renewable energy sources enjoy a priority in the grid feed in, the periods of grid-oversupply, as well as of deficits to cover the demand can be anticipated. In regions with high shares of renewable generation, time-periods with local energy and capacity oversupply can be observed already today. The currently mostly applied approach to handle this issue is the cutback of the renewable feed-in during the time of oversupply. With an increasing amount of generation based on wind and solar capacity the waste of energy is not reasonable due to the economic and ecological reasons. The “free” energy should not be wasted, but if possible, transmitted to regions, where it could be consumed. A possible alternative to the simultaneous generation and use of electricity is the storage of excess electricity and its later utilization during the time of appropriate demand.

Thermal power plants, historically developed and used for strictly defined operational conditions will be prospective facing different requirements. Two principal and opposite situations for their operation can be expected. Fluctuating feed-in will be in fact depending from the future weather conditions, but simply due to the quickly increasing capacity of the solar and wind capacity, the time periods with load oversupply will be occurring more and more frequently. In those periods thermal power plants and to some extend also storage facilities will have to take over the load control function and ensure the stable grid operation. In extreme situations, the thermal power plants won't be needed at all and will have to be disconnected from the grid supply. Nevertheless, even an opposite situation will have to be managed, where the grid feed in from renewables completely fails to appear. In these relatively improbable, but possible time periods the thermal plants will be required for the provision of the load control and backup power, at least as long as sufficient storage capabilities won't be applied.

To ensure the indispensable security of supply during each weather conditions, the enhancement of the flexibility between the generation and consumption will gain a crucial importance. According to the different circumstances in European countries, which include diverse climate conditions, generation mix, the composition and flexibility of the thermal fleet, grid strength and density, as well as demand-structure, the dimension of over- and undersupply will be occurring in diverse patterns. Under consideration of few essential drivers: on the one hand of the projected share of the volatile feed in- on the peak-load demand, on the other hand of the shares of the flexible thermal- and pumped-storage power plants, the following figure has been created. It indicates for selected European countries their need for the improvement of the system flexibility in the perspective of approximately next ten years.

With an increasing share of the fluctuating feed-in and with a decreasing share of the flexible capacity in the country, defined as capacity of gas turbines, combined cycle power plants, reciprocating engines and pumped storage plants, the need for the enhancement of the flexibility along the entire supply chain rises. It doesn't surprise, that countries with ambitious targets for the expansion of renewable energy sources, which possess a large amount of quite old and inflexible steam power plants demonstrate the highest need for action to improve their system-flexibility. An exceptional position with a share of renewable capacity exceeding the peak demand and with high amount of old steam power plants can be observed in Germany. Also United Kingdom, Denmark and Greece will probably have to put special efforts for the enhancement of their system flexibility (figure 11)

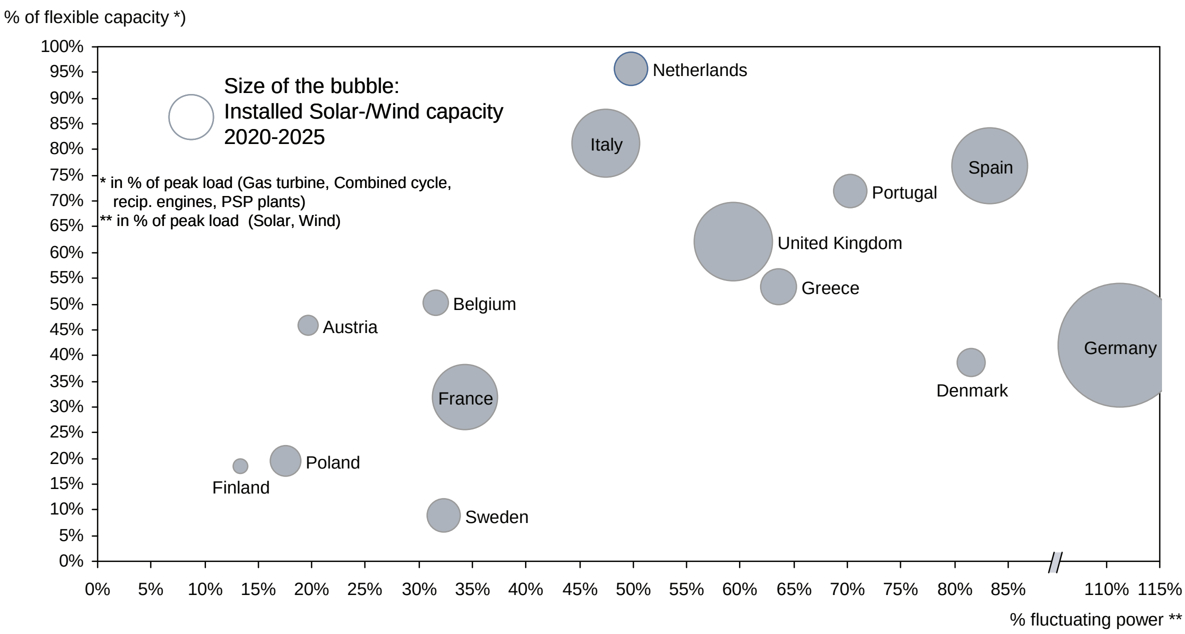

Figure 11: Need for action for the improvement of the system-flexibility in selected European countries in the time period 2020-2025

The challenges to integrate increasing amount of volatile renewable energy indicate needs for specific actions to address the issues of the future operation of the grid and

