ÉCOLE POLYTECHNIQUE
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– Hydropower – A Way of Becoming Independent of Fossil Energy?

An SHS project in the scope of the program *Economie politique*
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Abstract

It has been clear for a while now that fossil energy will eventually draw to a close. On account of this, there are many incentives to find efficient and environmentally friendly energy sources.

This article will investigate whether hydropower is a suitable alternative to become independent on fossil energy in the future. During our work we will mainly try to answer this question for the case of Switzerland.

Furthermore, we show what impacts can occur if hydropower is pressed ahead with. They are illustrated by the study of four large-scale hydropower projects and their effects. We then conclude that there are a lot of arguments that have to be carefully weighted when promoting hydropower.

Finally we will conclude, based on the predictions on future energy consumption and the possible development potential, that hydropower alone will not be powerful enough to reduce Switzerland's dependency of fossil energy.

Contents

1 Introduction

Nowadays our whole life is based on fossil resources. Imagine you drink a glass of orange juice for breakfast. Even though one might assume this to be an organic product, the reality is different: The packaging of the juice is most likely to be some sort of plastic. Transportation of the juice from the producing country to your supermarket needed fuel. What about the process of creating the concentrate before transportation? This also is likely to have used up energy.

Fossil energy is limited and will eventually draw to a close if its use is not reduced drastically in the next decades. A big part of the fossil energy is used for gaining power, either physically from a motor or by passing through the easily transportable electricity. To avoid getting into economical problems if the more and more scarce crude oil is getting more expensive, it is important to develop different ways of gaining power to reduce this dependency of a country of fossil fuels. Water as a renewable energy source is becoming a very important topic.

The idea of using hydropower as an energy supplier is not new and has been around for several hundred years. Using hydropower to gain electricity became popular at the end of the 19th century. Switzerland's oldest alternating current hydropower plant was built in 1886.

Our report will dive deeper into this subject and treat several relevant questions about the usage of hydropower. Hydroelectricity is not the only way to use water power as an energy supply. However, it is by far the most important way regarding the total of energy that can be produced. We will therefore only use a small section to mention other means of using hydraulic power but focus the rest of our work onto its electricity aspects.

For a first overview, Chapter 2 will point out some facts that give reason to the discussion of where Switzerland gets its energy from and why this question will become more relevant in future. The overall electricity consumption has been increasing continuously since electricity was first used as power supply. A second part of that chapter will provide a few more details of this history. In order to complete the overview, we describe the status quo of hydroenergy production techniques used in Switzerland.

The crucial point in our discussion is the development potential of hydropower in Switzerland. An analysis of the potential is made in Chapter 3. First the term is introduced and then an estimation of the value and a possible forecast over the next 50 years is given.

As we will see, there is not a lot of hydropower potential left to develop in Switzerland, apart from renewing old small hydropower stations or increasing the production of existing bigger ones. However, the development potential is a value that depends mainly on political decisions and on the weight that is assigned to the benefits of hydropower on one hand, and to its costs on the other hand.

To illustrate this, imagine the project of a hydropower dam with a height of roughly 30 meters at the beginning of the Valais, e.g. Martigny. This dam fed by the water from the Rhone river would lead to a lake of about 25 km length reaching up to Sion. The potential energy of the water from this lake could then be used to produce energy. You might think that this is a very silly idea: After all, this area is populated and there are many buildings that would be flooded. More than ten thousand people would have to be resettled.

So lets consider China's famous Three Gorges Dam project instead. This dam has a height of 185 meters and the resulting storage lake a length of 660 km. Hundreds of thousands of people had to be resettled. Clearly, the feasibility of any hydropower project depends a lot on how much the different cost and benefit aspects are weighted. When considering our initial question to decide whether hydropower is a way to become independent of fossil energy, it makes sense to think not only about replacing the existing fossil fuel based power production as much as possible by hydropower but also to make sure that hydropower provides a sustainable alternative to fossil fuel.

Consider our example again: Such a dam would certainly produce a lot of energy, but whether the flooding of such a populated region can be considered as a good alternative to a new thermal or nuclear power plant is very questionable. When looking at the sustainable point of view, the costs of building a hydropower dam become more relevant.

Chapters 5 and 6 contain the listings of the most significant costs and benefits resulting from hydropower production. Many of those aspects apply to small as much as to large-scale projects. However, they are usually revealed more clearly in large-scale projects. We decided therefore to consider four particularly interesting large-scale projects outside of Switzerland and outline their most striking costs and benefits as examples. Those four projects are the Three Gorges Dam in China, the Aswan High Dam in Egypt, the Ataturk Dam in Turkey and the Tucuruí Dam in Brazil. A short introduction of those projects is given in Chapter 4.

The profitability of a hydropower project in general depends on how much it is supported by a country. It would be out of scale for this project to aim answering the initial question by analyzing the entire world and its energy situation. So we will focus then again on Switzerland and use Chapter 7 to outline promotion measures that could be taken by the Swiss government in order to enforce the hydropower production of our country.

Chapter 8 will finally draw a conclusion from our article and try to answer our initial question.

2 Switzerland

2.1 Future Challenges in the Swiss Energy Domain

In this section we focus on future challenges in the Swiss electricity domain as hydropower plays an important role in Switzerland's electricity production.

In a country like Switzerland where the most important economic sectors are industry, service and information the reliable power supply is crucial. Hence, at any time a sufficient amount of electricity must be offered. Therefore, we first take a look at the evolution of demand and offer.

2.1.1 Demand

The electricity consumption increased in 2005 by 2.1% (1.9% in 2004) [37]. According to the association of Swiss electricity enterprises the demand for electricity will further increase during the next decades [55]. The national SwissEnergy program tries to counteract such that the electricity demand does not grow as fast as during previous decades. The program aims to promote energy efficiency and the use of renewable energy. In fact, without the launch of the SwissEnergy program by the Swiss government in January 2001, the consumption of electricity would be 4.7% higher [47]. Still, economic growth and population growth as well as the use of new technologies eat up the economized energy. Furthermore, environmental factors like extreme climatic situations such as cold waves during winter months can have a significant impact on the demand. Figure 2.1 shows the development spectrum of the electricity demand predicted by the association of Swiss electricity enterprises based on their internal as well as external studies.

2.1.2 Offer

From the annual balance perspective, the national demand for electricity could be satisfied by Switzerland's own electricity production in the past. However, electricity is exported during the summer and has to be imported during the winter to satisfy the demand. According to the federal office of energy (SFOE), this trend seems to continue as the last two decades show that the demand for electricity shifts more and more towards the winter half year. Nevertheless, in the past 54 years Switzerland always had an electricity export surplus. [37]

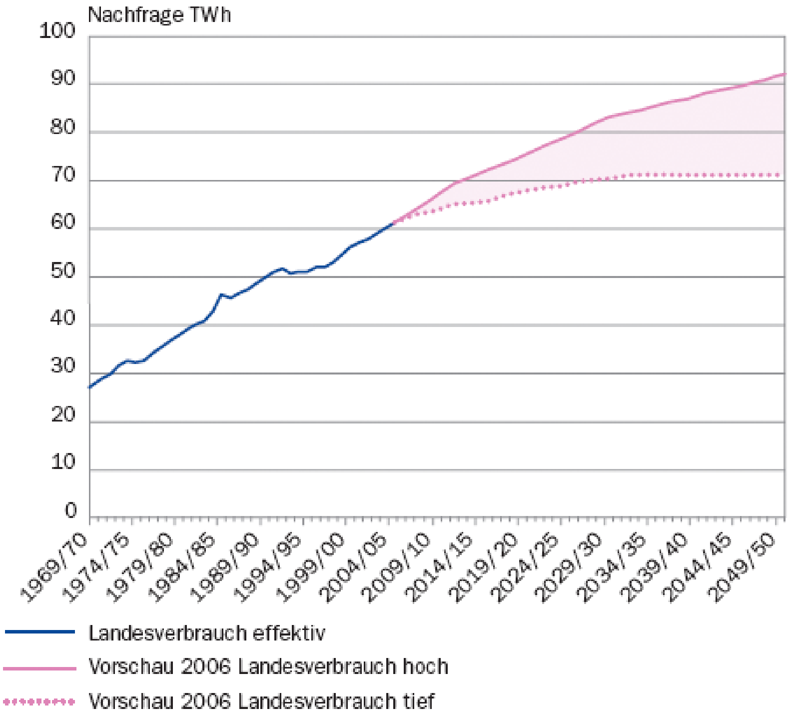


Figure 2.1: Outlook of Switzerland's electricity consumption

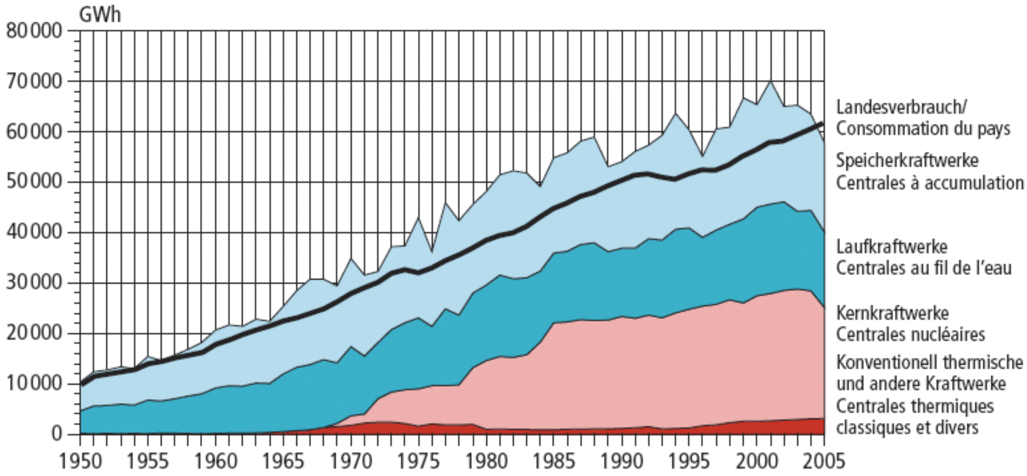


Figure 2.2: Evolution of the demand and offer in the past

2005 represents the first year since 1910 where Switzerland had an import surplus. A higher demand for electricity due to the cold winter months February, April and December was one reason. A lowered offer of electricity was the other reason. The nuclear power plant Leibstadt was shut down on March 28, 2005, due to the damage of one of its power generators and remained down till end of August 2005 [14]. The effect was a lower average availability of the five swiss nuclear plants of 78.3% in 2005 (90.2% in 2004) such that their total electricity production decreased by 13.4%. [37]

Such scenarios show that Switzerland's electricity supply is highly dependent on imports in order to fill gaps in its electricity supply.

2.1.3 Future

According the head of communication of the federal office of energy (SFOE), Mrs. M. Zünd, the so called stress situations in terms of electricity production are more and more likely to occur. There are different reasons for such a stress situation that causes a lack in the electricity supply. For instance the outage of a nuclear plant like mentioned in Section 2.1.2 or the low water level of rivers and reservoirs. Together with very cold weather conditions during the winter these situations are even worse. But also the dry and hot summers cause problems as the electricity consumption increases and the production decreases. Theoretically, after model calculations done by the SFOE, Switzerland is able to handle such extreme situation with its own resources [40]. However, the import of electricity is favorable because otherwise, especially the water level of the reservoirs would be lowered heavily.

Fact is that today Switzerland's primary energy sources for electricity production are hydropower and nuclear power. Furthermore, Switzerland relies on imports, mainly from France, in order to guarantee electricity supply throughout the year. So the Swiss Federal Department of the Environment, Transport, Energy and Communication (DETEC) states on its official website that the energy supply is currently working well. Nevertheless, Switzerland faces a problem in securing its energy supply as nuclear power plants have to be closed around 2020 [13]. Besides, as per the SFOE's spokeswoman Mrs. M. Zünd, the agreements between Switzerland and France that allow Switzerland to import electricity to special conditions also run out around 2020. Hence during the next two decades a significant gap between offer and demand occurs.

To counteract, Switzerland is negotiating with the European Union for an agreement whose goal it is to guarantee electricity supply in Switzerland and the countries among the EU. The agreement is crucial because import and export are necessary to balance the fluctuating domestic electricity production. In addition, a replacement for the running out nuclear power plants has to be found. Zünd stated that the SFOE will publish its study “Synthese-Bericht Energieperspektiven 2035” in February 2007, which discusses thoroughly the challenges and per-

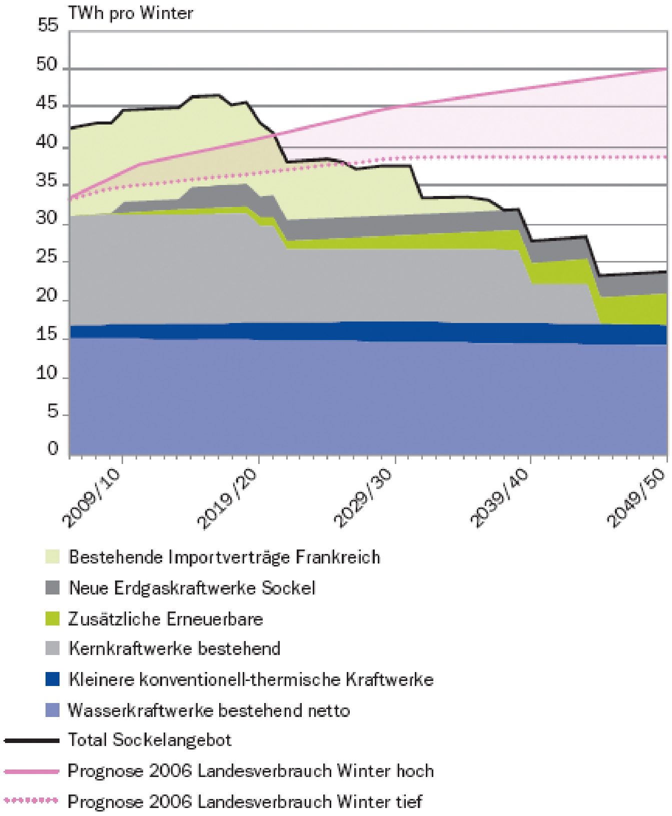


Figure 2.3: Development outlook of the electricity demand and the base offer during the winter half year

spectives of the Swiss energy supply. During an interview with the magazine Facts, the head of the DETEC, the Swiss federal council Moritz Leuenberger, stated that the construction of a new nuclear power plant has to be taken into consideration. This is necessary because the change to renewable energies takes time as the competitiveness of certain renewable energies need to be improved by research, development and the support during the market introduction, Leuenberger said [18]. In the meantime the liberal party (FDP) favors the construction of a new nuclear power plant whereas the social party (SP) favors the construction of gas-steam power plants.

