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Impact of Efficiency Improvements on the Overall Energy System

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Input Paper: Impact of Efficiency Improvements on the Overall Energy System

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1. Introduction

By energy efficiency we understand the reduction of the amount of energy necessary to satisfy the need for specific energy services. Thus, not considered is energy saving due to the partial or complete abstaining from satisfying the needs. Improvement of energy efficiency mostly means reduction of energy intensity.

Figure 1 shows the scope of energy efficiency considerations. The present paper addresses use of efficient energy technologies including also such aspects as grey energy as well as ecologic and economic efficiency. The focus is on Switzerland but global and regional perspectives are also provided for some issues.

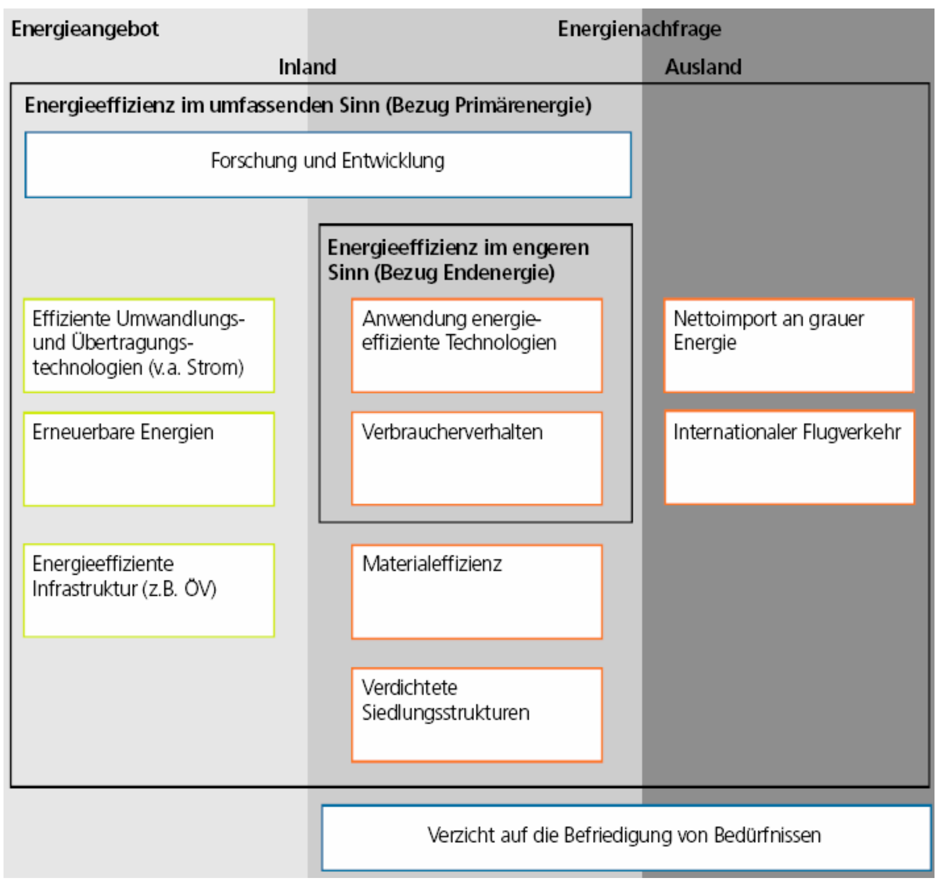

Fig. 1: Scope of energy efficiency considerations (energieschweiz, 2007).

2. Current Structure of the Energy System

Thesis I: *The internationally good performance of the Swiss energy system in terms of primary energy consumption and low CO_2 emissions is highly dependent on the structure of the Swiss energy system (hydro and nuclear), high conversion efficiency (hydro) and on the structure of the Swiss economy (no energy intensive industry, major role of the service sector).*

Figure 2 shows the energy flow in Switzerland in 2005.

