Axpo Energy Reports

Hydropower

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Introduction

A secure, affordable and sustainable electricity supply is fundamental to the functioning of Swiss society and the economy. Today, Switzerland benefits from very good conditions for a reliable supply thanks to hydropower, nuclear power, new renewable energies and its central location in the European power grid.

In the coming decades, this position will come under pressure unless suitable countermeasures are taken. The electrification of mobility and heating, in addition to population growth, will significantly increase the demand for electricity. Rising energy demand from data centres, cloud services and generative AI contribute further to this trend. At the same time, the planned phase-out of nuclear power will eliminate a substantial proportion of domestic electricity production in the long term.

The winter half-year are increasingly in focus. Switzerland already consumes more electricity in winter than it produces. In the winter half year, the demand for heat is higher and people generally spend more time indoors, which increases the power consumption of electronic devices and lighting. In addition, hydropower produces more electricity in the summer half-year due to the seasonal discharge profile, which includes a high proportion of run-of-river water water. Renewable energy expansion in Switzerland and neighbouring countries currently relies heavily on solar energy, which generates the majority of its yield in the run-of-river water. As a result, the seasonal difference between the summer surplus and winter deficit will continue to grow, making it increasingly difficult to ensure a reliable supply of electricity in winter.

In addition to close cooperation with neighbouring countries and the EU, the development of reliable, affordable and sustainable domestic electricity production is needed to secure the electricity supply in the future. In the Axpo Energy Reports, we look at four technologies that could substantially increase domestic electricity production in the winter half-year: Wind energy, new nuclear power plants, solar energy and gas-fired power plants.

This report shows how electricity generation from hydropower is expected to develop up to 2050. By presenting the current and future key pillar of domestic production, the report supplements the four reports of the Axpo Energy Reports project and thus enables a comprehensive assessment of the options for securing the future electricity supply, especially in winter.

This report addresses the development of hydropower in Switzerland up to 2050.

Disclaimer: This report was originally drafted in German and has been carefully reviewed by experts, particularly with regard to terminology and content accuracy. The translations are intended to make the report more accessible to a nationwide and international audience and have been produced with the utmost care. In the event of any questions regarding interpretation, the original German version is considered authoritative.

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01 Summary

Hydropower is the backbone of Swiss electricity production. Currently, the expected output of the more than 700 large-scale hydropower plants[1] (hereinafter simply referred to as hydropower plants) of around ~37.4 TWh of electricity per year – of which approx. ~15.5 TWh in the winter half-year of October to March – and is thus responsible for 60 percent of Swiss electricity production.[2, 3] In accordance with the targets set out in the Energy Act (targets of the Energy Strategy 2050), hydropower is to be expanded to over 39.2 TWh per year by 2050.[4] However, this goal and the expansion of reliable winter production by 2 TWh[5] are proving to be ambitious. While new construction projects and efficiency improvements increase production, these gains are largely offset by declines in production due to environmental regulations (particularly residual water requirements). We therefore expect a lower net increase.

Figure 1: Curnera reservoir.

[1] Hydropower plants with an installed capacity of more than 300 kW
[2] Swiss Federal Office of Energy SFOE, 2025, Status of hydropower use in Switzerland as at 31 December 2024
[3] Swiss Federal Office of Energy SFOE, 2025, Swiss electricity statistics 2024: Table 32, Outlook 2024/2025
[4] Energy Act (EnA), Art. 2 para. 2
[5] Electricity Supply Act (Electricity Supply Act), Art. 9a, para. 1

Electricity from Swiss hydropower generated 2025 – 2050

	Year		Winter (October-March)	
Current (2025)	**~37.4 TWh**		**~15.5 TWh**	
Round table[6] (see Section 3.1)	Optimistic: Pessimistic[7]:	+0.36 TWh +0.09 TWh	Optimistic: Pessimistic[7]:	+1.50 TWh +0.38 TWh
Renewals & Extensions[8] (see Section 3.2)	Optimistic: Pessimistic[7]:	+1.00 TWh[9] +0.25 TWh	Optimistic: Pessimistic[7]:	+0.55 TWh +0.14 TWh
Residual water until 2050 (cf. Section 5.1)[10]	Optimistic: Pessimistic:	–1.50 TWh –5.30 TWh	Optimistic: Pessimistic:	–0.75 TWh –2.65 TWh
Climate change by 2050 (see Section 6.1)	Little effect on annual production up to 2050[11]		Optimistic[11, 12]: Pessimistic[11, 13]:	+1.55 TWh +0.30 TWh
Total by 2050	**Optimistic:** **Pessimistic:**	**~37.3 TWh** **~32.4 TWh**	**Optimistic:** **Pessimistic:**	**~18.4 TWh** **~13.7 TWh**

Table 1: Overview of change in electricity generation from Swiss hydropower from 2025 to 2050.

On a positive note, the planned expansion specifically strengthens winter electricity production. While hydropower generation currently accounts for around 40 percent in the winter half-year, the projects of the Round Table are explicitly designed for winter power generation. In addition, climate change is partly shifting water availability from the summer half-year to the winter half-year.

The most important expansion projects include the 15 (+1 Clus) storage hydropower plants prioritised by the **"Hydropower Round Table"**, which together are expected to supply approx. 2 TWh of additional winter energy by 2040 in accordance with the targets set out in the 2023 Electricity Supply Act (StromVG). However, this requires that all projects agreed at the round table are actually implemented. Many of these projects are currently subject to risks, including profitability concerns, residual value agreements, approvals and objections and complaints. According to the Swiss Federal Office of Energy, based on current feedback from the project promoters (as of August 2025), only around 1.1 TWh of additional winter energy can be expected by 2040 and around 1.5 TWh until the winter energy potential is fully developed.[14] In the event of additional delays, these values may fall further.

In addition to the Round Table projects, other **renovations and expansions** of existing plants (e.g. expansions by raising dam walls, by collecting new inflows or by increasing the volume and output of the additional water discharge) will make an additional contribution to winter production, albeit to a limited extent of – in the optimistic case – around 0.6 TWh.[15]

[6] Figures based on target adjustment by the Swiss Federal Office of Energy for Round Table projects up to 2050. Source: Swiss Federal Office of Energy SFOE, 2025, Expansion of hydropower requires adapted project list
[7] Assumption: 25 percent of the optimistic scenario.
[8] Net annual and winter generation potential of the Round Table projects, as these projects have already been included in the "Round Table" category.
[9] Net of the potential of small-scale hydropower, which the Federal Council (2025) estimates at an additional 0.25 TWh.
[10] Optimistic = moderate interpretation of residual water restrictions according to Section 5.1; Pessimistic = strict interpretation according to Section 5.1.
[11] Not taking into account any negative impact of additional residual water restrictions due to increased winter runoff.
[12] Corresponds to 10 percent more production in winter, cf. Section 6.1. Source: Hänggi, Balmer et al. (2011, Effects of climate change on hydropower use).
[13] Corresponds to 5 percent increase in production of run-of-river power plants in winter according to SCCER-SOE (2019, Climate change impact on Swiss hydropower production), cf. Section 6.1; assumption: Only run-of-river power plants, without any positive contribution from storage power plants. Winter production of run-of-river power plants in the hydrological years 2014/15–2023/24 was 6.1 TWh on average according to the SFOE (2015–2025, Swiss electricity statistics 2015 to 2024, Table 9, Hydraulic production in the winter and summer half-year).
[14] Swiss Federal Office of Energy SFOE, 2025, Expansion of hydropower requires adapted project list
[15] Federal Council, 2025, Potential for renovations and expansions in large-scale hydropower

The expansion of hydropower is offset by an expected decline in production of several percent due to the legal **residual water requirements**. Since the introduction of the Waters Protection Act (WPA) in 1992, according to a commissioned study, Swiss hydropower has already lost around 1–1.5 TWh of annual production due to higher residual water volumes. By 2050, around 1–2 TWh could be added compared to today (2025). Stricter ecological requirements for the longitudinal cross-linking of fish and protected habitats could increase the further loss to ~2–3 TWh and, in the extreme case, by a further ~5.3 TWh.[16] In other words, the expansion of hydropower by 2050 will be largely consumed or even overcompensated by the losses in production caused by residual water. It is therefore essential to weigh up the interests of use and protection of hydropower.

Climate change will also have an impact on Swiss hydropower production. As the glaciers melt, additional meltwater is available for hydropower. Annual production has therefore increased by around 1–1.4 TWh since 1980. However, this effect is likely to decrease by 2050, estimated at around 1 TWh of annual production.[17] However, the retreat of glaciers also opens up new opportunities for hydropower through glacial lakes, with a potential for controllable winter production (seasonal storage) of around 2.4 TWh, of which almost half can be attributed to the three Round Table projects Gorner, Grimsel and Trift alone.[18] In addition, outflows are shifting, with probably positive effects for winter production: More precipitation falls in winter, while drier periods increase in summer. At the same time, the snow line is dropping and precipitation increasingly falls as rain instead of snow. This reduces natural storage of water in the form of snow and ice and – alongside drought – contributes to lower summer runoff. In addition, the snow melts earlier in the year.[19]

Overall, it is expected that the effects of climate change will have little impact on the annual production of hydropower, but will change the seasonality of water availability. For hydropower plants, this means higher flows are available for use in winter, but more frequent periods of reduced natural inflows in summer. Extreme weather events such as flooding or drought could occur more frequently and affect the production profile.

