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Long Drought Ahead?

The Future Revenue Prospects of Swiss Hydropower

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Long Drought Ahead?
The Future Revenue Prospects of Swiss Hydropower

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Abstract:

We analyze the impact of future European electricity market developments on Swiss hydropower. The results allow identifying important systematic drivers and structural aspects in regard to the deployment of renewable energies that will have an impact on future revenue prospects for hydropower. We base our analysis on the results from a scenario evaluation of the Swiss electricity market up to 2050 performed in Schlecht and Weigt (2015). The scenarios draw a picture of the expected system development for the next decades. The simulations reveal that the current challenging market environment is likely to persist for a prolonged period up to 2030/35 and afterwards turns around for a more positive revenue outlook for hydropower, when the European electricity markets are dominated by new renewable generation.

Key words: hydropower, Switzerland, electricity markets, renewable energy

JEL-code: L94

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1 Introduction

Swiss hydropower is not only a central pillar of the current electricity system covering more than 50% of total generation but also a pillar of the envisioned Energy Strategy 2050. It is considered to be the needed complement for intermittent renewable generation from solar and wind. Consequently, the already high output is expected to further increase by ca. 7 % on average (SFOE, 2013). However, the current prospect for Swiss hydropower looks less bright.[2] With the decreasing wholesale market prices in recent years and in addition the drop in the CHF-EURO exchange rate in 2015 the income situation for many Swiss energy companies deteriorated. The current price levels are well below 40 €/MWh whereas the full costs of hydropower are in the range of 50 to 80 CHF/MWh (Filippini and Geissmann, 2014). The reduced revenue prospects have forced many Swiss energy companies to write off several billion CHF of assets in the last years.[3]

The challenging situation has not only initiated discussions about potential short term support mechanisms for hydro plants[4] but also a more general debate by stakeholders on the future of Swiss hydropower (see Barry *et al.*, 2015, and Betz *et al.*, 2016). Within this debate the role of Swiss regulations, in particular changing the water fee regime, is seen as the main approach to improve the competitiveness of Swiss hydropower in the long run. The actual market prospects on the other hand are considered beyond the control of both Swiss companies and politics and are seen as an external boundary condition hydropower has to adapt to.

The aim of this paper is to take up this last point and shed more light on the future development of the Central European electricity market and its impact on Swiss hydropower. We are re-analyzing the results from a scenario evaluation of the Swiss electricity market up to 2050 performed in Schlecht and Weigt (2015). Based on the EU Energy Roadmap to 2050 by the European Commission (2013) and the reference study for the Energy Strategy 2050 prepared by Prognos AG (2012) the scenarios draw a picture of the expected system development for the next decades. Albeit subject to the usual uncertainties of model simulations and assumptions, the results still allow identifying important systematic drivers and structural aspects that will have an impact on future revenue prospects for hydropower. The simulations reveal that the current challenging market environment is likely to persist for a prolonged period up to 2030/35. However, in the long run - with an electricity system dominated by new renewable generation - Swiss hydropower will not only be an important system component but also have a positive revenue outlook.

The remainder of this paper is structured as follows. In Section 2 we shortly present the underlying model and data assumptions of our analysis. Section 3 then conducts an in-depth evaluation of price, revenue and quantity developments for Swiss hydropower. Section 4 discusses the implications of our findings and concludes.

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[2] E.g., see the 2015 Hydropower Congress of the Swiss Hydropower Association: http://www.swv.ch/Veranstaltungen/Veranstaltungen-SWV/Wasserwirtschaftstagungen-mit-Hauptversammlung/Archiv-Symposium-HV-2015

[3] E.g., see http://www.handelszeitung.ch/unternehmen/blackout-der-schweizer-stromkonzerne-731653

[4] E.g., see http://www.parlament.ch/d/mm/2015/Seiten/mm-urek-n-2015-11-04.aspx

2 Model and data

The analysis presented here relies on the model results from Schlecht and Weigt (2015) and is consequently based on the same model and input data sources.

The simulation is carried out with Swissmod, a numerical representation of the Swiss electricity wholesale market (Schlecht and Weigt, 2014) following standard electricity market dispatch and network models. The version of Swissmod used in this scenario analysis is designed as a numerical optimization problem maximizing welfare with elastic demand. The model is deterministic, assumes a perfect competitive market with perfect foresight, and uses an hourly resolution for a full year. Swissmod covers the whole transmission system of Switzerland (220 and 380kV) as well as its interconnections to neighboring countries. The transmission grid and modeled hydropower stations are depicted in Figure 1. Generation and demand is allocated on a nodal basis to allow an estimation of congestion aspects. Network constraints are explicitly modeled following the DC load flow approach by Schweppe *et al.* (1988) and Leuthold *et al.* (2012).

