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The Future of Swiss Hydropower
A Review on Drivers and Uncertainties

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Abstract:

Swiss Hydropower (HP) is currently facing a wide range of challenges that have initiated a debate about future prospects and its role within the envisioned energy transition. Building on this debate, this paper provides an overview of the status and prospects of Swiss HP by identifying and evaluating the different drivers and uncertainties that Swiss HP faces. Based on a review and the perceptions held by some of the main Swiss HP stakeholders the two main topics that need to be addressed are the market driven impacts and the political, legal and social aspects. While the market dynamics cannot directly be influenced by Swiss companies or authorities, the regulatory framework can and needs to be adjusted. However, this requires a comprehensive stakeholder process and is at least a medium-term process.

Key words: Switzerland, energy transition, hydro power, climate change, electricity market

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Executive Summary

The Future of Swiss Hydropower at stake?

Swiss Hydropower (HP) is currently facing a wide range of challenges that have initiated a debate about future prospects and its role within the envisioned energy transition. Contributing to more than 50% of Swiss electricity generation, HP represents a central pillar of Switzerland`s energy system and is a crucial component in attaining the intended Energy Strategy 2050 targets, in particular the phase-out of nuclear energy, which represents about 40% of the domestic electricity supply. However, the current market developments make it questionable whether Swiss HP will be able to fulfill this envisioned role which requires investments in new HP plants and retrofitting of existing ones to obtain the desired increase in production as well as adjustments of HP operation to address the volatility of renewables.

The steady decline in electricity prices coupled with a reduction in the spread between peak and off-peak prices has not only spurred the ongoing discussion about potential market adjustments (i.e., the capacity market debate), but it has also initiated a debate within Switzerland as to whether Swiss HP should receive financial support. In addition, long run uncertainties (e.g. impact of climate change) or the role of competing technologies (e.g. battery storage) add complexity to the short term challenges. Finally, Swiss HP plays an important role in regional economies and regional development, especially in mountain cantons, and has significant impacts on the ecology of the Swiss rivers and lakes system. In this context, stakeholders need to find a compromise between companies' profit perspectives, federal energy targets, cantonal and local budget requirements, and international regulations.

Building on this background, this paper provides an overview of the status and prospects of Swiss HP by identifying and evaluating the different drivers and uncertainties that Swiss HP faces.

Stakeholder Feedback: Economics and Regulation

By carrying out a questionnaire and a workshop in March 2015 we gathered information on the perceptions held by some of the main Swiss HP stakeholders on the drivers and uncertainties and their importance in the current debate. To this end, we clustered the different drivers into five general domains:

(1) *Natural factors* representing boundary conditions of the hydrologic system,

(2) *technical factors* representing engineering aspects,

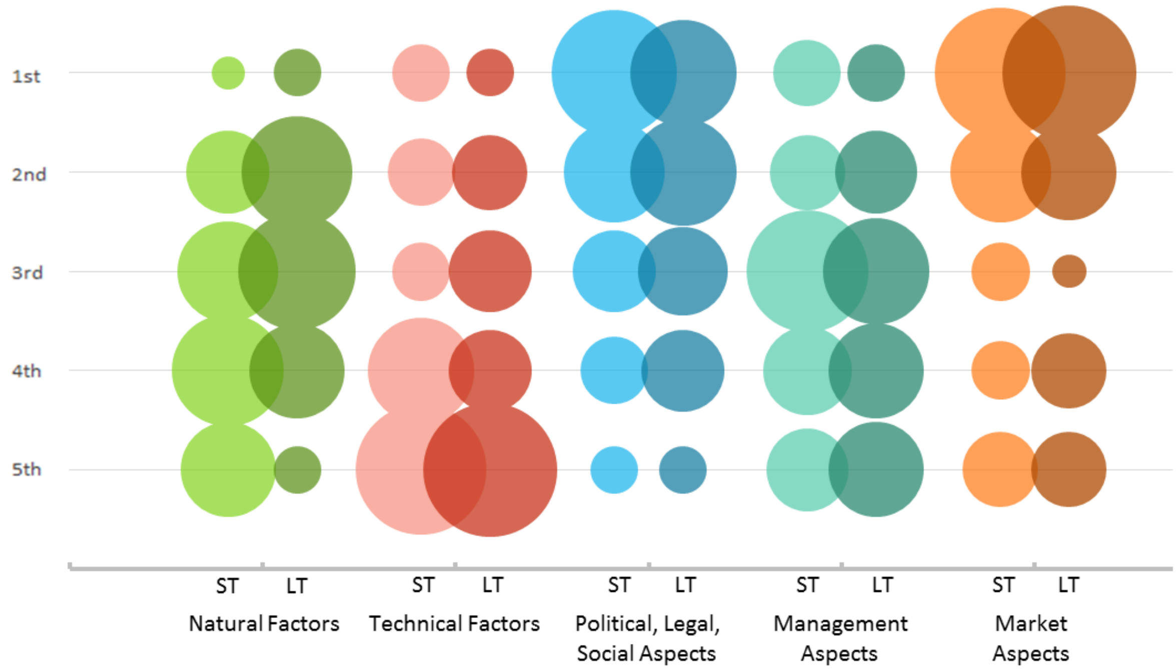
(3) *political, legal and social aspects* that relate to all the regulatory features that influence Swiss HP decision-making,

(4) *management aspects* that represent the active decision-making within a company, and

(5) *market aspects* that capture opportunities for revenue generation and the various market influences; and investigated their role in the short and long run.

As illustrated in Figure A, the stakeholder process highlights the dominance of the market and regulatory aspects in the ongoing debate. While natural factors, especially related to climate change, are perceived as important drivers in the long term influence, technical factors are not perceived as challenge in the current environment. Nevertheless, they are seen as an important part of the solution process, especially by increasing operational flexibility.

Figure A: Comparative Ranking of Drivers in the Short (ST) and Long Term (LT)



Note: The size of the circles represents the relative number of answers from stakeholders involved in the research

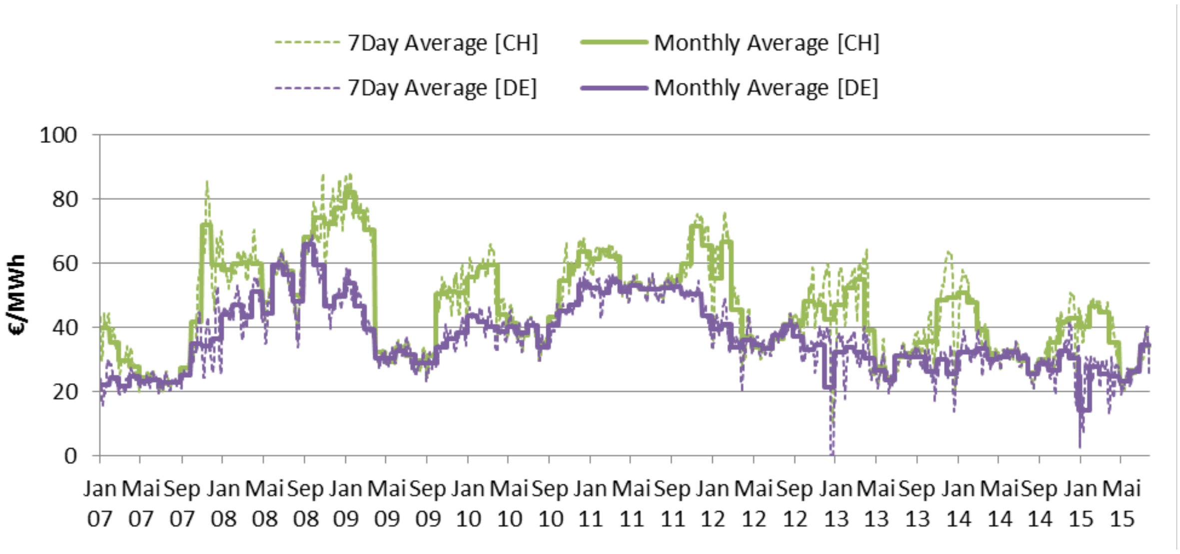
Short Term Challenges: Markets and Costs

One main insight from the questionnaire and workshop is that the current mismatch between low market prices and high production costs is perceived as the most pressing challenge for Swiss HP. This is reflected in the ongoing discussion about the potential need for support mechanisms to help Swiss HP counter the current market conditions.

Since 2011 electricity prices in Central Europa are on a consistent downward trend (Figure B). The main reasons for this development are: the low emission permit prices of the EU Emissions Trading System, low global coal prices, and the increasing share of renewable generation. All three drivers are likely to remain rather stable in coming years. The first two aspects play together to put coal fired units in a cost advantage compared to other power plants. Coupled with the price reducing merit order effect of increased renewables this pushes the price level to the marginal costs of coal plants, or about 30 to 40 €/MWh. None of the three market drivers can directly be influenced by Swiss companies or authorities.