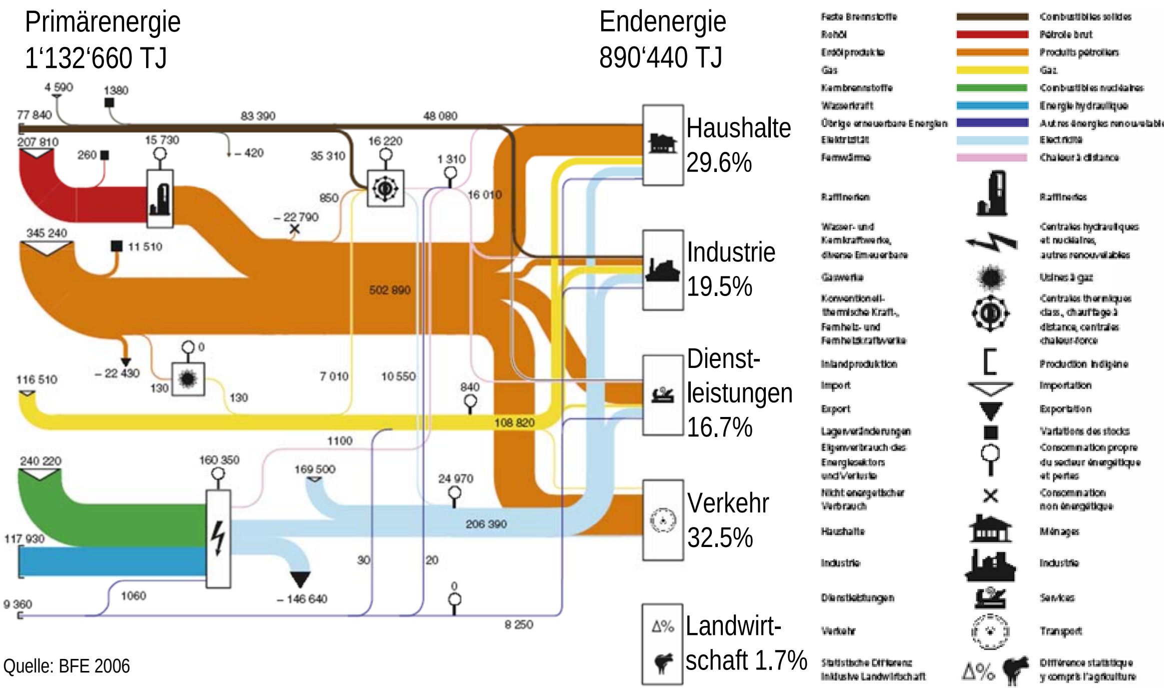

Fig. 2: Energy flow in Switzerland in 2005 (BFE, 2006).

The share of fossil fuels in current primary energy use amounts to 66% in Switzerland, compared to 80% globally. The total energy conversion losses at the final energy efficiency level amount in Switzerland to about 21% on average. According to (Jochem et al., 2004) currently energy losses at the level of useful energy amount to over 37% of the Swiss primary energy demand. The total loss from primary to useful energy is consequently close to 60%.

The current primary energy consumption in Switzerland corresponds to about 4800 Watt constant equivalent power level per capita (almost 42’000 kWh per capita and year). In addition there are about 4000 W per capita in terms of grey energy. While 6 t CO_2 per capita are emitted in Switzerland the grey energy consumption corresponds to additional 5 t CO_2 per capita (Jungbluth et al., 2007). The Swiss electricity sector is practically CO_2-free (18 g CO_2-eq. per kWh_e produced in Switzerland) while including imported electricity results in much higher but still internationally low average emissions from the Swiss electricity consumption mix (121 g CO_2-eq. per kWh_e consumed in Switzerland) (Dones et al., 2004).

3. Role and Significance of Efficiency Improvements

Thesis II: *Efficiency improvements have played a very important role in the past and will do so also in the future.*

Impressive efficiency improvements of major energy technologies (particularly fossil) have taken place in the past. Improvement of energy efficiency generally means reduction of energy intensity. Figure 3 shows the trend in Switzerland. The energy intensity has been improving in the EU by 1.4% per year in the 90'ies resulting in decoupling of the growth of GDP and energy consumption. However, the progress since year 2000 is much less pronounced (of the order of 0.5% per year).

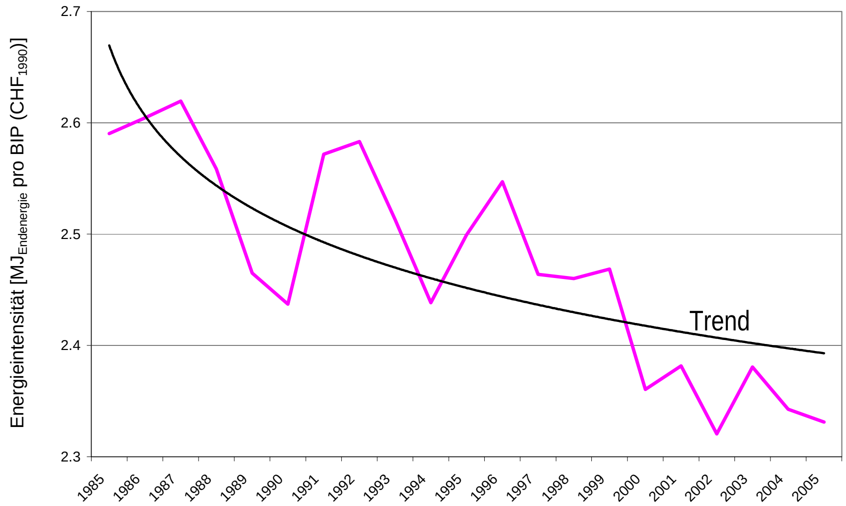

Fig. 3: Energy intensity development in the Swiss economy (BFE, 2006).

The importance of efficiency improvements is demonstrated in the alternative scenario of the IEA (IEA, 2006) where world-wide 58% of CO_2-emission reductions 2002 – 2030 in relation to the reference scenario are associated with efficiency gains. Figure 4 shows that the projected efficiency improvements are of fundamental importance for the development of the Swiss CO_2-emissions.