Taking all factors into account, domestic hydropower production is likely to increase only slightly, if at all, by 2050, and thus well below the target values of the expansion targets enshrined in the Energy Act (see table 1). The reasons are **target conflicts** between security of energy supply and environmental regulations as well as economic hurdles. The industry, politicians – and, in the context of reversion, the concession grantors (i.e. cantons and municipalities) – are faced with the task of systematically exploiting remaining potential where this is economically and ecologically justifiable in order to at least partially compensate for foreseeable or unavoidable losses in earnings (e.g. due to environmental regulations).

[16] Pfammatter & Semadeni Wicki, 2018, Energy losses from residual water determination
[17] Schaefli, Manso et al., 2019, The role of glacier retreat for Swiss hydropower production
[18] Federal Council, 2024, Analysis of the hydropower potential of glacier melting
[19] FOEN, 2021, Effects of climate change on Swiss waters

02 Current status of Hydropower in Switzerland

Switzerland is one of the most water-rich countries in Europe and has been using this resource intensively to generate electricity for over 150 years. As early as 1880, hydropower covered a large part of the electricity demand, and there was a period of significant expansion between 1945 and 1970. Today, approximately 700 hydropower plants with a capacity of ≥300 kW are in operation of which around 200 have a capacity of ≥10 MW. These are complemented by more than 1700 small and micro hydropower plants with capacities of less than 300 kW. Although the small and micro hydropower plants account for 70 percent of all hydropower plants surveyed in Switzerland, they together only supply around 0.6 TWh / a and thus a fraction (≈1.5 percent) of total hydropower generation.[20, 21, 22] On the other hand, the largest 10 percent of hydropower plants generate over 90 percent of total hydropower production.[22] In the following, the term "hydropower" refers exclusively to large-scale hydropower.

Three different types of hydropower plants are used in Switzerland:

- **Run-of-river power plants:** Hydropower plants without their own storage, which are dependent on the ongoing turbination of the respective water inflow. Their operating mode is determined almost exclusively on the water supply and less by market prices or electricity consumption. Because the rivers on which these plants are built carry water continuously, run-of-river power plants typically supply baseload energy and are considered base-load facilities. These are usually low-pressure units: Compared to storage and pumped-storage power plants, the usable drop heights are generally low and are in the single-digit to low double-digit metre range.
- **Storage power plants:** Hydropower plants that store energy in the form of water in reservoirs in order to generate electricity at short notice if required and thus be able to react flexibly to peaks in demand. In contrast to pumped storage power plants, the reservoir is filled exclusively by natural water inflow. Both storage and pumped storage power plants are high-pressure facilities, with usable water heads of often reaching several hundred metres and, in exceptional cases, up to 1880 metres (Cleuson-Dixence, world record).
- **Pumped-storage power plants:** Hydropower plants that pump water back into the reservoir when required. This makes particular sense for reservoirs that have a low natural inflow and where the topographical conditions allow for a lower basin.[23] Pumping typically takes place at times of low electricity prices, such as on sunny days with high solar production. Pumps can also be used to provide negative balancing energy. Modern pumped storage power plants can have an overall efficiency of 80 percent, accounting for the combined losses from both pumping and turbine operation.

The total installed capacity of all Swiss hydropower plants (≥300 kW) is around 16.5 GW, with an average annual production of 37.4 TWh (as at the end of 2024). This means that hydropower accounts for around 60 percent of Swiss electricity production. Roughly 48 percent of production is generated by run-of-river power plants (26 percent of total installed capacity), 48 percent by storage power plants (50 percent of total installed capacity), and 4 percent (net, i.e. less pump energy consumed) by pumped-storage power plants (24 percent of total installed capacity).[24] The high production of run-of-river power plants relative to installed capacity indicates the high ca-

[20] Swiss Federal Office of Energy SFOE, 2025, Status of hydropower use in Switzerland as at 31 December 2024
[21] Swiss Federal Office of Energy SFOE, 2025, small-scale hydropower
[22] EnviDat, 2026, Swiss micro-hydroelectric power plants
[23] Recirculation plants are a special form of pumped-storage power plants, where, unlike pumped-storage power plants, natural water inflows play a negligible role.
[24] Swiss Federal Office of Energy SFOE, 2025, Status of hydropower in Switzerland as at 31 December 2024

pacity factor of this type of power plant or, as described above, the fact that they predominantly supply baseload energy.

The seasonal distribution of hydropower generation is particularly important for winter energy. In the winter half-year (October – March), there is little rainfall compared to the summer half-year. In addition, a portion of the winter precipitation falls in the form of snow and is therefore only available as meltwater in the summer half-year. Accordingly, around 27 percent of the natural inflows used to generate electricity are currently captured in the winter halfyear, and 73 percent in the summer half-year. Thanks to the reservoirs, the ratio of actual hydraulic generation can be shifted to approx. 43 percent in the winter and 57 percent in the summer.[25] The lower production in winter is mainly due to the run-of-river power plants, which only generate about 35 percent (6.5 TWh) of their annual production during this period. Storage power plants, by contrast generate 45 percent (8.0 TWh) of their annual production in the winter half-year. While pumped storage power plants generate almost 63 percent of their net output in the winter half-year, in relative terms, this represents just under 1.0 TWh in absolute values.[24]

The locations of the hydropower plants are unevenly distributed according to the water resources and existing gradients, with production concentrated at some locations on the Central Plateau along the major rivers, but mainly in the Alpine regions. The plants built on the Central Plateau are mainly run-of-river power plants along the Rhine, Aare and Rhone rivers, while storage and pumped-storage plants are increasingly found in the Alpine regions. The four cantons of Valais (28 percent), Grisons (21 percent), Ticino (10 percent) and Bern (9 percent) together account for around 68 percent of national production expectations, with Valais and Grisons alone accounting for almost 50 percent. The public revenues resulting from hydropower utilisation – particularly through water rates – play a relatively large role in these cantons, as discussed in more detail below. Switzerland also owns shares in border power plants

[25] Average for the hydrological years 2014/15–2023/24. Based on Federal Office of Energy SFOE, 2025, Swiss electricity statistics 2015–2024

(e.g. on the Rhine, Inn, Doubs), which contribute around 11 percent (Swiss share) of hydropower production.[26]

Swiss hydropower uses water from a catchment area of 39 740 km², corresponding to 93 percent of the country's surface area. Along almost all of Switzerland's major outflowing rivers, the water passes through a series of run-of-river power plants arranged in cascade. On average the water is used in 12 power plant stages before it leaves the country; in some Alpine spring areas, the water is even used in up to 30 stages before it reaches the Rhine near Basel. If all the catchment areas of the individual power plant chains are added together, this amounts to 528,278 km², i.e. around 13 times the effective total area of the catchment areas.[27]

Hydropower is also economically significant. With its 60 percent share of the country's annual generation, it makes a significant and low-emission contribution to Switzerland's security of energy supply. The annual market volume can be estimated at CHF 2.2 billion.[28] Hydropower companies also pay water rates to cantons and municipalities, currently CHF 110 per kW gross output, which equates to around CHF 550 million per year nationwide.[29] This charge – which is practically independent of the actual annual generation and electricity market prices – increases the production costs of Swiss hydropower by almost 20 percent on average.[30, 31] The water rate is discussed in more detail in Section 4.4.

Thanks to high reliability and good maintenance, hydropower plants deliver stable production. Outages are rare and usually caused by external factors such as storms. Many facilities already have useful lifetimes exceeding 80 years. Many power plants (built 1950–1970) will soon face concession renewals (i.e. renewals of existing water usage rights) or new concessions (i.e. granting of new concessions as part of reversion).

[26] Swiss Federal Office of Energy SFOE, 2025e, hydropower Switzerland: Statistics 2024
[27] Schaefli, Manso et al., 2019, The role of glacier retreat for Swiss hydropower production
[28] Assumptions: Guide price 6 cents/ kWh and expected production of 37.4 TWh, net Pumped-storage power plants
[29] Swiss Federal Office of Energy SFOE, 2023a, water rate
[30] Geissmann & Filippini, 2014, Cost structure and cost efficiency of Swiss hydropower
[31] Geissmann & Filippini, 2017, Cost structure of Swiss hydropower

03 Expansion potential up to 2050

Figure 2: Mattmark reservoir.