On the other side of the income balance the production costs of Swiss HP are above the obtainable average market prices; with the exchange rate development adding to the challenge. Albeit for large HP plants the total production costs vary greatly between 3 to 10 Rp./kWh, the average cost level is assumed to be somewhere between 5 to 6 Rp./kWh. These costs can roughly be clustered in operational costs, financial costs, and fees. While operational and financing cost elements can be impacted by management decisions and efficiency improvements, the impact of fees and concession structures would require a change in the political and legal regulations for Swiss HP. Given that both the depreciation rules and the water fee framework have been designed for a world with regulated energy companies they need to be adopted to a market world driven by volatile electricity prices.

Figure B: Average Spot Prices at the EEX



Long Term Challenges: Uncertainty and Governance

Although the market conditions are considered the most pressing challenge for Swiss HP right now, there are also longer-term developments that require Swiss HP companies to reconsider their strategy. Especially the future legal and regulatory framework is seen as the second big challenge for Swiss HP. This is strongly related to the market challenge, as part of the solution is seen in adopting a different regulatory framework. As most electricity markets in Europe (including Switzerland) are in a phase of transition, long-term market trends and developments are hard to predict and energy companies face an environment with a high degree of uncertainty. While most stakeholders see HP as an integral part of the future electricity system the question for companies is how to address the transition phase and find new approaches to deal with cyclical markets, an uncertain policy framework, and new competitors.

A major element of this transition is the development of the regulatory elements impacting Swiss HP, especially water concessions and water fees. Making those elements more flexible will have an impact on the parties involved. The potential change will require agreements at a federal, cantonal and local level and will involve a complicated political decision process that is likely to materialize within a long time frame, only. Beside the concessions and fees, the whole corporate structure of Swiss HP may change, as the current so-called ‘Partnerwerke’ approach may not be suited for new fee mechanisms.

Another important regulatory aspect of HP concerns the ecological constraints, i.e. restrictions on water levels and water flows. Given the higher renewable shares, HP operation may become increasingly volatile with more frequent switches between full-load and no-load/low-load conditions. This in turn could lead to further ecological impacts that need to be addressed by new regulations. Finally, the social acceptance of HP seems to be decreasing, especially towards small HP. This is strongly related to competing land and water usage, and can impose further restrictions for HP. An enhanced stakeholder involvement (participation) can foster a critical dialogue and improve regional acceptance of particular HP projects, and provide better grounds for comprehensive, flexible and transdisciplinary evaluations.

Conclusion and Next Steps

Regarding the market challenges, the general consensus is that neither Swiss energy companies nor Swiss energy politics has much influence on the underlying developments. Naturally, the companies need to adopt as far as possible to the new circumstances by improving their performance, reducing costs, and potentially adjusting their financing and accounting structures. Similarly, the regulatory framework for energy companies and HP, in particular, needs to be adjusted to the new market realities. It seems advisable that with the higher flexibility of the market environment, also the legal elements should become more flexible. The adjustment of governance and policies is at least a medium-term process and involves a high level of uncertainty. The related changes are not likely to provide remedies for the current dilemma of Swiss HP.

An important issue in the whole discussion is the relationship between Switzerland and Europe. While the European market developments are the main drivers of those market aspects that condition the future of Swiss HP, the continuing uncertainty about the integration of the Swiss electricity market in the ongoing process of European market coupling as well as Swiss HP’s general access to the European market adds to the complexity of the issue. In addition, the stakeholders consider the differences in HP-specific regulations between Switzerland and European countries to be very important.

In conclusion, we can say that the next steps that are necessary to provide answers to the threats and uncertainties identified above will have to focus on improving the performance and flexibility of HP, developing approaches to deal with high levels of uncertainty, adjusting the company internal and external regulatory framework, and investigating the interplay between Switzerland and Europe. Especially, the third and fourth point will require a comprehensive stakeholder process, as changes in the concession and fee regulations, in particular, will have significant impacts on revenue distributions between companies, federal, cantonal and local stakeholders.

1 Introduction

Swiss Hydropower (HP) is currently facing a wide range of challenges that have initiated a debate about future prospects and its role within the envisioned energy transition. Contributing to more than 50% of Swiss electricity generation, HP represents a central pillar of Switzerland`s energy system and is a crucial component in attaining the intended Energy Strategy targets. Until 2035, the already high HP output shall increase by an additional 6%. At the same time, HP is expected to provide the needed flexibility and back-up to accommodate the large shares of new renewable generation (wind, solar, biomass), which is expected to increase from approximately 2 TWh to 14.5 TWh, equal to roughly 25% of Swiss electricity consumption. Similar increases in the role of renewables are expected for Switzerland's neighboring countries. In addition, several uncertainties and external factors have an impact on the current operation and future development of HP (i.e., demand, profitability, alternative storage and supply technologies, regulations, and climate change).

Changes in the HP system will be required to increase production and to address the volatility of renewables. These include investments in new HP plants and retrofitting of existing ones, as well as the adoption of HP operations which have to increase efficiency and flexibility. However, the current market developments make it questionable whether Swiss HP will be able to fulfill this envisioned role. The increased share of renewables over the last years, especially in Germany, has led to a steady decline in electricity prices and a significant reduction in the spread between peak and off-peak prices. This price development has not only spurred the ongoing discussion about potential market adjustments (i.e., the capacity market debate), but it has also initiated a debate within Switzerland as to whether Swiss HP should receive financial support. Finally, Swiss HP plays an important role in regional economies and regional development, especially in mountain cantons, and has significant impacts on the ecology of the Swiss river and lake system. In this context, stakeholders have to face a wide range of uncertainties, deal with the interplay of various time scales (short-term market dynamics, medium-term market developments, and long-term trends and uncertainties), and find a compromise between companies' profit perspectives, federal energy targets, and cantonal and local budget requirements.

This paper aims to provide an overview of the status and prospects of Swiss HP by identifying and evaluating the different drivers and uncertainties that Swiss HP faces. We first review a range of factors that influence Swiss HP; namely, natural and technical factors, political, legal and social aspects, as well as management and market aspects. Second, we provide feedback from Swiss HP stakeholders on this topic. And third, we evaluate the obtained insights to clarify which challenges should take precedence in being tackled by Swiss HP companies, policy makers and scientists.

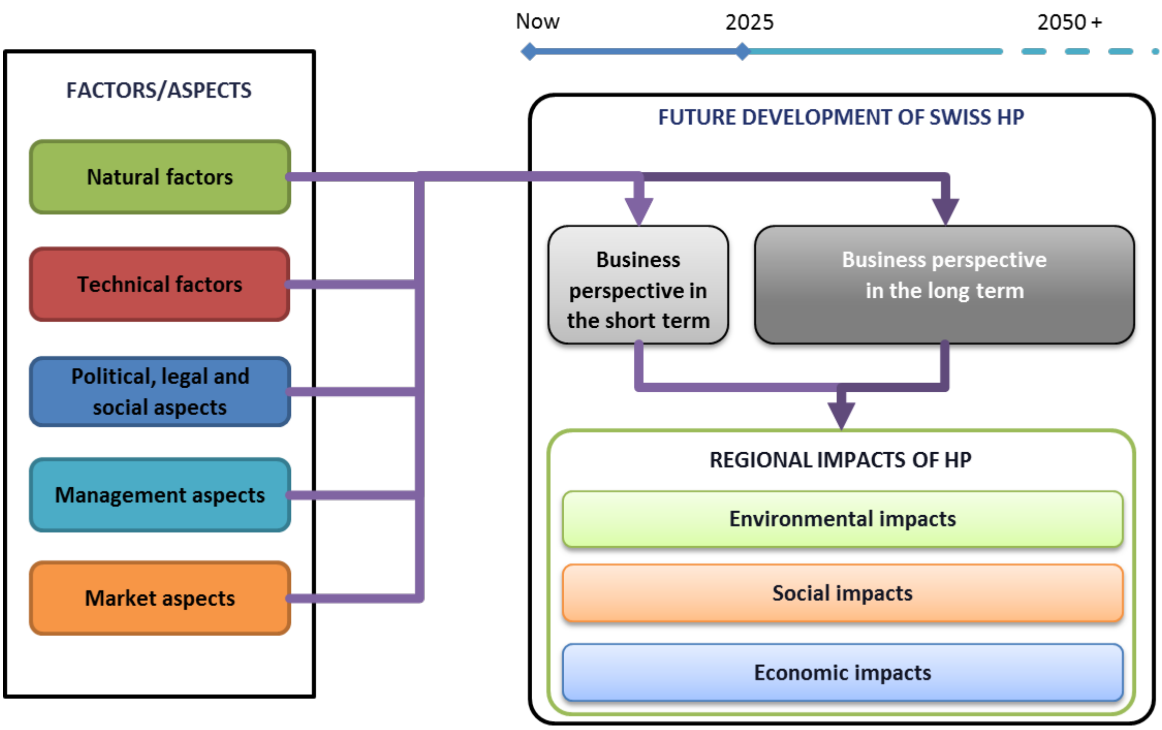
2 Review on Influencing Factors, Drivers and Uncertainties

To identify the challenges that Swiss Hydropower (HP) faces in its current and future environment, we structure the different influencing factors into five general domains (Figure 1): (1) *Natural factors* that represent the externally-given boundary conditions of the hydrologic system, (2) *technical factors* that represent the engineering aspects of HP production, (3) *political, legal and social aspects* that relate to all the regulatory features that influence Swiss HP decision-making, (4) *management aspects* that represent the active decision-making within a company, and (5) *market aspects* that capture both the opportunities for revenue generation and the various influences on those markets that are relevant in the HP sector.