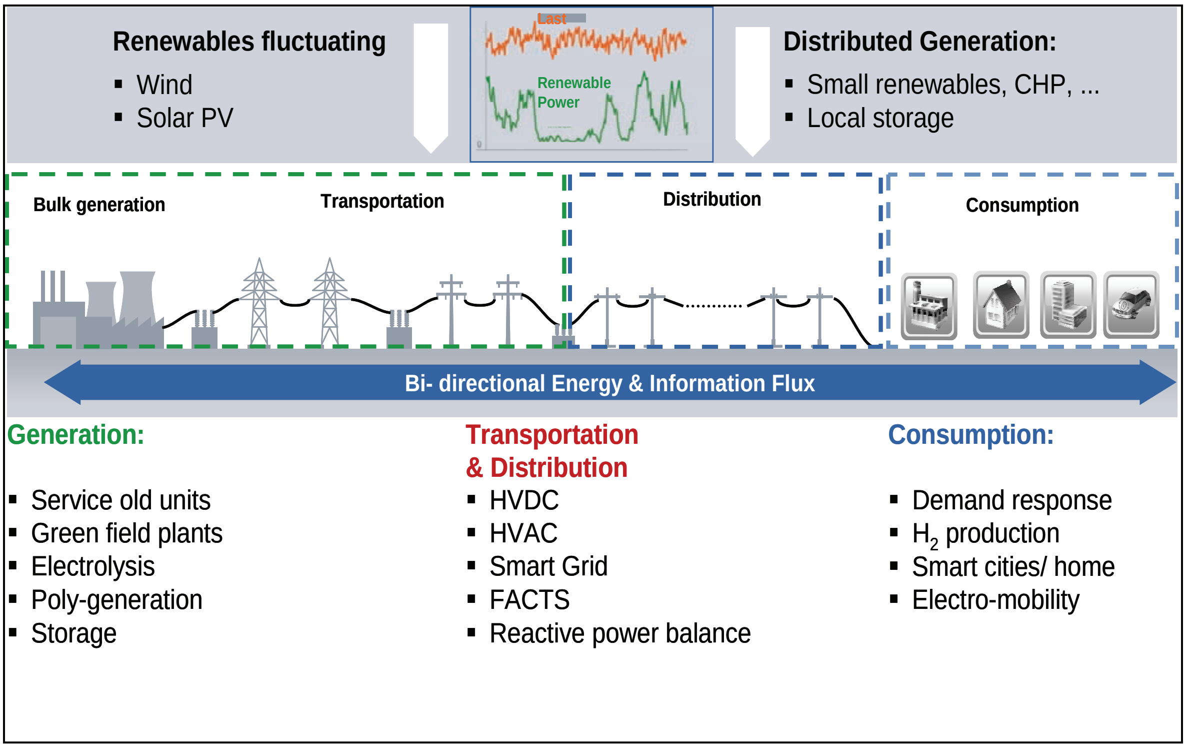

Figure 12: Opportunities for the enhancement of the flexibility in the electricity supply

thermal power plants. Moreover, the consumption side seeks practicable and economical ways to contribute to the system flexibility as well. Disregarding the emerging challenges multiple measures have been identified and could be applied already today to address the necessary accommodation of volatile renewable energy feed in. Despite possible solutions technical and economical multiple hurdles have to be overcome, as well as appropriate business models have to be developed and implemented yet. The enhancement of the system flexibility can take place at singular places of the supply chain and various options between generation and consumption can be applied to respond to the challenges resulting from accommodation of volatile feed in (figure 12).

11. Scenarios for the future power demand and generation mix in EU27+

Three scenarios were developed in order to have a clear understanding of how the power demand (s. chapter 5) can be satisfied by which generation mix. The scenarios describe the mix of generated electric energy and of installed power to produce it with regard to the primary energy resources like fossil, renewables and nuclear, it calculates the greenhouse gas (GHG) emissions and it estimates the investment costs for erecting the necessary power plant capacities to produce the electric energy as estimated. One scenario just carries forward the actual trend. In the following it is named **TREND**. The second scenario is conservative with regard to the reduction of the GHG emissions compared to the EU reduction ambitions and with regard to the increase of the usage of renewables for the generation of electric energy. It is called the **LoREN** scenario (low amount of renewables). The third scenario takes a progressive approach in using renewables and in the reduction of the GHG emissions. This is the **HiREN** scenario (high amount of renewables).

11.1 Main assumptions

In order to develop the three scenarios numerous assumptions had to be made. The main assumptions are as follows:

- The **TREND** scenario is just putting forward the actual trend.
- the CO_2 resp. GHG reductions rate is assumed to be - 60% in the **LoREN** and - 80% in the **HiREN** scenario in 2050 compared to 1990
- the renewable capacities will produce 50% resp. 80% of the total electricity in 2050
- there will be no use of uranium or coal as primary energy resources in the **HiREN** scenario. In the LoREN scenario their use will be reduced by 50%.

- In **LoREN** carbon-capture-and-storage-technology (CCS) will be applied to fossil power plants to filter out the CO_2 from of the combustion gas.
- to calculate the needed investment costs the 2011- prices for power plants are applied.
- the life cycle of power stations is assumed to 40 years for fossil, biomass and-nuclear power plants, 80 years for water and 20 years for wind and PV power-generators.

11.2 The scenarios

Due to the power consumption growth the generation will increase from 2008 to 2050 by 40%. This growth will be mainly generated in all scenarios by renewable resources. In HiREN the renewable generation jumps up to 80%, while in LoREN its share is about 50%. In the TREND scenario the renewables count only for 40% of the generated TWh´s. TREND has nearly the same fossil and nuclear generation as today while in LoREN the nuclear generation is cut by half mainly due to the German exit. Since in HiREN no nuclear and coal power plants will be used any more the fossil share in generation - which is mainly gas - is dropping to 20% (figure 13).

