Energy

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1. Introduction

Background

Energy consumption drastically increased in Switzerland in the 20th century (fig. 1). Since 1945, it has increased by a factor of eight. The massive rise is due to the increase in the consumption of crude oil combustibles, motor fuels and gas. However, electricity consumption has also continuously increased, while the proportion of coal has strongly decreased. In 2004, energy use was composed of 31.3% motor fuels; 25.7% combustibles; 23.1% electricity; 12.1% gas; and 7.8% other. The following discussions are to be understood against the background of this development.

In the context of climate change, the energy sector is usually discussed as a causal agent. Being the most important source of anthropogenic greenhouse gases, it plays a central role with regard to measures to reduce emissions. In this report, we look at this from a different perspective and consider the effects of climate change on the energy sector. How do warming and the changes in precipitation affect energy production and energy demand?

Energy use for transport is deliberately not taken into consideration. We assume that the transport sector will be less affected by the direct consequences of climate change than by indirect consequences (climate policy).

The effects of climate change on the energy sector will be discussed in more detail for the following topics:

- changes in energy demand (summer, winter)
- established production of electric power (hydropower, nuclear power)
- new renewable energy (wind, wood)
- economic aspects (energy prices, insurance)

This list is not exhaustive but represents a range of interesting and relevant issues. Climate change also affects other important areas of the energy sector, such as security of supply and the supply grid, as well as prospects for other energy sources (geothermal, solar energy, etc.). Within the limited range of topics, the working group did not deal with these areas.

The energy sector is influenced more strongly by other general conditions than by climate change. Thus, for instance, influencing factors such as economic growth, technological development, population growth and the opening of the electricity market have shaped the energy sector in the past and will continue to do so in the future.

Overview

In the future, less heating energy will be used in winter and more cooling energy used in summer due to climate change. There will be a shift

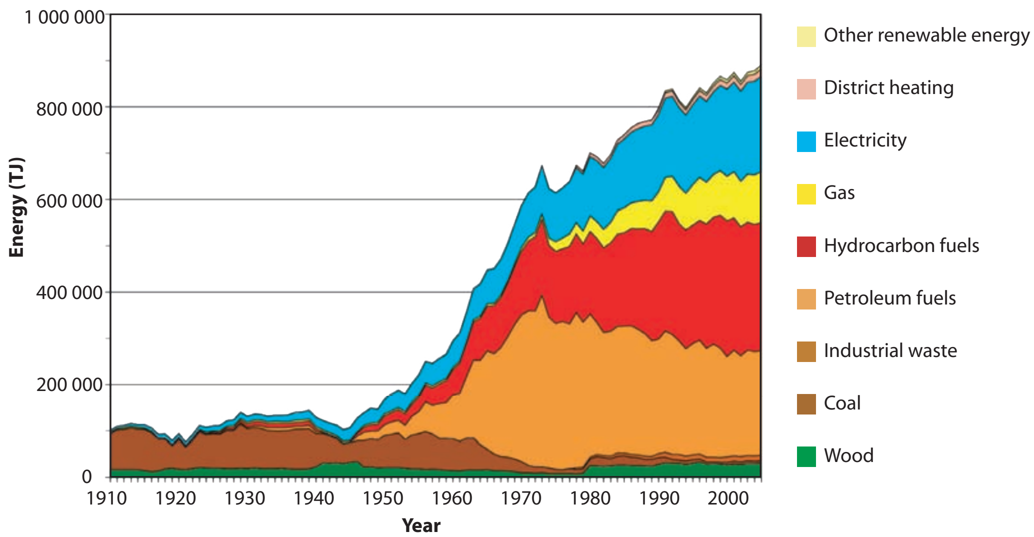

Figure 1: Energy consumption in Switzerland, split into different energy sources (1 TJ ≅ 0.3 GWh). (Source: SFOE Overall energy statistics 2005)

in the demand from combustibles to electricity. The increase in air conditioning will be particularly pronounced in the service sector.

Electricity supply will be affected by climate change due to the negative impact on hydropower and nuclear energy. Hydropower production may have decreased by about 5–10% by 2050 because of the smaller runoff. With increasing water temperatures, nuclear energy plants will obtain less cooling capacity from rivers. In summer 2003, the lack of cooling capacity resulted in a reduction in annual production of 4%. Heat waves like in summer 2003 will increase between now and 2050.