Regarding the importance of these domains in the short and long run, different stakeholders might point out different impacts upon HP, and consequently might set different priorities. In addition, the current and future development of HP is a major challenge for sustainable development (SD) in many Swiss regions. In some regions – particularly in the Alps – HP constitutes an important local industry: It is the backbone of regional economies that consequently might be heavily impacted by various changes in the above domains. In turn, the stakeholders in the different regions are important decision-makers in the HP development process and can induce important feedback loops to and from the regional layer.

To capture the related factors, drivers and uncertainties, in this chapter we present a literature-based overview of the five identified driving factors/aspects from a general perspective and then discuss them from a short- and long-term view, respectively. We will close this section with an overall assessment that also includes a discussion of the regional challenges of HP production.

Figure 1: Main Drivers and Impacts in the Hydro Power System



2.1 Natural Factors

HP is a renewable and relatively clean domestic energy resource, which helps in achieving the climate policy targets of the Swiss confederation (FOEN 2014a). Indeed, CO_2 emissions mostly accrue during the construction phase, while HP operation is basically emission-free (SFOE 2008). Nevertheless, methane emissions might result from the anaerobic composition of plant material in the reservoirs. Primarily, flat lakes in warmer climates and with high levels of organic substances are sources of methane and CO_2 emissions, which is not the case for most of the reservoirs in Switzerland (EAWAG 2011; SWV 2012a).

Given that HP plants rely on the natural water cycle, they are largely influenced by changes in those natural conditions. For HP plants in alpine regions, precipitation as well as melting snow and ice are the main drivers determining the seasonal generation (and storage) potential. Accordingly, weather patterns and forecasts are important for the operation of HP plants.

In Switzerland, the seasonality of the water flows shows a general pattern with high inflows during summer months and low levels in the winter months (FOEN 2014b). Over many years, this hydrological pattern and the consumption patterns have been quite stable and have led to storage levels with peaks during September and October and low levels in March and April (SFOE 2015). These patterns have determined the seasonality of the electricity imports and exports for many decades (SFOE 2013a). However, the annual runoff volumes can also vary; in 2013, for instance, the runoff was 5% to 15% higher than during the period from 1981 to 2010, due to the high snow falls in the Northern Alps and Valais (FOEN 2014b). Long-term patterns and particular short-term fluctuations are typically highly site-specific, depending on the local catchment area of the HP plant (Kumar et al. 2011).

Beside the hydrological aspects, HP plants are influenced by sedimentation, the deposit of particles such as sand, silt or gravels in a reservoir or river basin. These particles can reduce HP capacity by filling reservoirs, obstructing water intakes or damaging plant equipment such as turbines (IEA 2012; Müller and Schleiss 2010; Schleiss 2013). Compared to other regions in the world, fill rates are low in Switzerland. Moreover, HP operations have environmental impacts that are directly related to residual flows, hydro-peaking ("Schwall/Sunk") and bedload (EAWAG 2011; Pfaundler and Keusen 2007; SFOE 2008). As a consequence, HP can induce changes in ecosystems (flora and fauna), both upstream and downstream of the plant (Wüest 2012). Altogether, these issues are subject to environmental regulation (see Section 2.3) and will be addressed in an overall assessment of HP plants (see Section 2.6).

2.1.1 Short-Term Challenges

In the short run, the biggest challenge is the uncertainty of natural inflow conditions. The trade-off between using water now or later strongly depends on the availability of water both in the short and long run (Gaudard et al. 2014; Kumar et al. 2011). In general, HP plant operators should be able to predict their water inflows based on hydrological forecasting models, with the remaining uncertainties being managed by using different inflow scenarios in a deterministic optimization model (see e.g., Pérez-Díaz et al. 2010) or by using stochastic optimization models (see e.g., Fleten and Kristoffersen 2008). Improvement in actual modeling and forecasting can help to further optimize operational decision-making.

2.1.2 Long-Term Challenges

In the medium and long term, climate-related uncertainties may increase. Natural runoff can change with regard to annual volume, seasonality and variability, thereby altering the HP potential (Lehner et al. 2005). Whether these changes will have positive or negative effects depends on the specific region (Kumar et al. 2011). In Europe as a whole, the HP resource potential is expected to decrease by 6% by 2070 due to changes in runoff (Lehner et al. 2005), while in Central Europe the HP potential is estimated to be constant (Kumar et al. 2011). For Switzerland, forecasts vary. In a concerted effort, 15 Swiss research institutions (CH2014-Impacts 2014) estimate that the annual runoff is likely to remain stable over the century, while SFOE (2007) assumes a HP production loss of 7% until 2035, and Lehner et al. (2005) a reduction in gross HP potential of nearly 14% by 2070. However, the local topology is again an important factor, as the impacts are unevenly distributed between water catchments (Gaudard et al. 2014). For example, Ticino and Valais are likely to have less runoff than at present (SFOE 2012a).

Beside the overall potential, the seasonality of the water inflows is likely to change. The runoff is expected to increase in winter and decrease in summer (CH2014-Impacts 2014). In such case, the runoff seasonality will be closer to the current electricity consumption pattern. However, with increasing temperature, the latter may change as well (Gaudard et al. 2013). With storage and pumped-storage plants, adjustments in reservoir management can help to mitigate the negative effects of climate change (Gaudard et al. 2013). In contrast, run-of-river plants are more vulnerable, because they suffer from lower flexibility, but may be able to take advantage of the management of upstream reservoirs.

The inter-annual variability is of concern too. The impacts of climate change on it are still controversial. Climate models must deepen this issue by enhancing the downscaling methods (CH2014-Impacts 2014). Nevertheless, one can assume that a higher level of variability would be challenging for HP management. The extreme years would become more common. As a consequence, HP production might drop severely in one period alone. This could put pressure on the security of the electricity supply, since Switzerland is and will remain highly dependent on its HP production.

Climate change may also bring opportunities for Swiss HP. For instance, the retreat of some glaciers may create new lakes that could be used as new reservoirs (Gaudard 2015), thereby increasing Swiss generation potential. On the other hand, glacier retreat will also impact existing plants and lower their generation potential or increase problems related to sedimentation (Peizhen et al. 2001). Again, the actual impact is highly localized, and climate change can lead to an increase or a decrease in sedimentation flux depending on future precipitation and temperature changes (Zhu et al. 2008). In general, an increase in sedimentation in the future would lead to revenue reductions for HP, e.g., due to the lower efficiency of the equipment or due to higher maintenance costs resulting from increased maintenance work (Kumar et al. 2011).

2.2 Technical Factors

Regarding the technical aspects of HP plants, a classification of different types is useful:

- Run-of-river (RoR) plants normally have a low water head, and their generation is driven by the river's flow, which makes these plants strongly dependent on the natural inflows (IEA 2012). Their flexibility is typically low, and they are operated as base-load plants in Switzerland (VSE 2012, 2014).
- Storage or reservoir HP plants typically have a high head, a high flexibility, and storage makes the plants less dependent on the natural inflows in the short run. Storage HP plants deliver the peak load in Switzerland (VSE 2014). The high pressure of the water on the turbines allows storage HP plants to produce electricity while only releasing a small volume of water (Kumar et al. 2011).
- Pumped-storage plants (PSP) are similar to storage HP plants, but with an upper and a lower reservoir between which water is pumped or released, respectively, in periods of excess supply or demand. Thus, a PSP enables electricity from the market (from the grid) to be stored in the form of pumped water. An important distinction must be made between open-loop and closed-loop PSP. The latter plants necessarily have a negative energy balance, since they do not collect natural runoff (IEA 2012).