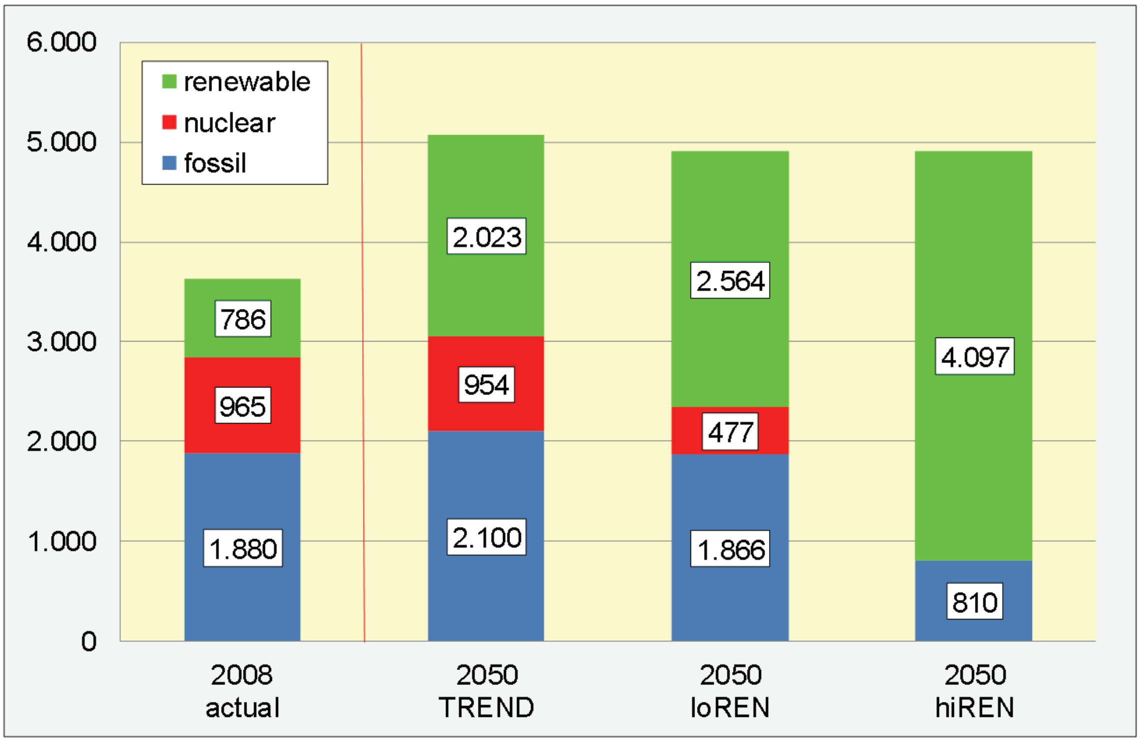

Figure 13: Generation mix in TWh

Totally different is the picture for the installed power capacities. Due to the high share of renewable resources for the generation of the electricity and due to the very low full load hours of PV modules or wind turbines the installed power capacities will rise

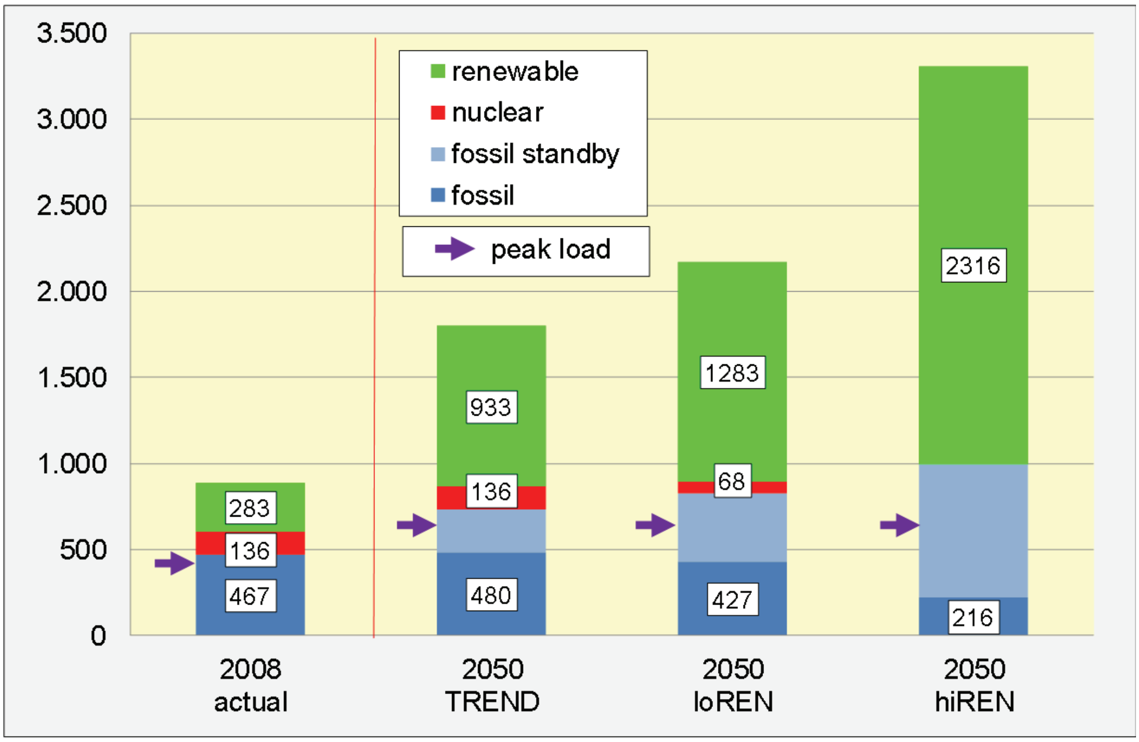

Figure 14: Installed power mix in GW

to extreme high values (figure 14). In HiREN the installed capacity of renewable power stations increases from 283 GW in 2008 to over 2300 GW in 2050 in order to generated the needed TWh´s. The installed capacity of renewables in HiREN is 150% higher than in the TREND and still 80% more than in the LoREN scenario. The nuclear power capacity was in 2008 136 GW. It will stay on that level in TREND and will be only half of that in LoREN. In the HiREN scenario no nuclear power plants are in use. The fossil capacities in daily operations will stay on the today´s level of about 450 GW in the TREND and LoREN scenarios and will go down to 260 GW in HiREN in 2050.