The natural site potential for new large-scale hydropower plants in Switzerland is considered to be largely exhausted. The remaining realistically exploitable potential lies primarily in the expansion and renewal of existing plants, in efficiency improvements and, in some cases, in new reservoirs in the high mountains as a result of glacier retreat.[32] According to the targets set out in the Energy Act, hydropower is to be expanded to more than 39.2 TWh per year by 2050,[33] which would correspond to additional net annual production of approx. 1.6 TWh. This goal is to be achieved primarily through the projects of the Hydropower Round Table and the renewal or expansion of existing plants.

3.1 Round table Hydropower (Winter electricity initiative)

In 2021, the Federal Department of the Environment, Transport, Energy and Communications (DETEC) set up a round table bringing together the energy industry, cantons and environmental organisations to identify projects for the expansion of Swiss hydropower. The initiative was launched in response to the challenges facing hydropower in the context of the Energy Strategy 2050, the net-zero climate target, energy supply security and the preservation of biodiversity. The committee identified 15 (+1 clus)[34] priority storage hydropower projects that looked promising in terms of energy efficiency and at the same time feasible with a comparatively low environmental impact. Together, these projects should enable additional controllable winter production of around 2.0 TWh by 2040. Many of the projects of the hydropower round table, especially purely reservoir enlargements,

[32] Swiss Federal Office of Energy SFOE, 2019, Swiss hydropower potential
[33] Energy Act (EnA), Art. 2 para. 2
[34] The 15 projects are listed verbatim in Appendix 2 of the revised Electricity Supply Act (StromVG), where the project types are also described. Chlus is a run-of-river/diversion power plant (without new storage) and was subsequently added to the project list. It is now explicitly equated with the other 15 projects in the StromVG (Art. 9a para. 3).

Hydropower projects and additional winter production potential

Project (canton)	**Additional Winter produc.**[35]	**Remark**
Gorner (VS)	650 GWh	New reservoir (Gorner Glacier)[36]
Lake Grimsel (BE)	240 GWh	Raising the Grimsel dam (+23 m)[37]
Trift (BE)	215 GWh	New storage power plant (Trift Glacier)[38]
Chummensee (VS)	165 GWh	New pumped-storage power plant
Gougra (VS)	120 GWh	Raising the Moiry dam
Curnera-Nalps (GR)	99 GWh	Raising the Curnera + Nalps dam walls (+12/+10 m)
Oberaarsee (BE)	65 GWh	Raising the Oberaar dam
Mattmarksee (VS)	60 GWh	Raising the Mattmark dam (+10 m)
Reuss cascade (UR)	60 GWh	Raising the Göscheneralp dam (+15 m)
Lac d'Emosson (VS)	58 GWh	Raising the Emosson dam
Lai da Marmorera (GR)	55 GWh	Raising the Marmorera dam
Lac des Toules (VS)	53 GWh	Elevation of Toules dam
Oberaletsch (VS)	50 GWh	New small-storage power plant (Aletsch Glacier)
Lago del Sambuco (TI)	46 GWh	Raising the Sambuco dam
Griessee (VS)	46 GWh	Raising the Griessee dam
Total 15 projects	**2 023 GWh**	
+1 Chlus (GR)	240 GWh	New discharge power plant between Küblis and mouth of the Rhine

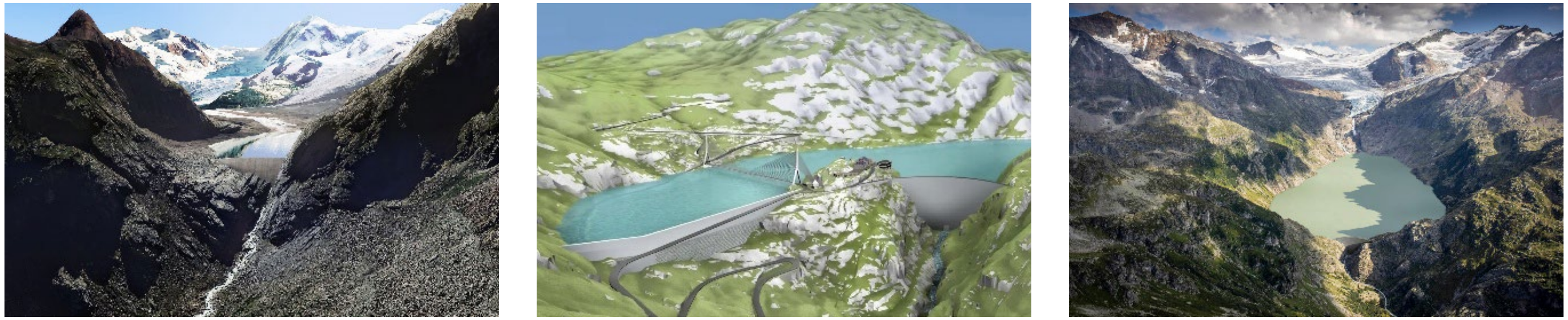
Table 2: Fifteen (+1 Clus) priority hydropower projects of the Round Table (storage hydropower) and their additional winter production potential.[42]

essentially involve a shift in production from the summer to the winter half-year.

Accordingly, the potential for additional, targeted, retrievable winter production is significantly greater than that of additional annual production: Many of these projects are primarily aimed at storing water that is already turbined[40] in existing cascades, seasonally in the future by means of new or expanded reservoirs and thus being able to use it more flexibly in terms of time, especially in winter. Viewed over the year as a whole, the Round Table projects will therefore generate hardly any additional electricity; annual production is expected to increase by ~0.4 TWh.[41] The participants also agreed on compensatory measures for nature and the landscape that go beyond the statutory minimum. A joint declaration sets out the principles agreed by the participating cantons, operators and environmental associations; the 15+1 projects are also listed (see table 2). They are spread over five cantons: 8 in Valais, 3 in Bern, 3 in Grisons, 1 in Ticino and 1 in Uri.[42]

The projects comprise 11 extensions to existing facilities (mainly dam wall height increases) and 5 new constructions (Gorner, Trift, Oberaletsch, Chummensee, Chlus; the first three projects are to be built on lakes newly created by glacier retreat). The three largest projects in terms of expected winter production – Gorner, Grimselsee and Trift – are presented briefly below.

35 Estimate from 2021. Figures may change in the course of project development.
36 **Gorner:** Project in Mattertal (operator: Grande Dixence / Alpiq); alternative project Lac des Dix (VS) was discarded as necessary in combination with Gorner.[42] The additional total annual production is 200 GWh.[39]
37 **Grimsel:** Increase of the existing dam wall by 23 m; already planned for some time, linked to the structure planning procedure by court orders (see below). The additional total annual production amounts to 12 GWh.[39]
38 **Triple:** New KWO storage power plant; reservoir (85 million m³) created from glacier retreat. The additional total annual production amounts to 145 GWh.[39]
39 Federal Council, 2024, Analysis of the hydropower potential of glacier melting
40 For example, the Round Table's largest projects – Gorner, Lake Grimsel and Trift – are among the existing Grande Dixence (Gorner) and Kraftwerke Oberhasli (KWO) power plant cascades.
41 Federal Council, 2025, Potential for renovations and expansions in large-scale hydropower
42 DETEC, 2021, Joint declaration of the Round Table Hydropower



Gorner project — Alpiq, Grande Dixence

Grimsel project — Oberhasli power plants

Trift project — Oberhasli power plants

Figure 1: Visualisations of the Gorner, Grimsel and Trift round table projects

The Round Table's largest project is the **Gorner** project in southwestern Switzerland, more precisely in the Mattertal (Zermatt). Grande Dixence SA is planning various optimisations there, including a new reservoir with 100 million m³, fed by several glacial streams, which could generate around 650 GWh of winter electricity annually. The project will be integrated into the existing Grande Dixence infrastructure, which already receives water from the Gorner region via the Z'Mutt pumping station. Due to its location in the BLN area (Federal Inventory of Landscapes and Natural Monuments of National Importance), the project is being carefully considered by the Swiss Federal Commission for the Protection of Nature and Cultural Heritage (ENHK) and environmental organisations. Viewed in isolation, an expansion of Lac des Dix would have the lowest impact on biodiversity and landscape per additional controllable GWh. However, choosing Lac des Dix would exclude Gorner, meaning that further projects would be needed to meet the expansion target. This would significantly increase the cumulative intervention per controllable GWh, which is why Gorner and not Lac des Dix was prioritised by the Round Table.[42]

The second most important project is to increase the **Grimsel** dam wall by 23 metres[43], which is expected to generate around 240 GWh of additional winter energy. This project had been controversial for years due to landscape conservation concerns. In 2020, the Federal Supreme Court ruled that Grimsel must first be designated as a site in the cantonal structure plan before licences can be granted. This adjustment to the structure plan was carried out by the canton in 2022 and approved by the Federal Government (DETEC) in 2023.[44] Association complaints are not pending as of January 2026: After the "Grimsel Dialogue," the major associations agreed not to lodge any complaints.