The prospects for new renewable energy will increase as a result of climate change. On the one hand, the demand for CO_2-neutral energy will increase due to climate change and climate policy, and on the other, the competitiveness of renewable energy will increase due to the rising prices of conventional energy. As measured by today's consumption, the contribution of new renewable energy to the Swiss electricity supply will increase to more than 10% (5500 GWh/a)[1] by 2050. Wind energy will contribute to this. By expanding all wind farm locations to the maximum, the total potential of 1150 GWh/a could be tapped by 2050. Individual plants have an additional potential of 2850 GWh/a. With an increase in mean wind speed due to climate change, an increase in mean wind power production can be expected. In the case of extreme events, production failures can occur at individual wind farm locations.

Wood energy will also profit from the improved competitiveness of new renewable energy. Energy wood potential will allow at least a doubling of today's use in the future, to more than 5 million m^3. In consideration of the long-term forestry trends and the developments in the timber industry, the potential could even treble. However, competition in the use of wood will increase due to the use of other materials. Forest areas will expand as a result of climate change and the potential for wood energy will continue to grow. At the same time, the acceptance of wood energy will increase, provided that progress is made in the reduction of particulate matter emissions.

Altogether, higher energy prices will slow down the increase in energy consumption. Consideration of energy efficiency will bring about a shift towards electricity. The demand for CO_2-neutral energy (new renewable energy and nuclear energy) will increase. Generally, climate change will lead to an increase in uncertainty, which is why systems with short pay-back periods will be preferred.

The risk of service interruptions will also increase in the energy sector due to climate change. Examples of this include the flood of August 2005, which caused interruptions in run-of-river power stations, and the high water temperatures in summer 2003, which led to reduced energy production in nuclear power plants. Insurance solutions for property damage and production losses will gain in importance.

Measures

The emerging supply gap must be reduced as much as possible. In order to achieve this, the energy-saving potential must be fully exploited, and renewable energy, as well as technologies to promote energy efficiency, must be more strongly promoted. The electricity-saving potential by 2035 obviously depends on how much is spent on avoidance costs; the accumulated potential of up to costs of 40 Rp./kWh has been estimated to 10,000–15,000 GWh. The theoretical reduction potential in primary energy consumption by 2050 amounts to a total of 60%, whereas "Energy perspectives 2035" by the Swiss Federal Office of Energy[2] and "Road map" by the Swiss Academy of Engineering Sciences (SATW)[3] suggest a technical saving potential of 20–25%.

Future electricity production should remain CO_2-free. In order to avoid any additional net emissions by a possible new fossil power plant, further measures would have to be taken (combination of widespread use of heat pumps and savings in the heating energy sector, biological sinks, carbon capture and storage, emissions trading).

Diversification and redundancy are effective measures against the impacts of climate change on the energy sector. A broadly based portfolio of conventional and renewable energy protects against the supply shortfalls of a single energy source. Likewise, a network of several regional, medium-sized biomass power plants, for

instance, is less sensitive to disturbances than one single large plant. In distribution networks, redundancy must be strictly considered, that is, the provision of at least two independent connections between every two nodes.
While the emergency plans of the Federal Office for National Economic Supply are aimed at short-term shortages, they cannot offset long-term trends. It is therefore important to consider adaptation measures on the demand side as well. In addition to technical measures (e.g. load rejection during peak electricity consumption), consumer behaviour is also important. Consumers can adapt the acquisition of energy services that are not related to the production process to the conditions of a changed climate.

Links to other topics

Water management
Water levels of reservoirs and rivers; competition in water use, amongst others with agriculture (irrigation demand in summer)

Insurances
Losses due to and insurance of production losses

Land ecosystem
Expansion of forest areas, increase in inferior energy woods

2. Energy consumption

As a result of climate change, less heating energy will be used in winter and more cooling energy used in summer. Fuel consumption will thereby decrease and electricity consumption increase.

Current situation

In "Energy perspectives 2035/2050" by the Swiss Federal Office of Energy (SFOE), two energy scenarios[4,5] are compared in order to study the effects of climate change on energy consumption in Switzerland. In the reference scenario, climate change is not taken into account. In the "warmer climate" scenario, a temperature increase of 2 °C in the summer months June to August and 1 °C in the remaining months, compared to the period 1984–2002, is assumed by 2030. Radiation will increase by 5%.
With climate change, the meteorological statistical data that are important for the calculation of heating and cooling demand will also change. As a result of warming, the number of heating degree days (see box) in the heating period will decrease by about 11% by 2030, and by 15% by 2050, compared to the mean value for the period 1984–2004 (fig. 2).
Conversely, cooling degree days (see box) will have increased in the summer months by about 100% by 2035 according to "Energy perspectives". A temperature increase of about 2.5 °C by 2050, as the climate scenario in this report suggests, will mean an increase of about 150% in the number of cooling degree days (fig. 3).

Heating degree days:
Difference between the preferred mean room temperature (20 °C) and the mean outside temperature, totalled for all calendar days with $T < 12$ °C.