The association of Swiss electricity enterprises sees the future electricity production in the further extension of the potential of renewable energies such as hydropower, the construction of new nuclear power plants or the construction of gas-steam power plants. Figure 2.3 shows the development outlook of the electricity demand and the base offer during the winter half year. In this figure the term “Sockelangebot” (base offer) comprises the existing power plants and long term agreements, extension of renewable energy, natural gas-fueled power plants and diverse small plants as well as improved performance in some hydropower plants. [55]

However, the political debate is launched.

2.2 Swiss Electricity Domain in History

We think that for some background on the current and future challenges in Switzerland concerning electricity consumption it is also useful to know something about the past. Obviously, electricity did not come up from one day to another – we will see that it has often been very demand-driven or has been further developed by the need of alternative. The classical example is the Swiss train system that was electrified by the fear of not getting coal anymore. The following subsections are mainly based on [59, 56, 27] which also contain more in-depth information for the interested reader.

2.2.1 Early Developments

The history of electricity goes back about 400 years. In 1601, the English doctor William Gilbert discovered that if one rubs certain materials at some others, they will attract or repel afterwards. He called these materials "electrica" and is therefore the creator of the term "electricity".

Around 1800 the Italian physicist Alessandro Volta presents to Napoleon a galvanic element - the first kind of battery. Shortly after the English chemist Humphrey Davy finds a way to let current pass through wires such that they glow. This marks the start of the era of electrical light which was the first and most predominant application of electricity at that time. The first model of an electrical motor was developed by the English physicist and chemist Michael Faraday in 1921. It was only about 15 years later when the first usable electrical motors were used. However, at that time the only energy source available were galvanic batteries which could not produce high currents.

The next milestone was the discovery of a dynamo-electric principle. This invention is due to Werner von Siemens and Charles Wheatstone. It opened to the world a much larger potential for power generation and gave rise to the development of heavy current engineering.

2.2.2 Continuous Current Era

Swiss engineers were at the forefront of the early development of new constructions of machines based on dynamos. It even was a Swiss who constructed the first direct current generator that was produced in series. In the same year, 1875, the first building in Switzerland was lighted by a direct current electric arc. It was a hotel in St. Moritz. Furthermore, it also is St. Moritz where the first hydropower plant, one with 7 kW power, was built.

Two Americans, namely Alexander Graham Bell and Thomas Edison were the next to open new fields in applications of electricity. Bell invented the telephone in 1876 and Edison created a carbon-wire lamp with a comparatively high endurance of 45 hours. Remarkably, at that time there had already been a Swiss federal law about water engineering police in place.

Starting in 1882, when the first city lighting was put into service in Lausanne, many Swiss cities started to develop an electric infrastructure. Soon after, the first hydropower plant in Thorenberg near Luzern started selling electricity to third parties. It also was the first alternating current power plant.

2.2.3 Emergence of Alternating Current

Since there is no efficient means to transport low voltage electricity over longer distances and continuous current is not easy to transform to lower voltages at the receiver, there was need for a new technology. The procedure of transforming alternating current was known early, but only in 1884 a first practical system was demonstrated. The existence of this system encouraged the production and distribution of alternating current and in only a short time span a distribution network with transformers was built.

2.2.4 Importance of Hydropower

The first power plants were built along rivers and were using the constant flow of the water. This was practical while there was no efficient means of transportation for long distances. After having solved this problem, people realized soon that the mountainous topology of Switzerland could be a cheap way to maintain lighting systems.

Towards the end of the nineteenth century, the electricity consumption increased drastically mainly due to technological advances. A big part of this demand was accommodated by a few new large hydropower dams. Furthermore, the altitude difference between reservoir and generator was increased to get more power. However, this was not always enough to meet the demand. Especially in winters with little precipitation there was a shortage in electricity. This is why at the end of the nineteenth and beginning of the twentieth century some thermal power plants were built as a standby power source. First, these were mainly steam-engines, later steam turbines were used. The use of these plants was a little cumbersome since they needed a certain warm up time before they were fully available. Whenever there was a failure in a hydropower plant, quick substitution for it was needed. Later on, diesel generators were developed that had faster reaction times. Already in 1904, the first pump storage power station was built (see Section 2.3.3 for an explanation of the different types of hydropower plants). This again facilitated the smooth running of thermal power stations.

2.2.5 Electrification of the Swiss Train System

The first electrical railway in Switzerland was the 1888 inaugurated *Tramway Vevey-Montreux-Chillon* (VMC). At that time it was using continuous current. 1898, the first rotating current railway and also first rack and pinion railway started operating. It was the famous *Gornergrat-bahn.* It was not until 1911 that the first railway with the current combination 15 kV, 16 2/3 Hz was established between Spiez and Frutigen. The SBB decided to adapt this combination for its network and in 1913 the first section through the Gotthard was electrified.

Due to the shortage of fuel and coal during the first world war, the SBB pushed its electrification such that in 1928 already 50% of the network was electrified. In 1960 its whole railway network was electrified.

With this history, Switzerland was among the pioneers of electrification of railway lines, especially because of the pressure for using its natural resource, water, instead of the non-domestic coal.

2.2.6 Heat Pumps - An Alternative Power From Water

Water has the property of having a high specific heat capacity. So it is well suited for the use in heat pumps. The concept of heat pumps has been known for more than 150 years. Namely it was Lord Kelvin who discovered in 1852 that the use of a heat pump is more efficient for producing heat than the use of primary energy. He showed that the heat energy that is absorbed by the heat pump is taken from the environment. It is not topic of this work to explain the details of a heat pump. For an explication of the principles, refer for example to [61].

During the Great Depression people tried to build profitable heat pumps in larger scales. In 1938, Zürich put heat pump facilities for heating of buildings into service. Since then heat pumps are more and more used in construction and the recent rise of oil prices lead to a boost in new heat pump establishments.

Basically, there are three different ways of extracting heat from the earth. One is to use the outside air which is the simplest but not the most efficient way to get a heat medium. The second is to use the heat of the soil by using water as a transport medium. The last one is to use groundwater or water from a lake that keeps approximately the same temperature throughout the year. As an example of a heat pump that takes its heat from a lake, the EPFL central heating is described in Section 2.3.4.

In recent years, when the *MINERGIE* standard became popular, it became clear that sewage water is a big leak of energy in these houses. It is estimated that the sewage water in Switzerland contains enough energy to heat more than 300’000 apartments [48]. Some installations are already running and many more are projected.

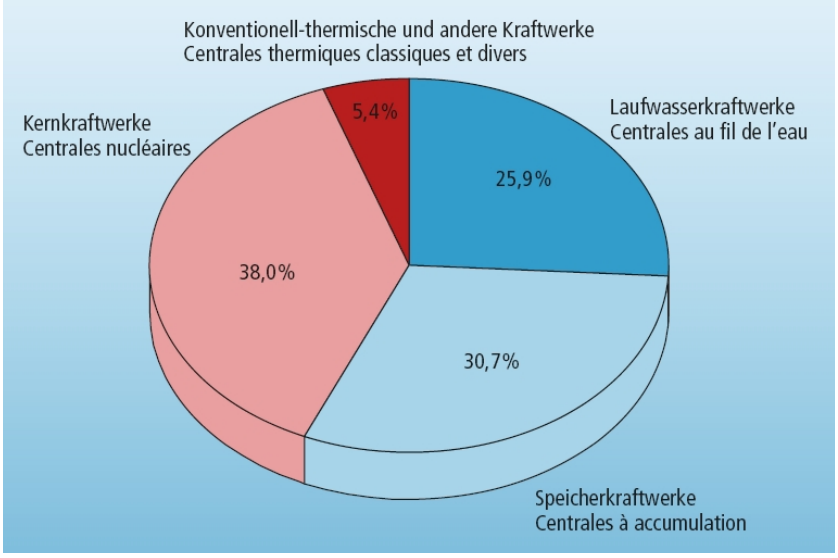


Figure 2.4: Electricity Production in Switzerland by Category

2.3 Status Quo

2.3.1 Introduction

As mentioned earlier, Switzerland is in a very good geographical position to use hydropower. Not only is it possible to use the alps as a water reservoir but also is Switzerland in a central position in Europe which makes it very suitable as an import and export hub for electricity. Certain types of hydropower plants even allow to buffer electricity temporarily in form of physical energy with a relatively high degree of efficiency.

Figure 2.4, taken from Statistique Suisse de l'éléctricité 2005 [38], gives a rough overview of how much of each different energy source is used in Switzerland (as of 2005).

2.3.2 Hydroelectricity in Swiss Power Production

With about 58% of its electricity produced from hydropower, Switzerland is one of the leading countries in Europe. Norway, however, produces about 99% of its electricity from hydropower.

The total amount of electricity used during the year 2005 was 57.3 billion kWh. The total amount of electricity produced by Swiss power plants was 57.9 billion Kilowatthours. So obviously Switzerland's net electricity balance is almost zero, which means the import-export ratio is about 1 (see [38]).

Consumption of electricity is likely to increase further on and has followed the tendency of the GDP for the last two decades as can be seen on Figure 2.5.

Taken the fact that consumption increases, who does use most of this electricity? According

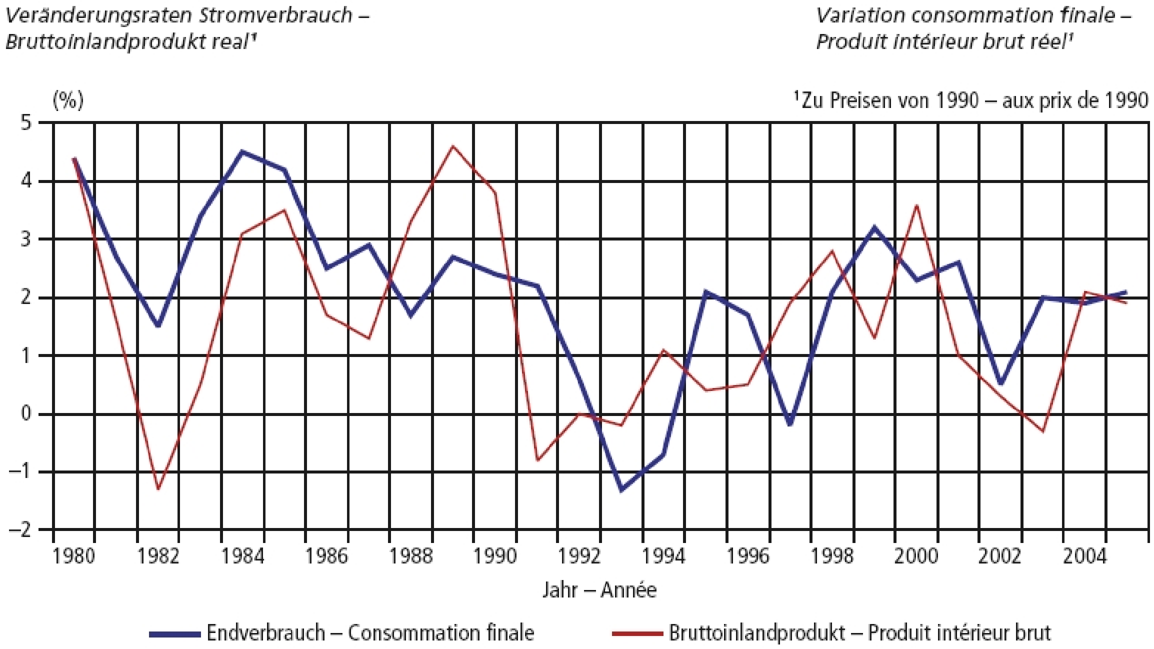


Figure 2.5: Key numbers for electricity and economy

to [38] roughly one fourth is used by households, one fourth goes to the industry, one fourth to services and the rest is split among agriculture, transports and loss due to distribution.

Figure 2.6 shows that about 23% of the total energy consumption in Switzerland is currently covered by electricity. Since electricity is produced to 58% from hydropower, this gives a total portion of a little more than 10% of the total energy produced from hydropower. Therefore, there are two possibilities to become more independent of fossil energy usage by using water:

- Extension of the percentage of electricity produced by hydropower.
- Development or promotion of other technologies that use energy generated from water without passing over electricity.

The first possibility will be the main topic of our discussion in the next chapters. The usage of water as energy resource without electricity is discussed briefly in Section 2.3.4.

2.3.3 Types of Hydropower Plants Used

Basically there are three different types of hydropower plants used. Their properties and usage scenarios are described below. Figures and examples in the following subsections are all taken from [7, 54].

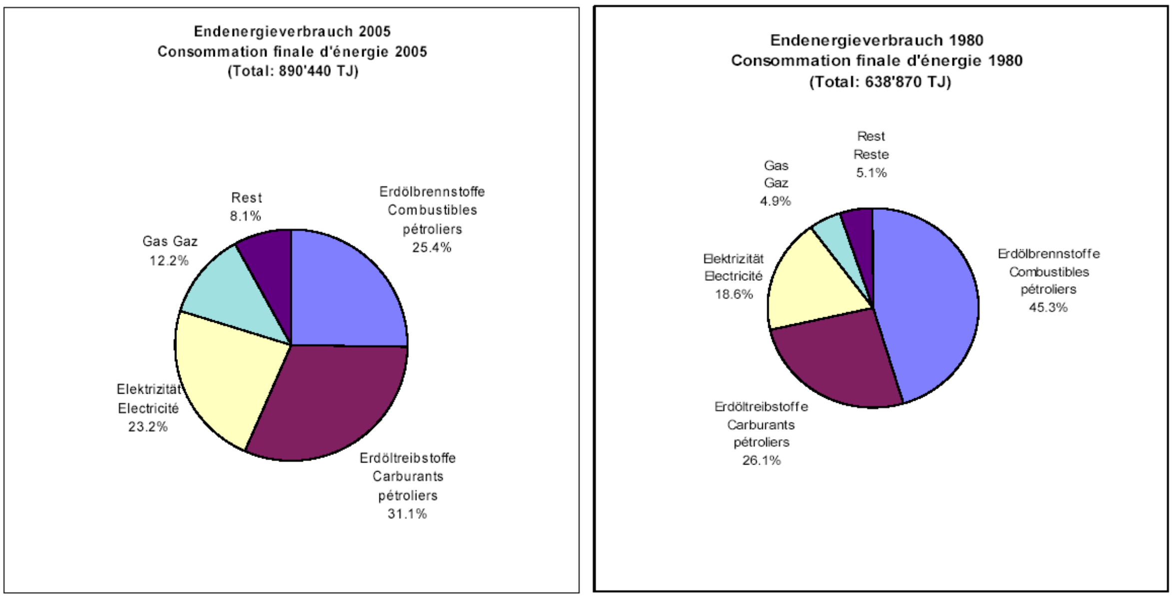


Figure 2.6: Total Energy Consumption in 2005 and 1980 [36]

Storage Power Stations

Storage power stations, schematically shown in Figure 2.7, base their energy on water stored in reservoirs that is used to drive turbines. Ususally, the altitude difference between the reservoir and the turbine is big. It can be more than 1500 meters. So the pressure exerted on the turbines is very high. In contrast, the volume of the water is relatively low compared to run-of-river power stations that are described below.