This is followed by the **Trift** project in the Bernese Oberland. A reservoir of around 85 million m³ and an underground power plant with an installed capacity of 80 MW are planned. The project is expected to generate approximately 145 GWh of additional electricity per year and enables a seasonal shift of around 215 GWh into the winter half-year (reflecting the storage facility's energy content). The Grand Council of the Canton of Bern approved the licence amendment in June 2023. At the end of 2023, Aqua Viva and the Grimsel Association submitted complaints to the association. Aqua Viva withdrew its complaint in July 2025, while the

[43] KWO Grimselstrom, 2025, expansion of Lake Grimsel
[44] DETEC, 2023, Structure Plan of the Canton of Bern

Grimsel Association's complaint is still pending. Trift is considered a reference project for the use of precipitation runoff after glacier retreat and – like all storage power plant projects – also offers flood protection for downstream valleys (in this case the Gadmental).[45]

The planned expansion of additional controllable winter production of around 2 TWh assumes that the Round Table projects can be fully realised. Currently, many projects are still subject to risks (profitability, residual value agreements, authorisations, objections/complaints). In August 2025, the Swiss Federal Office of Energy revised downwards the expectations for the projects prioritised at the hydropower round table: Based on the feedback from the project promoters, only around 1.1 TWh of additional winter energy is realistic by 2040, and around 1.5 TWh of additional winter energy is realistic until the potential is fully developed, instead of the originally envisaged 2 TWh.[46] Replacement projects for projects that are unlikely to be feasible are already under discussion.[47]

3.2
Extensions and renovations of existing plants

As hardly any new plants can be built, expansion efforts focus on enlarging and renewing plants and facilities at existing locations. The Swiss Federal Office of Energy estimates the annual technical production potential of expansions and renovations to be ~1.4 TWh, of which ~1.3 TWh expansions (including efficiency improvements), of which ~0.4 TWh (i.e. ~30 percent based on 1.4 TWh) as part of the Round Table projects. The technical potential of additional winter generation is ~2.1 TWh (of which ~1.6 TWh, i.e. approx. 75 percent, through round table projects) and can be developed primarily by raising the dam wall.[48, 49]

Potential for expansion and renovation

	Increase in production Year (TWh/year)	**Increase in production Winter** (TWh/year)
Extensions[50]	**1.25**	**2.06**
(… of which Round Table)	(0.36)	(1.55)
Renewals	0.1	0.04
Total	**1.35**	**2.10**

Table 3: (Technical) expansion and renewal potential.[48]

The values illustrate that, on the one hand, the Round Table projects play a major role in tapping winter production potential and – as mentioned earlier – many of the Round Table expansion projects provide little or no additional production throughout the year, but primarily transfer water from the summer to the winter half-year.[48] Table 3 sums up the figures just presented.[50]

Expansions and renovations can be roughly divided into four categories of measures as follows, whereby dam wall increases are the only measures that significantly increase seasonal storage and thus winter production: [51]

45 Grimselstrom KWO, 2025, construction of new reservoir and Trift power plant
46 Swiss Federal Office of Energy SFOE, 2025, Expansion of hydropower requires adapted project list
47 SRF, 2025, replacement projects
48 Federal Council, 2025, Potential for renovations and expansions in large-scale hydropower
49 A somewhat older study, BFE (2019), which is based on data from 2012, provides similar estimates of expansion and renovation potential. The Federal Council's study (2025) also lists a technical potential of ~0.3 TWh for small hydropower (capacity of less than 10 MW), of which ~0.2 TWh is from expansions and ~0.1 TWh from renewals, in addition to the aforementioned potential for large hydropower.
50 Including efficiency gains
51 Federal Council, 2025, Potential for renovations and expansions in large-scale hydropower

- **Extensions by raising the dam walls:** The technical potential of increased dam walls[52] is estimated at ~1.7 TWh for winter production and ~0.4 TWh for annual production.[51] Often, a few metres of increased dam walls are sufficient to create several million m^3 of additional storage space, which is valuable for winter relocation. Example: Raising the Grimsel dam by 23 metres generates ~0.24 TWh of additional winter energy, by reducing today's impoundment volume 94 million m^3 to 170 million m^3.[53] The majority of the Round Table projects involve moderate increases in the dam wall in order to increase storage volumes (e.g. Göscheneralp, Mattmark, Grimsel, Sambuco etc., cf. table 2).
- **Expansions through the intake of new inflows and an increase in the volume and output of the additional water discharge:** The technical potential of these measures is ~0.6 TWh of annual production and ~0.2 TWh of winter production. Together with raising the dam walls, these measures – compared to the other categories of measures – have the potentially greater impact on the environment.[51] When catching new inflows, either outflows from previously unused catchment areas are channelled into the engine waterways of nearby power plants or the capacity of existing water catchments is increased. As a result, production usually increases, especially in summer, unless the storage capacity is also expanded. Additional water discharge quantity and output can be increased with larger or additional turbines and generators.[51]
- **Efficiency gains:** In addition to the two categories of expansion measures just listed, which together with ~1.9 TWh of winter production (~0.9 TWh of annual production) account for most of the potential for expansions and renovations, there are measures that primarily serve to increase efficiency and have a total potential of ~0.2 TWh of winter production (~0.3 TWh of annual production).[51] Examples of such measures include stream water path optimisation, equipment replacement, river depressions, use of compensation water and installation of pumps (see Excursus Efficiency Increases).
- **Renovations:** With ~0.04 TWh of winter production (~0.1 TWh of annual production), renewals contribute by far the smallest part of the total winter production potential of extensions and renewals of ~2.1 TWh (~1.4 TWh of annual production).[51] This category includes complete renovations and replacement new buildings together. In the case of complete renovations, several plant components (e.g. catchment, turbine waterway, machines, control technology) are modernised at the same time. Replacement new builds, by contrast, completely replace older power plants and enable higher production thanks to a higher degree of expansion.

[52] Including storage expansions, whereby according to the Federal Council (2025), these have only a very small winter production potential of 0.03 TWh. The annual production potential can even be zero, as only water is transferred from summer to winter. Storage expansions, i.e. new reservoirs at existing power plants, have a similar energetic effect to dam wall elevations. In addition to dams, dams can also be raised. The term "dam wall elevation" is used in the following for simplicity and also includes the elevation of dams.
[53] KWO Grimselstrom, 2025, expansion of Lake Grimsel

Excursus: Examples of efficiency gains

Optimisations in the turbine water system aim to reduce energy losses (i.e. friction and speed losses) of the turbine water path and thus increase the energy equivalent (i.e. the energy produced per m³ of water used). Therecording measures for this include parallel tunnels, tunnel widenings/renovation or the replacement of clear-gauge tunnels with pressure lines. A headrace is defined as all installations between the water intake or reservoir and the control centre, such as gravity tunnels, pressure pipes, pressure shafts, surge chambers, and apparatus chambers.

Equipment replacement involves replacing outdated components such as turbines and generators to improve efficiency and partial-load behaviour, thereby reducing losses. Many hydropower plants were built in the 1950s and 1960s, or even earlier. Components of turbines and generators are subject to natural wear and tear over time, which can usually be fixed as part of the regular maintenance schedule. Thanks to technological advances, technical components have become more efficient. Replacing turbines and generators can therefore slightly increase the output and/or efficiency of a system and thus its power generation. One example worth mentioning is the Eglisau-Glattfelden run-of-river power plant on the Rhine (ZH): Following the replacement of all machine groups in 2012, annual production increased by around 30 percent, from around 240 GWh to 320 GWh.[54] The large outdated power plants have probably already been refurbished, so the remaining potential for additional yield from capacity increases combined with the increase of the additional water discharge volume at ~0.05 TWh in winter (~0.1 TWh of annual production) is less than the collection of new inflows (~0.2 TWh in winter, ~0.4 TWh on an annual basis).[55]

Deepening the river downstream of run-of-river plants can increase the usable gradient and, in turn, boost electricity generation.

In the case of concession renewals, higher residual water volumes can often be used for energy purposes with **doped hydroelectric power plants** in accordance with the Waters Protection Act (WPA).

Pumps can also be installed to move water from sub-catchments to higher-elevation reservoirs, enabling additional electricity production due to the greater available head.

[54] BAK, 2025, Rheinsfelden, Eglisau-Glattfelden power plant
[55] Federal Council, 2025, Potential for renovations and expansions in large-scale hydropower

04 Challenges in Maintenance, Extensions & new construction

The expansion of hydropower faces several challenges. These relate primarily to expiring concessions, permitting processes, economic efficiency and water rates. According to recent survey results[56], only ~0.02 TWh (i.e. approx. 1.5 percent) of the annual production potential of ~1.4 TWh can be economically realised through expansions and renovations without receivables. Operators identified uncertainties related to expiring concessions, residual water regulations, complaints and appeals, adjustment of the materiality threshold for subsidies, residual value agreements, other environmental requirements (e.g. compensatory measures, protected areas of national interest) and lack of profitability as the main obstacles to realising the potential.[56] These aspects are discussed below.