Cooling degree days:
Difference between the mean outside daytime temperature and the reference temperature (18.3 °C), totalled for all calendar days with $T > 18.3$ °C.

Service sector

The demand for heating energy by the service sector[4] will decrease slightly in the future even without global warming, due to higher energy efficiency and better heat insulation. By 2035, the demand will have decreased from 22,200 GWh/year to 20,800 GWh/year, in spite of economic growth. After 2035, the increase in energy efficiency and in heated area should roughly compensate each other, so that by 2050

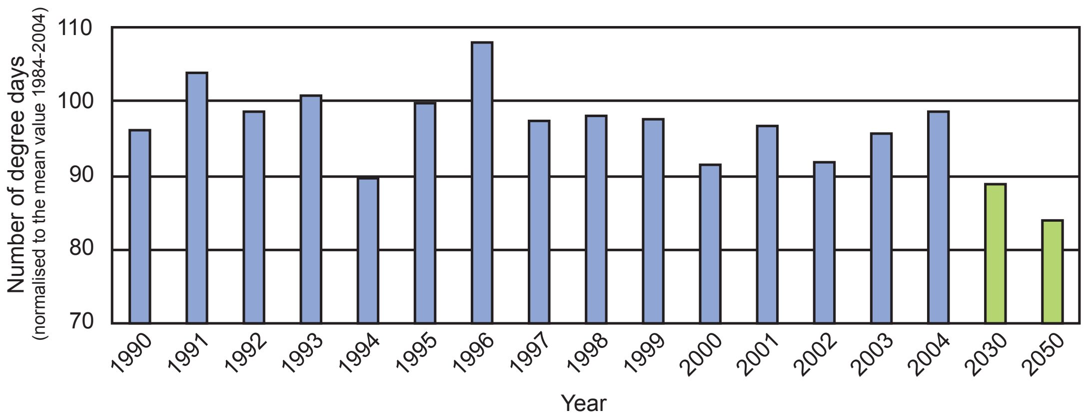

Figure 2: Annual heating degree days in the years 1990–2004, normalised to the mean value of the period 1984–2004. For the years 2030 and 2050, the expected values from the "warmer climate" scenario from "Energy perspectives 2035/2050" by the Swiss Federal Office of Energy SFOE are represented.[4]

the heating demand will still be around 20,800 GWh/year.

Due to warmer winters, the heating demand will have decreased by a further 13% to about 18,000 GWh/year by 2035. By the year 2050, heating demand will be about 18% below the reference scenario (just above 16,700 GWh/year).

Even without climate change, the electricity demand for room cooling will increase from about 1000 GWh/year in the year 2000 to about 1500 GWh/year in 2035, due to the increase in fully and partly air-conditioned areas. The proportion of air conditioning in the electricity demand thereby rises from 6% (2005) to 7% (2035).

Due to climate change, the specific electricity consumption for room cooling, as well as the demand for room cooling will further increase. The increase in cooling degree days means that the specific electricity consumption for room cooling will increase by about 46%. With regard to the demand for room cooling, it is assumed that by 2035 about 50% of today's non-air-conditioned areas will be partly air conditioned, and about 50% of today's partly air-conditioned areas will be fully air conditioned. Altogether, the service sector's electricity demand for air conditioning by 2035 will have increased to about 3200 GWh/year and lie about 115% above the reference scenario.

By 2050, the number of cooling degree days will have increased further. The specific electricity consumption for room cooling will have thereby

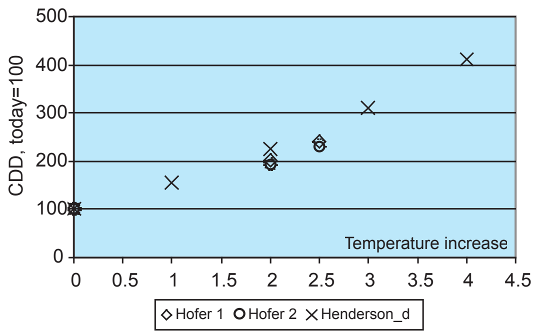

Figure 3: Change in cooling degree days (CDD) with a temperature increase of 1–4 °C in the summer months June to August (100=mean temperature in Switzerland today). Depending on the calculation method, the authors obtained slightly different values.[4]

increased by about 70% in comparison to the reference scenario. However, the proportion of air-conditioned areas will also have increased further, so that the electricity demand for air conditioning with building stock the same as in the reference scenario could be 170–200%, or 2800 GWh/year, above the reference scenario.