Beside this classification, HP plants differ regarding their size. In general, a distinction is made between large-scale and small-scale hydro plants (IEA 2012). In Switzerland, small HP refers to plants with a capacity of less than 10MW (SFOE 2013b).

The scale and type of HP plants determines the underlying mechanical structures and electro-technical aspects such as hydro turbines, generation sets, pumps or pipelines. Hydro turbines can be classified as impulse turbines, like the 'Pelton' turbine, or reaction turbines, like 'Kaplan' and 'Francis' turbines (Breeze 2014; Okot 2013). The efficiency of reaction turbines is lower than for impulse turbines, especially under part-flow conditions (Elbatran et al. 2015). RoR plants typically use 'Kaplan' turbines with a low water head and high water flow, while storage HP plants with a high water head (> 200 meters) use 'Pelton' turbines. However, in general, the 'Francis' turbine is the most commonly used hydro turbine, since it is applicable for a wider range of water heads and water flows (IEA 2012; Kumar et al. 2011; Okot 2013). In addition, for PSPs, the choice of a turbine is also influenced by its pumping ability as they can either use separate pump and turbine installations or make use of reaction turbines such as the 'Francis' turbine with reverse rotation for alternative pump and generation modes of use. However, even if investment costs for combined pump turbines are lower, the switching time between the two modes is increased and the efficiency reduced compared to a separate installation

(Müller 2001). Beside the performance of the turbine, the number and the array of the components can also have an influence on the performance and flexibility of an HP plant.

A second important technical aspect is the conduit system of an HP plant, consisting of pipelines, penstocks and tunnels in the rocks, regulating the water flow of the plant. The design of the conduit system can influence the water head and thus the generation potential of an HP plant. Finally, for storage plants and PSP, the dam itself is an important technical component defining the water head, storage capacity and thereby the seasonal generation potential. In general, three dam types are common: concrete gravity dams, concrete arch dams, and embankment dams (Breeze 2014). Short-term maintenance expenditures can also depend on the specific type of dam which is used (IEA 2012).

2.2.1 Short-Term Challenges

Most technical aspects can only be changed in the medium to long term, as they require replacements or new investments. Nevertheless, the changes carried out by upgrading the technical characteristics of a plant can have significant impacts on its short-term performance; i.e., the roughness of the pipelines, penstocks and tunnels can reduce the efficiency due to friction losses within the conduit system (Kumar et al. 2011). Consequently, upgrades in the design of the conduit system can improve a plant's efficiency. Similar upgrades of the turbines or changes in the pumping structure can enhance the flexibility of a plant.

2.2.2 Long-Term Challenges

As HP is a mature technology, the potential for innovation is small compared to other renewable generation technologies. Major breakthroughs or shifts are not expected. At the same time, owing to the maturity and high technical efficiency (about 90-95%) of HP plants, HP is likely to remain an important element in the mix of electricity systems. The focus of technological research is on low or very low head HP plants, hydrokinetic turbines, fish-friendly turbines, and variable-speed technologies, which allow a more flexible operation (IEA 2012; Kumar et al. 2011).

In general, in an existing HP system with little unused potential, as in Switzerland, the replacement of old turbines and the upgrade of existing sites constitute an important technology impact on performance. Also, new materials, such as penstocks out of fiberglass, are emerging and could increase the lifetime of the components and improve performance.

From a technical perspective, the greatest long-term challenge for HP is likely to emerge from technological developments in competing systems. While the flexibility of HP is a fitting complement to intermittent renewable generation from wind and solar sources of energy (IEA 2011a), the same flexibility may be provided by other means, notably other types of dispatchable power plants, increased interconnection, demand-side management, or new electricity storage technologies. Especially developments in the latter technologies may present a challenge for PSP, which currently represents 99% of storage capacity (Lueken and Apt 2014). Moreover, smart-grids and micro-grids represent a further challenge for HP. Due to the development of small electricity distribution networks incorporating distributed generation, different kinds of energy storage, as well as smart meters, HP may lose market shares. Consumers may gradually become "prosumers" (Grijalva and Tariq 2011; IEA 2011b; MIT 2011).

2.3 Political, Legal and Social Aspects

Swiss HP is influenced by a multitude of political, legal and social aspects. Those particularly include residual flow regulation and hydro-peaking restrictions, water fees and taxes, concession periods, flood and risk management and competing water usages. Some of the specificities of Swiss legal aspects rely on interactions between the federal and cantonal level: The federal authorities set a general legal framework for most of HP issues. Within this framework, the cantonal authorities have the legislative power. This leads to a situation with a relatively high degree of diversity between Switzerland's cantonal jurisdictions.

First of all, the federal authority sets the maximal length of a new or renewed concession to 80 years; concessions can be renewed if all major stakeholders agree. In reality, while some cantons follow the federally-specified length (e.g., Valais), others have decided to shorten this length to 60 years, and 40 years after renewal (Grisons), or even to grant the concessions to the cantonal public company for an unlimited period of time (Ticino). There are three ways to end a concession contract: The first way is by cancellation, ensuing from the end of the contract. The second is caducity, ensuing from a neglected exploitation of the concession right. Finally, there is the use of the buyback right by the granting authority (reversion, "Heimfall"). In this case, a distinction is made between the "wet parts" (all the parts of the HP plant in contact with water, which notably include the dam, pipes and turbines) and the "dry parts" (e.g., the generator and transmission lines). Unless otherwise stated in the concession, the wet parts are acquired for free by the community owning the concession right.[1] The dry parts can also be acquired by the same community, but this would require that the concession-holder receives the requisite compensation.

The federal authority also sets the maximal amount of water fees that can be applied to HP plants. While it was set to 100CHF/kW between 2011 and 2014, it is now set at 110CHF/kW for the period 2015–2019. From there, the cantonal authority can decide the amount of the fee and any other specific tax, as long as the total amount does not exceed the federal cap.[2] It is also worth mentioning that plants which do not exceed 1000kW of their theoretic potential power are not subject to water fees, while those produce between 1000kW and 2000kW are subjected to the fee, but following a linear rule between 0CHF (1000kW) and the federal cap (2000kW).

[1] There is a great degree of diversity between the cantons with regard to this point. Considering, for example, the three largest hydropower-producing cantons, Valais allocates 100% to its municipalities (or to the canton, in the case of the Rhone river), Grisons allocates 50% to its municipalities and 50 % to the canton, and finally, Ticino allocates 100% to the canton.

[2] Focusing again on the three largest hydropower-producing cantons, we see that all of them collect the maximal amount of tax. While Ticino collects 100% of the maximal water fee and allocates it to the canton, Valais collects only 40% of the maximal water fee and allocates it to the communes. However, it also levies a special tax on hydropower infrastructure, accounting for 60% of the maximal water fee, which goes to the canton. Grisons applies a similar process, but with a 50/50 apportionment.

Regarding Swiss environmental regulation, the Water Protection Act (Gewässerschutzgesetz, GSchG) sets the rules for residual water flow. The GSchG defines residual flows as the quantity of water which must remain in a river after water withdrawals. The minimum residual flow is calculated for different river sections based on the water flow rate and controlled by the respective authority (FOEN 2013a). But, the GSchG also contains several exceptions, such as allowed withdrawal levels and non-fishing waters. Since November 1992, the residual water flow restrictions have become mandatory and are incorporated in new or renewed concessions. Because of vested rights, concessions granted before this date, which have not been renewed yet, are not subject to residual flow restrictions (FOEN 2013b).

Hydro-peaking restrictions are a second important influence that environmental regulations have on HP plants, which are also regulated in the GSchG. In a river below an HP plant, the changes in runoff depend on the generation schedule and have a significant influence on the flora and fauna of the river (Wüest 2012). Moreover, the Waters Protection Act legislates on sediment transportation, as the latter cannot be modified without seriously affecting the downstream ecosystem.

Further environmental issues concern mainly small HPs and regard the water flows in protected areas under the Swiss Federal Constitution and Legislation (FOEN et al. 2011). In general, this refers to the protection of landscapes and waters, which can be an issue for both small and large HP plants.

Not directly related to regulatory restrictions is the issue of social acceptance. In the past, HP was accepted in the peripheral mountain regions thanks to the revenues and jobs that it generated. However, in some regions this issue was quite controversial (Romerio 2008). The taxes and royalties of Swiss HP represent a fiscal revenue of about CHF 560 million per year for cantons and municipalities (years 2006–2012; SFOE 2012b) and are an important economic factor for those regions.