4.1 Expiry of concessions: Residual value agreements & Residual water requirements

A hydropower concession is the time-limited right granted by the local authority – usually the canton and local municipalities, to a power plant company ("the concessionaire") permitting the use of a public body of water for electricity production. In Switzerland, the maximum licence period is 80 years, and in practice concessions usually last between 60 and 80 years. Upon expiry of the licence, this right of use expires. If the reversionary right is exercised, the buildings and installations associated with the water use are transferred to the municipality entitled to claim reversion.

In the event of a reversion[57], the hydraulic system components such as dams, waterways and turbines shall be paid to the concession holders without compensation; for the electromechanical system components, unless otherwise stipulated in the concession, a "cheap" remuneration[58] must be paid by the community to the previous concession holder. Many hydropower cantons such as Valais, Grisons, Ticino, Bern and Uri have political mandate to transfer the plants to majority control as far as possible in the course of concession renewals (i.e. renewals of the existing right to use water if reversion is waived) or new concessions (if reversion is exercised and a new concession is granted by the concessionaire).

Clear residual value rules are therefore crucial for high and long-term investments – such as dam increases – in the last decades of the concession. Residual value agreements determine in advance how investments that have not been fully amortised are valued and compensated at the end of the concession. Without such agreements, concessionaires are often reluctant to invest in major expansion projects because it is unclear how these will be compensated after the concession expires. Irrespective of the future shareholder structure of a power plant company, however, expansion of the plant is by no means guaranteed even after a concession renewal or new concession (if reversion is exercised by the concessionaire), as challenges such as approval and cost-effectiveness remain.

As concessions expire, the focus is also shifting to the statutory residual water regulations. Residual water refers to the minimum runoff in a body of water that remains below a water catchment. Since 1992, the residual water volumes to be observed have been regulated by law in the Waters Protection Act (Art. 31–33 WPA). An increase in the quantities of residual water during an ongoing concession is considered to be an infringement of acquired rights and is only permitted for reasons of public interest and in return for

[56] Federal Council, 2025, Potential for renovations and expansions in large-scale hydropower
[57] For a more detailed explanation of the legal aspects of reversion and residual value agreements, see e.g. hydrosuisse, 2023, Guidelines for reversion.
[58] Tangible value of the electromechanical system components (also known colloquially but imprecisely as "dry" system components) of a hydropower plant – such as generators, transformers or control technology – at the end of a concession period. While the hydraulic (colloquially, but imprecise "wet") plant components such as dams and waterways generally return to the community (municipality/canton) without compensation after the concession expires, the dry plant components must in accordance with the Water Rights Act (WRA; SR 721.80) Art. 67 para. 1 lit. a–b. a "cheap" remuneration, i.e. appropriate remuneration, to be paid to the previous concessionaire.

full remuneration if the infringement diminishes the substance of the acquired right. Once the concession expires, the acquired corporate right also lapses; the new concession must comply with the more extensive residual water regulations of Art. 31–33 WPA, which leads to permanent production losses, as explained in more detail in Section 5 below.

4.2
Permit & construction processes

Hydropower projects in Switzerland are subject to complex and lengthy permitting procedures. These include concession negotiations with cantons and municipalities, environmental impact assessments and planning approvals, which in many cases can be challenged through several courts, specifically on the basis of association complaints. These processes often result in lead times of well over ten years. The raising of the dam wall on the Grimsel (see Section 3.1) has been under discussion since the 1980s and is still legally blocked to this day; even smaller expansions generally take five to ten years to start construction.

The Federal Council and Parliament have set a target of an additional 2 TWh of winter electricity by 2040 in the Electricity Supply Act (StromVG) and strengthened the national interest in large hydropower plants. The "Hydropower Round Table" defines a prioritised list of projects (see Section 3.1).[59] As a supplementary instrument, the cantons should identify suitable water sections for new hydropower plants in their structure plans. Thanks to this prior balancing of interests, potential conflicts can be identified and reduced at an early stage, which increases planning security for projects.

The first projects under the new Legal framework will show how much the new regulations will actually speed up the permitting process. It remains crucial for energy companies to engage proactively in permitting procedures from an early stage, for example through open communication with municipalities and environmental associations, as well as through ecological impact clarifications. Experience from initiatives such as the Round Table has shown that early coordination can reduce the likelihood of objections or complaints.

Despite compromises, e.g. in the context of the Round Table projects, there is no guarantee that environmental associations or authorities, for example, will approve the pro-

[59] The Electricity Supply Act (StromVG) also contains a general acceleration mechanism for renewable energies, which, however, is tailored to solar and wind projects and has only a limited impact on hydropower.

jects. If additional receivables are also made (e.g. higher residual water volumes, see also Section 5.1), projects could fail due to a lack of profitability.

4.3
Effectiveness & subsidy mechanisms

Hydropower plants are very capital-intensive; investments for the construction or maintenance of new large-scale plants often amount to several hundred million francs. Their amortisation periods are very long at up to 80 years. Profitability depends heavily on future electricity prices, subsidy conditions and charges.

Between 2015 and 2020, electricity market prices were mostly below CHF 50/MWh, which meant that operators were barely able to cover the high fixed costs (amortisation, water rate, etc.). Although the rise in electricity market prices since 2021 has eased the situation somewhat, uncertainty remains high, as investments made today must pay off by the end of the century. Nobody can predict the development of electricity market prices, CO_2 prices or technological developments over these long periods of time. Investments in hydropower are therefore associated with considerable risks.

Raised dam walls increase storage capacity, i.e. the ability to transfer water from the summer to the winter half-year. However, it hardly increases annual production, as no new water inflows are tapped. The profitability of such projects is therefore primarily based on the winter-summer spread, i.e. the ratio between the value of the additional energy generated in winter and the value of the resulting summer energy (water is now turbined in winter instead of summer). As a result, many pure storage expansions – particularly the Round Table projects – are economically challenging, as they only enable a seasonal shift in production from summer to winter without significantly increasing total annual electricity production. The investments are therefore only offset by the seasonal price differences of the additional storage volume. For example, according to recent survey results[60], under current market conditions only ~0.8 TWh out of a total of ~1.4 TWh, i.e. slightly more than half of the technical potential, of additional annual production (see table 3) can be realised with the existing subsidy instruments (if granted), and ~0.4 TWh can only be realised if subsidy is increased or market conditions improve.[61]

With the Electricity Supply Act passed by the electorate in 2024, the support landscape for hydropower will consist of two key instruments in future: Investment contributions and the sliding market premium. From 2025, there will be a fundamental right to choose between these two subsidy mechanisms. The investment contributions are based on Art. 26 of the Energy Act (EnG):

- For **new installations and significant extensions,** the investment contribution amounts to up to 60 percent of the eligible investment costs. Under the current Energy Promotion Ordinance (EnFV), the Federal Council has set the amount at 50 percent, with the option of increasing it up to 60 percent for projects with additional winter production or storage expansions.
- For **significant renovations** of hydropower plants, the EnG provides for investment amounts of up to 40 percent of the eligible costs. According to the EnFV, this contribution was set at 20 percent for large hydropower plants, while small hydropower are supported with up to 40 percent, depending on the technology.

With the sliding market premium, the remuneration rate is determined on the basis of plant-specific production costs. According to the EnFV, however, it is capped at a maximum of 30 Rp/kWh for new installations or significant extensions, and 10 Rp/kWh for significant renovations. The subsidy is paid out as the difference between the remuneration rate and the reference revenue, which

[60] Federal Council, 2025, Potential for renovations and expansions in large-scale hydropower
[61] According to the Federal Council (2025), no cost-effectiveness figures are available for the remaining ~0.2 TWh of renovation and expansion potential.

is calculated in accordance with the federal government's methodology.

These support mechanisms are supplemented by project planning contributions of up to 40 percent of the project planning costs under the Electricity Act. The contributions are paid out during the project planning phase. If the project later receives a building permit, they are offset against the investment contributions or the sliding market premium (i.e. deducted accordingly). This is intended to at least partially indemnify investors in the event of project cancellation and thus reduce the risks associated with new projects. For existing plants, the market premium for large hydropower plants over 10 MW – in place since 2018 – serves as an additional support instrument. It is paid out if the production costs exceed the market proceeds and is limited to a maximum of 1 Rp. / kWh. However, this instrument is limited by law until the end of 2030.

StromVG thus provides effective instruments to support the profitability of hydropower. However, there is a need for improvement in the implementation of the ordinances: The term of the sliding market premium is short at 20 years for hydropower, and the complex calculation methodology leads to uncertainty for project developers. In addition, projects are further slowed down by administrative requirements, such as proof of "readiness for construction".