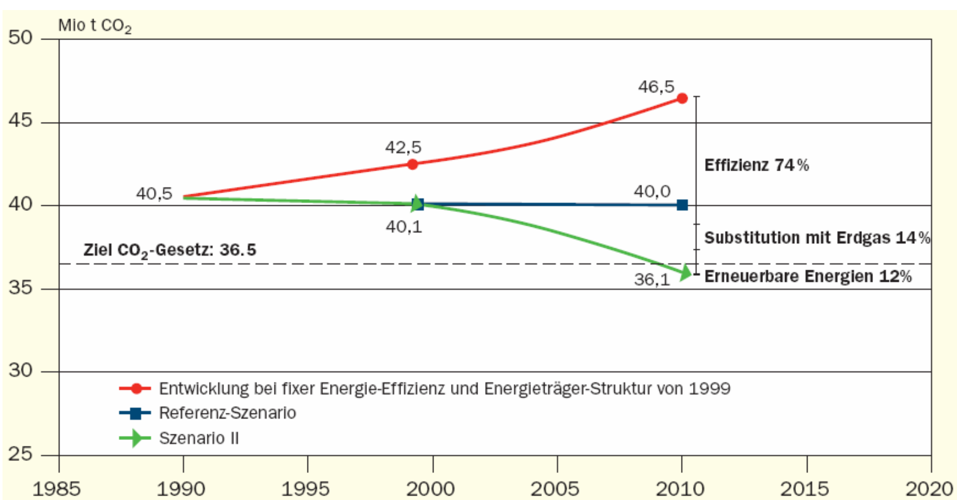

Fig. 4: Contribution of energy efficiency to the reduction of CO_2-emissions in Switzerland (Jochem et al., 2004; Hirschberg et al., 2003).

4. Efficiency Improvement Goals and Potentials in Perspective

Thesis III: *Efficiency improvements are necessary and highly important but alone not sufficient to respond to the principle goals of sustainable energy policies.*

The primary goals of a sustainable energy policy include protection of human health, minimising impacts on ecosystems, preventing the global warming and assuring secure supply of affordable energy. While detailed interpretation of these goals (i.e. which solutions are more sustainable than others) is a matter of an intensive debate and subject to trade-offs based on individual and group preferences, there is a quite wide consensus that reducing the dependence on fossil resources is a good strategy. Currently, large emphasis is put on the reduction of Greenhouse Gas emissions. Efficiency improvements are one very important tool for reaching the principal goals but it is unlikely that they alone will be adequate.

The respective roles of efficiency improvements and of carbon-free technologies are illustrated by the following example (Jancovici, 2003; Hirschberg, 2006) building on the Kaya equation (Kaya, 1990). The Kaya equation connects CO_2 emissions with population (N), production per person (GDP/N), energy intensity of economy (E/GDP) and carbon content of energy (C/E) in a simple equation:

$$CO_2 \text{ Emissions} = N \times (GDP/N) \times (E/GDP) \times (C/E)$$

To keep warming of the earth's atmosphere within bearable limits, global CO_2 emissions must be decreased 50% by 2050. In view of the economic equity needed for developing countries, emissions from developed countries should be reduced by significantly more (60-80%).

The implications of such an ambitious goal (though here we assume that a reduction by 50% would be adequate) can be deduced by considering the individual terms in the Kaya equation:

- Projected population growth by a factor of 1.5 (IPCC, 2000). This means that, to reach the goal the product of the remaining three terms needs to be reduced by a factor of three.
- The world GDP per capita is assumed to grow by very modest 1% per year (this is an extremely modest growth having in mind the historical developments and in particular trends in countries with largest populations i.e. China and India). As a result of such growth, the product of the two remaining terms needs now to be reduced by a factor of five in order to reach the goal.
- It is assumed (optimistically) that energy intensity will fall by 1.8% per year, which corresponds to the assumption in the Alternative IEA Scenario (IEA, 2006). This corresponds to the overall term reduction by a factor of 2.5. Thus, the remaining term needs now be reduced by a factor of two.
- Reducing carbon intensity of the world energy system by a factor of two in the next 40-50 years is a tremendously ambitious undertaking given that the trends unfortunately point in the opposite direction. Under less optimistic assumptions (moderate GDP growth 1.6% per year and historical efficiency improvement 1% per year, the reduction of carbon content would have to be even more drastic (factor 4). Under all circumstances, moving towards the postulated goal would require an impressive expansion of the carbon-free technologies, i.e. renewables and nuclear, a tremendous technological (and financial) challenge posed by the climate change issue. Table 1 further illustrates the dimension of the challenges both on the efficiency and supply sides (Pascala and Socolow, 2004); potential carbon emission stabilisation strategies are shown, each of them allowing to reduce expected carbon emissions in mid 21^{st} century by 1 GtC/year (current emissions are at about 7 GtC/year).

Table 1. Potential wedges: Strategies available to reduce the carbon emission rate in 2054 by 1 GtC/year or to reduce carbon emissions from 2004 to 2054 by 25 GtC.