2.3.1 Short-Term Challenges

All regulations that require specific water levels and flows naturally have an impact on HP operation. To meet the residual flow restrictions, HP plants have to release water permanently either through the turbine or through a bypass or spillway system, which reduces their generation potential (SFOE 2012a). Similar, HP plants are committed to reduce hydro-peaking by structural or operational measures such as slower start-ups of the turbines. This influences the operation of a HP plant, e.g., due to reduced flexibility (FOEN 2013c).

The authorities can also issue water release constraints during times of floods to keep inflowing floods within the reservoirs of the HP plants and reduce or stop water release if the water flow is high. Though this typically leads to short-term profit setbacks (Hernández et al. 2011; Zheng et al. 2013) it also contributes to long-term profitability by avoiding damage to the HP infrastructure. Moreover, it may have a positive effect on the public acceptance of HP plants that provide these services so far without any payment. However, flood control could become an additional income source for HP plants if non-energy services will be compensated in future (Pfammatter and Piot 2014).

Although these constraints are no new challenge for Swiss HP, any change in the electricity market can have a reinforced impact. Higher price volatilities due to intermittent generation and increased shares of renewable infeed can encourage a plant to operate in a more online/offline structure. This might lead to higher water peaks and times of low water flows and violate residual flow or hydro-peaking regulations.

2.3.2 Long-Term Challenges

All legal, social and institutional impact factors may be subject to changes in the future. According to the GSchG, residual flow restrictions could be adjusted (decreased or increased) if found to be necessary or of interest for specific sites. Moreover, many of the existing HP concessions will expire within the next few years or decades (see SWV 2012b; Figure 2). This will require a renewal of these concessions or the acquisition of new concessions, whereby residual-flow restrictions will become binding for these plants (FOEN 2013b). In general, the Swiss HP generation potential is expected to be reduced by 1.4 TWh/year until 2050 due to the Water Protection Act (SFOE 2012a).[3] In comparison, the optimized annual potential, which has not yet been exploited is about 4.5TWh, and is split evenly between new large-scale hydropower, the upgrading of current large-scale hydropower and small-scale hydropower (SFOE 2012a).

The concession renewal is an important aspect of the future HP development in its own right. Swiss federal law entitles the incumbent owner to negotiate the concession's renewal (or to opt for another solution) within a 15–25-year period prior to the concession expiring, which means that such negotiations need to take place presently or in the very near future. The value of these concessions is estimated at about CHF 40 billion, with the Valais' concession alone being within a range of CHF 10 to 20 billion (ASAE 2012; SWV 2012b).[4]

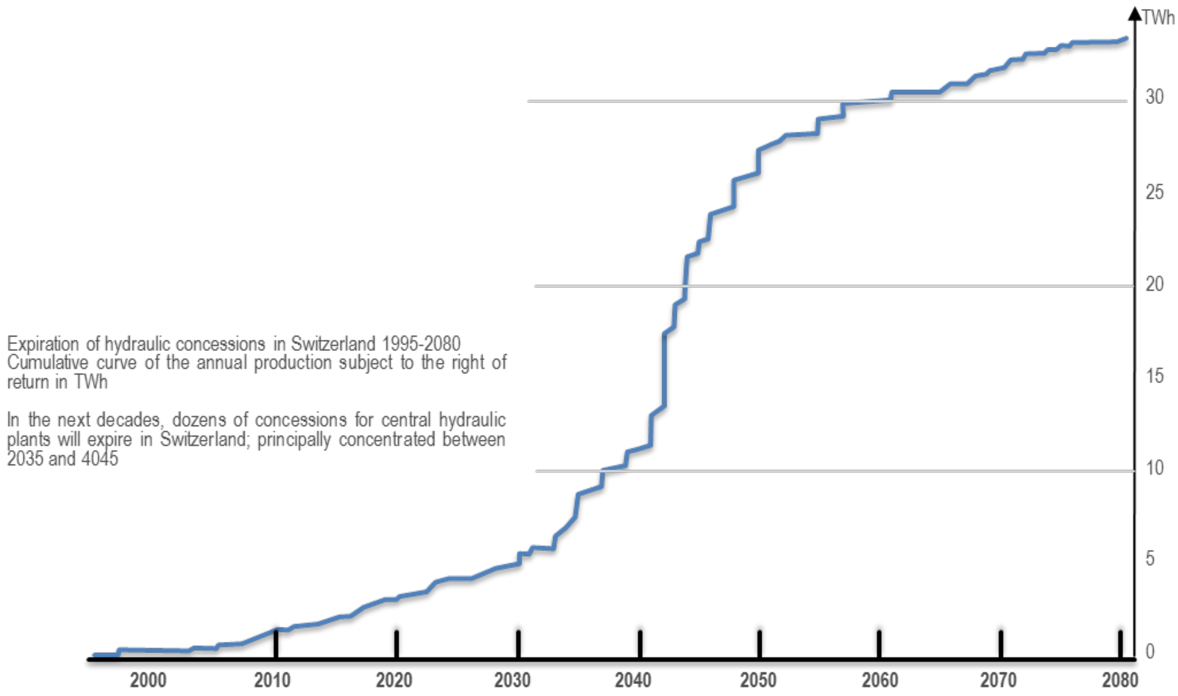
Moreover, the renewal/reversion ("Heimfall") of water concessions and the design of future water fees ("Wasserzinsen") and water taxes might result in a more flexible system than the current one. This would have a significant impact on HP utilization (SWV 2012b; Wyer 2008) and will bring about new institutional settings. This will ideally involve various changes, such as an adjustment to market conditions and flexible water fees based on resource rents (Ott et al. 2008; Pfammatter 2012; SFOE 2008).[5] Also new investments need to carry out an environmental impact analysis, which can increase a project's uncertainty, as specific ecological aspects can delay an investment, increase investment costs or prohibit the construction's authorization.

[3] The same study cites a research conducted by the Federal Office for the Environment, 'Forest and Landscape in 2002', which estimates that the total generation loss ensuing from the Water Protection Act between 1992 and 2002 reached 3,5%.

[4] In the European Union, water right renewal is also a politically charged topic. According to the European Commission, rights to water use should be allocated by a competitive and transparent process (Glachant et al. 2014).

[5] „Concession renewal/new concessions are, however, also an opportunity to demand that all environmental regulations are instituted (residual water, fishing) and that the conditions of the concessions are adapted to current market conditions, which in turn leads to higher production costs and can be a barrier to investment. Currently, there is a certain tendency to shorten the length of-the concessions, which in turn leads to shorter amortization periods and higher production costs." (SFOE 2008)

Figure 2: Swiss HP Concessions



Source : ASAE (2012), SWV (2012b); modified graph.

2.4 Management and Cost Aspects

The costs of HP plants are dominated by high investment and capital costs; e.g., capacity expansion costs are on average 14.1 Rp./kWh with 70% capital costs, 15% operation and maintenance costs, 10% water fees, and 5% being taxes and other costs (SFOE 2013b). For Switzerland, the production costs ('Gestehungskosten') of the existing HP capacity are between 5 and 6 Rp./kWh (SFOE 2013b). Variable operation and maintenance costs of HP plants are assumed to be zero in most short-term studies.[6] As with most hydro-related factors, the costs for HP plants are highly site-specific (SFOE 2014a).

Beside plant-related costs, trading costs arise in electricity markets. The variable trading fees at the European Power Exchange, for example, are 0.04 EUR/MWh in the day-ahead market. However, the low level should make these costs negligible. In addition, annual fees for trading can arise (cf. EPEX SPOT 2015a). Assuming that HP plants are becoming active on an increasing number of markets (see the next section), this may become more important in the future.

Finally, the management of a HP plant includes internal guidelines on short-, medium- and long-term targets, as well as on how the plants that are linked in a water cascade are to be operated. Altogether, this can be relevant when deciding on which electricity markets to participate in. Moreover, there will

[6] In general, average fixed operation and maintenance costs for RoR plants are around 60 EUR/MWh and for PSP and storage HP plants around 20 EUR/MWh (Schröder et al. 2013).

be mutual interaction between the institutional arrangements addressing political, legal and social aspects (see the previous section) and HP management decisions.

2.4.1 Short-Term Challenges

Management guidelines play a special role in the operations of an HP plant. Short-term water release can be influenced by target water levels for the storage reservoir that are usually defined by longer-term planning and are based on historical values. Such target values may become stricter or looser in the future depending on the effects of future drivers such as climate change (Gaudard et al. 2014; Labadie 2004; Pérez-Díaz et al. 2010).

Cascading systems are particularly influenced by operational decisions. The generation potential of HP plants downstream of a system depends on the operation of the HP plants upstream, and a joint operation can increase a system's flexibility and the overall revenue (Kumar et al. 2011; Zhang et al. 2013). However, if the HP plants within the cascade are owned by competing firms, a regulation of the HP system may be required to avoid strategic actions of the upstream plants (IEA 2012).

