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Author: Hauenstein, Walter

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Hydropower and Climate Change—A Reciprocal Relation

Institutional Energy Issues in Switzerland

Walter Hauenstein

Since the extremely dry and hot summer of 2003, the question of what effects ongoing climate change will have on hydropower in Switzerland—mainly on the amount of electricity that will be produced, but also on the safety of hydropower plants—has often arisen. Even though predictions of the potential impacts of climate change on hydropower generation are characterized by uncertainty, it can be assumed that within the next 25 to 30 years no significant adaptation of the infrastructure for hydropower generation will be urgently needed in Switzerland. Therefore, there are no major institutional challenges to be faced in this context. On the other hand, extending hydropower generation units to further reduce the emission of greenhouse gases will constitute a challenge to existing institutional arrangements, in Switzerland and elsewhere. In the case of Switzerland, interest in protecting waterways and landscapes will conflict with future efforts to mitigate climate change. Current legislation is based on sectoral considerations and not on a holistic vision of sustainable development. Thus this framework has some shortcomings in terms of constructive negotiation of processes leading towards long-term sustainable development.

Climate change in Switzerland

In the course of the 20th century, the mean annual temperature in Switzerland increased by 1.0 to 1.5°C. Some sources indicate that this increase reached 0.4 to 0.6°C per decade within the last 30 years. The very dry and hot summer of 2003 in Switzerland was 4 to 6°C warmer than an average summer. Based on long-term time series, it is unlikely that another such summer will occur for more than 1000 years; nevertheless, numerical models forecast that within the next 50 years, a summer like the one in 2003 will be nothing more than a slightly above-average event. Temperature increases so far in Switzerland seem to be above the global average.

The effects of temperature increase on precipitation can only be estimated using computer models. Model calculations presently available predict increased precipitation in winter and fewer decreases in summer than at present. Fluctuations between dry and wet years are expected to increase. Precipitation will increase over the period of an entire year; however, due to increased evaporation and evapotranspiration, the effect on runoff will be reduced.

Predicting future flood activity is even more difficult than predicting the development of average precipitation rates. Will floods increase or be more frequent? Observations of some rivers in Switzerland over the last 80 years show a tendency to higher peak flows in annual flood patterns, although this tendency has not been observed everywhere.

Impact of changes in runoff on hydropower production

What can be expected from these changes in terms of energy production in Swiss hydropower plants? The effects on productivity are different for alpine power plants with seasonal reservoirs and water intakes at typical altitudes of 1500 to 2500 m on the one hand, and run-of-river plants on rivers in the Swiss Plateau region below 500 m on the other hand.

Alpine power plants

Plants at high altitudes have benefited for several decades from an above-average amount of water from the melting ice of Alpine glaciers. The volume of these glaciers has been diminishing for many years. In the very dry and hot summer of 2003, melting was even more significant. Thus, there was even more water available during this summer than during a normal year. This effect is more pronounced in the Canton of Valais than the Canton of Graubünden (Grisons), where glaciation is less extensive. It is well known that the stock of existing ice is limited and is melting away, in the literal sense. It is estimated that in the year 2003 alone 5 times the amount of ice in an "average" year was lost. Great amounts of the remaining glaciers are expected to disappear within several decades. Water flow to Alpine hydropower in summer plants will then be much less than today,

FIGURE 1 The Gries dam in 1973, fed by the approximately 5-km-long Gries Glacier near Ulrichen, Canton of Valais. Since this photo was taken, the glacier has lost over 370 m. (©Luftbild Schweiz)

despite high temperatures, since nothing will be left to melt (Figure 1).

A positive effect on high-altitude hydropower can be expected from increased winter precipitation, which will still fall as snow at high altitudes and therefore have an effect on discharge only in spring and early summer. This precipitation will still help to fill Alpine reservoirs. It is virtually impossible to estimate whether this effect will compensate for the reduced flow from melting glaciers, however.

Run-of-river plants

The run-of-river plants on the rivers in the Swiss Plateau region are located at lower altitudes. Increased temperature due to climate change will therefore not only influence the amount of precipitation but also the proportion of rain compared to that of snow. More water will be available as rain and will therefore be directly discharged. Consequently, there will be more production in winter, which is usually more valuable. On the other hand, runoff will be reduced in summer due to less rainfall and the lack of snow reserves. The production pattern will therefore be different compared to the situation today, with more production in winter and less in (early) summer. Model computations for the river Thur show that the peak average discharge will no longer be observed in summer, as is the case today, but will shift to winter.