Storage power stations can be started in a few minutes in response to instantaneous demand. Once not needed anymore, they can be shut down very easily, too. This makes them very suitable for usage during peak periods of the day (midday) and in winter, when the demand is high and the water level of the rivers is low.

Some examples of storage power stations in Switzerland are:

Grande Dixence With its dam that of height 285 meters the fifth-highest water dam in the world. It has a high pressure pipeline with an altitude difference of 1800 meters from dam to turbine. Unfortunately, it burst in 2000, killing three people and is out of service since then. [60]

Verzasca Dam Although only the third highest dam in Switzerland, it is certainly the most famous of the Swiss dams due to its important role in the James Bond movie *Golden Eye*.

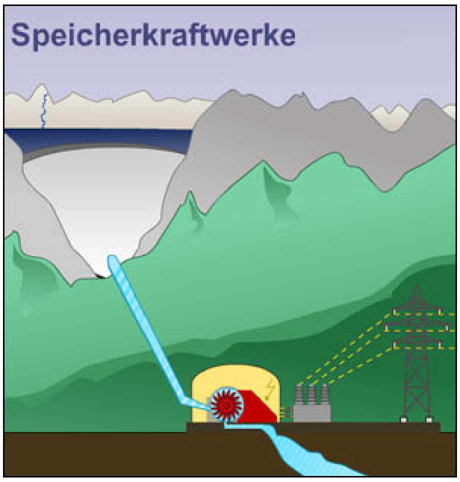


Figure 2.7: Storage Power Station

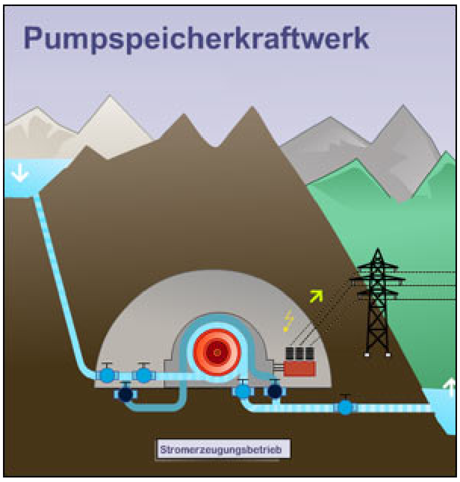


Figure 2.8: Pumped Storage Power Station

Figure 2.9: Run-of-river Power Station

Pumped Storage Power Stations

Pumped storage power stations work essentially like the storage power stations described above. However, pumped storage power stations have an additional feature that allows them to pump water up to the upper reservoir during periods of low electricity demand. On the peak periods of the day, they can then reuse the pumped water for electricity generation. Obviously, the pumping does not come for free as the pumps need energy, too. Today's plants have a degree of efficiency of roughly 75% [16].

The reason for having pumped storage power stations is mainly, that for several types of power plants, such as nuclear power plants and thermal power plants, it is not efficient to shut down and restart very often. They produce more efficiently if they run on steady power throughout the day. Therefore, pumped storage power stations buy cheap electricity from these nuclear and thermal plants and use it to pump the water up to the reservoir. During the peak periods, when the price for electricity is higher, the water is run through the turbines and the electricity is resold.

Because pumped storage power stations buy electricity from greenhouse gas emitting plants, some environmentalist don't like the idea of promoting the former. There is for example the Grimsel dam that is such a pumped storage power station. Recently, plans were discussed to increase the height of the dam to get, for one part, a larger buffering possibility. This new dam would also cause some rare pine trees to sink.

Run-of-river Power Stations

Run-of-river power stations are usually small dams in rivers (see Figure 2.9 for a schematic picture). The source of energy used is the flow of the river water that passes through the turbines and drives them. Altough the altitude difference between the upstream side of the dam and the downstream side is not very high compared to storage power stations, they benefit from a usually large volume of water available.

Run-of-river power stations accommodate the basic electricity demand throughout the whole day since they operate continuously. However, the amount of electricity that is produced depends on the flow of the river. That is why they are usually more productive during summers than during winters.

Some examples of run-of-river power stations in Switzerland are:

Laufenburg One of the early power plants in Switzerland, established in 1914. After a renovation in 1994 it produces now up to 106 MW which is pretty high for such a plant.

Aubonne Put into service in 2000, this dam is said to be integrated well in a protected environment.

2.3.4 Hydraulic Power without Passing Through Electricity

In this section we will only investigate the use of hydraulic force without electricity that are suitable for Switzerland. It is clear that for countries with coastal access there are more alternatives. For example tidal power stations or wave energy generators are a current topic of research in these countries. As a matter of fact, the most predominant use of hydraulic power without passing through electricity is the thermal use of water, the heat pumps.

To investigate the efficiency of heat pumps using large water reservoirs, we will use the experiences made by the heating installation of the EPFL which is largely based on them. The following section is based on the documentation of the "domaine immobilier & infrastructures" of the EPFL which is available in [15].

Heat Pumps at the EPFL

During the 1970's the Swiss government pushed the national organizations to try to reduce their energy usage. At the time the EPFL was built there had already been a pump station for water from the Lake of Geneva. It was primarily used for cooling and was taking water 900 meters from the shoreline in a depth of 68 meters. The water there has the property of having a relatively constant temperature year-round which is about 6 to 7 degrees Celsius. The decision was taken to use this pump station for the heating of the EPFL buildings by using a heat pump. During summer it could also be reversed to cool the buildings down.

The pump station is close to the gyms of the EPFL and UNIL. Through some further pipes it is brought to the heating central which is on the north-eastern corner of the EPFL just past the metro tracks. It can easily be recognized by its chimneys. The river 'Sorge' passes just at this point and is used as a reverse transport to the lake. The water passed to the Sorge after being used by the heating central is not altered chemically and has a temperature of about 2 to 3 degrees Celsius.

There are two loops for the heating. One passing through the first stage of the EPFL construction and a second one, at a somewhat lower temperature, through the buildings of the second stage of the EPFL construction.

It is also capable of delivering the cooling water for air conditioning and cooling of scientific instruments.

Can Heat Pumps Be Considered Hydropower?

One could argue that heat pumps don't use hydraulic power, but only use the heat capacity of water. Indeed, the energy that is drained from the water has its origin in solar power. The Lake of Geneva, for example, absorbs yearly a flux of energy from the sun that is equivalent to 150 million tons of fuel. One of the main concerns in power engineering is to being able to take advantage of these enormous amounts of energy from the sun. Because of the heat capacity, water is certainly a very good medium to extract this energy without major damage for the nature.

The power needed to pump the water from the lake is very small compared to the gained energy from the heat pumps. For the EPFL station, the efficiency factor is 4.83. It is also interesting to compare the CO_2 emission from a heat pump installation and a thermal power installation. Figure 2.10 shows such a comparison.

Independently of whether one considers heat pumps as being hydropower or not, the heat pumps have technically evolved in recent years and are already widely used as heating for new buildings. They therefore reduce some of the dependency from fossil energy which is the primary point of our consideration.

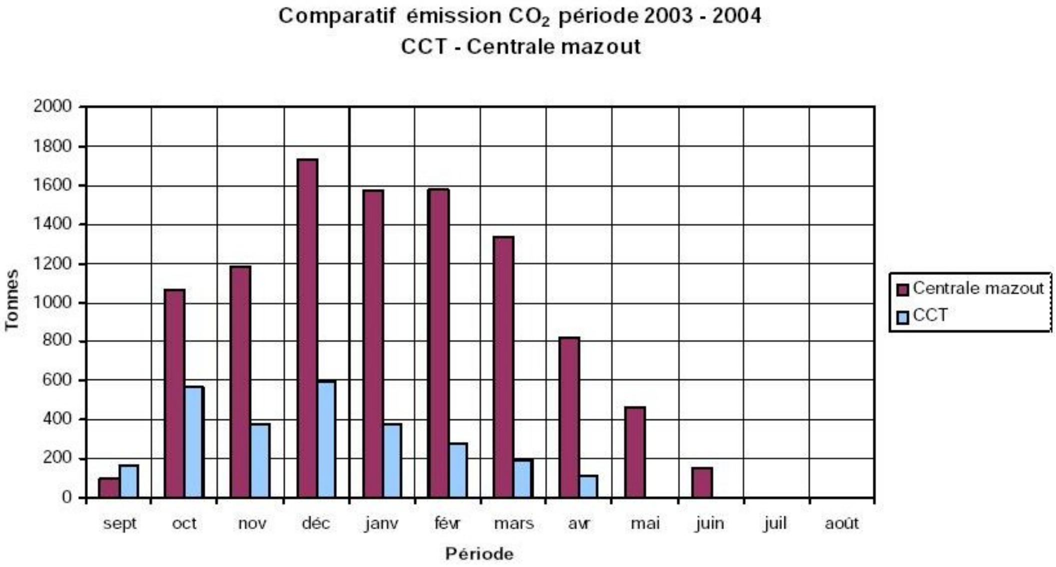


Figure 2.10: Comparison of CO_2 emission between a heat pump and an oil heating with equivalent energy production

3 Development Potential

Around 35'000 GWh per year are nowadays produced by our hydropower plants. As we know, this corresponds to 13.5% of the total energy consumption or 58% of the total electricity consumption in Switzerland. However, how much more electricity can we produce out of the water resources we have? Figure 3.1 from [45] shows the development in the past 50 years. This chapter will try to give some forecast for the future until 2050.

Using hydropower energy to a larger extent helps in reducing CO_2 and is therefore favorable. However, not only CO_2 but also other greenhouse gases like CH_4 are harmful to the environment and should be reduced according to the Kyoto Protocol. There are studies suggesting that greenhouse gas emissions from hydropower plants are not negligible. In Chapter 5 we will discuss this and other critical aspects of hydropower.

Despite its negative points, there are good reasons why energy generated by hydroplants should be developed. Chapter 6 gives an overview of its positive aspects.

The usage of hydropower plants can be influenced by promotion. In Chapter 7 different ways to promote hydroelectricity will be discussed.

3.1 Definitions

In order to get a measure of the potential that still lays unused in our water resources, the following four values are important to be distinguished:

The Theoretical Total Potential of hydropower is used to describe an absolute upper limit which depends on the amount of water available in Switzerland. However, different interpretations of this limit are possible. The water taken into account could be all water available for hydropower purposes, or every river and lake from a certain size, or even all waterdrops inside Switzerland.

According to the study [45] made in 2004 by Elektrowatt-Ekono by order of the Swiss Federal Institute of Energy, a rough estimate of the theoretical total potential of all waterdrops in our country (considering their height above 0) is about 100'000 to 150'000 GWh. However, this is not a reasonable upper limit for the potential of our water resources. It is simply not possible to make use of all that water.

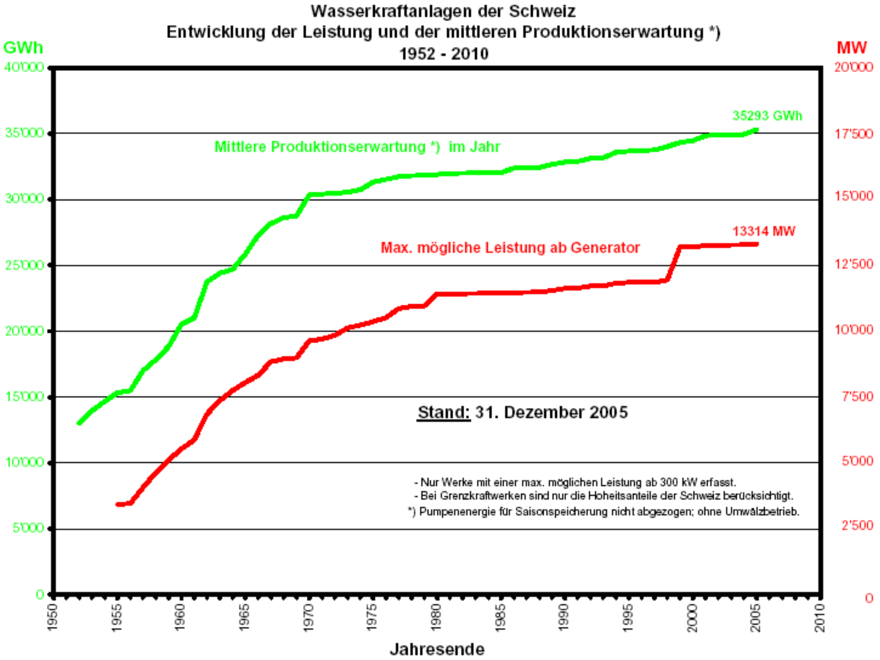


Figure 3.1: Development of Power and Production of Swiss Hydroplants between 1952 and 2005

The Technical Development Potential describes the possible production gain if new hydroplants are built or old ones extended or rebuilt. Its calculation is done independently of the market and political aspects and assumes that constructions are realized if they are technically rational.

This is a reasonable upper limit for the development potential which would be reached if the general conditions regarding market and politics were perfect and environmental concerns neglected. It is therefore the definition of the maximum development potential of our water resources.

The Development Potential describes the possible gain if political, environmental and financial aspects are considered. Whether a new construction is profitable depends on many different parameters. A few examples are supply and demand, electricity prices, construction costs, import and export, environmental regulations (taxes).

How all those factors are developing is impossible to know, hence the development potential can only be estimated.

The Total Potential measures the total energy that could be produced in the future. It corresponds to the sum of the current energy production and the development potential. Clearly, the total potential must be smaller than the theoretical total potential.

The total potential specifies a production potential in GWh for a certain year. If this value decreases in future, a negative development will take place. This could happen for example if there is too much electricity on the market which can be produced at lesser cost than hydropower or if the taxes to be paid by hydropower companies are increasing much, but also if the utilizable water is decreasing. The same, if the total potential increases, a positive development happens.

3.2 Calculations

The next sections provide an estimation of those potentials.