Option	Effort by 2054 for one wedge, relative to 14 GtC/year BAU	Comments, issues
	Energy efficiency and conservation	
Economy-wide carbon-intensity reduction (emissions/$GDP)	Increase reduction by additional 0.15% per year (e.g., increase U.S. goal of 1.96% reduction per year to 2.11% per year)	Can be tuned by carbon policy
1. Efficient vehicles	Increase fuel economy for 2 billion cars from 30 to 60 mpg	Car size, power
2. Reduced use of vehicles	Decrease car travel for 2 billion 30-mpg cars from 10,000 to 5000 miles per year	Urban design, mass transit, telecommuting
3. Efficient buildings	Cut carbon emissions by one-fourth in buildings and appliances projected for 2054	Weak incentives
4. Efficient baseload coal plants	Produce twice today's coal power output at 60% instead of 40% efficiency (compared with 32% today)	Advanced high-temperature materials
	Fuel shift	
5. Gas baseload power for coal baseload power	Replace 1400 GW 50%-efficient coal plants with gas plants (four times the current production of gas-based power)	Competing demands for natural gas
	CO_2 Capture and Storage (CCS)	
6. Capture CO_2 at baseload power plant	Introduce CCS at 800 GW coal or 1600 GW natural gas (compared with 1060 GW coal in 1999)	Technology already in use for H_2 production
7. Capture CO_2 at H_2 plant	Introduce CCS at plants producing 250 MtH_2/year from coal or 500 MtH_2/year from natural gas (compared with 40 MtH_2/year today from all sources)	H_2 safety, infrastructure
8. Capture CO_2 at coal-to-synfuels plant	Introduce CCS at synfuels plants producing 30 million barrels a day from coal (200 times Sasol), if half of feedstock carbon is available for capture	Increased CO_2 emissions, if synfuels are produced without CCS
Geological storage	Create 3500 Sleipners	Durable storage, successful permitting
	Nuclear fission	
9. Nuclear power for coal power	Add 700 GW (twice the current capacity)	Nuclear proliferation, terrorism, waste
	Renewable electricity and fuels	
10. Wind power for coal power	Add 2 million 1-MW-peak windmills (50 times the current capacity) "occupying" 30×10^6 ha, on land or offshore	Multiple uses of land because windmills are widely spaced
11. PV power for coal power	Add 2000 GW-peak PV (700 times the current capacity) on 2×10^6 ha	PV production cost
12. Wind H_2 in fuel-cell car for gasoline in hybrid car	Add 4 million 1-MW-peak windmills (100 times the current capacity)	H_2 safety, infrastructure
13. Biomass fuel for fossil fuel	Add 100 times the current Brazil or U.S. ethanol production, with the use of 250×10^6 ha (one-sixth of world cropland)	Biodiversity, competing land use
	Forests and agricultural soils	
14. Reduced deforestation, plus reforestation, afforestation, and new plantations.	Decrease tropical deforestation to zero instead of 0.5 GtC/year, and establish 300 Mha of new tree plantations (twice the current rate)	Land demands of agriculture, benefits to biodiversity from reduced deforestation
15. Conservation tillage	Apply to all cropland (10 times the current usage)	Reversibility, verification

5. Efficiency improvement potentials and implications for the Swiss energy supply

Thesis IV: *Similar to the global case also Switzerland needs more energy efficiency as well as new technologies. By 2050, we can save at most 30% of energy demand with these methods in a way that is socially compatible. But that we cannot reach the 2000 Watt level per person is not decisive for the climate since quite ambitious CO_2-emission reduction goals could be reached in any case. Furthermore, constraints in primary energy consumption do not guarantee sufficient reductions of fossil fuel uses and thus needed reductions of Greenhouse Gas emissions.*

This chapter builds on (Schulz, 2007) and Bauer et al. (2007).

Our energy system can be designed today to be more sustainable: more ecologically with less oil and at the same time more economical and socially bearable through use of the least expensive efficiency increases and energy savings measures. Ambitious steps in this direction and thus towards lower CO_2 emissions should be addressed. Figure 5 shows the development of the Swiss primary energy use and supply with and without constraints. The results represent least cost solutions.