The peak load in 2008 was about 500 GW. So the installed power capacity of 600 GW fossil or nuclear power plants could easily cope with the situation. With the increasing capacity of wind and PV power stations in the future there must be adequate fossil or nuclear power capacity to handle the peak load situation in case there is no wind and sunshine.

	Scenario	peak load (GW)	installed power (GW)
2008	acual	490	880
2050	TREND	680	1800
	loREN	680	2200
	hiREN	680	3400 (!)

Table 3: Peak load and installed power

In all three scenarios there must be enough reserve power installed (light blue capacity in figure 14) to guarantee supply in the peak load situation. The peak load in 2050 will be about 700 GW. The needed installed fossil and/or nuclear capacity must therefore be in the range of 850-950 GW, which is the case in all three scenarios. Table 3 gives an overview on the power capacity situation.

In certain time periods where the sun is intensively shining and the wind is heavily blowing the generated TWh´s might not be used because of the lack of demand. In those cases the photovoltaic and wind power stations must be switched off. As long as there are no useful and big size power storages and enough demand side power shift capacity where the generated energy can be stored or used the switching off is the only way to handle the situation.The share of the renewable power capacities influenced heavily the investment costs for the time period 2010 to 2050. Figure15 reflects this situation. While in TREND the total investment costs sum up to 3.200 bill.€, the investment costs for the HiREN scenario are nearly twice as much. The lion´s share with 5.100 bill.€ (5,1 x 10^{+12} €!) is for the erection of the renewable power capacities. It is more than three times as in the TREND scenario and twice as in the LoREN scenario. The fossil and the nuclear power plants do play only a minor role with regard to the investment costs, especially in the HiREN scenario.

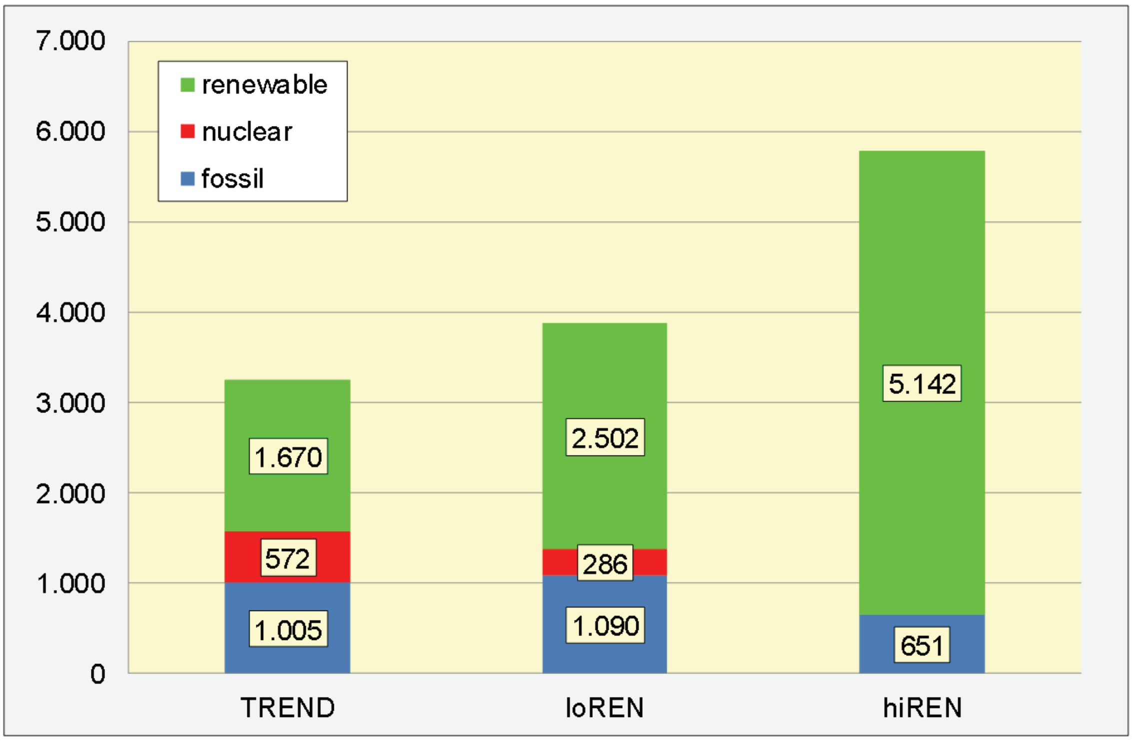

Figure 14: Investment costs in bill. € during the period 2010-2050

While in the HiREN scenario the CO_2 emissions are reduced by nearly 80% compared to 1990 the reduction in the two other scenarios reaches after all two thirds of the origin emissions.. In the HiREN scenario this reduction is achieved mainly by the high share of the renewables in the generation mix and since no fossils are used besides gas. The TREND scenario accomplishes 66% CO_2 reduction by using nuclear power and CCS technology filtering the CO_2 out of the combustion gas. The same is true for the LoREN scenario. Here the lower share of nuclear generation is compensated by a higher share of renewables. All three scenarios achieve very good results with regard to the GHG goal of the European Union. The question is the acceptance of the used technologies by the public.