3.2.1 Technical development potential

The study made in 2004 by Electrowatt-Ekono [45] to determine the development potential of hydropower found three possibilities to increase the electricity production:

1. The annual production can be increased by building or restoring plants in order to use more of the water resources.
   The technical development potential of the average annual production without taking construction costs and political risks into account was estimated as 7'570 GWh.

2. During winter, Switzerland needs to import electricity and in summer, exports are possible. The production during the winter is less because the rivers filling the storage lakes bring more water in summer. If the storage capacity of the lakes is big enough, the water can be stored for the winter. However, the lakes are mostly not big enough. So too much electricity needs to be produced in summer and also water has to be wasted. A solution to be able to better adjust power production is to enlarge the storage capacity of a lake by heightening its dam.
   An example is the Grimsel lake in the Bernese Oberland. According to the KWO-Director Gianni Biasiutti in an NZZ article in October 2005 [42], the lakes can only store 25% of the inflow water and 75% need to be processed immediately. Since 90% of the water is received during summer time, more of the energy needs to be produced in summer and also there may be waste of water since not everything can be used. A project of heightening the dams by 23 m has been proposed, however, it was not accepted due to environmental reasons.
   For the estimation of the winter part, the study calculates with the potential that is received when certain dams are heightened by 3 to 15 m and gets to an amount of 1000 GWh.

3. The nominal power specifies the maximum continuous power from a plants generator. It

corresponds to the bottleneck capacity of the plant and is limited by the weakest part of the system. More engine power is possible if this part is replaced. This doesn't produce more energy in total but lets the plant produce the energy faster.
As an estimation of this value, the study gets to some thousands of MW. It cannot be added to the potential as there is no actual potential increase, but the faster produced resulting energy can be sold to a higher price. For a more detailed explanation, please refer to Section 7.1.3 and Figure 7.2.

3.2.2 Development Potential

In order to analyze the competitiveness of hydropower, also economical and political aspects need to be taken into account. A more accurate estimation of the development potential has been made in the same study by identifying 20 different factors that influence the development of hydropower and by categorizing them in their degree of influence and controllability.

They can be distinguished into economical, governmental (regulatory) and other factors.

The most important economical factors are electricity supply and demand, the need of adjustable energy (for what pumped-storage plants are favorable) and electricity prices. Their influence grows on a European level with the liberalization of the electricity market, a regulatory factor that is fixed in a EU directive.

Other regulatory factors are fixed by the Swiss national government or by the cantons in order to make environment friendly technologies more favorable even though their productions are actually less profitable. Taxes, subsidies and laws make sure that nature and environment are protected “as much as possible”.

Repressive factors for hydropower technologies are water fees that need to be paid to the cantons for the exploit of water resources and the law for residual water which ensures that there is enough water left in the river after the plant.

Regulations that help hydropower to become more competitive are CO_2 incentive fees which would lead to a rise in price of energy produced by thermal powerstations. Also the Emission Trading Scheme in the EU which is based on having limited allowances for CO_2 emissions favors hydropower.

A third category of factors influencing the development potential are neither regulatory nor market dependent. Some examples are construction and exploitation costs, the cost of electromechanical material and advances in technology.

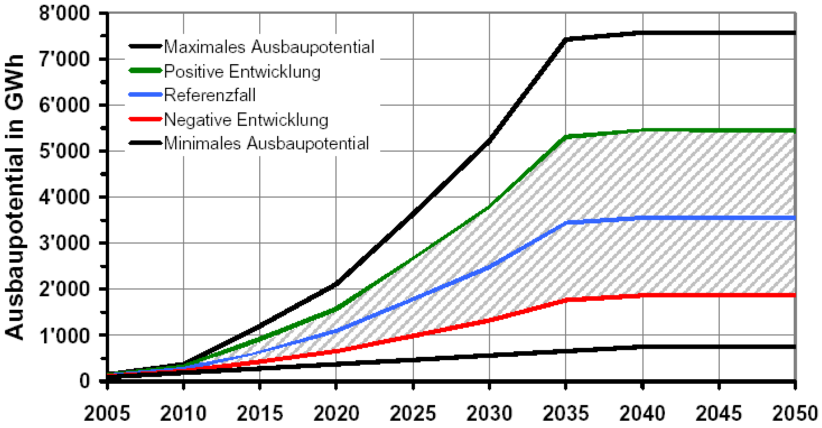


Figure 3.2: Development Potential of Hydropower until 2050

The study uses those factors to obtain an estimation of development potential of hydropower until 2050. An upper limit is set by the value of the technical development potential that is assumed to be reached in 2035. A lower limit is set by assuming that only the necessary replacements are made and that no new plants are built. Between those boundaries, three scenarios have been used:

- Reference case. This scenario assumes that future investments into hydropower will stay about the same as in the past. During the last 15 years, hydropower has not received major subsidies and its use has augmented because of mainly market dependent factors as electricity prices rise.
- Negative development. Hydropower is assumed to become less competitive because repressive regulations are made and other factors affect adversely this energy.
- Positive development. Most factors develop advantageous for hydropower energy.

Figure 3.2 shows the different scenarios for the development potential. In the first phase until 2015, the current trends have been used, later the different curves increase depending on the scenario.

The total potential corresponds to the sum of the current potential plus the development potential. However, due to the law for an appropriate amount of residual water from 1992 and also because of climatic changes [39], a decrease of utilizable water is expected and taken into account as well. This leads to a declination of the total potential once the development potential is reached.

The different scenarios for the total potential of hydropower are shown in Figure 3.3. In average (middle line, blue), a production gain of only 5% is expected until 2050. This corresponds

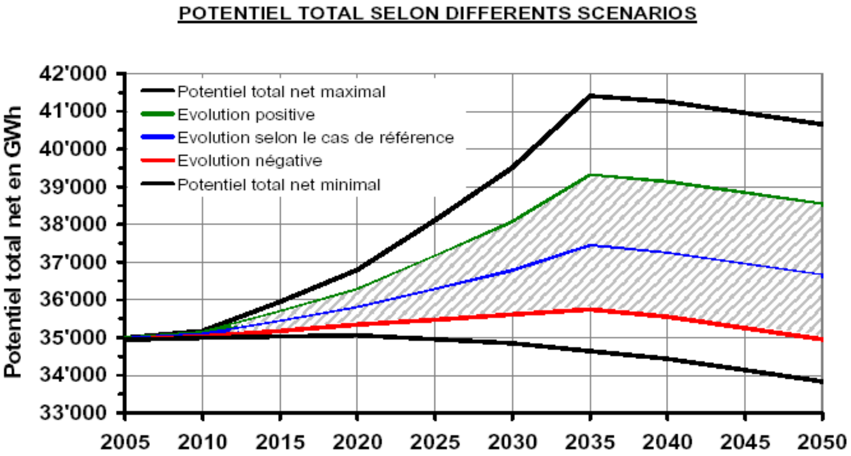


Figure 3.3: Total Potential of Hydropower until 2050

to 36’600 GWh, compared to 35’000 in 2005. On the other hand, a production gain up to 10% (38’500 GWh) could be possible if conditions are developing favourable for hydropower including that it is supported strongly by the government. In order to give those numbers some relation, it can be compared to the theoretical total potential (of all waterdrops) for which an estimation of 100’000 to 150’000 GWh has been given in Section 3.1.

4 Large-scale Hydropower

Until now we have been looking at how much Switzerland could increase its hydropower usage. We have taken it as granted that developing hydropower production is a good idea. However, this is not necessarily the case. There are both advantages and disadvantages for this way of energy production. In the Chapters 5 and 6, we will look thoroughly at those costs and benefits and refer to the examples of dams mentioned in this chapter.

The benefits of hydropower as a renewable source of energy are of course not only interesting for a small country like Switzerland. Also for larger countries with the appropriate resources hydroelectricity can be profitable. The hydropower projects of those countries have usually quite a different dimension than what we know from Switzerland.

There are costs and benefits that are only revealed when looking at some of those bigger projects. In order to discuss them as well, our examples will not only be focused on Swiss plants but also on some remarkable other projects. A overview of each of them is given here.

4.1 China – The Three Gorges Dam Project

The social, economical and technical development of China during the last decades created an urge for new energy sources. With the Three Gorges Project, China aims to create the worlds largest hydroelectric dam.

4.1.1 Dimensions

The dam is planned to reach an annual average power generation of 84.7 TWh once the project is fully completed in 2008 (one year earlier than originally scheduled). Its reservoir spans 660km of the Yangtze river, the worlds third longest river, and its crest height is 185 m. With a normal storage level at 175 m, the total capacity of the reservoir will reach 39.3 billion m^3. [10]

4.1.2 Motivations and Goals

According to the *C*hina *T*hree *G*orges *P*roject *C*orporation (CTGPC), the legal person officially responsible for the project, the primary benefits of the project are

Flood control: The Three Gorges Area has seen some major flood disasters in its history. The dam is supposed to reduce the danger of large floods, especially in its downstream regions.

Power generation: Electricity from the *Three Gorges Hydropower Plant (TGHP)* is to be distributed to “Central China, East China, Guangdong and Chongqing with a maximum transmission range of 1000km.”

Navigation: Due to its very long reservoir the Three Gorges Dam should enable large ships to navigate the Yangtze up to Chongqing south-west of the dam site and the navigation capacity of the river should be upgraded “from ten million tons to fifty million tons.” [10]

4.1.3 Particularities

As extreme as the dimensions of this project are its costs and its social and environmental consequences. Due to the inundation of the area more than one million people have to be resettled, cultivated land is destroyed, currently undiscovered cultural and historical places made inaccessible. The biosphere changes and the natural habitats of certain species disappear completely. Hence local and world wide protest movements have emerged around the project.

The example of the Three Gorges Dam illustrates in an impressive way that in a hydroelectric project not only the benefits of hydropower can be considered. In order to assure its sustainability all the economical, socio-cultural and environmental circumstances should be taken into account.

4.1.4 Evolution and Current State

Even though the construction of the Three Gorges Dam started first in 1994, the idea of damming the Yangtze has been around for a long time in China. It reaches back to 1918 when Dr. Sun Yat-sen, a founder of the People’s Republic of China, suggested in his book *Strategy for State, Part II: Industrial Plans* that “A dam should be set here to let ships go downstream and use the water resource as power.”[10]

Throughout its history the Three Gorges Project was much debated in China as well as in the rest of the World. Numerous feasibility studies were conducted to scientifically prove that the dam could or could not, indeed, fulfill its goals in a durable manner. Political and private institutions emerged around the project on both the critics and the supporters sides and contributed to the world-wide debate about the project.

One of the major feasibility studies, for example, was conducted by a Canadian consortium, the *CIPM Yangtze Joint Venture* and financed by the Canadian International Development Agency (CIDA) in 1986. The consortium was formed by three private companies and two state-owned utilities and supervised by, among others the World Bank, and China’s Ministry of Water Resources and Electric Power. The study was completed in 1989 and concluded that “a 185-meter-high dam with a reservoir level of 160 meters is technically, environmentally, and economically feasible”, and recommended that “the project go ahead”[28]

Probe International, an independent Canadian energy and environmental think tank used Canada's "Access to Information" laws to obtain a copy of the study and had nine different experts review it. The reviews were published in 1990 in the book *Damming the Three Gorges: What Dam Builders Don't Want You to Know* criticizing fiercely the quality of the study and concluding "that the engineers failed to live up to standards of practice required of engineers licensed in Canada". Essentially, Probe International accused both the CIDA and the consortium of having produced a seriously biased feasibility study because it bore "good prospects of winning hundreds of millions of dollars worth of business for Canada."[28]

In spite of the ongoing debate the Dam was approved at the March 1992 session of the National Peoples Congress by two thirds of the delegates. In September 1993 the China Three Gorges Project Corporation was founded and fifteen months later the project was officially started.

In summer 2003 the ship lock started its operation and the first generator unit began generating electricity. In September 2004 the Three Gorges Project could demonstrate its flood-control function withholding what is said to be the third largest autumn flood in the Yangtze history[10]

Even though the worlds largest hydro-electric dam will not be completed until 2008, China already holds another hydropower record: It hosts more than 86 thousand dams. And more of them are to come, for example upstream of the Three Gorges Dam, about a dozen more dams are planned to be built[8]

4.2 Brazil – The Tucuruí Dam

Brazil has experienced rapid growth of economic and population during the last decades. It is currently the ninth largest economy in the world [58]. Since a big export product is steel which is very power consuming to treat, Brazil needed to build more power plants in recent years.

Hydropower accounts for about 90% of the total power consumption in Brazil. The second largest dam of Brazil is the Tucuruí dam that was built in the state of Pará in the North of Brazil and has as the main afflux the river *Rio Tocantins.*

4.2.1 Dimension

The Tucuruí dam was built in two phases. Phase I was finished in 1984 and had a capacity of about 4 GW. During Phase II which is currently (2006/07) put into service, more turbines were installed and the capacity now reaches about 8 GW. The crest height of the dam is 106 m. The Tucuruí lake contains a maximum of 45.8 billion m^3 which makes it the 13th largest storage lake in the world. [63, 62, 31, 17]

4.2.2 Motivations and Goals

The Tucuruí dam has been studied quite extensively by the *World Commission on Dams (WCD)* in [31]. The study states that:

> The initial drive behind the construction of a hydropower complex was to provide electricity for the town of Belém and the surrounding region. By the time the Tucuruí was under serious consideration, the primary focus of the project changed to one aimed at providing power for the energy intensive electro-metallurgical industry in the region. Ultimately industrial interests drove the building of the Tucuruí complex.

As a secondary objective, the navigability past the dam had to be ensured. This was driven by industrial concerns that wanted to ship more along the river.

4.2.3 Particularities

The Tucuruí lake has some particularities that are partly due to the fact that it is in a tropical region, partly due to decisions during planning and construction. These are mainly related to water quality and greenhouse gas emission problems.

The main problem is, that the reservoir is in a region of tropical forest. This forest was not stubbed before the reservoir was filled so that there is a lot of organic matter that is now flooded. Obviously this matter started decomposing and gave rise to a big amount of greenhouse gas escaping from the lake. Furthermore, the water quality below the dam is poor which caused the fish population to drop drastically. We will drive deeper into this subject in Section 5.2 and will also see that the current research is at a strife about the quantification of the emitted greenhouse gas from such reservoirs.

Clearly, the dam has many more positive and negative points that have been studied. The interested reader should look at the study from the WCD in [31] and especially at chapter 7.2 thereof, where possible improvements for future large scale projects are presented.