The profitability of hydropower is also strongly influenced by charges paid to the public sector. Overall, these charges (water rate, other taxes and charges) amount to around 1.4 Rp / kWh on average, which accounts for just over a quarter of the total production costs and in the European Comparatively high; around 80 percent of this is attributable to the water rate, see the following section.[62, 63]

4.4 Water rate

The water rate is a charge that operators of hydropower plants pay to cantons and municipalities for the right to use public hydropower potential. The assessment basis is primarily the licensed gross capacity (kW) or usable gradient and available water volume. Under federal law, the maximum rate is currently CHF 110 / kW in accordance with Art. 49 of the Water Rights Act (WRG). Companies have virtually no influence over these parameters in their operations. In the cost structure of a hydropower plant, the water rate is one of the largest individual blocks: On average, it makes about 1 Rp. / kWh, i.e. approx. 20 percent of the production costs, and is therefore on the order of magnitude equal to the amortisation.[59, 60]

The current design is "rigid": The water rate is largely fixed per kW and not linked to electricity market prices and thus the economic situation of the plants. As a result, the cost per kWh varies with the production volume (in years with low production, the cost per kWh increases) and remains high even when electricity prices are low. Today, when many plants have to sell their energy at market prices, these fixed charges cannot be passed on to end customers. This raises production costs relative to competing technologies, weakens the competitiveness and profitability of Swiss hydropower, makes reinvestment more difficult and, in extreme cases, can contribute to the decommissioning of economically marginal plants.

[62] Geissmann & Filippini, 2014, Cost structure and cost efficiency of Swiss hydropower
[63] Geissmann & Filippini, 2017, Cost structure of Swiss hydropower

05 Deep dive: Effects of statutory residual water & surge/sink requirements

Environmental regulations have a direct impact on hydropower generation. This includes, in particular, the rules for determining the residual water volumes and for damping artificial flow changes (surge/sink) in storage hydropower plants.[64]

5.1 Production losses due to Residual water specifications

Since 1992, the Swiss Water Protection Act (GSchG) has required all hydropower operators to comply with so-called residual flow rates below their water catchments. These are minimum water volumes that must always remain in the natural riverbed and therefore cannot be used by the main turbines. The aim of these requirements is to preserve the ecological functions of the watercourse despite water abstraction. A distinction is made between the renovation of water uses existing before 1992 pursuant to Art. 80 WPA and the stricter requirements for new water uses[65] from 1992 pursuant to Art. 31–33 WPA.

Pursuant to Art. 80 WPA, existing plants had to reduce their water withdrawals by 2012[66] at the latest as far as was possible without interfering with existing water usage rights justified by compensation. In order to ensure the prescribed residual water quantities, structural measures were usually necessary, usually by constructing compensation flow systems[67].

If concessions are renewed for existing power plants, they must meet current environmental requirements, which are usually stricter than when the plant was built. These include, in particular, the residual water regulations pursuant to Art. 31–33 WPA. Compliance with these regulations generally leads to additional losses in production compared to residual water remediation in accordance with Art. 80 WPA: As part of this residual water remediation, the residual water volumes stipulated in Art. 31–33 WPA are often not fully reached due to the extensive protection of concessionaires' existing water usage rights.

However, residual water requirements generally lead to losses in hydropower production, both for existing concessions as well as for concession renewals and new concessions, as some of the water that could previously be used in full now has to remain unused in the body of water, i.e. not all of the water flowing in can be used for energy production.

5.1.1 Production losses to date

According to a study commissioned by hydrosuisse, the production losses caused by residual water renovations between 1992 and the end of 2017 amounted to around 560 GWh of annual production.[68] The majority of this – around 350 GWh per year – came from residual water requirements for power plants under existing concessions, i.e. they are attributable to residual water remediation in accordance with Art. 80 of the Swiss Federal Act on Wastewater Protection (WPA). A further 210 GWh was attributable to concession renewals or new concessions pursuant to Art. 31–33 WPA with increased residual water volumes, which will be discussed in more detail in the next section. These losses were not sudden, but rather staggered[69], as only a few power plants were refurbished each year or their concessions expired. On average, there was

[64] Further ecological rules, such as the restoration of fish passage and the bedrock balance, are not discussed below.
[65] I.e. new plants as well as concession renewals and new concessions of existing plants. For a brief explanation of the difference between a concession renewal and a new concession, see Section 3.1.
[66] As the implementation of the residual water remediation was staggered and took much longer in practice, around 90 percent of the remediation work was actually completed in 2020.
[67] A doping system is a technical device used to discharge a specified quantity of water (doping water or residual water) into the watercourse in a power plant in a controlled manner in order to ensure the legally prescribed minimum discharge below the water catchment.
[68] Pfammatter & Semadeni Wicki, 2018, Energy losses from residual water determination
[69] The study by Pfammatter & Semadeni Wicki, 2018, looks at a period of around 25 years up to 2017.

an annual production loss of around 3 percent per refurbished power plant up to 2017.[70]

5.1.2
Expected future production losses

In the context of concessions that will increasingly expire in the near future – many power plants built between 1950 and 1970 are facing concession renewals or new concessions, cf. Section 1 – the production losses under Art. 31–33 WPA will become much more significant compared to those under Art. 80 WPA, as explained below.

According to hydrosuisse, production losses of around 1–2 TWh per year can be expected by 2050 compared to 2025 under the applicable statutory regulations (see Figure 3, Scenario 1), which corresponds to annual production losses of around 11 percent. Taking into account ecological residual water increases for protected habitats and biotopes (scenario 3), losses of 2–3 TWh per year can be expected. If environmental requirements are further tightened (e.g. additional residual water requirements for certain bodies of water or inflow-dependent residual water volumes; scenario 4), losses could reach as much as 5.3 TWh per year by 2050.[70]

As a pragmatic rule of thumb, the losses in production caused by residual water can be spread evenly over the year, i.e. half over the winter half-year (October–March) and half over the summer half-year (April–September). A large proportion of usable natural inflow occurs in the summer half-year (currently around ~73 percent in summer and ~27 percent in winter, cf. Section 1). However, as the residual water quantity generally represents a year-round minimum levy with seasonal increases in the summer half-year, production losses in summer are not much higher than in winter.[71] The first implemented new water uses[65] also show: Although residual water discharges tend to be higher in the summer half-year, the average decline in production over the summer and winter half-year is roughly at the same level overall. One of the main reasons for this is the limited capacities of the individual versions, which means that the seasonal surcharges do not translate, or only partially translate, into additional production losses. Or to put it another way: In summer, residual water can be increasingly secured by overflows, which do not lead to losses in production.

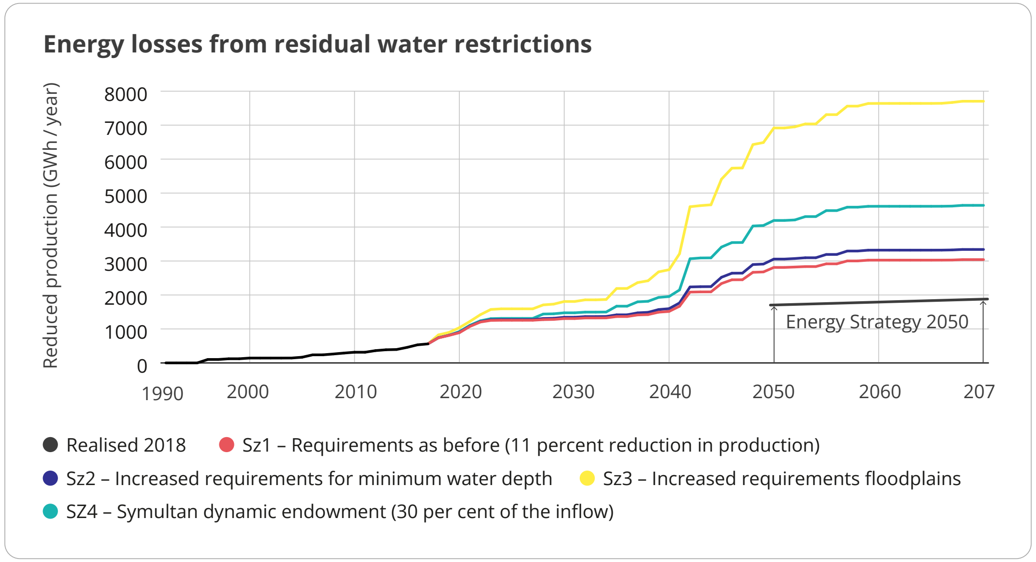


Figure 3: Cumulative curve of the calculated energy losses from residual water restrictions for each based on stored scenario over time from 1992 to 2070 according to Pfammatter & Semadeni Wicki (study hydrosuisse 2018) and compared with the values on which the ES2050 is based.