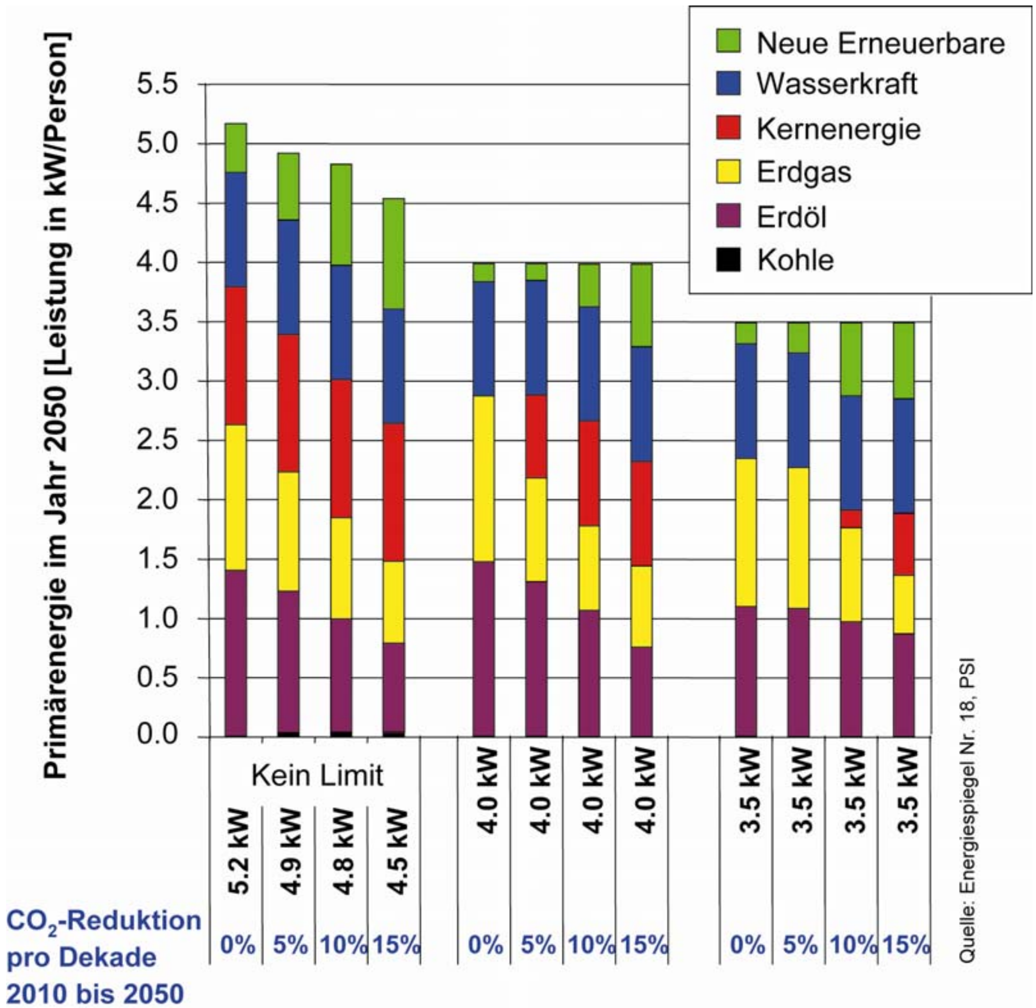

Fig. 5: Primary energy demand in the year 2050: Scenarios without limit; with 4 kW and 3.5 kW per person; and prescribed CO_2 reductions per decade between 2010 and 2050 of 0%, 5%, 10% and 15%, respectively (Schulz, 2007; Bauer et al., 2007).

Does it make sense to focus on the maximum reduction of energy use? This alone will not sufficiently reduce oil and natural gas use; CO_2 emissions will remain too high. We can also significantly reduce CO_2 emissions without focusing solely on energy use alone. Indeed, CO_2 reduction should be the predominant goal. Setting this goal has the effect that a slight increase in primary energy use will also produce lower additional costs, Swiss air will be cleaner, and dependence on fossil energy imports will be decreased. On the basis of climate policy, Swiss CO_2 emissions should be reduced at least 50% by 2050. That means, assuming that Switzerland reaches the 2010 Kyoto target, a reduction of almost 15% per decade between 2010 and 2050. This ambitious path is technically possible only with the most extreme efforts, and will require considerable investments

We need realistic but challenging intermediate targets for the middle of the century: 3-4 tonnes of CO_2 per person per year with 1500-2000 Watts from fossil sources (unfortunately realistically not including grey emissions and energy) should be placed on our agenda.

A redesign of the energy supply will cause significant costs (Figure 6). For a 15 percent CO_2 reduction per decade, the discounted cumulative additional costs of the energy system by 2050 are at least 70 billion Swiss Francs, independent of the limitation of energy use. Reducing energy demand to 4000 Watts per person (without CO_2 reduction) at a cost of barely 10 billion Francs is still relatively cheap. Further reductions will be much more expensive. We would do better to invest our money in technological developments for a low CO_2 energy supply, rather than following the path of maximum energy reduction.