4.3 Egypt – The Aswan High Dam

The Aswan High Dam situated in southern Egypt, 13 km south of the city Aswan, was built between 1960 and 1971. The dam impounds the river Nile to one of the world's largest man-made lakes, namely lake Nasser. The lake extends into the country of Sudan where the lake is called lake Nubia. Without the dam the river Nile would flood every year during summer as waters from its main tributaries the White Nile and the Blue Nile flow down the river. These floods made the soil around the Nile fertile as they brought nutrients and minerals. Since ever, the floods were of great importance for people living along the river Nile even though they were not always favorable. In such years the water wiped out easily most parts of the crop. Therefore, the British occupants began with the construction of the first dam in 1899 and it was completed in 1902. Its main purpose was the flood control. [57]

4.3.1 Dimensions

The Aswan Dam has a volume of 44.3 million m^3, a height of 111 m, a length of 3600m, a width of 980m at the base and 40m at the crest. Its reservoir, lake Nasser, has a length of 550km, a width of 35 km at its widest point with a surface area ranging between 5248 and 6000 km^2. The lake has a maximal storage capacity of 165 billion m^3 and is therefore the fourth largest storage lake in the world. The maximal water throughput of the dam is 10'000m^3 per second and powers twelve generators of 175 MW output each. The annual total output of hydroelectric power of the plant is 10TWh. [57, 41]

4.3.2 Motivation and Goals

The construction of the Aswan High Dam had several reasons in terms of agriculture and industry. The dam allows *flood control* to protect agriculture and people from the floods on one hand and to guarantee water supply during dry seasons on the other hand. In addition, the enlargement of the agricultural area by *irrigation* and to change from traditional, seasonal irrigation to permanent, all year irrigation was anticipated. Besides flood control, *power generation* and the improvement of *navigation* were other key factors. [57]

4.3.3 Particularities

As the Aswan High Dam was completed in 1971 this example allows us to state something about the long term effects of a larger scale dam project. The dam's positive and negative effects in terms of economical, environmental and social aspects are discussed in Chapters 5 and 6. Key words are such as loss of cultural goods, resettlement, fishing, agriculture, erosion, sedimentation of silt or stagnant water.

4.4 Turkey – The Ataturk Dam

The Ataturk Dam impounds the river Euphrates and is part of the Southeastern Anatolia Irrigation Project or short GAP (its Turkish acronym). The dam was built between 1983 and 1995, but is used for power generation since 1992. The GAP is the largest development project ever undertaken in Turkey. Its water resource development program aims the construction of 22 dams and 19 hydroelectric plants distributed over nine provinces in the Euphrates-Tigris basins. The anticipated total output of hydroelectric power per year is 27 TWh. Up to know, eight hydraulic power plants were completed. Once the project is completed it includes a network of irrigation channels and tunnels to deliver water for 1.7 million hectares of land. Besides power generation and irrigation the GAP includes also the development of urban and rural infrastructure, forestry, education and health sectors as this region is one of the poorest in Turkey with an-alphabet rate of 40 percent. [57, 25, 35]

4.4.1 Dimensions

The Ataturk Dam has a volume of 84.5 million m^3, a height of 169 m, a length of 1614 m and a with of 15 m at the crest. Its reservoir has a maximal storage capacity of 84.5 billion m^3 and a surface of 817 km^2. The annual total output of hydroelectric power is by 7.8 TWh (2005). Together with the other seven power plants the total annual output is by 18.7 TWh. [51, 46]

4.4.2 Motivation and Goals

The main goals of the Ataturk dam were *power generation* and *irrigation* in order to industrialize the region, extend agriculture and to increase tourism. This dam is the most important among the GAP as it contributes more than 30 percent of the anticipated total output of hydroelectric power. [25, 46]

4.4.3 Particularities

The fact that the Ataturk dam impounds the river Euphrates which also supplies other countries, namely Syria and Iraq, makes it a very interesting example. Together with the other dams of the GAP, Turkey controls the natural source of life of its two neighbor countries. It is obvious that this situation causes disputes between Turkey and its neighbors in terms of water supply and has a latent conflict potential. More information related to this topic is mentioned in Chapter 5.

5 Costs of Developing Hydropower Dams

For a systematic discussion, this chapter as well as Chapter 6 is subdivided into the following different aspects:

The economical aspect describes impacts onto the local economy of a region.

The environmental aspect identifies impacts on the environment of a hydropower dam.

The social aspect describes impacts from building a hydropower plant on the people living in the region.

Anyhow, in some cases the subtopics of a certain aspect could be likewise mentioned under a different aspect.

5.1 Economical Aspect

Economical costs can be summarized in two parts:

1. How much does it cost to construct the dam
2. What is the damage caused to the local (or even global) economy such as fishery and agriculture

5.1.1 Costs of Construction

Examples – China, Three Gorges Dam

The China Three Gorges Project Corporation (CTGPC) has an official budget of 203.9 billion CNY (Chinese Yuan) which corresponds to about 26 billion USD (or 33 billion CHF) for the whole Three Gorges Project. Figure 5.1 shows the structure and sources of the capital for the project. The largest part are state investments called the “Three Gorges Fund”. [10]

In may 2006 the Xinhua News Agency reported that the CTGPC did not agree with some “‘Western estimates’, which put the cost at between 40 billion and 50 billion U.S. dollars.” According to Li Yong’an, the general manager of the CTGPC, the project should actually come in under budget. The total costs should not exceed 180 billion CNY (ca 23 billion USD or

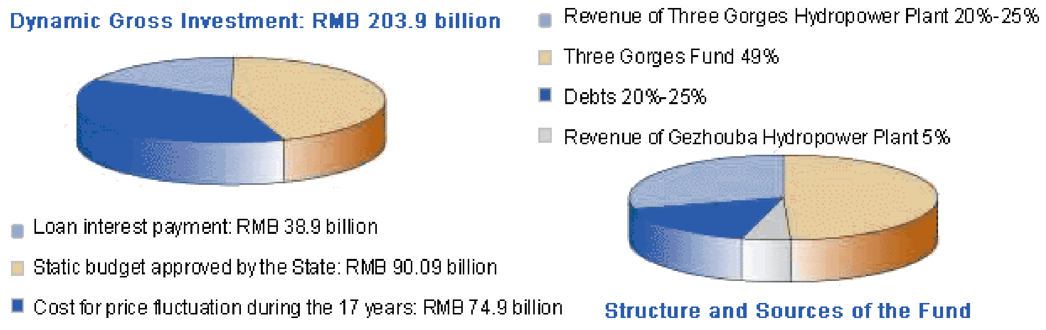


Figure 5.1: Structure and sources of the Three Gorges Project funds according to the official project web-site[10]

29 billion CHF) mostly because of the low inflation over the last 12 years, which had kept cost rises to a minimum. [3]

In another news report Xinhua cited Yang Ya, the chief accountant of the CTGPC, saying that the Three Gorges Dam would return its construction costs within the next ten years. [2]

5.1.2 Fishery and Agriculture

Examples – China, Three Gorges Dam

Since the dam affects the ecosystem, it also indirectly influences the economical situation of the people depending on this system such as fishermen and farmers. Both have to adapt their production to the changing environment. More details on possible effects on the fish population or the fertility of the river shores are discussed in Section 5.2.

Apart from the fact that the dam might introduce changes to the environment it also has a direct impact on the farmers whose fields are flooded by the dams reservoir. If they want to continue their farming activities they are forced to resettle to higher ground. The higher regions of the reservoir valley might however not be as fertile as the river shores. Additionally it is unsure if this region is not already occupied by other farmers. This might be considered a social rather than an economical problem, however, there is an implicit trade-off between the production of electricity of the dam versus the production of agricultural goods in the region. Resettlement issues will be further discussed in Section 5.3.

Examples – Egypt, Aswan High Dam

The Aswan High Dam stops the fertile silt coming down with the Blue Nile from the lake Tana in the Ethiopian highlands. As this natural fertilizer failed to appear down the Nile after the dam, agricultural land along the river and in the Nile delta lost much of its fertility. In order to handle the loss of fertility artificial fertilizer was used. This caused chemical pollution and had a lower water quality as consequence.

The lack of silt means also a low concentration of nutrients for the fish stock. The fish stock downstream after the dam was decreased tremendously. Even the Mediterranean fish stocks in the Southeastern Mediterranean sea were affected heavily. The average fish catch off the Egyptian coast dropped in 1969 to less than one-fourth. It took the fish stock more than 20 years to recover.

Erosion is another problem. Erosion occurs down the river and is especially problematic in the Nile delta. As no silt is carried by the river, farmland is washed away and shoreline stabilization is damaged. Besides, significant erosion along the coast lines takes place as the sand is missing which was usually brought by the Nile into the sea. Continuous erosion and reduced river flow allow the saltwater to further encroach into the delta. The higher concentration of salt threatens the brackish water lake fishery which is the largest source of fish for Egypt. [57, 52]

5.2 Environmental Aspect

The environmental cost of using hydropower has been subject to controversial discussions during the last few years. A key event that triggered these discussions was, in a global politics scope, the Three Gorges Dam in China which we will discuss in detail further down. A second project, more concerning local politics, was the planned enhancement of the Grimsel dam in central Switzerland.

In times where global warming is very high on the global politics agenda, there is one question that merits to be treated in enough detail: Are hydropower plants a significant source of greenhouse gases? In Section 5.2.5 we will try to answer the question, also by giving an overview about the current research in this area.

5.2.1 Problems due to Stagnant Water

Stagnant water, as opposed to a natural river flow, can have severe effects on the environment further down the river or around the reservoir itself.

Examples – China, Three Gorges Dam

Even though the water level in the Three Gorges Dam is planned to reach its final height of 175 meters first in 2008, Fan Xiao already describes several concerns due to stagnant water in the reservoir of the Three Gorges Dam[64]:

Water pollution in the reservoir: The slower the water in the reservoir is flowing the less it is able to wash and transport away waste and pollution it gets in touch with.

Since the water in the tributaries of the Yangtze is generally flowing slower than in the main channel, problems with stagnant water are even more severe there. Actually, the water quality in the main channel is much less of a concern than the in the tributaries because pollutants from the main channel are aggregating there.

New wastewater-treatment plants for the cities in the region of the reservoir have been built or are under construction. They should eventually increase the capacity of the region to treat its wastewater to more than 67%. Some plants are, however, not fully functional yet, and others are not able to use their full capacity because the wastewater-collection system is badly developed.

Another concern is related to the flood control operation of the dam. To be able to compensate for the dry winter periods and for possible floods during the summer periods the dam will operate at a water level of 175 meters during the winter and 145 meters during the summer. Since the water level in the reservoir is decreased and increased once a year, a 30 meters zone is created, which will be dry during the summer and inundated during the winter.

On one hand, this is creating an about 305 km^2 large zone that could provide fertile farmland during the summer to the people living in the region.

During the transition from the inundated to the dry period, however, pools with (possibly polluted) rest water will form and could become a source for germs and transmitters of diseases. This is a potential danger for people living and working near the river bank. The water of the pools will be mixed into the reservoir when the zone is flushed again during autumn.

In addition, waste and agricultural products such as chemical fertilizer and pesticides that were deposed in this zone during the summer season will be flushed back into the river when the level of the reservoir is rising.

Sedimentation of silt in the reservoir: The sedimentation of silt poses different problems, the most obvious being the reduction of the storage capacity of the reservoir. If too much silt builds up behind the dam, flood control, which is one of the primary goals of the project, would become less effective.

Apart from reducing the storage capacity, the silt, which stays in the reservoir instead of flowing through to the other side of the dam, also has large influence on the rivers ecosystem.

Scientists from the National Taiwan Ocean University in Keelung have found that the sediment loads at the river mouth of the Yangtze have decreased by about 55% since before the reservoir was filled. The concentration of certain minerals has changed, which caused the dominant type of phytoplankton in the river to be replaced by another species. Since the phytoplankton is at the very base of the food-chain, the health of the rivers ecosystem depends on it. It is, of course, very important also for the local fishery. More details about the impact of the dam on the flora and fauna will be given in later paragraphs. [29]

Examples – Egypt, Aswan High Dam

Disease: Due to stagnant water the danger of Schistosomiasis (bilharzia) disease is raising. The disease is transfused by snails that live in the water. The snail population grows rapidly in the stagnant water of lake Nasser as well as downstream in the irrigation canals, which used to dry out before the dam was built at least once a year. The snails are antagonized with pesticides, which also lowers the water quality.

Sedimentation of silt in the reservoir: The silt that is missing on one side of the dam is filling up the upstream side of the dam. The silt that is trapped above the dam lowers the water storage capacity of lake Nasser slowly but continuously.

5.2.2 Impact on Flora

Flooding a region with water by building a new dam causes plants to sink. This has consequences in two stages:

1. The plants might be of a rare species or be precious because of their age, for example. This was one of the main discussion points when the Grimsel dam suggested to be enhanced by 23 meters. It would have caused some pine trees to sink that are considered being primeval forest.
2. Once the plants sunk, they start to decompose. This decomposition causes CO_2 to be produced in considerable amounts. A more detailed analysis of CO_2 emissions from hydropower plants is provided in paragraph “Greenhouse Gas Emissions from Hydropower Plants” below.

Examples – China, Three Gorges Dam

As mentioned earlier, the dam has a direct impact on the amount of sediment, and thereby on the concentration of minerals found in the lower part of the river. This concentration and the amount of fresh water during the summer period have a large influence on the development of the phytoplankton in this part of the river.

By measuring the amount of CO_2 absorption Taiwanese scientists determined the amount of phytoplankton in the region surrounding the mouth of the Yangtze, which is considered a “high-productivity-zone” for fishery. They found that from 1998 to 2003 this zone had shrunk by about 86%. [29]

Furthermore the change of the ratio of silicates to nitrates in the water caused the dominant phytoplankton species to shift to flagellate, which is considered bad for fish since it can reduce the amount of oxygen in the water and secrete toxins.

5.2.3 Impact on Fauna

It is commonly agreed that hydropower dams have effects on the fish. The problem exists in two directions:

- The fish being on the upper side of the dams cannot safely pass it to get to the lower regions of the river. They run a high risk of getting minced by the turbine if they anyway try to pass

- Fish that usually live in the ocean want to move to the source of rivers to spawn. Most dams prevent them of doing that and the fish population of the river will eventually be extinct.

A lot of effort was put into finding solutions to this problem during the last years. Some of the dams that are not very high provide a staircase like construction with water flowing down on it. Just like humans climb stairs, fish can swim and jump up these stairs.

Another idea of building dams that are fish-friendly is inspired by beaver dams and fixed-wing airplanes [44] Beavers usually build dams that are not more than 3 meters high and that are made up of a stair-like structure. These steps are of a height that fish can pass, unlike the usually much higher dams built by humans.