[70] Note: Figures for the reference year 2025 were derived from Pfammatter & Semadeni Wicki (2018) with regard to the reference year 2018 applicable to the study. The losses up to 2050 compared to 2018 are 2.3 TWh, 2.9 TWh in the mean case (scenario 3) and 7 TWh in the pessimistic case (scenario 4). Source: Pfammatter & Semadeni Wicki, 2018, Energy losses from residual water determination

[71] Although accumulators shift electricity generation towards winter, the residual water supply acts “at the front” when it comes to water withdrawal: Even though storage accounts for around 43 percent of hydropower generation in the winter and 57 percent in the summer (see Section 1), residual water specifications primarily limit the catchment.

In the long term, a 50/50 split in terms of losses in summer and winter production could even prove optimistic, as climate change tends to shift the distribution of run-off towards winter (more winter runoff, less summer runoff, see Section 5.1). At first glance, one might assume that more winter drainage will also lead to more winter electricity production. In practice, however, this is not necessarily the case: One reason for this is that higher minimum winter drains lead to higher legally prescribed residual water volumes (Art. 31 para. 1 WPA). These minimum residual water quantities are derived from the natural low runoffs and apply all year round. If climate change increases minimum drains in winter, correspondingly higher residual water volumes are specified for new water uses[65]. Even if, according to the current state of research, climate change hardly directly affects the annual electricity production of hydropower as a whole and mainly influences the seasonal distribution within the year (cf. Section 5.1), this residual water mechanism can consequently lead to an overall decline in annual electricity production for new water uses[65].

Since the study by Pfammatter & Semadeni Wicki (2018) commissioned by hydrosuisse, the discussion about residual water has evolved. Today, for example, work is being done to consider ecological requirements and benefits to the energy industry together. A new approach is cantonal spatial planning for protection and use. It pursues the idea of deliberately setting different levels of protection and use for water bodies across catchment areas. This means: Some streams or sections would be completely protected and no longer used at all. On the other hand, other suitable sections are likely to be used more intensively, for example with slightly lower residual water requirements.

However, there is currently no legal basis for this overarching cantonal approach: The current law does not provide for any real spatial planning protection and utilization planning. A clear distinction must be made between the catchment area-related protection and use planning pursuant to Art. 32 WPA, which already exists today and is used in expansion projects such as Linth-Limmern, Lago Bianco and the Pradapunt power plant project. This

protection and utilisation plan pursuant to Art. 32 WPA is always catchment area-related and relates only to the respective project area: Protection and utilization interests are weighed against each other in the project area without any compensation or facilitation of utilization being possible in other bodies of water in the canton.

5.2 Surge/sink-related loss of flexibility

Surge/sink refers to the rapid, artificially caused fluctuations in runoff beneath storage power plants, which pollute aquatic ecosystems (e.g. due to drifting or stranding of organisms). According to Art. 39a GSchG, significant impairments caused by hydropeaking/sedimen- tation must be prevented or eliminated – primarily by structural measures and secondarily by operational measures. For existing plants, the corresponding renovations must be implemented by the end of 2030. The cantons will coordinate this and the operators will receive compensation for the costs associated with the necessary planning and realisation of measures. According to a report by the Federal Office for the Environment, around 10 percent of the renovation projects had been completed by 2022, with a further 45 percent in the planning stage.[72] The low implementation rate to date is well known to the cantons, environmental associations and operators. The main reasons for this are the complex initial conditions – particularly the long hydropeaking stretches, i.e. long river sections downstream of power plants where discharge fluctuates strongly and rapidly due to peak operation – as well as the extensive structural measures required. These interventions are necessary to reduce the ecological impact of runoff fluctuations, especially in winter. Such large-scale renovations also create numerous new conflicts of use (e.g. with agriculture, settlements, groundwater, forest or other habitats).

Operational hydropeaking and sink measures –such as limiting maximum or minimum turbined water volumes – significantly restrict the flexibility of storage power plants. Their operation is no longer only influenced by price signals, but also by ecological requirements. On the other hand, structural solutions – such as downstream or balance reservoirs, bypasses or diversions and diversion power plants – hardly affect the use of storage power plants. In principle, the GSchG is designed in such a way that structural measures are prioritised, which should keep operational restrictions to a minimum. In practice, however, operational measures are increasingly being implemented, as structural solutions are often difficult to realise.

An estimate shows: If all Swiss storage power plants were to be refurbished exclusively with operational measures to tackle the problem of surge/sink, almost 60 percent of these plants would no longer be able to be flexibly controlled. In the winter half-year of December to February, this proportion could rise to around 75 percent. Although this does not result in any direct losses in production and the seasonal transfer from summer to winter remains possible in principle, the loss of controllability is serious. Storage power plants are particularly valuable because they can generate electricity when supply is tight, thereby dampening high market prices. Limiting the flexibility of Swiss hydropower therefore significantly reduces its contribution to energy supply security and can have a price-increasing effect.

[72] FOEN, 2024, Renaturation of Swiss waters

06 Deep dive: Impacts of climate change

Switzerland is warming up much faster than the global average: Since pre-industrial times, the temperature in Switzerland has risen by around 2.9 °C within the reference period 1991–2024, more than twice as much as the 1.3 °C global temperature; with 3 °C global warming, on average, around 4.9 °C would be expected in Switzerland.[73] In addition to more hot days, drier summers and less snowy winters, more heavy precipitation is expected in the coming decades.[75, 74]

These effects of climate change also present challenges for Swiss hydropower: On the one hand, a change in water availability due to the melting of glaciers and other snowmelt and precipitation patterns is foreseeable. Added to this, extreme events such as periods of drought, heavy rainfall and flooding are becoming more frequent. At the same time, the formation of new glacial lakes also create opportunities.

6.1 Change in water availability

Since 1850, Swiss glaciers have lost over 60 percent of their volume, a process that has accelerated since the 1980s. This has had a slightly positive effect on hydropower in recent decades: Melting glaciers release additional water that was once bound in the ice. Studies put this contribution at around 1–1.4 TWh per year on average since 1980 (approx. 4 percent of hydropower production).[75]

Climate models assume that a large proportion of the smaller glaciers will have disappeared by around 2050 and that the larger ones will continue to lose mass.[76] "Peak water" (the maximum glacier melt runoff) has probably already been reached in many catchment areas, followed by a decrease in the meltwater contribution. Over the course of the 21st century, the runoff fed by glacial melting is expected to decrease by around 1 TWh by the middle of the century, partly due to the loss of glacier mass and partly due to assumed effective climate protection measures.[77] Regions with a high proportion of glaciers are particularly affected. In Valais, for example, around 9 percent of hydropower currently comes from glacier melt. This value could halve over the next few decades.[77]

The influence of the meltwater flow is strongly seasonal. Glacier melt provides its additional runoff mainly in summer and early autumn. As such, the retreat of the glaciers will primarily affect summer production in the future. Winter production, on the other hand, is only slightly affected, as the reservoirs are already largely filled in the autumn, regardless of how much meltwater has accumulated in the midsummer.[78] In addition to glacial melting, climate change is changing the water cycle: [79]

- **Rain instead of snow:** Due to the increasing snowfall limit, more of the winter precipitation falls as rain rather than snow, especially at altitudes.
- **Dry summer:** In summer, it tends to be warmer and drier; the decline in snow cover and glacial ice reduces the available water reserves at this time of year.

[73] MeteoSwiss & ETH Zurich, 2025, Climate CH2025 – Scientific Report
[74] NCCS, 2018, CH2018 – Climate Scenarios for Switzerland – Technical Report
[75] Schaefli, Manso et al., 2019, The role of glacier retreat for Swiss hydropower production
[76] Huss, Linsbauer et al., 2025, Glacier of Switzerland Status, forecasts and significance
[77] Schaefli, B., 2018, glacial melting: Low impact on Swiss hydropower
[78] Only a few very large alpine storage power plants that can store a particularly large amount of summer water for months are likely to feel the fall in their winter production slightly.
[79] FOEN, 2021, Effects of climate change on Swiss waters

- **More precipitation in winter:** [80] Overall, precipitation tends to increase in the winter half-year, while precipitation tends to decrease in the summer half-year.

- **Previous snowmelt:** Snow melts earlier because less snow accumulates in winter and higher temperatures allow the melting process to begin as early as spring.

These four effects hardly influence the annual production of hydropower, but shift seasonal water availability: Inflows tend to increase in the winter half of the year and fall in the summer half of the year. For hydropower plants in Switzerland, climate change and the associated hydrological changes can therefore lead to higher inflows in the winter half-year. As a result, run-of-river power plants, in particular, will, on average, generate more electricity in winter and less in summer. For storage power plants, the shifted flow regimes also mean that inflows increase in the winter half-year and thus more winter electricity production is possible.