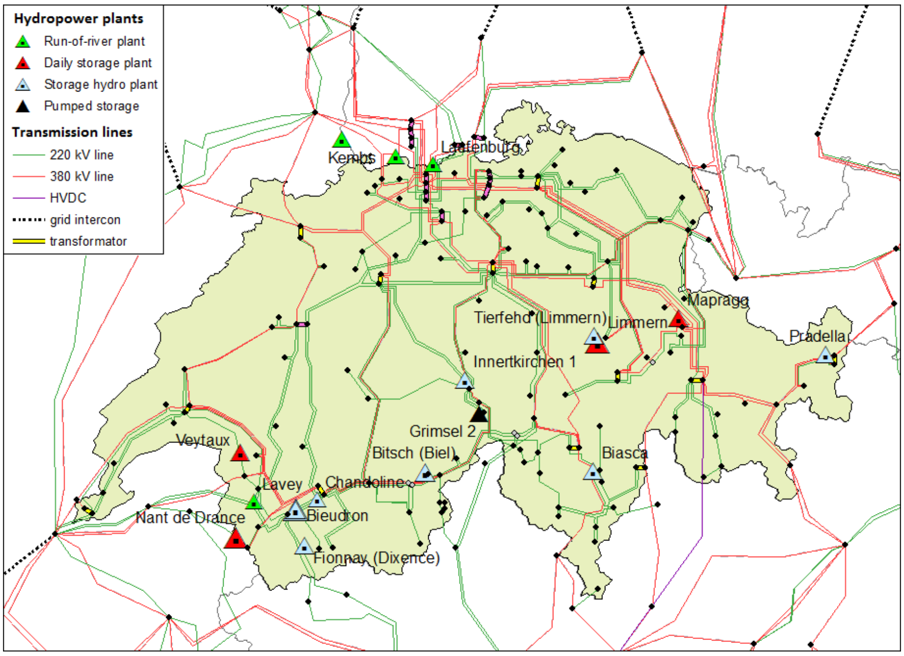

Figure 1: Underlying Swissmod GIS database with power lines and hydropower stations

Due to the high dependence of the Swiss electricity market on hydro generation a particular focus of Swissmod is put on the representation of the different hydro plants and their interaction. The model captures different forms of hydroelectricity in Switzerland: run-of-river, storage, and pumped-storage power plants and integrates them within a network representation of the hydraulic system in Switzerland containing rivers and lakes in the country. Water flows in the system are endogenously determined, so that the outflow of an upstream hydropower plant results in an inflow to a downstream power plant with a defined time lag. Consequently, storage possibilities (upper basin, lower basin) are optimized by the model.

The basic transmission grid representation within Swissmod is taken from Swissgrid (2012), the ENTSO-E grid map, ENTSO-E (2013) data, and adjusted using locational information from the collaborative mapping project OpenStreetMap. The details of the existing Swiss hydro generation portfolio are taken from SFOE (2012) and complemented with hydrological information from BAFU (2012). For hourly electricity demand, we use input data from ENTSO-E for the neighboring countries and from Swissgrid for Switzerland and calculate hourly average values of the years 2011-2013.
Regarding renewables in-feed, we use a flat generation profile for geothermal plants and hourly values for solar and wind on country-level from Hirth (2013). We use the 2009 data for our analysis, as the weather profile of this specific year yields country total in-feeds close to average years and are thus well-suited for the analysis of a reference trend scenario. For the regional distribution of renewables within Switzerland[5] we use regionally differentiated potentials from Hergert (2013) for wind and from Meteotest (2012)[6] for solar energy and assume that renewables capacity is built-up proportionately to the regional shares of the potentials.

2.1 Scenarios

For this analysis, we take the results from the base scenario of our earlier paper (Schlecht and Weigt, 2015). Those scenarios represent the expected developments of both the Swiss and European electricity system from 2020 to 2050. For the underlying generation capacities as well as fuel and CO2 price trends in the EU, we use the EU Energy Roadmap to 2050 by the European Commission (2013). For Switzerland, we use the power plant portfolio from the SFOE's reference study for the Energy Strategy 2050 prepared by Prognos (2012). The yearly demand level is scaled accordingly using the forecasted demand of the aforementioned reports while the hourly profile is kept on the structure of the years 2011-2013. Network extensions follow the Ten-Year Network Development Plan of the ENTSO-E.