Building several of these dams adds up to the same potential energy as building one higher dam. There just needs to be a way to use this energy as efficiently as possible, preferably also solving the minced fish problem mentioned above.

Here the airplane idea kicks in. Instead of the conventional fast turning turbines, there is the proposal of using a wing-like structure that is turning slower and has not much influence to the pressure around the structure which avoids that fish get decompression sickness. It also allows fish to pass between the elements without getting hit by one.

It needs to be said that this project still seems to be in early prototype stage and except of the National Geographic article no related information (not even from the company producing it) could be found.

Examples – China, Three Gorges Dam

Rare Species: Even though the China Three Gorges Project Corporation (CTGPC) claims that “most” of the rare species do not live in the region affected by the dam but on higher terrain[10], there are at least two examples of culturally “important” fish species which are affected by the dam.

The Chinese Sturgeon is an endangered species. It is sometimes called a living fossil because it has supposedly existed on earth for the last 150 million years. Every autumn sturgeons return from the sea to the upper part of the Yangtze in order to spawn. Chinese scientists are currently trying to breed sturgeons artificially and release them in to the Yangtze. [24]

The Baiji (Chinese River Dolphin) is now considered to be extinct. The baiji is traditionally thought of as a river god and lived only in the Yangtze. During a six-week expedition in the end of 2006 a group of experts from all over the world (among others some Swiss scientists) tried to find baiji in the Yangtze, without success. [4]

5.2.4 Natural Disasters

Examples – China, Three Gorges Dam

Landslides and Earthquakes: In his report “The Three Gorges Revisited” Fan Xiao states that the Three Gorges area is prone to geological disasters such as landslides and earthquakes. Nearly 2500 slip masses and 90 gullies created by mud-rock flows are officially identified along the Yangtze and its tributaries. Furthermore, the dam is very close to two main fault lines. Both have been seismically active. One of them, the Zigui-Badong Fault, was responsible for tremors up to 3.4 on the Richter scale since the beginning of the impoundment of the reservoir in 2003. It also caused earthquakes of up to 6 on the Richter scale in the past. [64]

The increasing water level of the reservoir is softening the base of certain known old landslides and is considered to be one of the main triggers for a landslide that took place at the village of Qianjiangping on one of the tributaries of the Yangtze, the Qinggan River, in 2003. The landslide blocked the river completely and produced 20 meter high waves. At least 14 people died in the disaster, hundreds of houses and several hectares of farmland were destroyed.

Some experts are worried about the 30 meters zone that will be covered with water during the winter season and uncovered again during the summer. The continuous changes of the water level could turn some geologically fragile areas even more unstable than they already are possibly leading to further landslides in the reservoir region.

It is known that filling the reservoir of a large dam can cause a certain type of earthquakes since caves and mines can collapse because of the flood water. This kind of tremors are usually limited locally and not very powerful since they are close to the surface. Some experts believe, however, that filling a dams reservoir could induce earthquakes that lie 1 to 2 points higher in the Richter scale than the known records in the region.

In case of an unpredictably large earthquake in the region the dam itself would be in danger. With the Three Gorges Dam bursting the resulting disaster would of course be enormous.

5.2.5 Greenhouse Gas Emissions from Hydropower Plants

For a long time hydropower was accepted as a clean energy source. Its contribution to the greenhouse effect was assumed to be negligible. Recent studies, as for example [21] suggest that the greenhouse gas (GHG) emissions from hydroelectric reservoirs is much higher than assumed and can even be more important than the emissions from a conventional power plant that uses oil or gas. Warmer climate is especially favorable to these emissions and in colder regions the problem is less acute.

First of all, it has to be said that the research in this area is a bit fuzzy and hard to quantify. Before we give an example of the rather tempered dispute that has been launched around quantifying the problem of GHG emissions from hydroelectric reservoirs, we want to focus on what the researchers commonly agree upon.

Agreed Upon Influences From Hydroelectric Reservoirs

Several editorial comments about the various existing point of views tried to find common points in the polar debating positions existing in this field. They find in [22] and [11] that:

- There is at least some GHG emission from hydropower reservoirs, although the amount is very unclear.
- It is commonly agreed upon the terms that need to be taken into account:
    - Pre-dam emissions of CH_4 from the river and from periodically-flooded wetlands.
    - Emissions of CH_4 from the reservoir itself.
    - Emissions of CH_4 from the water as it flows through the turbines and spillways (relative losses to the atmosphere likely being different for the two).
    - Emissions of CO_2 from organic matter that decomposes as a result of the flooding that created the reservoir behind the dam.
    - Loss of CO_2 binding due to the lost forestal area.
- The problem is more important in tropical regions as there the biological processes of decomposition are faster than in colder regions.

- The data upon which the results are based should be more representative. Reasons to believe that they are not are for example that GHG emission is seasonably dependent and decreases over time as the decomposition of organic matter in the new reservoir is getting less.
- If the influence of national and industrial interest on this research is reduced, the results could earn more confidence.
- Everybody agrees that there is “no free lunch” even for renewable energy.

Disputed Points – Tucuruí Dam versus Dams of Northern Ecosystems

Although the points mentioned above seem to be pretty concrete, researchers in this area are very much at variance in what concerns quantification of the problem of GHG emissions. Let us describe the forth and back of publications during the last years hereafter.

It seems to be P.M. Fearnside who started the discussion in 1997 with a paper called “Greenhouse Gas Emissions from Amazonian Hydroelectric Reservoirs: The Example of Brazil’s Tucuruí Dam as Compared to Fossil Fuel Alternatives” [20] and a revised version of it in 2002 [21].

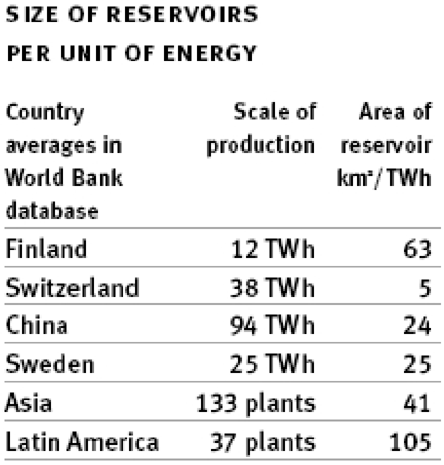
The “International Rivers Network” (IRN), a NGO trying to support development of natural river flows and therefore not favorable to dam building, supported Fearnside by presenting similar results shortly after.

In 2003 the International Hydropower Association (IHA) worked out a fact-sheet titled “Greenhouse Gas Emissions from Reservoirs” [5] which concluded that in Northern ecosystems “Relative to typical values for hydro, coal-fired generation emits about 100 times more GHG and natural gas combined cycle turbines about 40 times more”. They claimed that the reason for the very different numbers given by e.g. Fearnside are partly due to the negligence of the fact that on the same surface without reservoir much GHG would be produced anyway. Another reason they claimed was that only extreme cases of dams are taken into account rather than an average dam.

A year after the fact-sheet of the IHA, the IRN came up with a response to the IHA that reads in its introduction “The IHA’s assertions are variously irrelevant, incomplete or simply wrong“ [34]. The IRN paper follows mainly the arguments given in Fearnside’s papers.

Other important players in this exchange are Rosa and Santos who investigated in the very same topic using the same example, Brasil (see [26]). Their results are less conclusive than the results presented by Fearnside or the IRN and claim that it is not possible to give any exact results at this time.

Fearnside, on the other side, is claiming in a reply to Rosa [19] that ”Luis Pinguelli Rosa and coworkers have effectively made a career of trying to prove me wrong” and accusing them of publishing technically incorrect claims.



SIZE OF RESERVOIRS PER UNIT OF ENERGY

Country averages in World Bank database	Scale of production	Area of reservoir km^2/TWh
Finland	12 TWh	63
Switzerland	38 TWh	5
China	94 TWh	24
Sweden	25 TWh	25
Asia	133 plants	41
Latin America	37 plants	105

Figure 5.2: Size of Reservoirs per Unit of Energy

What we conclude after browsing through the different articles is, that the discussion has mainly become a political discussion. In fact, the controversy is much like the overall debate over global warming that is highly influenced by interest groups and various national interests. In order to get any conclusive numbers there is need for a research group that has representants from all the political groups, led by an independent organization that could be a subgroup of the United Nations.
We absolutely do not claim that any of the cited researchers has made bad research or even tried to purposefully manipulate data. We only claim that the background discussion is political rather than scientific.

Importance of the Shape of Lakes

As an interesting sidenote researchers commonly agree that the GHG is proportional to the surface of the reservoir. Figure 5.2, taken from [5] shows an interesting fact about Switzerland's hydropower reservoirs. The reason for this favorable number is likely to be that Switzerland profits from its mountainous regions and narrow valleys, so that much energy can be gained by damming the water high up in the mountains and placing the turbines in the valleys, gaining additional power. Taking into account that many of the Swiss reservoirs are built in altitudes where not very much biological matter is found, it seems that the problem of producing GHG is not very acute, even if the more pessimistic assumptions as proposed by Fearnside prove to be true.

5.3 Social Aspect

Social costs that a hydropower dam might cause are very diverse and change from case to case. Some very widespread ones are

- The need for resettlements from flooded areas.
- Social problems arising after the change of economical conditions (e.g. unemployment).
- Loss of cultural heritage and natural scenery.
- If dams change the distribution of water in some region, this can lead to social conflicts.

Each of the above mentioned points is illustrated with examples in the sections below.

5.3.1 Resettlement

Examples – China, Three Gorges Dam

When reaching its final height of 175 meters above sea level, the Three Gorges Dam reservoir will span 1,084 km^2. That is, a total of 632 km^2 of land will have been submerged during its impoundment.

The number of people previously living in the submerged area that have to be resettled until the completion of the project is another heavily disputed figure. For a long time, the official number was 1.13 million people but this has already been surpassed and the official estimation has been adjusted to 1.4 millions.

Some people believe that these numbers are still by far too low. Dai Qing, a Chinese journalist and long-lived opponent against the TGP, for example, estimates that a total of 1.9 million people will have to be resettled eventually. [50, 33]

Examples – Egypt, Aswan High Dam

Due to the construction of the dam most of lower Nubia was flooded such that the people who lived for centuries along the river were uprooted. More than 90'000 people were forced to move to settlement areas in Egypt and in Sudan, others were forced to refuge where they could. The Egyptian government put a real effort in the resettlement of the cultural goods as described in the Section 5.3.3 but much less in the civilization which used to life in this area. [57, 32] The at time of the resettlement 19 year old Amr Ya'quoub described the situation as follows:

> We had to leave our dead, our memories and everything we had ever known – the trees, the Nile, the houses, and the places where we used to play. When we arrived at the new village we missed everything, even the smell of our old land. There was no

> cultivated land, no shops, no transportation, no vegetables, we had to get everything from outside. [32]

The people did not have the Nile anymore, which was an important part of all their religious and social ceremonies. Most of the young Nubian's have never seen their homeland and do no longer speak their native language, instead they speak Arabic. The few that stayed have formed societies whose goal it is to preserve their heritage. [32, 9]

5.3.2 Ecological and Economical Dependence of the Local Population

As discussed earlier, the environmental changes in a dam area can have major economical consequences for the population in this area. Of course, this can in turn lead to social instabilities in the region.

Examples – China, Three Gorges Dam

People living in the Three Gorges, especially farmers and fishers, are directly dependent on the Yangtze river and its ecosystem. Drastic changes in the ecosystem (e.g. loss of fertile farmland due to the reservoir, loss of fertile silt in the lower region of the river, reduced fish population, etc.) would ultimately translate into drastic changes in the economical basis and eventually in the social structures of a large part of the local population.

Also potential natural disasters described above, e.g. landslides, earthquakes or diseases induced by the dam as well as possible flood disasters due to increased silt disposal in the reservoir could cause social tragedies if no precautions are taken.

In other words, all the potential environmental and ecological problems that we described for the TGP area above can also be expected to have a social impact on the region.

5.3.3 Loss of Cultural Heritage and Natural Scenery

Examples – Egypt, Aswan High Dam

The construction of the Aswan High Dam threatened many cultural sides of the ancient Egypt to sink in the dam's reservoir lake Nasser. In cooperation with the UNESCO, many of them were moved to safer locations. During a four year, 40-million dollar project, temples like the Abu Simbel were cut into 1050 sections, displaced and reassembled. Nevertheless, lots of valuable cultural sites were flooded when the construction of the dam was completed. Figure 5.3 shows the Pharaoh's face of one of the statues that guarded the temple and how it was lifted away by a crane. [9]

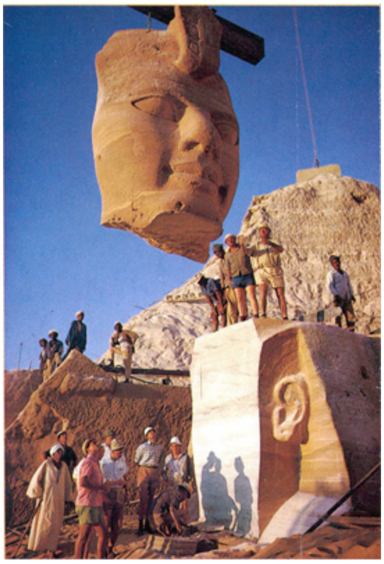


Figure 5.3: The Pharaoh's visage is moved away

Examples – China, Three Gorges Dam

The inundation of a large part of the Three Gorges could be considered as a damage to its natural scenery. The periodic changes of the water level in the reservoir are considered to do particular damage to the shores.

Another big concern is that historical cultural relics that might still be hidden in the Three Gorges area will never be discovered once the reservoir has been filled up. In 2004, Dai Qing, a Chinese journalist and opponent of the project, said that even though one of the main cultural branches in China emerged along the Yangtze, the TGP construction committee did not consider protecting cultural relics as an important issue:

> "You saw in Egypt how much money was spent during construction of the Aswan dam to save relics and move them to the Metropolitan Museum. But very little money has been set aside for relics in the Three Gorges budget, and even that has been taken out of the resettlement budget. But the resettlement budget needs money so badly for the resettlement!" [12]

The China Three Gorges Project Corporation (CTGPC), on the other hand, claims that most of the natural landscapes will be preserved, since the mountains in the gorges are significantly higher than the future water-level in the reservoir. In fact, they hope that Three Gorges will become more attractive as a touristic destination since the dam is supposed to make navigation and therefore travelling on the Yangtze easier.