Related to the issue of spatial connectivity is the temporal connectivity, since water needs some time to flow from one plant to the next (lag time). This can influence short-term operation, especially for plants with small storage capacities (Cheng et al. 2012; Fleten and Kristoffersen 2008) and create feedback effects, for instance if upstream system plants change their operation schedule due to renewable feed-in.

2.4.2 Long-Term Challenges

The development of investment costs is the main aspect of the long-term challenges. It is difficult to predict how HP costs will change in the future. For instance, Schröder et al. (2013), assume that capital costs for HP plants will remain constant until 2050. However, in Switzerland, investment costs, as well as short-term costs, are more likely to increase in the future, since the best HP construction sites are already in use. The development of less optimal HP sites for new plants may increase costs, because of less favorable operation conditions (Gaudard and Romerio 2014; SFOE 2013b).

2.5 Market Aspects

HP plants can participate in many different electricity market segments: energy-only markets (day-ahead markets, intra-day markets, forwards/futures markets), reserve and balancing markets, system stability service markets and green markets (see e.g., SFOE 2014a; Swissgrid 2014a).

The Swiss reference day-ahead (Swissix) and intra-day markets are operated by the European Power Exchange (EPEX SPOT) with products varying in block length; e.g., all peak-load hours or single hour trading. While the day-ahead market uses a single auction format, the intra-day market utilizes continuous trading with different block products and 15-minute periods traded up to 75 minutes before delivery (EPEX SPOT 2015b, 2015c). Due to its time resolution the intra-day market offers HP plants the possibility to make use of their flexibility by adjusting the generation schedule to changes in the market prices (Frontier Economics and SwissQuant 2013).

While prices in the intra-day market are, on average, similar to the day-ahead prices, the trade volume in the Swiss intra-day market is significantly lower than that in the day-ahead market: ca. 1.5 TWh in 2014 compared to 20.5 TWh on the day-ahead market (EPEX SPOT 2015d, 2015e). Price volatility in the intra-day market is normally higher than in the day-ahead market, making it attractive for PSP plants (Frontier Economics and SwissQuant 2013). In addition to short-term trading, long-term trading via future contracts is possible at the exchange, e.g., the 'Swiss-Power-Base-Future' (EEX 2015a). This is mostly used to deal with price risks in the market. Future contracts offer price predictions for the spot market (IfnE 2007).

A large share of electricity is also traded bilaterally over-the-counter (OTC), especially with long-term contracts. For OTC trade, tenders as well as broker-platforms such as 'GFI' or 'Spectron' are often used (Georg et al. 2013; IfnE 2007). Given the electricity consumption in Switzerland in 2013 (ca. 60TWh) and the trade volume at the Swiss day-ahead and intraday market (ca. 20TWh), nearly two-thirds of the electricity consumed was not traded at the power exchange (EPEX SPOT 2015d, 2015e; SFOE 2013a).

Swiss HP generators can also participate in foreign electricity markets. In general, electricity prices in Italy are normally higher than in Switzerland, while electricity prices in Germany and France are slightly lower (EPEX SPOT 2015e; Georg et al. 2013). However, trade in neighboring markets is limited by the available cross-border transmission capacity. The individual line capacities are transformed into so-called net transfer capacities (NTC) for each border and allocated on the basis of explicit yearly, monthly and daily auctions (Swissgrid 2014b). In addition, border capacities are allocated intra-day via implicit market coupling with the German and the French market. For participation in the Italian market, intra-day border capacity is auctioned explicitly (Frontier Economics and SwissQuant 2013; Georg et al. 2013; Swissgrid 2014b).

In addition to the energy markets, several markets address system stability aspects and are operated by the Swiss transmission system operator (TSO) 'Swissgrid'. Among these markets, the reserve and balancing markets provide the main system stability mechanism. A distinction is made between primary, secondary and tertiary reserves, depending on the activation time (Swissgrid 2015a).

The primary reserve (PRL) needs to be available within seconds. Thus, in order to participate, power plants need to be online and their capacity bids must consist of symmetric offers (generators need to be able to increase as well as decrease their output by the offered capacity). PRL tenders are agreed on weekly basis with a total of 71MW, and remuneration follows the pay-as-bid principle, whereby only the capacity, but not the energy delivery is remunerated. Generators in Germany, France and Austria can also participate in the PRL tenders for Switzerland, while Swiss generators are able to participate in the primary reserve markets of these countries (Swissgrid 2015a, 2015b).

Secondary reserves (SRL) need to be online within seconds or minutes. Power plants which want to be active in the SRL market need to be online and generate below their maximum but above their minimum generation capacity in order to increase or decrease their output. Bids in the SRL market are symmetric as well tenders on a weekly basis. 400MW of negative and positive SRL are requested by

Swissgrid. In addition to a pay-as-bid price system in remuneration of capacity, the energy delivered in case of call-up is also remunerated. However, based on the sign of the reserve recall as well as the sign of the Swissix prices, the remuneration of the delivered energy follows some rule of thumb (Swissgrid 2015b).[7]

The last reserve type, tertiary reserves (TRL), has a longer call-up time and entities need not be online to offer TRL. In the TRL market, capacity and energy delivery is advertised separately, while offers are asymmetric. Thus, the delivery of energy (positive TRL) is distinguished from the generation reduction or consumption of energy (negative TRL). Swissgrid purchases around 450MW of positive and 300MW of negative energy. Tenders take place on a weekly as well as on a daily basis, whereby in the daily tenders, 4-hour blocks can be offered. Capacity which is bid into this market needs to be available within 15 minutes after the reserve call by Swissgrid and needs to be available for at least 15 minutes. This is different for the negative tertiary reserve offered in the weekly tenders. Here, capacity needs to be available within 20 to 35 minutes. Both capacity and energy delivery is remunerated on the pay-as-bid principle (Swissgrid 2015b).

In general, HP plants are flexible enough to participate in all three reserve markets. According to VSE (2012), both RoR and storage HP plants offer PRL in Switzerland, while SRL is only provided by storage HP plants. In addition, HP plants provide positive TRL, while negative TRL is offered by nuclear power plants as well as PSP plants.[8] Average prices in the PRL and SRL markets are higher than in the TRL market, making PRL and SRL markets possibly more attractive (see Swissgrid 2015c). However, even if TRL market prices are lower, this market can be attractive for PSP plants, especially in times of negative spot market prices (SFOE 2014a).

Beside reserve and balancing services, Swissgrid demands additional system stability services, such as active power losses, voltage stability or black-start capacity. Active power losses can be offered by balance groups, which have signed a contract with Swissgrid, and are requested in monthly tenders that are pooled. As in the reserve markets, the accepted bids are remunerated on a pay-as-bid basis (Swissgrid 2015a, 2015b). However, since active power loss requests are rather low, this market has only limited potential for HP plants (see Swissgrid 2015d). Voltage stability services encompass the provision of reactive energy (Swissgrid 2015a) and are purchased through bilateral contracts with prequalified suppliers. Thus, the participation potential is limited (Swissgrid 2015b).

In order to restart the transmission network after larger breakdowns, Swissgrid signs bilateral contracts for black-start capacity with prequalified power plants. In Switzerland, black-start capacity is provided by nine storage HP plants (Swissgrid 2015a). The future market potential is low, because the demand for black-start capacity is limited – although HP plants are technically able to provide black-start capacity.

[7] See Swissgrid (2015b) for the rule of thumb used in the remuneration of the energy in the secondary reserve market.
[8] As pooling has been allowed since 2012, the supply in the Swiss reserve markets may change (Swissgrid 2014c).

The so-called green markets allow for the marketing of electricity generated by renewable energies via certificates or labels. Since 2013, it is mandatory for Swiss generators to prove the origin and quality of their electricity with the aim of increasing transparency for consumers. Therefore, generators need to label their electricity by using 'Guarantees of Origin' (GoO). Making use of green platforms like the 'Ökostrombörse Schweiz', the 'Green Energy Marketplace' or 'BUYECO', GoOs of renewable energies can be traded OTC (Swissgrid 2014a). In addition, GoOs for Nordic hydro, Alpine hydro and Central Northern European wind can be traded at the EEX. However, only GoOs from HP plants which do not receive any further support, such as the Swiss feed-in tariff for renewables, are allowed. At the EEX, GoOs are continuously traded, while the minimal contract size is 1,000 GoOs (1000MWh). But, trade on the EEX with Alpine hydro GoOs is relatively small so far (EEX 2015b). In general, GoOs can be extended by additional labels – such as 'naturmade star' or 'TÜV SÜD' – for marketing electricity from renewable energies (Swissgrid 2014a).