As a general rule, the following applies: Water volume and electricity production are not in a linear relationship; the decisive factor is the type of power plant and the design of the plant. The central parameter is the catchment volume, which is determined by the dimensioning of the catchment, daily discharges and the residual water volume to be maintained. The higher winter discharges are expected to continue to remain mostly below the maximum catchment volume and can therefore be fully utilised – minus doping water. In summer, however, the Swiss hydropower plant fleet is already unable to cope with all incoming water volumes, resulting in overflows, particularly at river power plants. As a result, the volume of summer water captured remains largely stable, even with lower summer discharges. Overall, the usable capacity can therefore increase due to the changed seasonal discharge patterns, even with the same or slightly decreasing annual discharges, especially for run-of-river power plants without storage. In the case of storage power plants, on the other hand, the total annual inflow volume remains the decisive factor for electricity production.[81]

Various studies have modelled the effects of water availability on electricity production. Viewed over an entire year, for example, a model calculation for Swiss hydropower as a whole (run-of-river and storage power plants combined) for the period 2021–2050 concludes that the average annual production hardly changes, but that the seasonal distribution changes significantly: Winter production increases by around 10 percent, while annual production of approx. 0.9 percent to 1.9 percent (0.3–0.7 TWh).[82] The Hydro-CH scenarios paint a similar picture, with a longer-term focus on the year 21002018: In winter, without effective climate protection[83], there is on average around 30 percent more water in rivers (with consistent climate protection [85] 10 percent), compared to around 40 percent less water in summer (or 10 percent less with consistent climate protection), with a sharp decline, especially in late summer[84, 85].

Another study is analysing the impact of climate change on the electricity production of eleven Swiss run-of-river power plants. The result: Winter production will increase for almost all power plants in the future, on average by around 5 percent by the middle of the century (2060) (in terms of a winter reference

[80] Note: The climate models exhibit significantly greater uncertainties in the precipitation projections than in the temperature projections. In addition, not only the amount of precipitation is relevant, but also the evapotranspiration – i.e. the sum of the evaporation of water (soil, lakes, plant surfaces) and the release of water from plants via their leaves (transpiration) into the air – which increases in summer with climate change and even with increasing summer precipitation can lead to a negative water balance. In contrast, the “rain instead of snow” projection (rising snow line) is relatively robust.
[81] SGHL & CHy, 2011, Effects of climate change on hydropower use
[82] Compared with the reference period 1980–2009. Source: Hänggi, Balmer et al. (2011, Effects of climate change on hydropower use). Note: Although this source is a somewhat older study, as BFE (2019) notes, however, its results are still considered valid by scientific representatives.
[83] “Without climate protection” corresponds to RCP 8.5. “With climate protection” corresponds to RCP 2.6 according to Swiss Climate Scenario CH2018, i.e. global warming is limited to below 2 °C (target maximum 1.5 °C) by reducing greenhouse gas emissions to “net zero” by 2050 in accordance with the 2015 Paris Agreement on Climate Change. RCP stands for “Representative Concentration Pathway” and describes the concentration of greenhouse gases and aerosols in the atmosphere in the year 2100.
[84] FOEN, 2021, Hydro-CH2018 Research projects
[85] Compared to the reference period 1981–2010. Source: FOEN, 2021, Effects of climate change on Swiss waters

production of 1.217 TWh for the 11 plants), regardless of the climate scenario considered.[86] By the end of the century, this value will increase to around 10 percent in the scenario without climate protection, while remaining largely stable with climate protection. The total annual production of run-of-river power plants is expected to stay roughly unchanged in the climate protection scenario. Without climate protection, however, reductions of around 3 percent are expected by the middle of the century and around 7 percent by the end of the century.[88] These results are consistent with studies from neighbouring countries such as Austria.[87]

The shifted flow regimes also lead to higher winter half-year inflows for storage power plants, increasing their potential for winter production. In contrast to run-of-river power plants, however, the effects of climate change on the generation patterns of storage power plants are more difficult to generalise. The specific effects depend heavily on the respective design (e.g. storage volume) and operational boundary conditions. Even with lower summer inflows in the future, a storage power plant with a comparatively small reservoir may still need to turbinate part of these inflows in summer to avoid overflows, with correspondingly lower summer production due to climate change. By contrast, a storage power plant that can already retain virtually all of the summer inflows for the winter is unlikely to see any change in summer generation patterns in the future.

In connection with higher natural winter runoffs, it should also be noted that this can lead to an increase in the quantities of residual water[66] applicable all year round and prescribed by law for new water uses (see Section 5.1).

6.2
Increase in extreme events

Climate models predict more frequent extreme weather.[88] For hydropower, heavy precipitation (especially in winter due to winter storms) on the one hand and summer droughts on the other are particularly relevant. Heavy precipitation in Alpine catchment areas can lead to more rapid snowmelt and flooding.[89, 90] If such events hit already heavily filled reservoirs in late autumn or early winter, operators could increasingly be forced to discharge water via flood discharge systems instead of using it as turbines. However, depending on how full the reservoir is, reservoirs can also retain large volumes of water in the event of flooding and thus make a significant contribution to flood protection. At the same time, more frequent flooding events and increased bedrock transport [91] increase sedimentation in reservoirs, which costs longer-term usable storage volumes.[92] In extreme cases, floods and debris flows can damage hydropower plants to such an extent that they have to be taken out of service for an extended period of time for repairs. A recent example is the Moesa region in Misox in Graubünden: Following a storm in June 2024, hydropower plants had to be shut down for an extended period of time; damaged supply lines and debris caused production downtime lasting almost a year and extensive repairs.

In contrast, dry periods in summer can lead to very low discharges, localised water shortages and significantly lower levels in many tributaries. Run-of-river power plants in particular experience noticeable production losses during such low water phases. For example, in 2018, the hot and dry summer re-

86 Compared with the reference period 1981–2010. Source: SCCER-SOE, 2019, Climate change impact on Swiss hydropower production
87 AFRY, 2023, Impact of climate change on hydropower in Austria
88 Climate models "Climate CH2025" and "Climate CH2018," as well as the hydrological scenarios "Hydro-CH2018". Sources: MeteoSwiss & ETH Zurich, 2025, Climate CH2025 – Scientific Report; NCCS, 2018, CH2018 – Climate Scenarios for Switzerland – Technical Report; FOEN, 2021, Hydro-CH2018 Research projects
89 FOEN, 2021, Hydro-CH2018 Research projects
90 FOEN, 2021, Effects of climate change on Swiss waters
91 Rivers transport not only water during high outflows (e.g. flooding), but also increasingly sand, gravel, scree and woodland.

duced the average inflows, reducing the hydropower generation capacity (net storage pumps) during the summer half-year by more than 20 percent compared to the long-term (40-year) average.[92] The climate models[90] assume that such dry and low water events will last longer and more frequently in the future, causing summer hydropower production to fluctuate more strongly. In addition to the aforementioned contribution to flood protection, further demands on the multi-purpose use of reservoirs could also increase in the future, for example through their use as an additional water resource in times of water scarcity.[92]

6.3 Special case of new glacial lakes

Glacier retreat is leading to the formation of numerous new lakes in former glacier areas (periglacial areas), such as those emerging in the Gorner and Trift glaciers. The inventory compiled by Eawag and swisstopo already identifies around 1,200 lakes in former glaciated areas; a total of around 3,600 topographic sinks are known in today's glacier beds, of which around 400–650 could become new glacial lakes by 2100.[93] Due to their small size, the majority of these lakes are not suitable for new reservoirs. However, a few could theoretically be developed into reservoirs if the geology, volumes, inflows, gradient and usable height difference are suitable.

For hydropower projects known today that would be technically feasible in periglacial areas by 2050, an additional theoretical production potential of ~1.5 TWh per year is assumed, of which ~1.1 TWh from new plants and ~0.3 TWh from expansions of existing plants. The potential for controllable winter production (seasonal storage) is even ~2.4 TWh per year[94], of which almost half can be attributed to the three projects Gorner, Grimsel and Trift alone (see Section 3.1). By way of comparison: The accumulation potential outside periglacial areas is ~0.9 TWh per year, which is only about a third of the accumulation potential in periglacial spaces.[95]

These orders of magnitude emphasise the central importance of the periglacial environment for achieving the energy policy expansion targets. At the same time, such projects are controversial in terms of the landscape; ~0.5 TWh (i.e. approx. one third) of the additional annual production potential is even located in floodplain areas of national importance and thus in principle excluded areas pursuant to Art. 12 para. 2 of the Energy Act (EnA). Most of the remaining potential also conflicts with floodplain areas with different levels of protection, but is not located in exclusion areas.[95] The political balance between energy potential and alternative measures on the one hand and nature and landscape conservation and tourism interests on the other ultimately determines how much of this theoretical potential can actually be utilised.

[92] Swiss Federal Office of Energy SFOE, 2023, Swiss electricity statistics 2022
[93] Federal Council, 2024, Analysis of the hydropower potential of glacier melting
[94] Note: The potential for controllable winter production is significantly greater than that of additional annual production, because water that had to be turbinated before the expansion due to reduced storage capacity can be stored seasonally after the expansion.

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