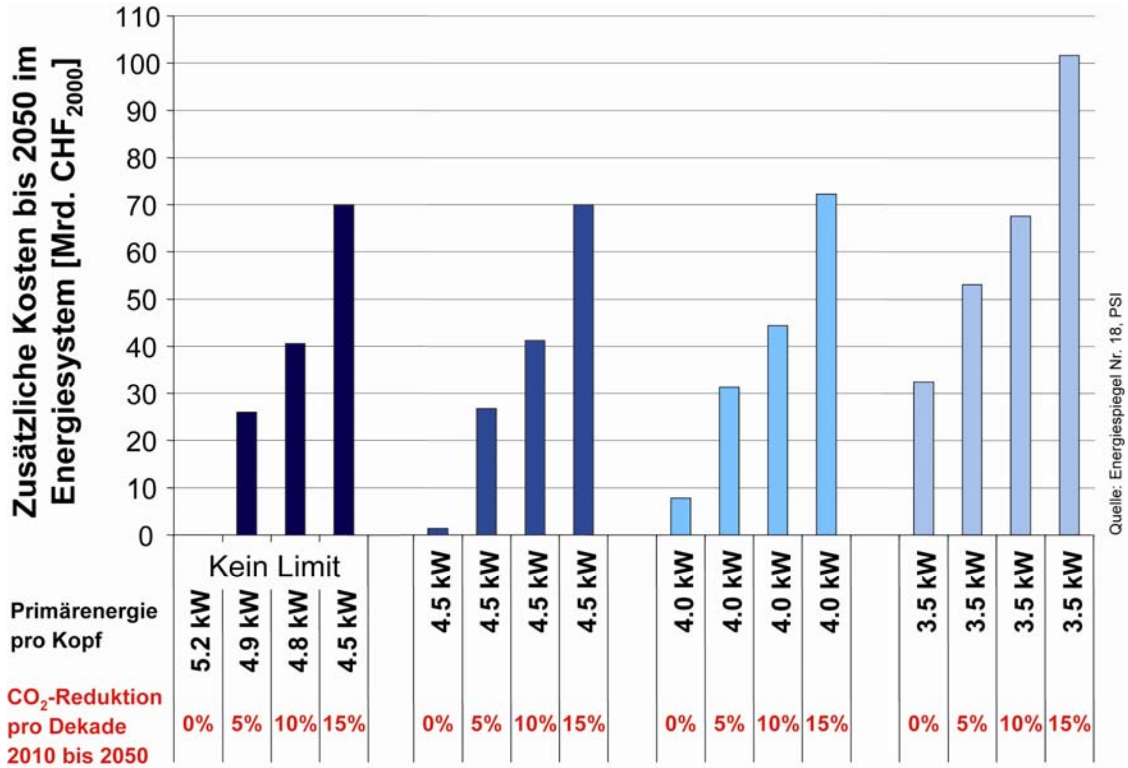

Fig. 6: Discounted cumulative additional costs in the energy system to 2050 in comparison to the scenario without primary energy limits and without CO_2 reduction, far left (Schulz, 2007; Bauer et al., 2007).

6. Efficiency improvement potentials and implications for specific sectors in Switzerland

Thesis V: *Large efficiency improvements are feasible, particularly in buildings and transport sectors and are manifested through substantial demand reductions.*

The largest blocks of energy use and CO_2 emissions today are the construction and operation of buildings, transportation, and consumer goods from the industrial and commercial branches.

Today more than 80% of space heating in private homes and apartments comes from oil and gas. These fuels can be largely avoided, even if housing space grows by around 40% as expected by 2050. The figures below show end-use energy for space heating in two possible scenarios. Energy saving construction and renovation to Minergie and MinergieP standards could reduce the heat demand to less than 40% of the current values. And if there is a massive shift to heat pumps and to district heating using biomass cogeneration or large central power plants, then we would need only a very low share of fossil fuels for heating. We could reduce the annual CO_2 emissions by 10 million tonnes (about 20% of today's total Swiss greenhouse gas emissions).

The transport sector is more difficult as the traffic is projected to increase further. If we continue to drive our cars more, and still want to save CO_2 in the transport sector, we must adopt more efficient drivetrains by 2050 that emit significantly less CO_2 per km. However we will still not be able to avoid fossil fuels. Hybrid drivetrains could economically replace the gas and diesel motors that are today dominant. Gasoline has no place in the future if we are striving toward an average of 3500 Watts per person because of its relatively high consumption. Natural gas could gain acceptance next to diesel, as it is an efficient fuel and produces less CO_2. Building up the needed infrastructure would also be necessary, i.e. natural gas stations and pipelines. This would only be realistic in cooperation with the rest of Europe. With such a technology shift it would be possible to reduce energy end-use by a third and CO_2 by 5 million tonnes per year, even if it is assumed that private transport will climb 40% by 2050.

Thesis VI: *Electricity in the future will be more important than ever for our service economy. Electricity can efficiently replace other energy carriers, so its CO_2 free production is key to an effective reduction of CO_2.*

Lower total energy use, and above all lower CO_2 emissions, also means that electricity becomes more significant within the energy sector, and that demand will increase (Figure 7).