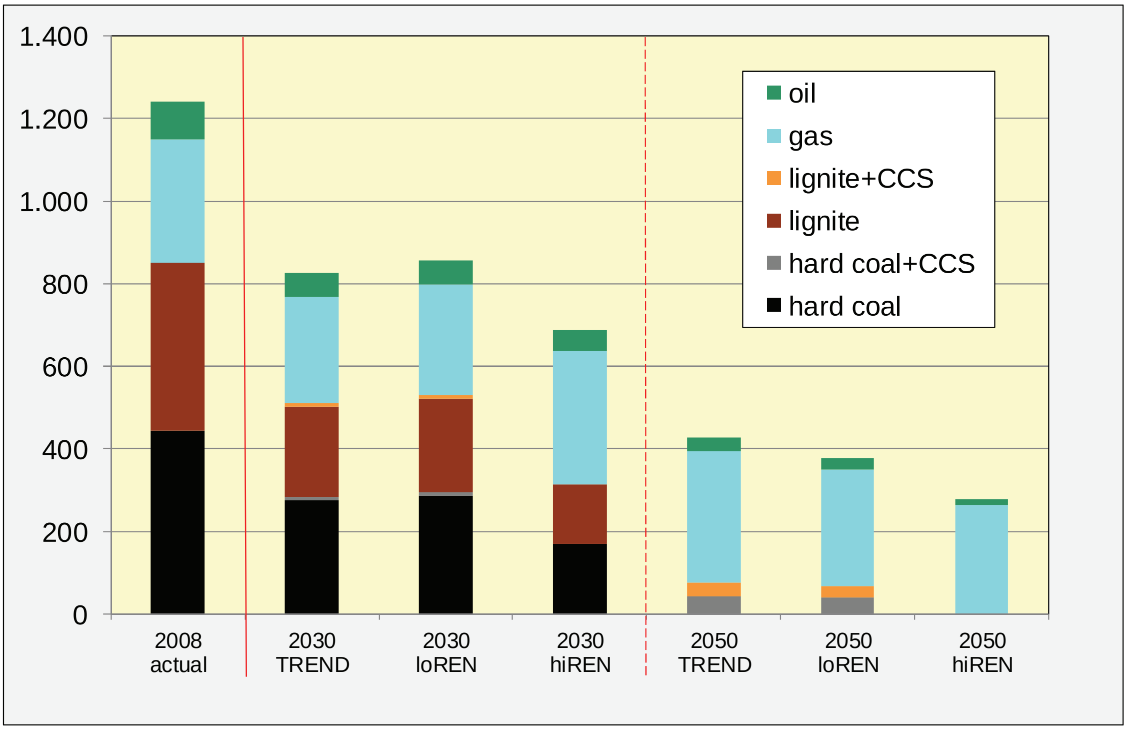

Figure 15: CO_2 emissions in mill.t in 2030 and 2050

12. Outlook for a future power supply system

The power supply system of the future will be dependent on the availability of the type and amount of the primary energy source. Since it is common understanding that fossil sources like gas and oil will run short in this century we have to look to other energy sources. Coal will still be an option but we have to solve the CO_2 challenge. The CO_2-capture-and-store (CCS) technology is an option but there is already opposition in the public because of the unclear long-term storage question.

The same is true with the nuclear energy. The nuclear option in form of the breeder reactor technology would be a long term solution for the power supply. But as long as we do not have a true secure technology at hand and until there is no solution ready for the nuclear waste problem people would not accept it. A long term solution might be the nuclear fusion technology which is still to be proven. Even if it will work it is unclear if the environmental challenges will be solved and accepted by the people.

Still the nuclear technologies for fission and fusion should be explored for a future feasible solution.

As consequence of the uncertainty in the fossil and nuclear field the use of renewable energies is more and more considered as a solution for the future: water, wind, bio mass, sun radiation and geothermal heat. Water, bio mass and geothermal heat can be incorporated into the electricity generation quite nicely. But they have restrictions: the available and economically usable water resources are limited as are the bio mass resources. Furthermore the ashes problem is not solved: where to deposit the huge amount of ashes out of the bio mass combustion process.The use of the geothermal heat is a very interesting option but the technology is not yet economically proven and only locationally available. The petro thermal system is not yet explored for the geothermal use. So at present wind and sun radiation are the options at hand.

Both are available basically everywhere. Their main disadvantage is their volatile and uncertain character. To counterbalance this we have to use huge storages of water or gas (H_2, CH_4 or similar) and we have to provide fast reacting fossil power plants to jump in when needed.

Hydro and gas storages are at present not available with the necessary storage capacities. Long term H_2 and CH_4 can be options. Water pump storages can have only supplementary character. Therefore today we have to use fossil power station, mainly gas power plants, to overcome the unavailability of wind and sun at certain time periods. This is possible, but it means high investment and operation costs for the needed standby power plants. Typically the standby cost are 30% of the full power costs.

The specific character of wind and sun leads often to smaller power stations. So we have to deal much more with distributed power generation instead of centralized big generator plants up to now. Nevertheless we will have also partly concentrated wind and solar thermal generators in form of big off shore wind parks and big solar fields. This has high potential and this should be explored more deeply.

For the backup support we still must have huge fossil power stations. So the future structure of the power generation will look like the principal layout in figure 17. It will be a combination of big and small generators, the small ones for the more local supply and the big stations for the system backup and as a bridge for time periods with no wind and useful sun radiation.