Private households

Excluding the impact of global warming, the demand for heating energy will decrease in private households from 55,000 GWh/year in 2000 to about 48,000 GWh/year in 2035, due to improved energy efficiency and heat insulation. For hot water consumption, the decrease is 1–2%. Including the impact of global warming,

the demand for room heating will decrease by a further 10% and amount to 44,000 GWh/year by 2035. By 2050, heating demand will have decreased by an additional 10% compared to the reference scenario.
As a result of global warming, an increase in electricity consumption for air conditioning in residential buildings in summer is to be expected. Marginal additional consumption is also expected for cooling and freezing appliances.
For Switzerland, there is currently no solid data available regarding air conditioning of residential buildings. The results for other countries can only be applied to Switzerland to a limited extent, since for most regions, construction methods, heating and cooling techniques, attitudes and behaviour differ significantly from Swiss circumstances. In Switzerland, it is assumed that the specific cooling demand will be smaller for the residential sector than for the service sector (different internal loads, day/night consumption rhythms etc.) and that air conditioning in the residential sector will be largely decentralised using compact or split systems (with air or water cooling). Altogether, an increase in electricity consumption by about 10% compared to the reference scenario is expected by 2050 (fig. 4).
The additional electricity demand expected for air conditioning can be restricted if innovative concepts, such as free-cooling (dissipation of heat into the air during the night), geocooling (dissipation of heat into the ground using the same geothermal probes that deliver ambient warmth for the heat pumps in winter) or solar cooling are increasingly introduced.

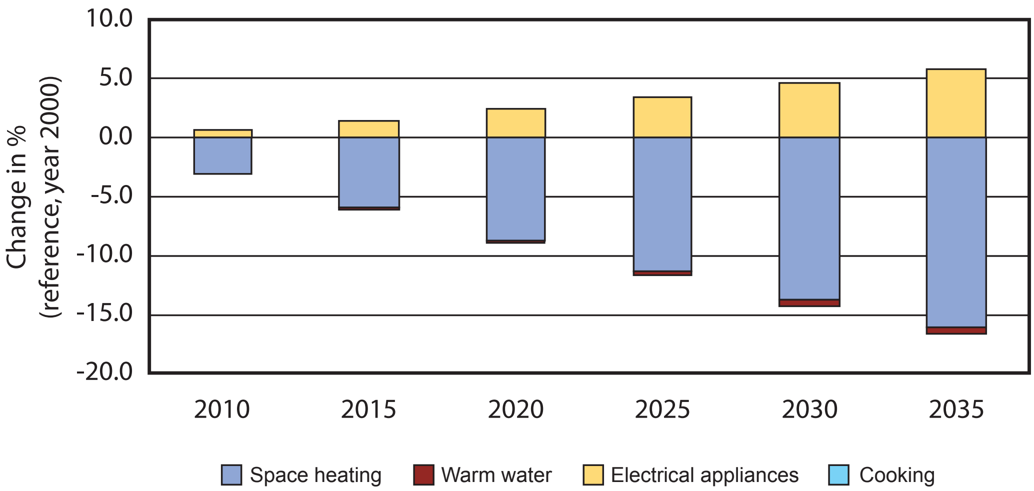

Figure 4: Changes in energy consumption in private households according to type of use, compared to the reference scenario (today: 75,000 GWh)[5].

3. Established electricity production

In the near future, domestic electricity demand will no longer be able to be met by domestic energy production. Due to climate change, there will be production losses for hydropower. Against the background of climate change, the supply gap must be closed through the stronger promotion of renewable energy and the use of technology to enhance energy efficiency, as well as by new CO_2-free production capacities.

Current situation

Electricity production in Switzerland is largely CO_2-free thanks to the two mainstays, hydropower and nuclear power. Municipal waste incinerators and industrial combined heat and power plants account for the largest proportion of conventional thermal facilities.
The net capacity of the five nuclear power plants is 3220 MW. They produce about 25,000 GWh electricity per year, which corresponds to around 40% of the Swiss electricity demand. In 2020, the first nuclear power plants will reach the end of their operating time. Swiss production capacities will decline strongly thereafter. At the same time, import contracts for electric power with Electricité de France (EDF) will gradually run out.
Electricity consumption is likely to further increase in the future. In the past, electricity consumption increased by 1.8% per year with a growth of the GDP by 1%. SFOE estimates that by 2035, growth will be 22.3% slower compared with 2003 if today's policies continue. The introduction of a CO_2 tax would slightly increase growth (+23.2%), since the expected increase in energy efficiency will be accompanied by an increase in electricity consumption. If the linear trend continues, the electricity demand will be about 33% higher by 2050 compared to 2003. The Axpo[6] suggests slightly higher values in its scenarios (fig. 5). The spread of the different scenarios shows the uncertainties regarding future electricity demand.
From 2020 to 2030, domestic electricity demand will not be able to be covered by domestic power production and existing import contracts. After 2012, the import of electric power will regularly exceed the export of electric power in the winter half-year.