One estimate of future production in an imaginary power plant on the Rhine predicts an increase of 5% over the whole year, with an increase of 12% in winter and an increase of 1% in summer. Today, no definite prediction of the effects of climate change on production in hydropower plants can be made. Present model calculations nevertheless show that there will be some effects on the overall quantity of electricity produced, and that there will probably be a lack of available water in summer, especially once the glaciers are gone.

The unpredictable economic factor

What can be done? Since most plants were built after the middle of the 20th century, they are due to be in operation for several more decades. It will be necessary to renew these plants in 20 to 40 years. Today, it is too early to make any predictions about changes in layout that will occur when these plants are renewed.

A far more important effect on hydropower is the liberalization of the electricity market, with its differentiation of electricity products such as peak energy or regulating power. This opens new and very interesting markets for hydropower plants with storage reservoirs, ie reservoirs fed not only by normal discharge but by water pumped back up using excess production during times of low consumption, eg at night. In fact, many owners of hydropower plants are today studying new projects to add more pumped storage capacity to their existing plants in order to increase available power.

The need for energy on demand is not only caused by the new markets, but also by the increased amount of unregulated energy available, for instance from the many wind turbines in Germany. This new appraisal of storage plants is to a certain extent independent of the availability of water, and therefore of climate change. What is projected for Switzerland will probably be relevant to other Alpine countries such as Austria, France, Italy, and Slovenia. Northern European countries such as Norway or Sweden will possibly feel similar effects.

FIGURE 2 A flood wave bursting through a settled area in the mountains near Zignau, Canton of Grisons, on 18 July 1987. Hydropower plants can help to mitigate such events. (Photo by T. Venzin)

Climate change and the safety of hydropower plants

The effects of climate change on hydropower are not limited to production patterns. Safety aspects are involved as well. Due to melting permafrost and more frequent storm rainfall, slope instabilities will become more frequent, and landslides and flood waves will thus endanger plants (Figure 2). Due to their location in or close to rivers, hydropower plants are the most jeopardized structures in the total electricity supply system. On the other hand, it must be noted that these plants are designed to withstand even very high floods. A considerably increased threat to the plants themselves is therefore not expected.

FIGURE 3 View of the remaining rock wall of the Zuetribistock after the second rock slide. The cloud of dust shows how unstable the mountain was at the time. (Photo by M. Kobel)

In 1976 a flood in the Canton of Ticino, carrying large quantities of solid material, caused the clogging of the spillway of a dam. The subsequent overflow caused some damage to the foundation of the dam. Consequently, all the spillways of large dams in Switzerland were checked and measures were taken if needed to improve their proper functioning.

On 24 January, 1996, some 750,000 m^3 of rock fell from the Zuetribistock in the Canton of Glarus; this was followed by another 2,200,000 m^3 on 3 March, 1996 (Figure 3). The rock mass buried some buildings and the access road to the compensation basin of a hydroelectric power plant, forming a new, natural dam across the valley and a lake upstream of it. In order to avoid flooding from potential breaking of this natural dam, a bypass tunnel was built to drain the lake behind the dam.

These 2 examples of natural hazards and their effects on hydropower plants may be attributed to climate change. They at least show the extent of effects that might be expected in connection with climate change. On the other hand, it must be mentioned that similar events have occurred in the past. Therefore, the impacts of recent climate change may not be the only cause of such events.

Hydropower and flood protection

As mentioned above, it is possible that flood intensity will increase with higher temperatures. Damage caused by floods in Switzerland over the 25 years from 1972 to 1996 amounted to some US$ 3.6 billion, or US$ 144.6 million annually. This corresponds to roughly half the income from water taxes paid by all hydropower plants in Switzerland. Most of this damage occurs in mountainous regions.

What do floods have to do with hydropower? Hydropower plants with storage reservoirs have a significant attenuating influence on flood peaks. Estimated retention capacity during several flood events in the Canton of Valais showed that the peak flow of these floods could be reduced from roughly 1000 m^3/s to 800 m^3/s in the Rhone River in Sion, the capital of the canton, located relatively far below the major dams. Similar evaluations in different areas confirm an attenuating effect of Alpine reservoirs on peak flows of some 10 to 20%. Hydropower plant dams therefore play an important role in flood protection. If flood peaks increase with climate change, the role of these dams in flood protection will become even more important.