2.2 Limitations

The model results presented here are subject to limitations stemming from external scenario assumptions and model choices. Since we base our model on the external scenarios outlined above the forecasted framework conditions from these scenarios are an important determinant for our model results. Especially fuel and CO2 prices, but also generation capacities and other factors influence the price pattern and hydropower activities reported here.

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[5] Regarding the location of geothermal power plants, the website geothermie.ch provides a map of planned projects. Yet, since it is unclear which projects are actually going to be realized, and the project map includes projects spread over most of Switzerland, we assume an equal distribution among load centers by reducing demand proportionately. http://www.geothermie.ch/index.php?p=deep_geothermal_projects

[6] The Meteotest (2012) study, which was contracted by the Swiss Federal Office for the Environment (FOEN), only contains the aggregate solar and wind potentials for Switzerland. However, Meteotest provided us with a regionally disaggregated version of the solar potentials.

Since we employ a perfect foresight model, uncertainties regarding the operation of hydropower, such as hydro inflow or price uncertainty are not represented in the model. With increasing variability in power markets, this factor could become more important.

We do not regard startup and ramping constraints in the power market, and thereby are likely to underestimate short-term price variability especially of the Swiss neighboring countries with large shares of thermal generation. On the other hand, since we simplify demand flexibility to short-term demand elasticity and thereby neglect possibilities of load shifting that might be present in 2050, we also neglect a potential containing factor of price variability. Additional sources of revenue for hydropower, which we do not regard in this scenario analysis, could stem from being active on the intra-day and balancing markets, which could become more important with higher variability from new renewables in the system.

Lastly, we only take a subset of 18 of the biggest hydropower plants of Switzerland into account as endogenously modelled part of hydropower. The remainder of hydropower supply is assumed to follow standard seasonal production patterns and taken as exogenous model input. Out of the 18 endogenously modelled plants, 4 are run-of-river hydropower plants, 9 are storage plants and 5 are pumped storage plants.

3 Analysis

The objective of this report is to re-analyze the Schlecht and Weigt (2015) model results to shed more light on the specific situation of hydropower in Switzerland. For that purpose, we scrutinize the development of price levels, hourly price patterns, revenues and overall hydropower activities over the scenario horizon from 2020 to 2050.

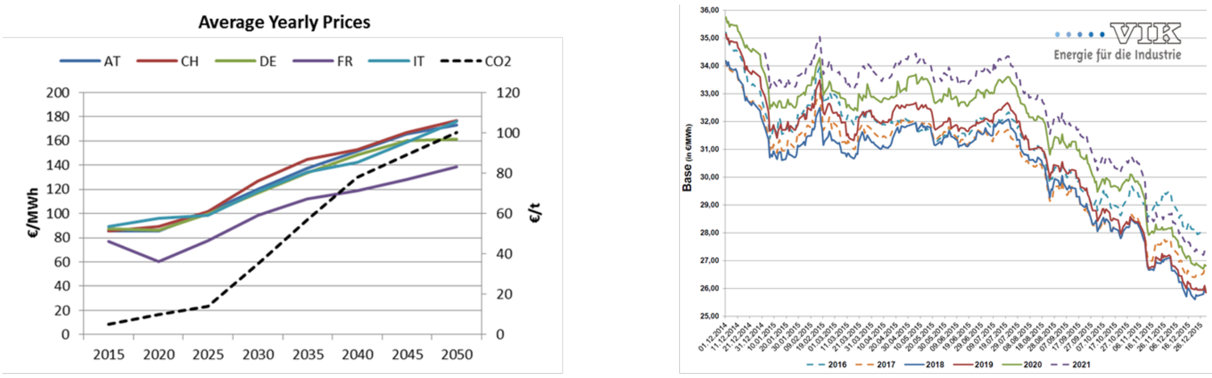
3.1 Average price trend

Hydropower plants are usually constructed for a long time period (some hydropower plants in Switzerland still in use are from before 1900) and usually have high fixed and low variable costs. This cost structure makes them highly dependent on the long term evolution of prices on the power market. Given the highly interconnected European market and the fact that Switzerland's power plant fleet is mostly composed of low variable cost power plants such as hydro and nuclear facilities which are rarely price-setting, Swiss prices are determined mostly by international trends.[7] Since in Germany, Italy and Austria the price setting plants are often fossil fueled power plants, the CO2 and fuel price development will be the biggest driver.