Climate change

Climate change is an important influencing factor in power production. Hydropower strongly depends on water supply (precipitation and meltwater), which is directly affected by climate change. Nuclear energy depends on sufficient amounts of cooling water.
The established energy sources, hydropower and nuclear energy, will be influenced by future climate change as follows:.

- In the short term, more water will be available for hydropower due to melting glaciers, and more electricity will therefore be produced in summer. In the long term, water supply and production will decrease in summer. The reduction in runoff is due to decreasing precipitation and increased evaporation.[7] The reduced runoff could result in a decrease in hydropower production of 7% on average by 2050.[8] In addition, an increase in floods is expected in the midlands due to climate change. Part of this water cannot be used for power production. The loss in electricity production is therefore larger but not quantifiable.
- Due to higher water temperatures, water-cooled nuclear power plants will obtain less cooling capacity from rivers, and production will decrease. In summer 2003, the performance of nuclear power plants had to be curbed by 25% for two months. This reduced the electricity production for the year by 4%. Water temperatures in rivers will continue to increase up to 2050 (see Water management chapter). As a result, there will be production restrictions.
- The pressure to reduce the use of fossil energy will increase with climate change. Being CO_2-free, hydropower, nuclear power and new renewable energy do not contribute to climate change and will not be burdened by possible steering taxes.

Measures

Electricity production should remain CO_2-free. Against the background of climate change, important measures to close the supply gap are as follows:

- Intensified promotion of renewable energy and technologies to enhance energy effi-

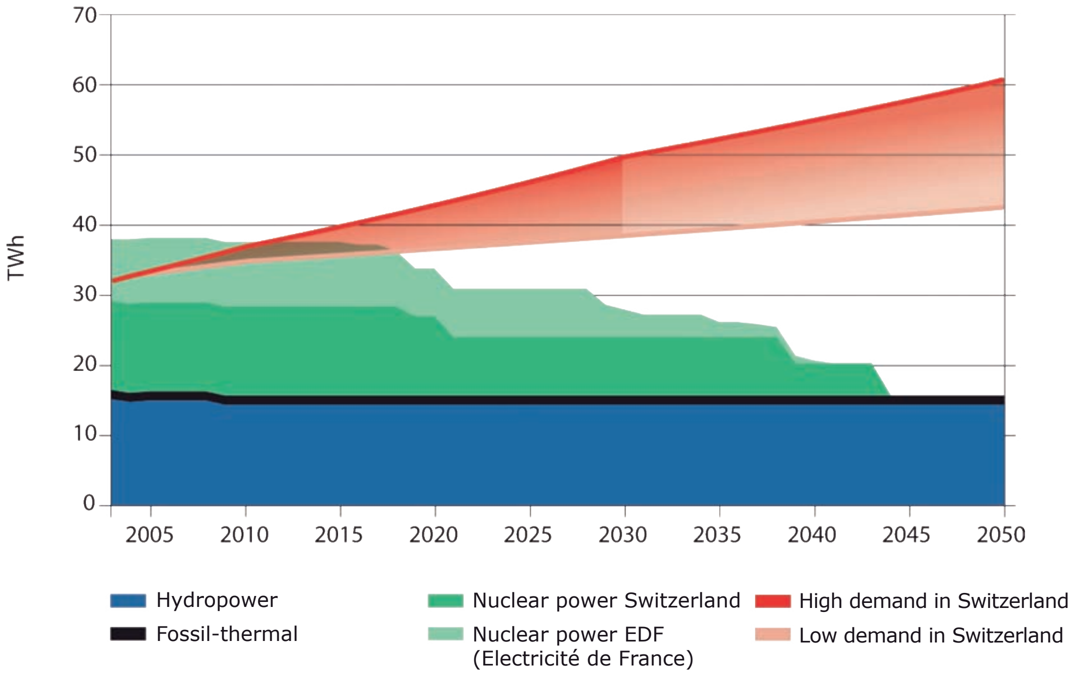

Figure 5: Production capacities and electricity consumption in Switzerland in the winter half-year. According to the projection, domestic power production and existing import contracts will be unable to cover domestic electricity consumption after 2012 (high power demand scenario) or 2019 (low power demand scenario).[6] (1 TWh = 1000 GWh)

ciency, as well as tapping the full potential of energy savings. In addition to research and development, pilot plants are necessary in order to demonstrate the feasibility of such technologies and to gain experience. Though by enhancing energy efficiency, electricity demand will tend to increase.