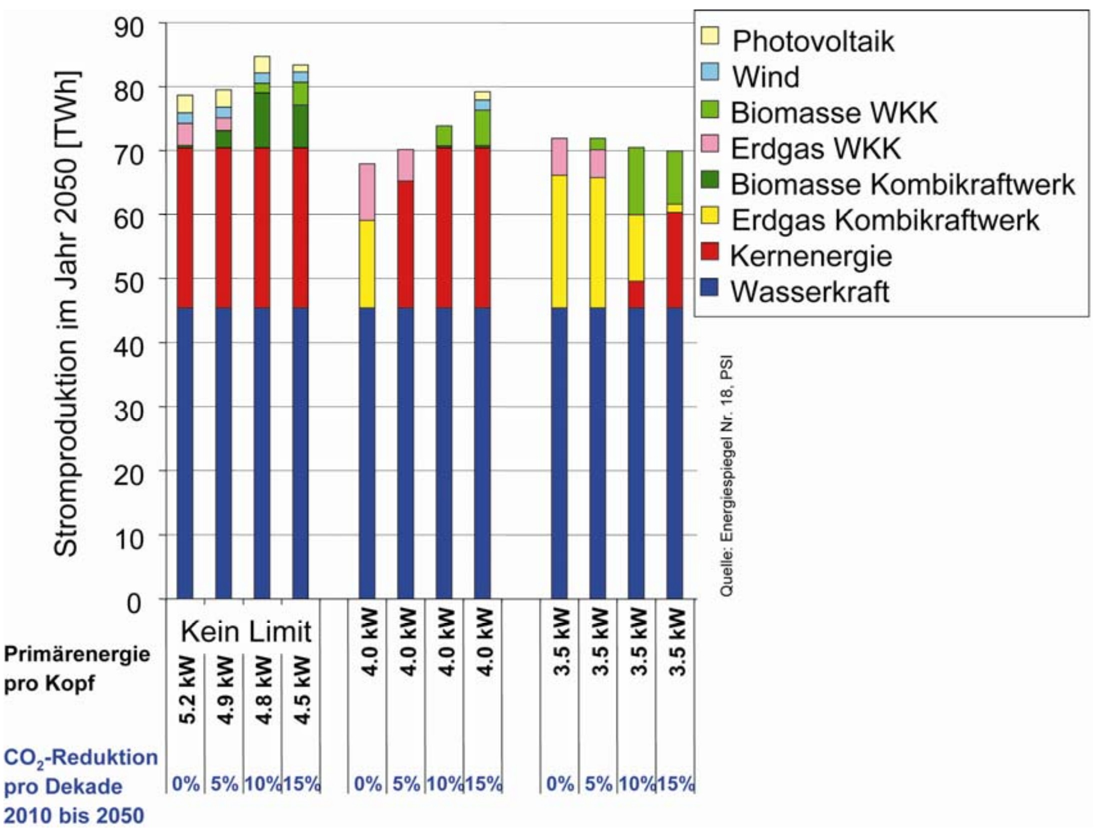

Fig. 7: Electricity production in Switzerland in the year 2050; Production represents the domestic use. Significantly less CO_2 for Switzerland means that nuclear energy must also remain a significant component in the future. With strict limits only on primary energy use, nuclear energy loses share to natural gas due to nuclear's lower efficiency (Schulz, 2007; Bauer et al., 2007).

The prime example of the efficient substitution of electricity for fossil fuels is heat pumps. Electricity can also often replace oil or natural gas in industrial processes. If CO_2 emissions are halved in order to meet the Kyoto targets (that means close to a 15% reduction per decade from 2010), then by 2050 the electricity share of the total energy use will grow from 23% today to 35-40%. It is projected that without targeted measures for saving electricity our use will climb from

57 TWh/year today to 85 TWh/year in 2050. If we manage to reduce primary energy use by 30%, electricity demand will climb to 70 TWh/year in spite of savings. For example, the use of heat pumps contributes to higher energy efficiency, but is responsible for an increase of electricity demand of up to 8 TWh/year. The composition of our electricity mix will also be decisive for Swiss CO_2 emissions: effective, affordable measures against climate change will demand massive amounts of new renewable energy and also nuclear plants, even if we fully exhaust the hydropower potential.

Figure 8 shows the potentials for energy savings within the various sectors according to the Swiss Federal Office of Energy (BFE). They are of the order of 1/3 at the level of final energy. These findings are by and large consistent with those resulting form PSI's analyses as presented above.

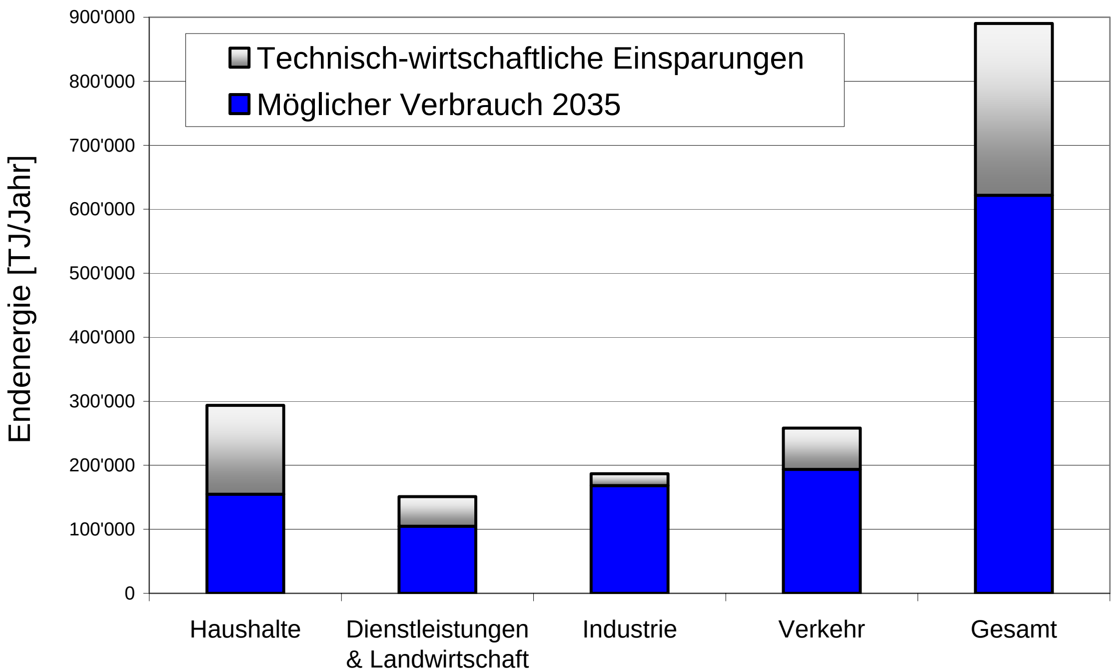

Fig. 8: Possible energy consumption in 2035 and conservation potentials (energieschweiz, 2007).

7. Ecologic and Economic Efficiency of Energy Technologies

Thesis VII: *Total costs though not uncontroversial reflect the economic and environmental efficiency of the various options. They increase the competitiveness of nuclear and renewables towards fossil. Through technological advancements the ranking of the various options can change. Most renewable technologies have the highest potential for improvements.*

The ecologic performance of energy systems can be represented on the aggregated level through the environmental external costs. The economic performance, on the other hand, is reflected in the production (internal) costs. The potentials and costs for new renewable and new nuclear technologies are analysed in detail in (Hirschberg et al., 2005)

Sustainable development promotes productivity and protection of the environment. The valuation based on total (internal and external) is therefore a suitable approach to express the overall economic and environmental dimensions of sustainability and thus the overall efficiency of the options. Though some social aspects (e.g. public health) are reflected in total costs, their limitation lies in a limited representation of the social dimension of sustainability. The latter can be better represented in Multi-Criteria Decision Analysis (MCDA), which depending on stakeholder preferences can lead to a different ranking of technologies than that based on total costs. For MCDA-results we refer to the literature (e.g. Hirschberg et al., 2000; Hirschberg et al., 2004). Here the latest total cost estimates for Switzerland are provided in Figure 9 (Hirschberg et al. 2007).