2.5.1 Short-Term Challenges

In general, electricity prices in the day-ahead market have dropped over the last years. While in 2008 the Swissix peak price was about 75 EUR/MWh and the base price around 63 EUR/MWh, the average peak price in 2014 was around 45 EUR/MWh and the base price around 40 EUR/MWh) (EPEX SPOT 2015e). In addition, following the removal of the CHF/EUR cap by the Swiss National Bank in January 2015, the exchange rate development worsened the situation for Swiss producers. The fall in prices has posed the greatest challenge that Swiss HP has faced in recent years, as the obtainable price level is consistently below the production costs of 5 to 6 Rp./kWh. To address this challenge, HP plants need to optimize their market participation across all relevant market segments.

In the near future, the market conditions are unlikely to change, and the Swiss market will remain dependent on European developments (see Section 4 for details). However, the electricity market developments are likely to have an impact on HP operations. Existing energy and reserve markets can move in the direction of shorter bidding periods and closure times, and thus provide an advantage for flexible generators like HP plants. Future market segments that focus on long-term factors, such as capacity markets or payments, only have indirect feedback effects on HP operations by altering the available plant mix. However, for actual short-term operations, the energy and reserve markets will remain the relevant benchmarks.

Of particular relevance for the Swiss market is its integration with the European Market. However, due to the Swiss immigration referendum in February 2014, negotiations regarding a preliminary bilateral electricity agreement between Switzerland and the European Union were cancelled (see SRF 2015). Thus, the Swiss future within the European institutional framework is not clarified so far. A fully coupled Swiss market would increase competitive pressure due to easier cross-border trade between foreign electricity suppliers, but would also provide better access for Swiss HP to foreign markets. The European Electricity Index (ELIX) gives an indication of how electricity prices would look like in a fully integrated European market (cf. EPEX SPOT 2015f; SFOE 2013b, 2013c).

2.5.2 Long-Term Challenges

In general, market aspects can be influenced by a variety of potential future drivers. For HP plants some future developments will offer opportunities, but also pose threats. Many mountain areas in the Swiss Alps have a comparative advantage in HP-based electricity generation with PSP. Thus, they can export electricity to other regions. However, this may change with altering market and price conditions (Meister 2012; Scheidegger 2012).

Regardless of whether Switzerland is integrated in the European market, electricity supply in Switzerland is likely to change. According to the 'Energy Strategy 2050', the electricity supply provided by renewable energies – such as photovoltaics (PV) and wind – is planned to increase significantly until 2050 (SFOE 2013c). This will lead to changes in the merit-order and have an impact on the level and variability of electricity prices. And, due to the stochastic pattern of PV and wind supply, electricity prices will be difficult to predict. In addition, the uncertainty about future emission permit and fossil fuel prices makes long-term price forecasts on the electricity markets even more difficult. Altogether, these developments and uncertainties make it difficult to determine whether investments in new or in upgraded HP plants are optimal. Therefore, new decision-support models are needed.

Furthermore, both reserve markets and the intra-day market are likely to gain importance due to higher balancing requirements caused by a higher share in intermittent renewable energies in the future (Frontier Economics and SwissQuant 2013). In addition, new markets may emerge. In many countries, capacity markets or capacity payment mechanisms have been established or are being debated. Even if the establishment of a capacity market in Switzerland is unlikely in the near future, such a market may become relevant in the long term (ElCom 2014). A market design reform could give HP plants an opportunity to increase their profitability and increase incentives to invest in flexible technology (Joskow 2008). This might also be influenced by potential new technologies which allow for increased system flexibility (see Section 2.2.2).

2.6 Regional Challenges and the Need of an Integrated Assessment

As underlined by the above analysis, Swiss HP is and will be impacted by a multitude of factors. In turn, decisions on HP operations and investments affect the economic, social and environmental development of the respective regions in which those plants are situated, particularly in mountain areas where HP is often an important economic and political factor. Indeed, HP generates income and employment as well as important fiscal and other revenues for cantons and municipalities (AEV 2009; AG Wasserkraft 2011; Kt. Graubünden 2012; Plaz and Rütimann 2010; Rieder and Caviezel 2006; SFOE 2008, 2013b; Sigg and Röthlisberger 2002). Accordingly, HP plays an important role in maintaining regional economies in many remote areas, which in turn partly rely on the future of HP in Switzerland. Hence, the various interdependences among the above factors, drivers and uncertainties need to be assessed in the regional context of HP plants (operations and investments projects).

First of all, this regional context includes the economic aspects that are related to market developments, such as the effects of changing market and price conditions on a region's electricity exports (Meister 2012; Scheidegger 2012), as well as the institutional arrangements (political, legal and social aspects), namely with regard to future HP concessions, water fees and water taxes. As various authors emphasize (e.g., Banfi and Fetz 2006; Banfi et al. 2004, 2005; Ott et al. 2008; Pfammatter 2012; Plaz and Hanser 2008; SFOE 2008; SWV 2012b; Wyer 2008), this might be more flexible than the current system. To be successful, the settings of these new arrangements should be designed and structured to foster closer interactions between the authorities and the companies, and established in the form of public-private partnerships (IHA 2010; Toman et al. 1998). This might involve new forms of governance, stakeholder dialogues and participation (CommGAP 2009; Cuppen 2012; Kaptein and Van Tulder 2003; Schlange 2009; Wheeler and Sillanpää 1998). And the new design must account for future production technologies, environmental policy and regulations, market structures and energy prices, and thus integrate the natural and technical factors as well as market and management aspects of HP, including the development of smart grids, micro grids and new storage technologies.

Regarding the natural factors, it is important to acknowledge the extent to which HP interferes with the natural water cycle, and the fact that HP relies on the availability of land and water in the respective regions of production. This requires that policy makers carefully consider the comparative use of land and water resources among HP systems, tourism/leisure and agriculture, as well as the indirect consequences of climate change (Beniston 2012; Gaudard and Romerio 2014; Gaudard et al. 2013, 2014; Romerio 2008; SFOE 2008). As pointed out by Beniston (2012), climate change influences the run-off regimes and water availabilities and will have feedback effects on the interplay between HP and other water users. Because of these competing water claims, HP usage can become a multi-objective problem (Labadie 2004), thereby demanding more complex HP management. In general, Swiss HP is likely to be influenced by increased competition among water users (Hill Clarvis et al. 2014), potentially caused by climate change. However, HP companies could benefit from these new queries by diversifying their services' portfolio (e.g., flood management, snow production). The environmental impact of HP poses another challenge. Although this effect is highly case-specific (IEA 2002), the decision to invest in either new small scale plants or in large scale plants and a renewal process for existing plants will need to take account of new environmental standards.

Altogether, HP involves synergies and trade-offs among economic, social and environmental criteria which need to be carefully evaluated in order to optimize HP projects and their operation. Environmental concerns can be identified in various domains along the entire value chain of hydro-energy, ranging from the effects that hydraulic systems have on socio-economic development in mountain regions, and the impact that they have on ecosystems, landscapes and downstream water flows, to overall impact that they have on markets and institutions. The stakeholders that are involved include energy companies, investors, politicians, public administrations and non-governmental organizations, as well as local citizens and businesses that are variously involved in decision-making regarding the future of HP.

Informed decision-making must rely on comprehensive assessments that integrate the issues concerning HP operations (short-term challenges) and investments (long-term challenges) and that also take the various impacts and stakeholder concerns along the entire value chain, and in a saptial context, into account. For this purpose, regional impact analysis and sustainability assessment (SA) provide useful tools that have been developed by different institutions and in various contexts (see Voegeli et al. 2015 for an overview). They go beyond traditional methods of environmental impact assessment and economic project appraisal, such as computational general equilibrium models, cost-benefit analysis, non-market valuation and life-cycle assessment.

To address the challenges of SD on a regional and corporate level, as anchored in the Swiss Federal Constitution and the Federal Council's strategy (Swiss Federal Council 2012), an integrated framework is required that allows us to match the various social, economic and ecological goals of sustainability and development with stakeholder concerns in a coherent fashion. This must, in particular, enclose an inquiry into the economic, environmental and social impacts of HP projects and operations in a given spatial context. The evaluation should be tailor-made for the specific context and encompass some kind of stakeholder engagement (Bond et al. 2012; Toman et al. 1998), foster a critical dialogue about higher acceptance of the particular HP projects, and provide better grounds for comprehensive, flexible and transdisciplinary SA (Scrieciu 2007).

Given the mutual interaction between institutional arrangements and HP management decisions, it is essential to translate results from a regional SA level to a corporate level (corporate social responsibility, CSR). This will help to inform decision makers about the social and environmental impacts of a company's operation and guide it toward SD (cf. Hediger 2010), and thereby generate a feedback loop on the operational and investment aspects of HP.