[7] In the power market, reference prices are determined by power exchanges in which generators and loads submit their bidding curves representing their marginal propensity to supply or demand power respectively. The exchange matches supply and demand bids and determines the market clearing price, which then every accepted bid receives or pays respectively. This mechanism makes the price especially dependent on the price bid set by the last power plant that was accepted into the market, also called the marginal power plant.

Being based on the EU Energy Roadmap to 2050 (European Commission, 2013) those underlying price assumptions are significantly higher than current fossil fuel prices. Coal prices are assumed to remain relatively stable on a price level comparable to the pre-crisis prices in 2008 while natural gas prices are increasing even beyond those levels. Consequently, the average price level of the scenarios is more than twice as high as currently observed future prices (Figure 2).

Therefore, the price results of the simulations are to be taken with care. At least for the next five to ten years the price level is likely to remain well below the modeled price level of close to 100€/MWh. Since the assumed fuel prices remain relatively constant over the model horizon, the CO2 price is the driving force behind the observed electricity price changes. Given that the EU is expected to come up with more stringent climate targets in the future, at least some increase in the CO2 price is to be expected and consequently also the current observed low market price levels are bound to increase in the long run.



Model Price Forecasts

EEX Base Year Future

Figure 2: Simulated price development (left) and EEX future prices (right)

3.2 Price patterns

While the average price development is especially important for run-of-river power plants, which generate base-load electricity regardless of the hourly price, storage plants and even more so pumped storage plants are highly dependent on the hourly price pattern. Since the storage reservoir enables plant owners to time their discharge, they make use of price fluctuations during the day to sell electricity at high prices. In addition to that, pumped storage plants pump water from lower reservoirs into higher reservoirs in times of low prices to discharge later at higher prices.

Especially due to the large amount of renewable energies that is forecasted to feed into the Central European power grids in the future, the daily price pattern that is today still largely influenced by base-load technologies such as nuclear power will change significantly. To illustrate the change of the daily pattern over the modeled time horizon, Figure 3 shows the evolution of hourly prices relative to peak evening prices. Contrary to the price level the price pattern is likely a more robust forecast as it is largely defined by the share of intermittent renewables.

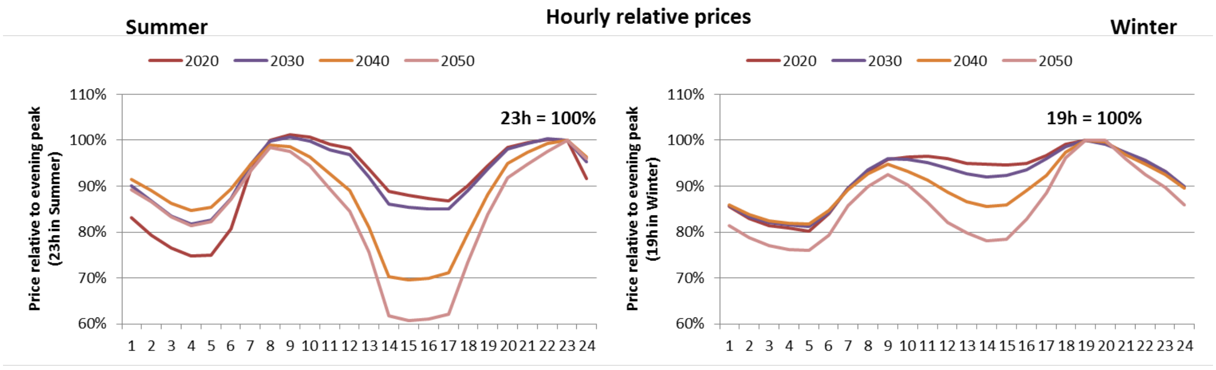


Figure 3: Relative daily average price patterns for Switzerland by season

While in 2020 the lowest prices still occur during night time hours, when the market is dominated by inflexible thermal power plants that produce base-load energy, that pattern is changing substantially for the summer season in the scenarios for 2040 and 2050. By then, the large amount of solar power in the system leads to consistently low price in summer afternoons, and even in winter when solar radiation is comparatively low, solar power drives day-time prices significantly downwards. Given the consistently larger relative price spreads in the years 2040 and 2050 compared to 2020, the earning possibilities for pumped storage plants will increase significantly.

However, the transition to the improved earning possibilities of pumped storage plants will be long and painful: The 2030 scenario yields even less systematic price differences (which pumped storage plants exploit to generate profits) than the already suboptimal 2020 situation. In the transition period of 2030 the night-time hours are no longer as cheap as they used to be in 2020 but the afternoon hours are not compensating for it by then.