As far as the cultural heritage of the region is concerned, they point out that

> “Some relics are preserved at its original location or transferred or copied to another place, such as Baiheliang sculpture, Zhang Fei Temple, Shibaozhai and Qu Yuan Temple. The ancient tombs of the submerged area have been unearthed on the basis of survey.” [10]

5.3.4 Dams and Social Conflicts

Examples – Turkey, Ataturk Dam

Water as Strategic Power – Conflict Potential: Water is the source of life. As mentioned in the previous Section 4.4.3, Turkey controls the natural water supply of its two neighbors Syria and Iraq. This strategic situation allows Turkey in case of a war to use the waters of Euphrates and Tigris as “ecological weapon.” However, due to dams of the GAP in Turkey, the water flow of the Euphrates and Tigris were already reduced by 45%, respectively 10 percent. In fact, Syria’s and Iraq’s agriculture as well as their own projects to produce hydroelectric power suffered due to the reduced water flow. Therefore these countries rely even more on imports from Turkey and hence the dispute regarding water rights continuous. Syria and Iraq claim 2/3 of the Euphrates water but Turkey is not willing to offer more than the in 1987 with Syria agreed outflow of 500m^3 per second. The problem remains and the Euphrates-Tigris region is therefore a potential conflict area for a war in the 21^{st} century. [25]

Examples – China, Three Gorges Dam

The Three Gorges Dam as a Potential Target for Attacks: A huge dam like the Three Gorges Dam could be considered a safety risk as it is a potential target for attacks of foreign forces during a war or for acts of terrorism. If the dam was to be attacked and would burst, the whole downstream area could be inundated.

6 Benefits of Hydropower Dams

Of course, the main benefit of hydropower dams lies in the power generation itself. Otherwise there would be no reason to accept all the different kinds of negative effects as we discussed in Chapter 5. Besides there are other positive aspects like flood control, irrigation and navigation. However, they vary from dam to dam in terms of importance.

6.1 Economical Aspect

A list of factors that make hydropower from our point of view a favorable form of power supply for Switzerland is given below:

- Water is a natural resource in Switzerland. We don't depend on imports from another country in order to produce electricity using water. Hence hydropower contributes considerably to secure the electricity supply.
- The costs of producing hydropower are immune to price rises of fossil fuels.
- By storing water, energy production can be adapted to a large extent to the needs. For an additional explanation, see Section 7.1.3 and Figure 7.2.
- Pumped-storage plants offer a way to store a surplus of produced electricity.
- Hydropower production is locally controllable, so communities or regions can take influence on their electricity supply.
- Hydroelectric plants tend to have longer lives than fuel-fired generation. Some plants now in service have been built 50 or 100 years ago.
- Labour cost also tends to be lower since plants are generally heavily automated and have little personnel on site during normal operation.
- The electricity generation in hydropower plants has been field-tested for a long time. It is also very secure compared to nuclear energy.
- Electricity generation can be turned on and off without problems. This is not possible in thermal and nuclear power plants.

- The Swiss Alps have good locations that allow efficient plant constructions and utilization of water resources.
- Multi-use dams can be used as well for irrigation, flood control or even recreation.

6.1.1 Power generation

As we mentioned at the beginning of this chapter the produced electricity represents the most significant benefit. If we look at Switzerland, where hydropower has a share of almost 60%, this form of electricity production is no more to be thought away. Also for other countries hydropower represents an important power source in order to secure the increasing demand.

Examples

The following table shows the annual average power generation of three large hydroelectric power plants. As a comparison, we listed how much of the overall Swiss electricity consumption the corresponding plant could cover. (In 2005, the total consumption was 61.6 TWh. [36])

Dam	Generation [TWh/y]	Perc. of Swiss Consumption
China, Three Gorges Dam [10]	84.7	137.5%
Brazil, Tucurui Dam [63]	21.0	34.0%
Egypt, Aswan High Dam [41]	10.0	16.2%
Turkey, Ataturk Dam [46]	7.8	12.7%

6.1.2 Navigation and Tourism

Examples – China, Three Gorges Dam

As mentioned initially, one of the major goals of the Three Gorges Project was to improve navigation and increase trade on the Yangtze river by enabling 10000-tonnage freighters to navigate between Shanghai and Chongqing. According to the China Three Gorges Project Corporation (CTGPC) the dam has already proved to increase the navigation on the Yangtze:

> "Ever since it was built, the ship lock has run well without major failures and met the navigation requirement of the Yangtze navigation with cargo increased by 2/3 compared to maximum level in the history."[10]

As mentioned above, the CTGPC also anticipates, that the improvement of the navigation on the Yangtze will lead to an increased tourism in the Three Gorges. The dam site itself, of course, is also considered to be a major attractor for tourists.

However, not everybody shares the CTGPC's enthusiasm.

In a report published in May 2006 in the Chinese National Geographics magazine, Fan Xiao, a geologist from the Sichuan province writes that the ship-lock, which is supposed to take boats upstream as well as downstream through the dam, is becoming a potential bottleneck for the river traffic. The lock was planned to have a annual capacity of 50 million tons. However, the actual capacity is only 36 million tons today. [64]

Furthermore, the so called roll-on/roll-off ships which are carrying loaded trucks, are not allowed to pass the ship-lock any longer. This is for safety reasons since some boats are carrying dangerous goods such as gasoline and chemicals, which could explode while the boat is passing the ship-lock. Therefore, the trucks carried by the ships have to be unloaded and drive around the lock where they can be loaded on another roll-on/roll-off ship.

6.1.3 Irrigation

The construction of dams represents also the chance to enable constant irrigation throughout the year in order to improve agricultural productivity.

Examples – Turkey, Ataturk Dam

Thanks to the massive irrigation network of the Southeastern Anatolia Irrigation Project (GAP), 236'019 hectares of land were brought under irrigation in Southeastern Turkey. The irrigation started first in 1995 in the Sanliurfa-Harran Plain and covered an area of 30'000 hectares. According the Regional Development Administration, which is in charge of the GAP, the per capita added value in agricultural production was 596 US Dollar before irrigation started and grew to 1'135 US Dollar till 2004. Further construction of irrigation schemes over 142'099 hectares is in progress. [46]

Examples – Egypt, Aswan High Dam

The dam's water reservoir lake Nasser had a great impact for the Egyptian people between 1979 and 1987. In this time, the Nile above the dam brought only little water. During these successive years of low water more than 70 billions m^3 of water were taken from the lake Nasser in order to supply the irrigation systems. [41]

6.1.4 Creation of Jobs and New Industrial Sectors

The construction of a large hydroelectric dam is a big effort and requires the collaboration of companies from all over the world and in a wide variety of industrial sectors. First the project has to be planned, challenging engineering tasks and socio-political questions have to be solved, the project needs to be promoted and funds have to be raised for the construction. During the construction itself the need for man power, construction equipment and building material is highest. And eventually, after its completion, the dam needs maintenance and management.

Near the dam site, whole new cities might emerge providing a new market for economical development.

Even the negative effects of a dam on the ecological system of the region have led, in some cases to the development of new industries providing solutions to the problems imposed by the changes in the environment. One could argue that, to a certain extent, this could be classified as an economical benefit. It is, however, clear that the impact of the ecological change on the other economic sectors has to be taken into account as well when determining whether the creation of this kind of new industry really leads to an overall economical benefit in the region.

Examples – Egypt, Aswan High Dam

As mentioned in Section 4.3 the dam impounds the river Nile to one of the largest man-made lakes, the lake Nasser. Around the lake, a new fishing industry has been created. But the industry has problems due to long distances to any significant market.

Downstream, the agriculture suffered from the lack of fertile silt that used to flow down with the river such that the demand for artificial fertilizer arouse. A prospering fertilizer industry has been created but a lot of farmers cannot afford the expensive fertilizer. [57]

Examples – China, Three Gorges Dam

Project Alliances of Foreign Suppliers: The main equipment for the Three Gorges Dam was divided between six top foreign companies forming two project alliances. Seven out of fourteen 700MW power units were assigned to the project alliance consisting of Alstom, Kvaerner and the Swiss-Swedish company Asea Brown Boveri (ABB). The other six to the project alliance between Voith, Siemens and General Electric.

The two Chinese equipment suppliers Harbin Power Equipment and Dongfang Electrical Machinery had been working with the above mentioned two foreign project alliances. Harbin cooperated with the ABB alliance and Dongfang with the Voith consortium. Both had benefit from extensive technology transfer requirements by the Chinese government. [43] According to the Power Engineering International in May 2004 [1], the Chinese government had a policy of exchanging market share for technology. International manufacturers had to transfer technology to designated state-owned companies like Harbin. They had to use these companies as local sub-contractors but nevertheless take the responsibility for the quality of performance and delivery of these local companies. On this note, the last two power units were almost entirely constructed in China.

Within its project alliance, ABB provided eight generators. Furthermore ABB was contracted to build four High Voltage Direct Current (HVDC) power transmission lines to transmit electric power from the Three Gorges Dam, Central China, to Eastern and Southern China.

New Water Treatment Plants: Because of the negative influence the dam might have on the water quality in its reservoir, China had to increase its effort in monitoring and controlling the water quality in the Yangtze. As mentioned in Section 5.2.1 new water-treatment plants were built or are currently under construction in the reservoir area. Two such plants have for example been built in the metropolitan Chongqing which is now capable of treating 60% of its wastewater instead of releasing it directly into the Yangtze.[64]

6.2 Environmental Aspect

Waterpower is a renewable energy. Its advantages for the environment are:

- There are no wastes or residues to dispose as it is the case for nuclear energy for example.
- Fossil fuels are limited resources. Water however will always be available.
- The Swiss CO_2 law from 2000 states that CO_2 emissions of 2010 have to be reduced by 10% compared to the emissions from 1990. Hydropower can be produced without major CO_2 emissions. Figure 6.1 from [23] shows how much (in kg) of the different greenhouse gases is produced by different energy generation technologies in per kWh electricity. The emissions from hydropower and nuclear energy are very small compared to emissions from conventional thermal plants. As we saw in Section 5.2.5, it is still a disputed point to which extent large hydroelectric dams can really be considered to have a low CO_2 emission.

Examples – China, Three Gorges Dam

The China Three Gorges Project Corporation (CTGPC) explains the benefits of the “clean” hydro-electricity the TGHP provides as follows:

> “Compared to the coal-fired power stations with equivalent electricity generation, Three Gorges Power Plant will decrease emission of 100 million tons of CO2, 2 million tons of SO2, 0.37 million tons of nitrogen oxide and a lot of waste water and solid waste. It will bring a great benign influence in improvement of environment, especially preventing acid rain and greenhouse effect in East and Central China.” [10]

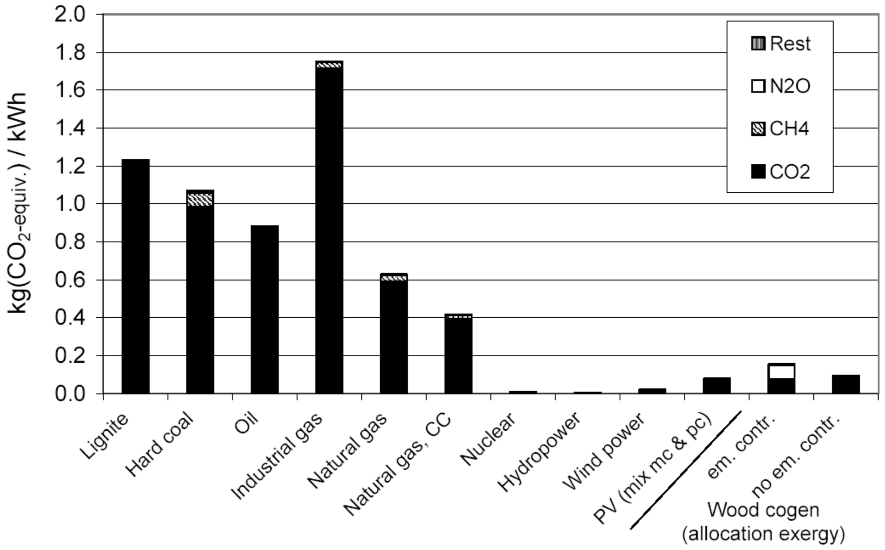


Figure 6.1: Overview of full chain GHG emissions for different electricity generation systems.

It remains to be seen, whether the benefits of this large hydropower plant will really outweigh all the possible environmental costs of the project, i.e. if the Three Gorges Dam will prove to be the clean and durable source of energy as which it is promoted.

6.3 Social Aspects

One effect of building dams is, that floods can be controled to some extent. This certainly avoids loss of money which is an economic aspect. More importantly it also avoids social costs such as absondence of many people, famines or even loss of many lives.

6.3.1 Flood control

Examples – China, Three Gorges Dam

As mentioned earlier, providing flood control was one of the major goals of the Three Gorges Project. Table 6.1 shows a list of the worst flood disasters of the Yangtze river during the 20th century. Preventing this kind of disasters could, of course, save a lot of money and, even more important, a lot of human lives.

Unfortunately the aggregation of silt in the lower part of the Three Gorges Dam's reservoir could drastically reduce its capacity thereby rendering the flood control less effective. Sedimentation is indeed considered a major problem by certain experts as discussed in Section 5.2.1.

In order to be efficient, the flood control mechanisms of the Three Gorges Project have to be

1931	The flood in 1931 struck an area of 130,000 km^2 with 3.39 million ha farmland and 1.8 million houses inundated, 28.55 million people affected, and 145,000 people killed, causing approximately an economic loss of 1.345 billion YinYuan.
1935	The flood in 1935 hit an area of 89,000 km^2 in the middle and lower reaches of the Yangtze River, with six provinces, Hubei, Hunan, Jiangxi, Anhui, Jiangsu, Zhejiang and 10 million people affected, 1.51 million ha of farmland inundated, 142,000 people killed, causing approximately an economic loss of 0.355 billion YinYuan.
1949	The flood in 1949 inundated 1.81 million ha farmland, affected 8.1 million people and cost the lives of 5699 people in the middle and lower reaches of the Yangtze River.
1954	The damages caused by the flood in 1954 in the middle and lower reaches: totally 3.18 million ha farmland and 4.27 million houses inundated, 18.884 million people and 123 counties and cities affected, 33169 people killed and the interruption of the Beijing-Guangzhou Railway for 100 days.
1998	The flood in 1998 struck a large area of the Yangtze Valley. The country went all out to fight against the flood for nearly 3 months with large quantities of people and materials employed. More than RMB 13 billion worth of flood-fighting materials were dispatched from all around the country, and about 6.7 million people and hundred thousands of soldiers took part in the fighting. However, the flood still caused great losses with 239,000 ha farmland inundated, 2.316 million people affected and 1526 people killed in the four provinces of Hunan, Hubei, Jiangxi and Anhui.