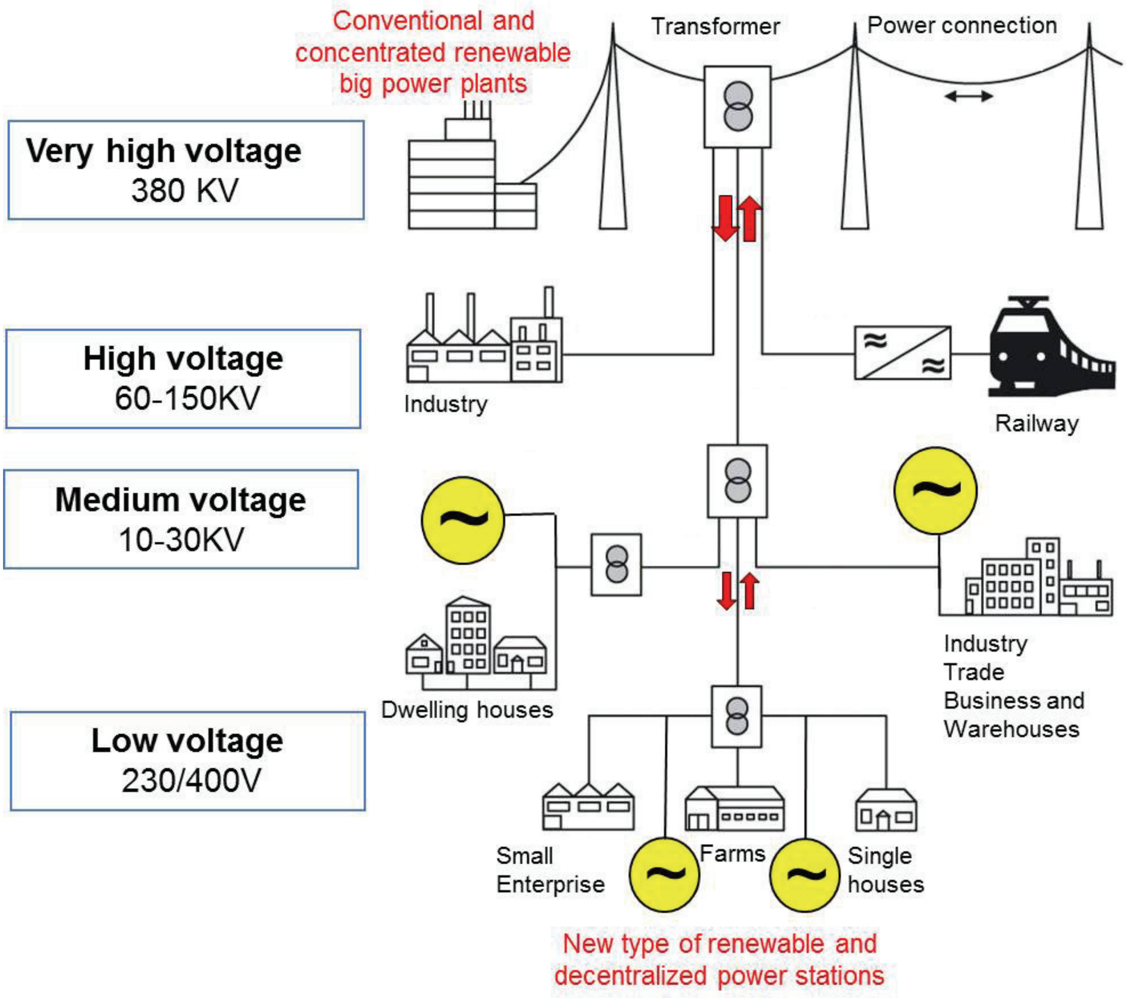

Figure 16: New structure of the power generation scheme

This new scheme of power generation will require a new power network scheme. For the local power supply so-called micro networks will bind together the different types and huge numbers of generators and will organize the local balance of the power system. If a micro network cannot achieve the balance then it will get support from the neighbour micro grid or the strong backup system (constant frequency!).

The backup network might be an AC or DC network. This is a matter of technical and economical optimization, a matter of loss avoidance and a matter of smooth transition from today´s installation to the future system. This new scheme requires very sophisticated control systems which must optimize the local and the global control jointly. A huge task! The cooperation of a big number of local networks with active customers and small storages and a strong backbone network with powerful generators is called in modern terms a Smart Grid (figure 18).

The power supply system infrastructure will be linked in the future to other infrastructures. Beyond the storage capability, the production and utilization of hydrogen or synthetic hydrocarbons offer additional wide-ranging opportunities (figure 19). Coupling of the electricity and chemistry opens multiple synergies between infrastructures for power-, heat- and mobility-sectors. It unlocks efficiency gains and savings of fossil energy and consequently of CO2 emissions

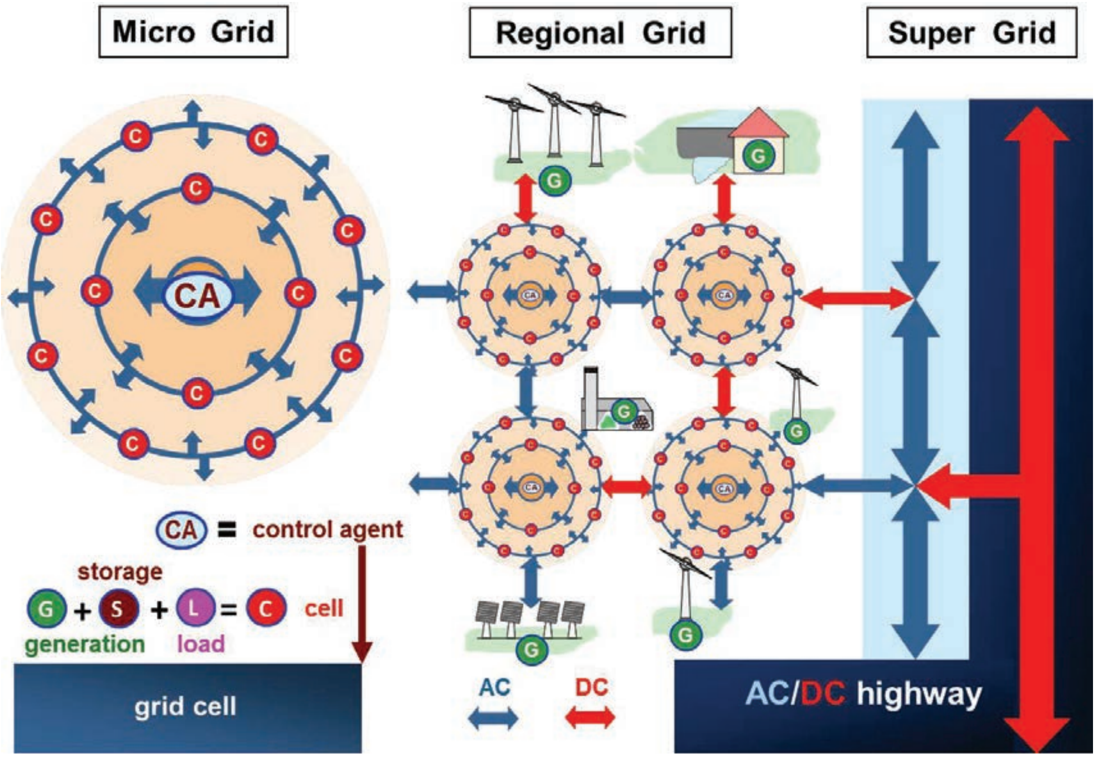

Figure 17: Structure of a future power supply system (Origin: Siemens)