3.3 Value factors of storage plants

For storage plants without the ability to pump, the most important determinant of economic viability is the upper end of the yearly price duration curve (Figure 4, left panel) from the yearly maximum price to the full-load hours of the storage plant. Since the number of full-load hours of storage plants is usually limited, plant owners can be expected to rationally choose the hours with the highest prices during a year to discharge at full capacity.[8] The amount of full-load hours of a storage plant depends on the relation of turbine capacity to reservoir inflow, with reservoir size being a further constraining factor.

Since the absolute price level is highly uncertain and, as noted above, depends highly on fuel and CO2 price assumptions, we limit the analysis to the structural aspects of the price curve. The left panel of Figure 4 shows a trend of future price curves to exhibit a much stronger decrease of high price levels. Whereas the price curve of 2020 shows a rather steady decline over the hours, the 2050 profile shows a sharp decline in the first few hundred highest priced hours and then a rather gradual decline at a

[8] Given uncertainty of future prices and precipitation and potential further constraints like residual flow requirements the realized production profile can deviate from this ideal. However, the basic incentive structure remains valid.

much lower relative price level than in the 2020 and 2030 runs. To highlight this effect we also show the development of relative value factors for different power plant classes as characterized by the number of full-load hours (Figure 4, right panel). The value factor of a certain technology represents its market value (Hirth, 2013) divided by the average base price. The market value is defined as the average price a certain technology can achieve in a given market. In the case of storage power plants (assuming perfect foresight) this is equivalent to the average of the highest prices during the year up to the number of full load hours of the power plant.

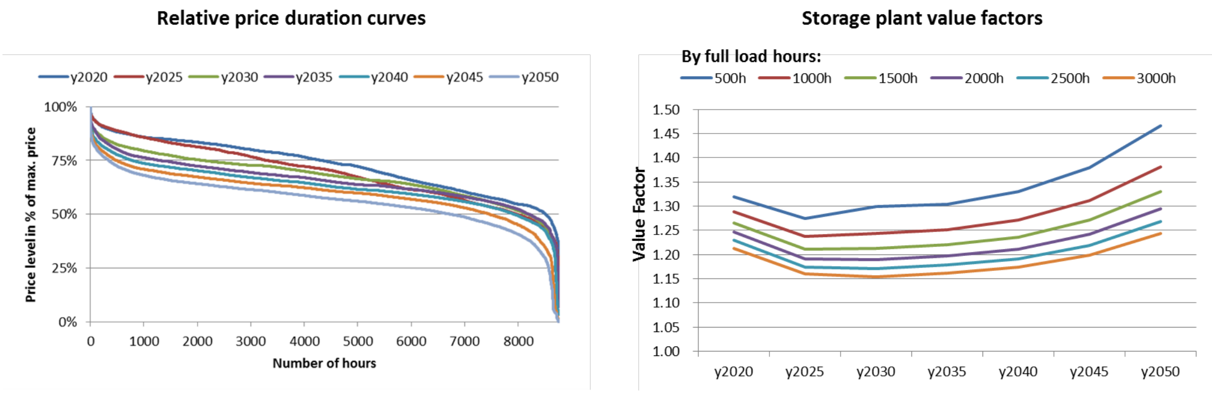


Figure 4: Price duration curve and value factor development until 2050

As the right panel of Figure 4 shows, the gap between the value factor of storage plants with only few full-load hours (i.e. 500) and many full-load hours (i.e. 3000) increases significantly up to 2050. This means that in the future it will be relatively more beneficial for plant owners to invest in high generation capacity rather than running the same reservoir with a smaller turbine capacity at more full-load hours. In other words, it may be beneficial for hydro plants to shift towards a lower reservoir inflow to turbine capacity ratio by increasing turbinating capacity.

While this is especially relevant for seasonal storage plants that aim to maximize the obtainable revenue from their limited water inflow the price pattern also shows important drivers for pump storage and run-of-river plants. Similar to the discussion on price patterns above, the left panel of Figure 4 shows a clear increase of extremely low prices hours in the long run. This is a result of the large increase in solar and wind capacities and highlights the need and potential for storage capacities. But the low prices also pose a threat to inflexible run-of-river plants. Given their base load nature they will have to face periods with extremely low prices. Even a slight increase of flexibility could allow those plants to reduce the price damping effect of those periods.

3.4 Revenues and overall activity levels

The price curves outlined above are the most important determinant for the overall hydropower revenues and activity levels shown in Figure 5. The left panel clearly shows the fact that overall pumping activity is dropping significantly below 2020 levels in the transition period to 2050. Only in 2045 pumping quantities are above 2020 levels again. Since we assume the same precipitation and overall water availability levels in our scenarios, turbinating activity only varies along with pumping. Since pumped water is only a fraction of overall hydro discharge, turbinating only changes slightly.