Table 6.1: *Floods records of Yangtze River (1931, 1935, 1949, 1954, and 1998)* according to the official website of the Three Gorges Project[10]

extended with a well functioning flood forecast system for the contributing area of the Three Gorges Dam. Therefore the Changjiang Flood Forecasting Assistance Project was launched the 1st of August 2003.

The project is a cooperation between the Institute for Forest, Snow and Landscape Research, the Institute for Atmospheric and Climate Science, both part of the Swiss Federal Institute of Technology Zürich, the Swiss Federal Office for Water and Geology (FOWG) in Berne, the MFB-GeoConsulting GmbH in Messen and the Changjiang Water Resources Commission (CWRC), Bureau for Hydrology in Wuhan, China. In addition the project is assisted by the Swiss government through the Swiss Agency for Development and Cooperation.

Know how and technology transfer took place from the Swiss partners to the CWRC collaborators. This comprised training of CWRC staff in the use of a Geographic Information System (GIS), remote sensing and hydrological modeling, the installation of a satellite receiving station as well as the installation of tools for image processing and GIS software. [30]

7 How Should It Be Promoted?

As Chapter 3 lays out, the future of hydroelectricity production depends largely on the development conditions. The previsions say that even under favorable conditions it is only possible to get about 10% more energy out of our water resources. Currently, there are 35'000 GWh produced by hydropower plants, so there are about additional 3500 GWh possible.

However, if the conditions are unfavorable, the energy produced by hydropower will even decrease in future. Since the profitability of hydropower can be influenced to a considerable amount, it makes sense to think about how it could be promoted.

In this chapter, we will propose some measures that could be taken to keep hydroelectricity production at least at the current state. We distinguish thereby between measures that affect only Switzerland and others that concern the cooperation with countries in the European Union.

7.1 Measures that Affect Switzerland

There are different ways to steer the attractiveness of hydropower production, and therefore its development potential, in Switzerland. They can be subdivided into five areas as follows.

7.1.1 Legal Measures

Several federal laws and their regulations take influence on the production of hydropower. By applying or when modifying them, the government has a way to affect either the profitability of hydropower or to influence even the possibility of a plant's construction at all. [39]

The water law (federal state law §721.80) is one example. As it states the fundamental conditions for using public or private water resources, it has an important influence on the construction of hydropower plants. Legal permissions are needed if there is an impact onto watercourses that causes an impairment to their quality.

Another one is the energy law (federal state law §730.0) which aims to contribute to a reliable, economical and environmentally sustainable electricity supply. In order to promote an environmentally sustainable power production, it says that before deciding to construct a new or change an existing fossil fuel power plant the cantonal authority has to check whether the required energy cannot be covered by renewable energy. It also states economically advantageous conditions for selling such energy. However, those conditions are only valid for small hydropower plants with an output of less than 1 MW.

The CO_2 law falls in this category, too. But as it may introduce a monetary policy, it will be mentioned in the financial part below.

Many other federal state laws (protecting environment, water, forest or the fish) contribute their share to the regulations of hydropower plant construction.

The same kind of influence can be taken on a cantonal level by the appropriate authority and cantonal laws.

7.1.2 Financial Measures

Construction and operation of a hydropower plant suffer from constantly growing financial charges and risks. The costs of licenses are increasing. This makes on one hand the construction more expensive but also it increases the cost at the time the license has to be renewed. During the operation of a plant, there is the water fee and other taxes to be delivered to the state. The Swiss federal office of energy states in an article of 2006 [39] that Switzerland is amongst the countries having the highest federal charges on hydroenergy.

Possibilities to financially stipulate hydropower productions are already contained in laws. There are funds and grants for the renewal of hydropower plants, and the energy law contains guaranteed purchasing prices for hydropower from small plants under 1 MW output (cf. Legal measures).

Initial costs of power plants using renewable energy sources is usually higher than the market electricity price because their technologies are still new and not well established [53]. A subsidies model called feed-in tariffs that is regulated by law is used to increase the profitable quantity of power produced by such a technology. The feed-in tariff sets the price to which this electricity is sold to a value that is higher than the market price. Figure 7.1 shows how this shifts the market equilibrium.

Hydropower technology, however, is already relatively mature. So only small hydropower projects belong into this category of subsidies.

The financial promotion of bigger hydropower projects could lead to the subsidization of a single energy resource. In order to avoid this, promotion measures should aim to meet the true costs. This can be achieved by internalizing the external costs of CO_2 emission with high external costs or by favoring CO_2 neutral production techniques with relatively low external costs. This is the principle of a CO_2 tax.

The CO_2 law (federal state law §641.71) follows from the Kyoto protocol and aims the reduc-

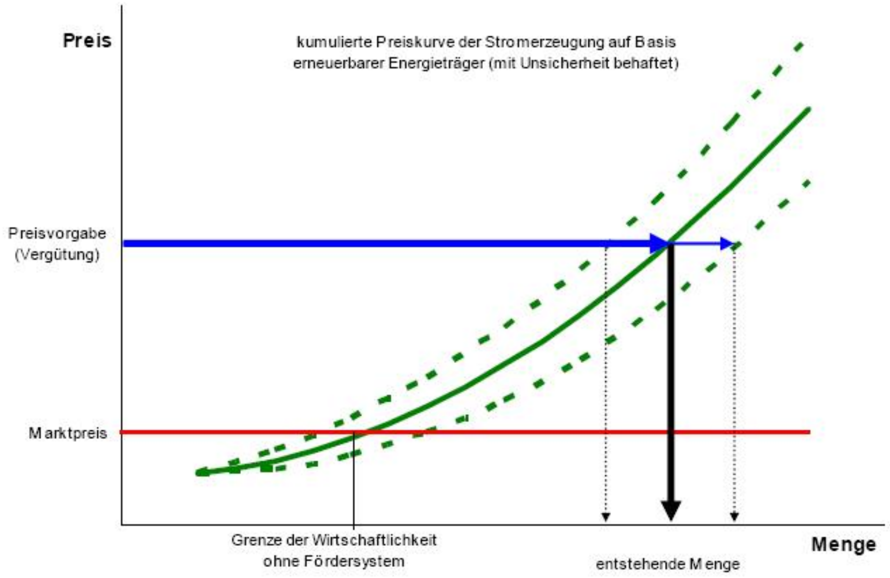


Figure 7.1: Shifting the equilibrium with feed-in tariffs

tion of CO_2 that is emitted by the production of power using fossil fuels. It states that if the reduction cannot be reached by optional measures, the federal state will introduce an incentive tax (the CO_2 fee) that has to be paid per quantity of emitted CO_2. As this will lower the profitability of fossil fuel power plants it is advantageous for hydropower plants.

7.1.3 Constructional Measures

Instead of building new plants, the generated hydropower can also be increased by extending and renewing existing plants or by restoring old plants.

About 75% of a year's precipitation falls during summer and only 25% in the winter. So more power can be produced in summer. However, in winter much more electricity is needed. So ideally, a hydropower plant would be able to store the water from the summer in its storage lake and use it up when electricity is demanded. But for example the storage lakes of the Grimsel plant (cf. Section 3.2.1) only have enough capacity to store 25% of the inflow water. The rest needs to be processed immediately, and if the electricity isn't needed, this is a waste. The water potential could therefore be increased by enlarging the dams and therefore the lakes if possible. However, such projects have usually impacts on the environment (more ground will be flooded) and are therefore rejected as it was the case with such a project for the Grimsel lakes.

The importance of a hydropower plant is also determined by its nominal power (cf. Section 3.2.1). This maximal continuous power is limited by the weakest part of the entire system and it is a measure of the speed at which energy can be produced. If the weakest part is re-

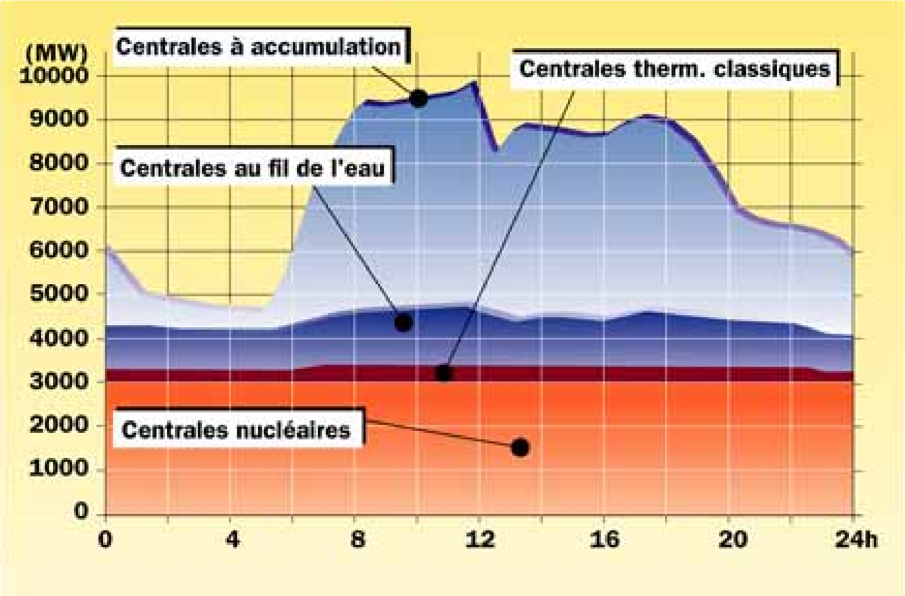


Figure 7.2: Swiss electricity production during a day in 2003

placed, the station is not able to produce more energy in total as the storage lakes are still of the same size. However, the plant will be able to produce more energy in a certain time. [45]
Figure 7.2 from [6] shows a diagram of the electricity production during 24 hours including a distinction between the four different production techniques (from bottom up): nuclear power plants, conventional thermal plants, run-of-river power stations and storage power stations.
The diagram shows clearly that at daytime more power is required by the consumers and that it can be produced only by storage power plants. The demand increases the price of electricity. So the energy a storage power plant is able to produce in this time can be sold at a higher price.

7.1.4 Administrative Measures

Nowadays, the regulations for hydropower plant operation have become stricter. So it takes longer for a project to go through the different authorities in order to receive the authorization for a realization. Furthermore, the approval process for gas turbine stations or for combined cycle power plants are usually simpler and faster [39]. So in order to improve the competitiveness of hydropower, the approval procedures could be simplified. This will lead to a shorter and lower priced realization time until the power station is profitable.

7.1.5 General Measures

It is important to distinguish the two terms green energy and renewable energy. Green energy is a term used for environmentally friendly energy sources, typically it refers to renewable and non-polluting energy sources. As we have outlined in Chapter 5, hydropower from big projects does have its impacts on the environment. However, small-scale hydropower plants (stations with a power generation up to 10 MW in Switzerland) are respected as being green energy [49].

At the production of hydropower, it is worthwile to make sure that the requirements for the production of green energy are fulfilled. Green energy labels are becoming more and more important and this might help to increase the value of hydropower. More on those labels will be written in the next section.

7.2 Cooperation with Countries of the EU

The Swiss energy market is very strongly correlated to the energy market of the European Union, and the power exchange is important to the Swiss economy. In order to keep a good position in the European energy market, the government needs to pay attention to the European situation.

The electricity supply and demand and the prices cannot be affected. However, in order to keep Swiss hydropower in a good position, those should be watched closely and corresponding measures should be taken. Some factors that can be influenced will be introduced below. [45]

Such a factor is for example the participation of Switzerland in the balancing power market. As we have mentioned in Section 2.3.3, pumped storage power stations are an excellent means to store power if there is too much of it around but more importantly also to produce more power in a short period if it is needed. Since such peak electricity is more expensive than the average one, balancing power is a good business and should be kept.

Another means that can be used to promote hydropower are the CO_2-certificates of the European Union emission trading scheme. Emissions trading is an administrative approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants. Each participating country proposes a national allocation plan including caps on greenhouse gas emissions for power plants. Then, permits are issued to industries granting a certain amount of carbon dioxide emission. The companies are able to trade freely with those permissions. The goal of the emission trading scheme is to achieve that companies will reduce their emissions, if this is possible at a low cost. They are then able to sell the permits to other companies for which this cost is higher. So carbon dioxide emissions are reduced at the lowest cost possible. The participation of Switzerland in the emissions trading scheme helps to increase the profitability of hydropower plants as they emit only little greenhouse gases.

A market mechanism known as tradable renewable certificates (TRC) or green tags can also make hydropower more interesting in an economic sense. Contrary to the taxes from the emissions trading scheme, green tags function as a non-governmental subsidy on green energy. They represent the separable bundle of environmental, economic and social attributes associated with the generation of renewable power. A producer of green energy can optionally demand such certificates. The certificate associated to this energy can be sold on the free market when the energy is fed into the electrical grid. Green tags can be bought by electricity consumers (companies, organizations or private persons) on a voluntary basis.

This scheme is relatively new and it cannot be used as the only means to promote the production of renewable energy. Nevertheless, green tags on the European energy market can serve as additional subsidies for hydropower.

8 Conclusion

Hydropower, in terms of electricity production, has a long tradition in Switzerland. With a share of almost 60 percent, hydropower plays a major role in securing the Swiss power supply today, and is therefore indispensable.

In Chapter 2.1 we have seen that the demand for electricity is increasing and that this trend is not about to change anytime soon. According to Chapter 3, a certain development potential of hydropower still exists but should not be overestimated. In fact, Switzerland will face a challenge to even maintain today's level of electricity production from hydropower during the next 45 years. The arising gap between demand and offer cannot be covered with hydropower on a long term basis. Therefore the question "Hydropower – A way of becoming independent of fossil energy?" has to be answered with "No." Fact is that the construction of new nuclear power plants or combined cycle power stations has to be taken into consideration in order to fill Switzerland's electricity gap in the future. However, combined cycle power plants would represent a step backwards to the dependency of fossil energy. On the other hand, technologies like heat-pumps are a possibility to reduce the dependency on fossil energy by replacing the conventional oil heating.

In Chapter 5 we have seen that the construction of dams imply a heavy burden. Costs from an economical, environmental and social perspective are massive and should not be underestimated. Nevertheless, Chapter 6 revealed that with hydropower impressive amounts of electricity can be produced.

The finding of our paper is that Switzerland is in fact far away from becoming independent of fossil energy. Thus Switzerland would do good in trying to sustain at least today's share of hydropower in its electricity production. In order to do so, measures as we described in Chapter 7 have to be taken.

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