Mitigation of climate change by hydropower

Hydropower as the most important source of renewable energy in Switzerland helps to reduce the country's CO_2 output:

- Total energy consumption in Switzerland in 2002 was 853,000 TJ. The total consumption of fossil fuels for the construction of all hydropower plants was estimated at some 50,000 TJ, ie 6% of annual consumption. The major components of hydropower plants have a lifetime of 40 to 80 years.
- The operation of hydropower plants itself is practically free of CO_2.
- Hydropower has an extremely high earning ratio. A hydropower plant can produce 150 to 250 times as much energy as is needed for the construction and operation of the plant. By comparison, a wind generator produces roughly 30 times and a photovoltaic plant 10 times the amount of energy used for construction and operation.
- Hydropower accounts for some 12% of total energy consumption in Switzerland, not taking into account the higher value of mechanical or electrical energy as compared to heat.

Diverging interests: mitigation of climate change versus water ecology

While hydropower has many positive ecological features, it also has certain negative impacts on the water ecosystem. This leads to conflicts of interest: water ecologists would like to increase residual flows downstream of water intakes (Figure 4). Less water could thus flow through the turbines and the production of clean, renewable energy from hydropower would diminish. This is in direct contrast to the need for hydropower to reduce overall CO_2 release in the atmosphere from energy applications.

Thus, in terms of hydropower, the two ecological goals of climate protection and protection of natural water ecosystems are in conflict. This conflict, and the lack of efficient instruments to handle it, will probably be the main obstacles to making optimal use of hydropower in future energy policy.

Hydropower worldwide

The extent to which climate change will influence hydropower in other regions of the world outside Switzerland is unknown. It can be assumed that the situation will be comparable in neighboring Alpine countries. But observations in Switzerland can probably not be extrapolated to other mountain chains in different regions and different geographical conditions, such as latitude or local position on the continents.

Worldwide, hydropower accounts for 19% (2650 TWh) of annual global electricity supply, utilizing one third of its economically exploitable potential (8000 TWh). Of these 8000 TWh, roughly 35% are in Asia, 19% in South America, 19% in Europe, 13% in Africa, 12% in North America, and the rest in Oceania. Actual production (1999) ranges from some 20% of this economically exploitable potential in Asia to some 50% in Europe. Since hydropower projects have the advantage of avoiding emissions of greenhouse gases, SO_2 and particulates, and since their social impacts can be mitigated by taking appropriate steps early in the planning process, the International Hydropower Association strongly recommends that "the remaining hydro potential should be developed to the maximum possible extent, provided it is implemented in a technically, economically, environmentally, and socially acceptable way."

This is and will be a demanding task. Institutions are challenged to negotiate solutions that promote sustainable development, taking into account not only technical and economic feasibility, but, even more important, environmental benefits and social impacts. This will require legislation based on long-term visions of sustainable development.

FIGURE 4 Dry river bed in the summer of 2003. This is an increasingly frequent view, due on the one hand to dry summers, and on the other hand to the use of water for hydropower, leading to conflict between proponents of two different ecological goals: climate protection and protection of natural water ecosystems. (Photo by S. Anderegg)

Conclusion

Hydropower will be influenced by climate change. In Switzerland, this change will affect production patterns. However, it is still very difficult to predict definite effects. So far, very significant effects are not expected within the next 25 to 50 years—the approximate service life of a large number of Swiss hydropower plants. Thus the operation of the plants will probably be influenced more significantly by political and economic conditions than by climate change. On the other hand, a clear political vision is needed to confront the conflict of interest between regional protection of watercourses and global protection of the climate. In the author's view, it is necessary to improve the political climate for hydropower in order to help the meteorological climate. Worldwide, there is a considerable potential for further development of hydropower, which should be exploited according to the rules of the International Hydropower Association, among others, for the sake of the climate.

AUTHOR

Walter Hauenstein
Schweizerischer Wasserwirtschaftsverband, Rütistrasse 3a, 5401 Baden, Switzerland.
w.hauenstein@swv.ch

Walter Hauenstein holds a degree in engineering and a PhD from the Swiss Federal Institute of Technology. He has worked as a technical advisor for water supply systems and a lecturer in hydrology. He has extensive experience in the fields of hydropower, flood protection, hydraulic engineering, and revitalization of rivers, and is the publisher of the journal Wasser, Energie, Luft—Eau, énergie, air. *He is currently Director of the Swiss Association for Water Resources Management.*

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