The right panel of Figure 5 shows individual profit components of hydropower plants. In all numbers, a general upward trend can be seen that is determined mostly by the general expected increase in the price level. Two findings are interesting to note in this development. First, the net income of pumping plants (revenue minus pumping expenditures) is consistently above the revenue of hydro plants without pump facilities in all years. Thus, despite the large reduction in pumping activity and the lower price spreads up to 2035 the option to pump still provides a benefit for power plants. Whether this is sufficient to cover the needed investment costs is a completely different question though.

Second, with the increase of pumping activity from 2035 onwards the gap between revenue as well as net income development of pump plants compared to pure storage plants seems to widen. This again highlights the shift of the price pattern till 2050 that shows significant price spreads due to high renewable generation that can be exploited by pump storage plants.

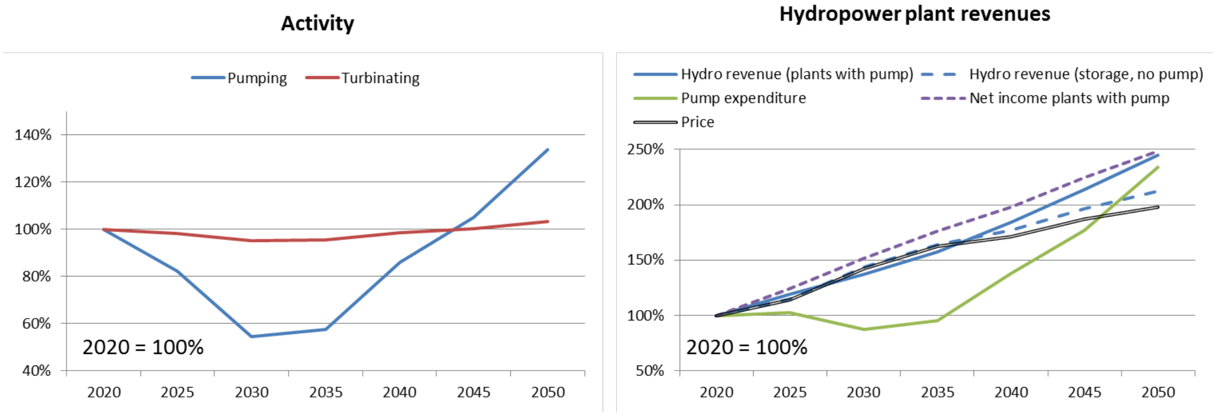


Figure 5: Hydropower activity and revenues in the scenario runs

3.5 Hydrology / quantitative effects

The changed operating pattern of storage power plants due to economic circumstances also result in changes to the way hydropower impacts the hydrology of the hydrologic system it is embedded in. Especially the hydrology of the downstream river is affected. An important aspect in this regard is the number and length of activity cycles of hydropower plants. The environmental consequences of many production cycles of short duration are different from fewer production cycles of longer duration, even if both operation patterns result in the same total quantity of water discharged.