- Supply of new, CO_2-free production capacities. To close the supply gap, a gas-fired power plant, as a temporary solution, and a new nuclear power plant, as a long-term solution, were recently proposed. In order to avoid any additional net emissions this caused, further measures would have to be taken (biological sinks, carbon capture and storage (CCS), emissions trading). Carbon capture and storage technology will only be available after 2030 or later. Storage is particularly critical, since it is required over long periods of time – similar to the storage of nuclear waste – and therefore is a political issue. This is true for storage in Switzerland as well as abroad.
- Switzerland will decide in a democratic political process what form its future energy supply will take. A comprehensive and objective compilation of all the scientific facts (natural, social, economic) is required in order to make an educated decision. Decisions regarding future electricity production will affect the degree of international dependency of the Swiss energy supply on gas, electricity and other imports. Therefore, tapping the potential of domestic renewable energy as much as possible is to be aimed for.

4. New renewable energy

The direct impacts of climate change on power production from renewable energy are classified as being between neutral and slightly positive. While the growth of biomass will tend to be favoured and solar radiation will increase slightly, extreme events will have a potentially negative impact. However, more important than these direct influences is the fact that increasing energy prices and climate protection strategies will improve the general conditions for the promotion and introduction of renewable energy.

As measured by today's consumption, the contribution of new renewable energy (NRE) to the electricity supply of Switzerland could increase from 3% today to 10% (5500 GWh/year) by 2035.[9] By 2050, a further increase will be possible. Basically, this 10% comprises a large part of the potential for small-scale hydropower and wind power, substantial contributions from biomass and geothermy, as well as a relatively small contribution from photovoltaics. The potential of NRE will be limited by the higher production costs.

Climate change increases the prospects for NRE. The increasing demand for energy and the measures (agreed on and anticipated) to limit greenhouse gas emissions increase the demand for CO_2-neutral energy. At the same time, subsidy needs decrease with higher energy prices. If the subsidies remain constant, faster market penetration is expected.

The production of NRE will be influenced by environmental factors on different time scales. The efficiency of renewable energy forms depends on weather and climate, among other factors, and is affected by climate variability and extreme events. The climate scenario of this study shows a change in mean values and does not comment on the changes in variability. There is evidence for an increase in temperature variability in summer and a slight decrease in winter.

Variations in climate could also affect medium-term planning for NRE production. A possible approach could be to model the entire chain, from the climatic boundary conditions as input data to energy production.

Wind energy

Potential

Switzerland today has about 5.4 MW[1] of wind power installed and produces around 5.4 GWh/year of its electricity from wind. This represents barely 0.01% of the entire domestic electricity production in the year 2003. Even with the 15 GWh electricity from photovoltaics, the contribution of the new renewable energy has up to now still been low.

The potential for wind energy is limited in Switzerland. An expansion of wind power to 600 GWh/year will be possible by 2035. By 2050, a total potential of 1150 GWh/year could be tapped through maximum expansion of all the wind farm locations. If measured by electricity production in 2003, the proportion of wind power would amount to 1.8%. The potential of individual installations amounts to another 2850 GWh/year.[9]

The general technical possibilities of integrating wind energy into the electricity grid include the provision of backup capacities, disconnection of superfluous wind power, and storage. In Switzerland, wind power can be integrated into the electricity grid without difficulty, even at its full potential; maximum expansion of wind power would still not influence the stability of the electricity net. Short-term fluctuations in wind power production could easily be absorbed by hydropower. New storage technologies such as hydrogen will even further improve the compensation possibilities in the future.

Climate change

The impact of climate change on the mean wind speed in Switzerland is not clear. Possibly there will be a change in the mean wind speed and an increase in extreme events. Both would have an impact on wind power production. Mean wind speed directly affects electric power output, with an increase in mean wind speed leading to an increase in mean wind power production. In the case of extreme events, production interruptions may occur at individual locations. However, a breakdown of all the wind power plants is statistically unlikely..

Measures

For Switzerland, the impacts of climate change on the use of wind power are of a rather indirect nature. The challenge is in fact to enhance the expansion of wind power in neighbouring countries. The following measures will contribute to the optimal integration of wind energy:

- Improved wind forecasts and at the same time, a reduction in schedule reporting time, with which network operators are notified about the expected electricity production in advance for planning. The shorter the schedule reporting time, the more accurate the predictions of the expected electricity production from wind power.
- Improved planning base for consideration of environmental concerns, in particular those of nature conservation and landscape protection.
- Grid networks – the larger the net, the smaller the demand for backup power, i.e. conventional production capacity that needs to be available in order to compensate for reductions in wind power production as a result of unfavourable wind conditions.
- Transparent, cross-linked and well functioning markets can considerably reduce the costs of integrating wind power. In this respect, a liberalisation of the electricity market may be helpful, if it enables feed as well as load compensation over as large a catchment area as possible.