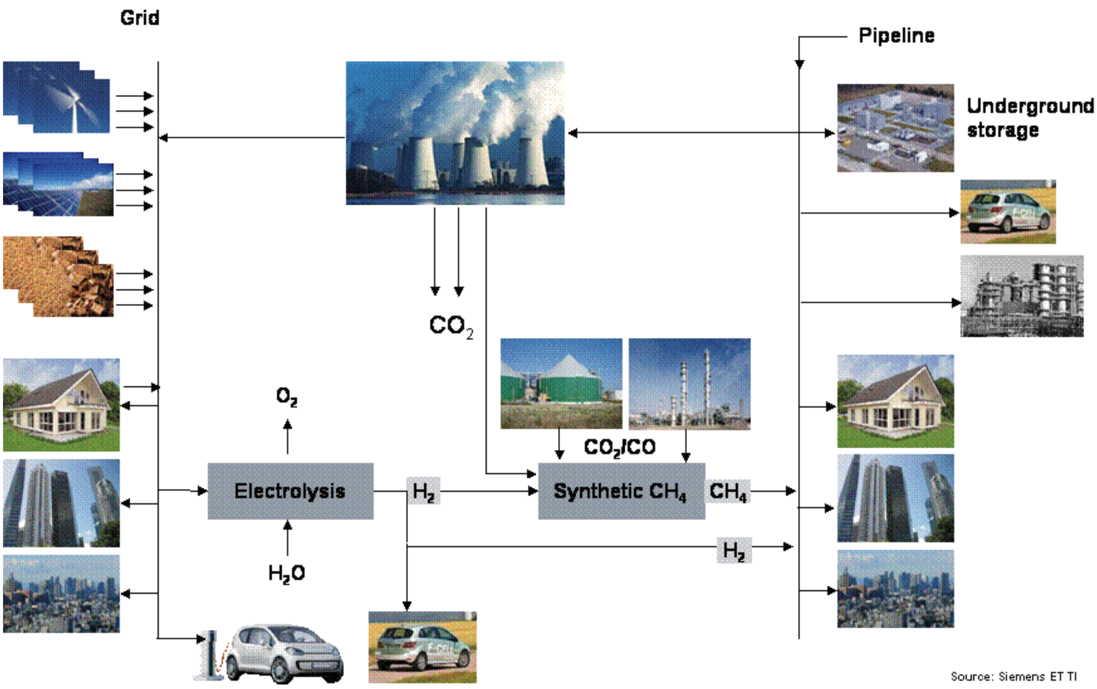

Figure 18: Synergies between the infrastructures for electricity, heat and mobility

Although several technical basics of such a new and complex system are already well understood, as well as selected components already commercially available, further actions are still needed. They include an accelerated development of few key system components like storage technologies, or electric cars and their infrastructure.

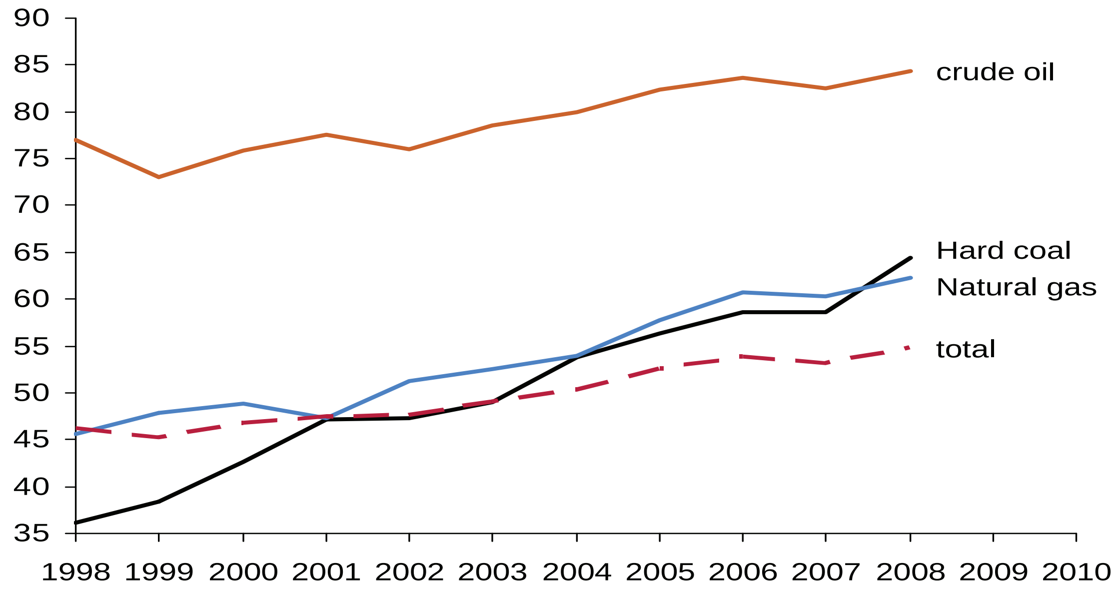

Figure 19: EU27 import-dependency of fossil fuels

The implementation of another key system enabler, which is a reliable and secure bidirectional information and communication technology, which will be connecting the multiple system-components between and within infrastructures in an intelligent way, is urgently needed as well. Beyond the technology development, improvements of system economics have to be realized. They will be depending on the one side on the future cost degression for new technologies, on the other side on the availability and prices of fossil fuels, like crude oil and natural gas. Because they are mainly being imported to Europe the European energy policy is requested to provide a right frame work to decrease the historically rising energy import dependency (figure 20) and improve in this way the security of the future European energy supply.