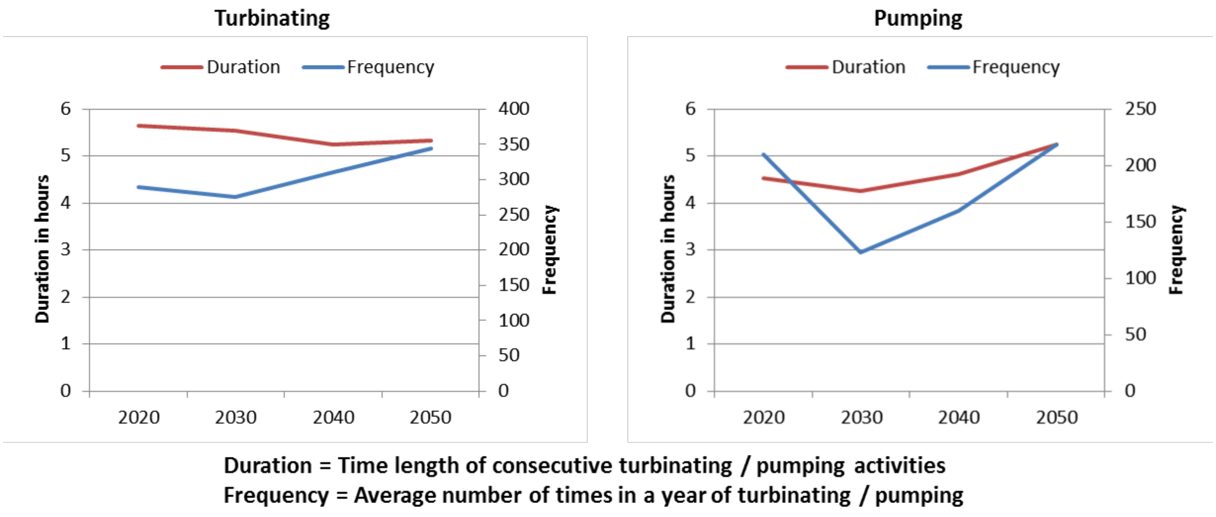


Figure 6: Number and duration of activity cycles

As depicted in Figure 6, the frequency of turbinating cycles slightly increases along with a shorter duration of cycles over the modeled time horizon. This can be attributed to the greater overall variability in power prices with higher amounts of renewable energies in the power grids. Regarding pumping, the picture is less clear. While the duration per pumping cycle seems to have a general upward trend, the frequency first decreases (again, this can be attributed to the general lack of profitable pumping opportunities in the transition years) and increases again until 2050.

3.6 Daytime-timing of pump activity

As a mirror image of the daily price patterns shown above, the timing of pumping in hydropower stations also changes significantly over the model horizon. In the last decades Swiss hydro energy, besides providing base-load capacity from run-of-river plants, was a secure supply during noon and evening peak hours and pumped storage plants transferred nighttime electricity into the next day's peak hours. This picture is already altered by the current solar-driven price developments in Europe's electricity markets and will continue to transform up to 2050. As shown in Figure 7 the pumping times of Switzerland's hydropower plants will move towards daytime hours when abundant solar generation is available. In turn, the stored energy will be utilized when RES capacities are insufficient to cover the demand levels, namely in the morning and evening hours. The nighttime hours remain an important storage time during the winter months but the majority of pump activity will be transferred to summer daytime.

Interestingly, despite its pumping activity during summer afternoons in 2050, Switzerland's summer exports also peak during precisely these afternoon hours. This is related to Switzerland's own solar capacities and the fact that hydro generation also peaks in summer, and pumping capacity not being large enough to absorb this surplus supply.

Albeit the changes in the daily pattern of pump operation are significant, the seasonal pattern remains largely unaffected. The stored energy is utilized within a few days and not transferred between seasons. This becomes obvious when examining the yearly storage level curve. The current pattern shows low storage levels in late winter months and the spring months and high levels following the Alpine snow melt in the late summer months. The pattern remains basically unchanged till 2050.[9] While the value of seasonal storage increases until 2050 given that in summer electricity supply will become more abundant than nowadays and in winter remains scarce, the system is restricted by the storage limits which remain unchanged in the scenarios and therefore cannot increase seasonal storage.[10]

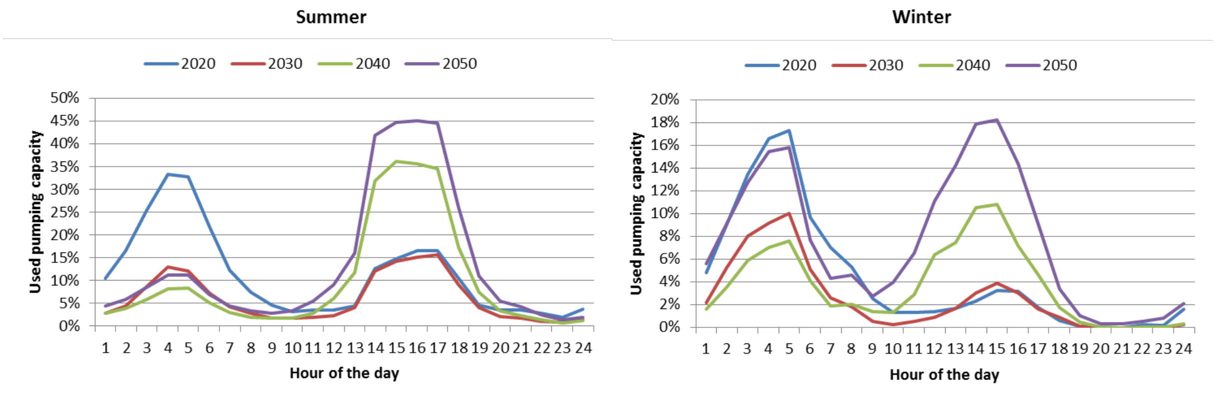


Figure 7: Average hourly pumping by season

4 Discussion and Conclusions

Taking account of the limitations embedded in every modeling endeavor and the uncertainty of the underlying assumptions, especially the fuel and CO2 price levels, we can still draw important conclusions regarding the future development of Swiss hydropower. The most important aspect is the slow adjustment of the price profile over the decades. Albeit renewable energies are steadily increasing in Europe it will still take a long time till this will lead to a reversal of the price pattern with steady low daytime and high morning and evening prices. In other words: the transition towards a renewable dominated system is the challenge for hydropower as it comes with persistent flat price patterns. The finally renewable dominated system itself is again beneficial for hydropower as it provides ample opportunity for utilizing their high flexibility and storage capabilities.