Biomass: Wood energy

Potential

The total ecological biomass potential was 34,000 GWh in 2001.[9] Wood, groves, hedges and orchards contributed the greatest proportion, with 12,800 GWh (fig. 6). The ecological biomass potential allows for a distinct increase in electricity production. Firstly, the amount of biomass products suitable for energy production will likely increased. Secondly, the development in conversion technologies will be able to improve the conversion efficiency to electricity by a factor of 2–3.

In 2004, 2.8 million m^3 of wood was used in Switzerland, primarily for heating. In particular, there has been a strong increase in the use of automatic wood heaters in the past decade. The energy wood potential allows for at least a doubling of today's use to more than 5 million m^3 in the future, provided that progress is made in the reduction of particulate matter emissions.[10] The potential could treble as a result of long-term trends in forestry (tree species appropriate to the location, graduated ecological forestry, extensive forest management, regional mechanical harvesting), as well as of developments in the timber industry (increase in sawing capacity). However, competition in the use of wood will increase because of other utilisers (building materials). Supply and demand will determine the price and, therefore, the use of wood.

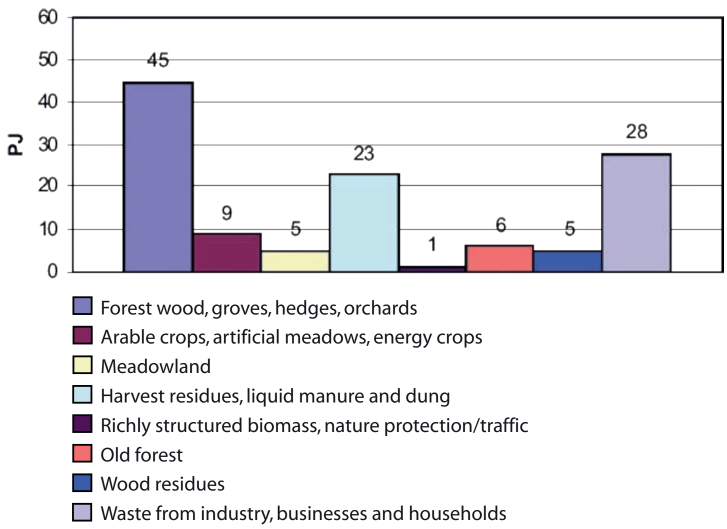

Figure 6: Ecological biomass potential in the year 2001, split into different sources.[9]
(1 PJ = 278 GWh)

Impact of climate change

Climate change will generally have a positive impact on the use of wood energy. Firstly, forest areas will expand (see Land ecosystems chapter) and the potential for wood energy will grow. Secondly, the acceptance of renewable energy and of measures to promote energy efficiency will increase in response to climate change and as a result of climate policy. In politics, federal administration and the economy, willingness to introduce measures to promote the use of wood energy is increasing.

Climate change and the increased use of wood energy will affect forests. The forest landscape will change. Altogether, there will not be more wood in the forests but the proportion of energy wood and wood of inferior quality will increase. A possible increase in extreme events, such as the Lothar storm in winter, December 1999, would cause large biomass losses and correspondingly, forced utilisation.

Short-term climate forecasts

Out of the ordinary climate conditions such as the European heat wave and drought period in summer 2003 but also the cold winters in the 1960s, already affect energy production and energy consumption in today's climate. For some time now, there have been attempts to predict these climatic fluctuations by means of numerical climate models. However, like the weather, the climate system has chaotic elements, and predictions are highly sensitive to small uncertainties in the initial conditions. Recently developed probability forecasting now considers this sensitivity by calculating not one but many projections with slightly different initial conditions. From this ensemble forecast, it is possible, for instance, to calculate the probability of a cold January or a hot summer (fig. 7). Such short-term climate predictions must be interpreted and used with caution at the moment; their quality varies depending on the region, and in particular, on the required forecasting period. However, probability forecasting enables prediction of expected weather for more than one week ahead and thereby offers interesting planning possibilities for professional use, such as in energy management.[11,12]