In this manner, the integration of wind and solar power and opening the implementation of electricity to produce hydrogen and synthesize gaseous or liquid hydrocarbon will open the door to a new European "electricity age". It offers substantial opportunities to establish a full renewable energy supply, increase energy efficiency mainly by the change from mechanical to electrical drives and to improve the European supply security by decreasing the import dependency of fossil energy carriers.

13. Conclusions and recommendations

13.1 Conclusion from the scenarios

The European commission has laid down three main targets in their roadmap 2050 document:

- decarbonisation, i.e. 80-95% reduction of the GHG emissions compared to 1990
- security of energy supply, i.e. reduction of import dependency
- security of competitiveness, i.e. affordable energy prices

The decarbonisation target can be reached totally with the HiREN scenario, the two others scenarios come with a CO_2 reduction of approx. 65% close to the -80% goal. The HiREN scenario reduces the import of oil, gas and uranium raw resources and thereby the import dependability drastically. But this is extreme costly (6.000.000.000.000 € investment costs in the next 40 years)

So the HiREN scenario might influence the EU´s competitiveness to a certain degree. If the investment costs are divided by the kWh´s produced in the period 2008-2050 the kWh **costs** are increased by 3 ct/kWh (**cost is not price!**). This is substantial compared to the current generation costs from fossil energies of 3-5 ct/kWh, nearly a doubling. (It is noted that in this cost analysis no costs for fuels, operations, further infrastructure investments and taxes are included. It's absolutely impossible to estimate those costs for such a long period of 40 years).

In both, the TREND and the LoREN scenarios, the import dependability from fossil primary energy resources still stays high. The EU would depend to a large extend from countries like Russia, Middle East and North Africa. Furthermore both scenarios run the risk of the acceptance of the nuclear and CCS technology by the public. In case these technology are not accepted by the citizens their further existence and application is obsolete.

	TREND	LoREN	HiREN
Decarbonisation	+	+	++
Security of supply	--	-	++
competitiveness	0	0	--

Table 4: Summarizes the result of the scenarios with regard to the EU 2050 main goals

The HiREN is the best choice with regard to environmental aspects and the supply security. The TREND and LoREN scenarios are less costly and therefore contribute to the competitiveness of the EU significantly (Table 4). A precondition to establish a power supply system with an extreme high share of renewable generation is to enforce the transportation and distribution grid. The transportation grid must be extended to a high capacity backbone network in order to deal with the fluctuation of renewables such as wind and sun generated power. Parts of such a backbone network can include point-to-point DC links to prepare for big power transfers over long distances. For example big power transfers are needed in Germany to transfer offshore generated power by big wind parks to the industry centres in the southern and western regions of Germany over some 500 km. Later these point-to-point links can be incorporated more smoothly into the meshed transport network if DC power switches are available. With these DC switches high capacity DC networks can to establish.

Another prerequisite is to either provide extreme large seasonal storage capacities or fast reacting gas turbine power stations to jump into power production when the wind is not blowing and the sun not shining. This situation can occur in winter time over some days or even some weeks. Since we do not have today those big storages to fill the gap the only choice is to use conventional gas turbine power plants. **A 100% backup power capacity must be provided for the renewable generators.**

In case we would have huge gas storages (CH_4 or H_2) - big enough to store the electric energy equivalent of some weeks of the electricity demand – the total system could be fed only by renewable power. But these renewable capacities must be big enough to supply the actual power demand and to fill the storages with synthetically produced gas; this capacity must be a multiple of the actual load. A futuristic vision!

13.2 Recommendations and need for action

The transition from the today power supply scheme to a future system as described above will be a matter of decades. Therefore it is important to have a clear and sound strategy. The implementation of the strategy might be different in the various member states of the EU27+, but it should follow the same basic concept and rules. All European countries have the same challenge with the fossil and nuclear energies and with a few exceptions the same problem of primary energy import dependency. For the European Commission and all member states the following basic recommendations will apply:

- massive increase of power efficiency of devices, products, systems, installations and plants
- development and funding in programs to reduce peak power
- funding of research and development in all fields of power generation (renewable, fossil and also nuclear), transmission and storage technologies

- increasing use of renewable energies for electricity and also heat production.
- step by step reduction of the import dependency of EU27+ on fossil energies like gas, oil and coal by a continuous transition to renewable energies
- funding of technologies which increase the efficiency of power stations
- stimulation of investments in modernized or new power stations and power networks
- stimulation of investments in low loss long-distance transmission schemes (backbone network: HVDC, UHVAC) and intelligent energy-active distribution network technologies
- stimulation of investments in smart control, protection and self-healing functions

All programs of the EU Commission and the member states must have a long term character and **should not be driven by short term actions** which change from year to year dependent of the political climate. Basic for all actions must be a **sound and farsighted foundation** of the electric supply system taking into account all dependabilities and requirements of a sustainable and stable system. Singular and ideology oriented interests will not lead to a functional and optimized total system. The design of a future supply system has also to take into consideration environmental requirements. Even using renewable energy generators does not mean always environmental compatible solutions. **We should not seek for fast and populist, but firm and sound solutions**. The above described HiREN scenario (reduction of the GHG by 80% until 2050 compared to 1990, expansion of the renewables as primary energy resource to 80% of the total electricity production and the phase-out of nuclear and coal power plants) is the most attractive and ambitious out of the three investigated scenarios. But it is very expensive. Will the society accept these costs?

Coordination of actions between the member states in the power and transmission sector is basic to achieve the common goal. For long term investments the industry **needs stable conditions and perspectives**. Otherwise the European goals with regard to a future, sustainable power system will not be reached.

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