Within our model scenarios the price level is high enough to provide a solid revenue stream for hydropower even in absence of price spreads between peak and off-peak conditions. However, the observed low market price level coupled with such a flat price profile up to 2030 is extending the current low revenue situation for another 15 years. The likelihood of significant changes in these developments is hard to predict. The current European market situation with excess fossil generation

[9] Note that we do not include temporal shifts on the water inflow side due to e.g. climate change effects.

[10] Another reason for the limited seasonal storage is the price pattern in electricity. The price spread between hours with abundant RES injection and hours that require peaking fossil units will be the same in the short term – either in summer or winter – as in the long term. Consequently, using pumped storage to optimize between those hours on a short term basis is more efficient than only using it once to transfer energy between summer and winter.

capacities and large shares of renewables is likely to remain even if renewable support schemes would be abolished. The ongoing debate on capacity mechanisms and markets would even increase the excess capacity problem keeping energy prices low. At the same time the financial problems of large suppliers may lead to a decommissioning of fossil capacities that could lead to price increases. Also fuel price increases or a significant increase in CO2 prices could improve the revenue conditions for hydropower, but again the trends currently do not show signs of large increases in the next years.

Albeit the persistent flat price profile up to 2030/35 is challenging for all hydropower plants in Switzerland the impacts are different for the different plant types. For run-of-river plants the revenue prospects are expected to be the most challenging. Given their base load character they have to calculate with the average price which is under pressure by the merit-order effect. Without significant increases in fuel or emission prices the revenue prospects remain bleak. Any further increase in renewable generation puts further pressure on their revenue as they cannot benefit from price spreads. Our results show that in the long run also run-of-river plants could benefit from an increase in their flexibility. As in a renewable dominated electricity system the share of hours with extremely low prices is increasing, already a bit of storage capacity could shift the average obtainable price significantly upwards.

For seasonal hydro storage plants the average price level is not as important as long as peak prices remain sufficiently high. Again those depend on fuel and emission prices as prices in peak conditions are likely to remain determined by fossil power plants for the next decades. The flat price profile is also a significant challenge for storage plants if it is coupled with a low average price. However, in the long run, with expected high emission prices, the peak price level should become sufficiently high for storage plants to obtain reasonable revenues. Nevertheless, those high prices are likely to occur on fewer hours during a year making an increase in turbine capacity a potentially interesting option for storage plants.

Finally, pump storage plants suffer greatly by the persistent flat price profile but profit the most from the new price pattern in a renewable dominated world. As they obtain revenue from the price spread and not the absolute price level, a difference between a 30€/MWh nighttime price and a 80€/MWh daytime price is as valuable as a spread between a 0€/MWh afternoon price and a 50€/MWh morning and evening peak. And given that the upper price level will be defined by fossil power plants for some decades to come the price is likely to be significantly above 50€/MWh in the long run if emission prices are increasing.

Summing up the findings we can conclude that the current price challenges for Swiss hydropower are inherent to the electricity system structure with a mix of excessive fossil capacities and significant shares of renewables. They are likely to remain existent for up to 15 years if no significant price increase occurs and will shift towards benefiting flexible hydro production in the long run. Consequently, hydropower companies need to develop measures to address those structural aspects. On the one hand they need to optimize their market participation and exploit the high flexibility of their plants with respective trading strategies profiting from the increase in price volatility. On the other hand the costs structure of Swiss hydro needs to be adjusted to the market developments. The current share of long term financial liabilities and fixed water fees does not coincide with a volatile market environment with potential long running low price cycles. Within the SCCER-CREST White Paper on Hydropower Betz *et al.* (2016) take up this discussion and provide recommendations for respective policy actions.

Last but not least the market driven changes in hydro production profiles will also have a lasting impact on the Swiss lake and river hydrology and subsequent ecological consequences. Further research on those interactions is needed to evaluate a respective compromise between economic and ecological objectives.

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