Nuclear power has the lowest total costs both now and in 2030. External costs of fossil-fuel technologies are dominated by the damage caused by global warming (though estimates of this are highly uncertain). Some of the currently expensive renewable options will become more competitive later. Consideration of external costs improves the competitiveness of the renewables and nuclear power options in comparison to those based on fossil fuels.

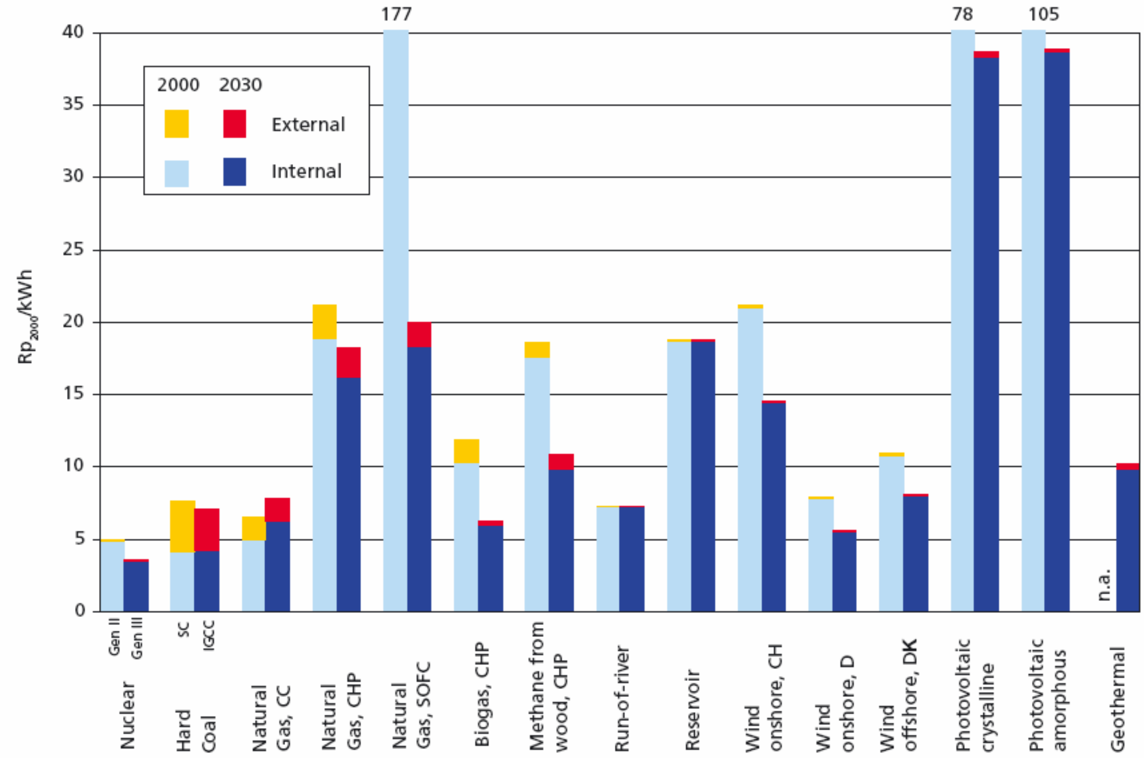

Fig. 9: Full costs of electricity generation options in 2000 and 2030. (Gen II/III = Generation II and III reactors; SC = Supercritical; IGCC = Integrated Gasification Combined Cycle; CC = Combined Cycle; CHP = Combined Heat and Power; SOFC = Solid Oxide Fuel Cell) (Hirschberg et al., 2007).

8. Conclusions

This paper provides support for seven theses summarized here:

Thesis I: *The internationally good performance of the Swiss energy system in terms of primary energy consumption and low CO_2 emissions is highly dependent on the structure of the Swiss energy system (hydro and nuclear), high conversion efficiency (hydro) and on the structure of the Swiss economy (no energy intensive industry, major role of the service sector).*

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Thesis VII: *Total costs though not uncontroversial reflect the economic and environmental efficiency of the various options. They increase the competitiveness of nuclear and renewables towards fossil. Through technological advancements the ranking of the various options can change. Some renewable technologies have the highest potential for improvements.*

Given that policies aiming at reducing the risks of global warming and promoting sustainable development in the energy sector will be followed, the world will have to learn how to be more efficient when dealing with energy and how to promote carbon-free or low-carbon energy technologies. Satisfying demand will require a mix of all options satisfying these requirements.

What is clear is that the redesign of our energy system will be difficult, and the transformation toward which we are striving will not happen by itself. It will require targeted and long term policy measures to move people in a new direction. And the earlier the necessary changes can be introduced, the simpler and the cheaper reaching these goals will be.

Acknowledgement

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