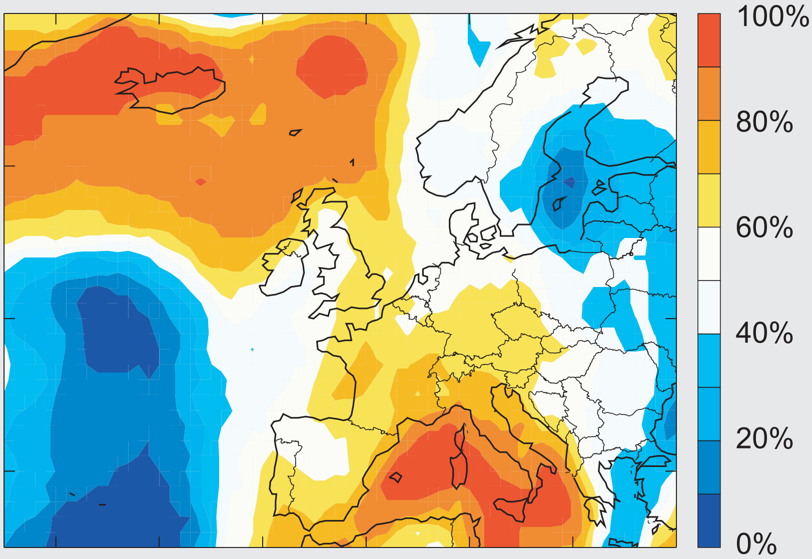

Figure 7: Probability of temperatures above the climatic mean for summer 2003: Prediction made in 1 May 2003.

5. Economic aspects

It is widely agreed that energy prices will rise due to the scarcity of oil resources and climate change. This trend will reduce the energy intensity of the gross national product and weaken the increase in global energy consumption. Adequate adaptation measures in the energy sector will not only limit the damage costs but also the costs for the energy system itself, so that in the best case there may be real synergies between adaptation and mitigation.

Development of energy prices

Energy prices will not go down again to the low level of the period 1985–2000 and could further increase in the medium- to long-term due to political shifts. The following developments will contribute to this:

- The global demand for energy will strongly increase. The International Energy Agency (IEA) expects an increase of 50% in the demand by 2030.[13] 60% of the increase would have to be covered by oil and gas.
- In Switzerland, the demand for energy services will also continue to increase (see section 3). At the same time, there will be a shift from heating energy (combustibles) in winter towards cooling energy (electricity) in summer as a result of climate change (see section 2). Depending on the scenario, the increased demand can be covered with less final energy, while the proportion of electricity increases with efficiency strategies.
- Due to climate change, hydropower and nuclear energy production in Switzerland will decrease in summer if fixed costs remain constant.
- Climate change increases the variability of the hydrological cycle. More frequent extreme events will result in more interruptions and damage. Examples of this are the flood in August 2005, which led to interruptions for river power stations, or the high water temperatures in summer 2003, which resulted in reduced energy production by nuclear power plants.

An important influencing factor in the development of energy prices is the question of whether the external costs of CO_2 emissions can be sustainably internalised (for example by certificates, steering taxes, support measures). There is large uncertainty about the long-term development of CO_2 legislation. For one thing, there is uncertainty about the prices for oil, gas and electricity. In the case of high energy prices, it can be assumed that the politically determined CO_2 costs will decrease, since high energy prices would further increase the costs of fossil energy. For another thing, the CO_2 costs depend strongly on the question of whether all nations worldwide will take part in climate protection agreements in the context of the Kyoto protocol. In the event that important nations continue to opt out, there will be a geographical shift in energy production. Altogether, higher energy prices will slow down energy consumption. Due to considerations of energy efficiency, there will be a shift towards electricity. The attractiveness of CO_2-neutral energy (new renewable energy and nuclear energy) will increase.

Generally, climate change will lead to an increase in uncertainty, which is why systems with short pay-back periods will be preferred.

Economic modelling of adaptation and mitigation measures

As a result of climate change, the proportion of the gross national product that is available for consumption will decrease for the following reasons:

- The damages caused by climate change will have to be resolved by the national economy.
- Preventive actions against the damages will have to be taken and financed.
- Climate protection measures to reduce greenhouse gas emissions will require additional expenditures.

From an economic perspective, the first two items are considered to be adaptation costs, the third package of measures comprises the mitigation costs. In order to arrive at an optimal long-term strategy, future costs and benefits of climate change will have to be estimated and compared. This is achieved by discounting future consumption and future deadweight losses using an interest rate of typically 1.5 to 5%, depending on the time horizon. Such a sober economic approach has the advantage of suggesting the optimal behaviour of the global community of nations: Both doing nothing and taking exaggerated measures are more expensive than a tailor-made climate protection policy that maximises long-term welfare.

From such analyses, it can be deduced that a specially tailored climate policy will pay off economically. Deadweight losses will be minimised and remain within the magnitude of less than 2% of the reference development without climate change. Finally, the proportion of energy costs in the gross national product will decrease slightly as a result of climate protection measures.

Literature and notes

1 GWh/a = gigawatt hours per annum. 1 GWh = 1 billion kWh. 1 Petajoule (PJ) = 278 GWh. MW = megawatt (power)

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