3 Stakeholder Feedback: Insights from the Questionnaire and the Workshop

To gather information on the perceptions held by the main Swiss HP stakeholders on the drivers and uncertainties of HP in Switzerland, we invited stakeholders – from industry and business, universities and research institutes, NGOs and the public administration – to participate in a workshop. We asked them to fill in a questionnaire whose results were, along with information from our literature review, used to prepare that workshop. In the following, we provide an outline of the questionnaire and the workshop as well as the main findings from both.

3.1 The Questionnaire and Workshop Outline

The questionnaire was divided into three parts: The first part aimed at obtaining basic personal information. The second part included a set of questions regarding the five general themes that were identified in the above literature review: natural factors; technical factors; political, legal and social aspects; management aspects; and market aspects. For each group of factors/aspects, the participants were asked to rank the different factors and sub-factors on a five-point scale (very important, important, moderate, limited, insignificant, "no opinion") according to their importance for the development of Swiss HP in the short term (up to 2025) and in the long term (from 2025 to 2050). Moreover, the participants had the opportunity to name extra sub-factors and identify major drivers that were not covered in the questionnaire. The third part consisted of questions related to the impacts of HP on environmental, social and economic systems. It had a similar structure to the second part.

A link to the online questionnaire was sent to all the potential participants during the workshop registration process, and they were invited twice to fill in the questionnaire. A total of 35 people participated in the survey. Of the total number of participants, 16 reported that they were employed in the *Business/Industrial* sector, while 12 were employed at a *University or Research Institute*, 3 worked for the *Administration* sector, 1 for an *NGO,* and 3 clicked *Other* as their activity sector.

The workshop took place with 45 participants on March 12, 2015, in Berne, Switzerland. It aimed at opening debates and raising questions about the main drivers and uncertainties regarding the future of HP in Switzerland. In the first half of the workshop, input speeches by Christian von Hirschhausen (TU Berlin/DIW Berlin) and Atle Midttun (BI Norwegian Business School) highlighted the future of HP from a Central European and a Scandinavian perspective, respectively. Subsequently, the main results of the questionnaire were presented. We first highlighted particularly interesting findings, which were subsequently taken up as topics in the panel discussions on the short- and long-term aspects of HP in the second half of the workshop.

3.2 Results of the Questionnaire

The following section focuses on the main tendencies in the future development of Swiss HP that were identified from the survey responses. The main results of the questionnaire are shown in Figures 3 and 4. They reveal that, from the participants' points of view, all factors are evaluated as being generally important, but with a clear ordering:[9]

First, *political, legal and social aspects* along with *market aspects* are considered to be the most important issues, both in the short and the long term – even though there are slight shifts in evaluation between these time periods.

Second, the *management aspects* are considered very important at least in the short term. The importance of this factor does not seem to change between the short and the long term.

Finally, in the short term, the relative importance of *natural factors* seems to be fairly similar to that of *technical aspects*, as both are the least important, according to the participants' assessment. However, it appears that the *natural factors* are evaluated as becoming more important in the long term.

[9] We do not want to put too much weight on these results, as the number of observations is rather small, but nonetheless give a short overview.

Figure 3: Relative Influence of Factors on the Future of Swiss HP in the Short (ST) and Long Term (LT)

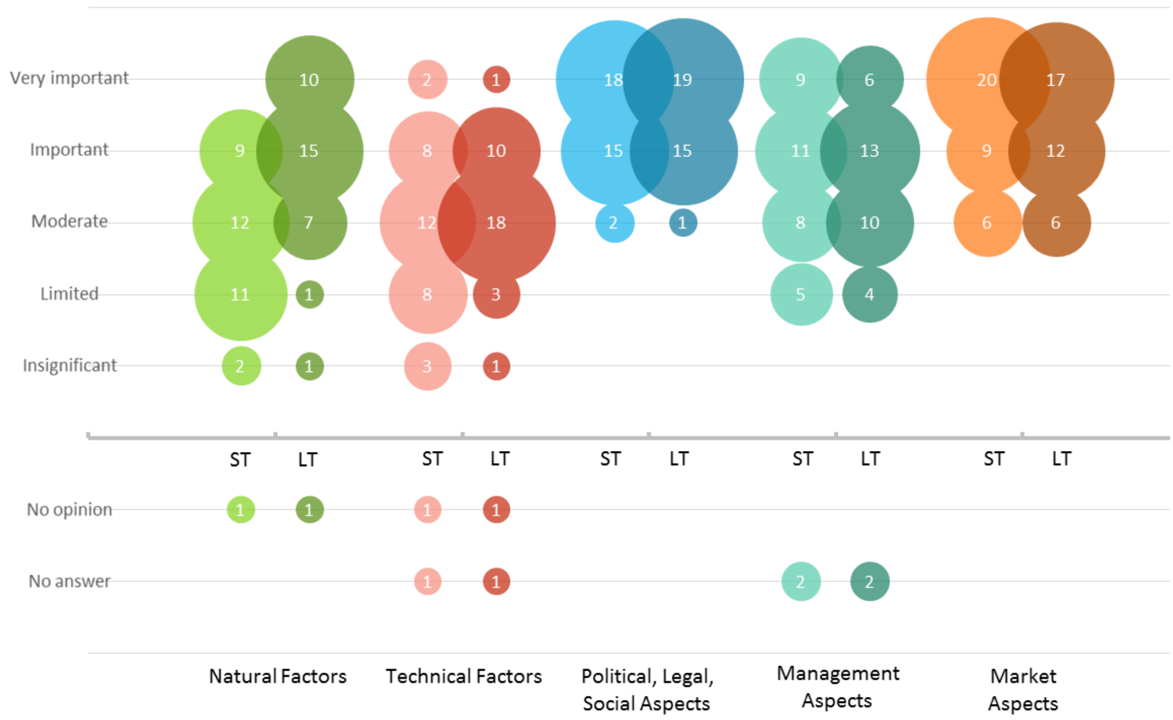
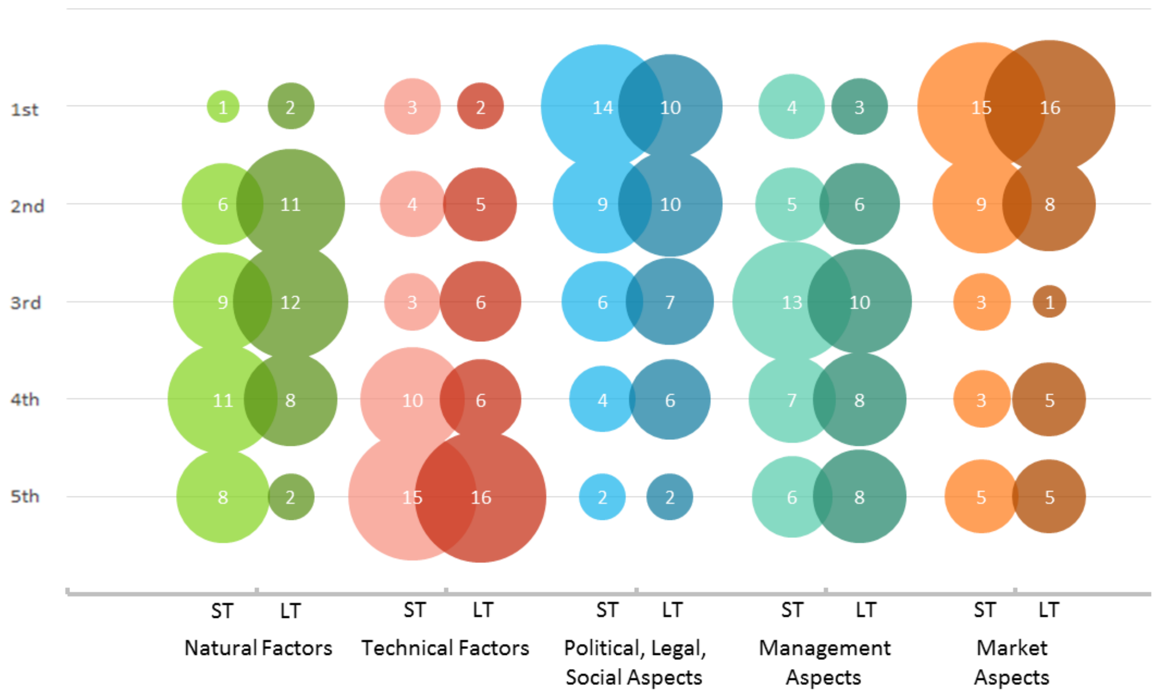


Figure 4: Comparative Ranking of Factors in the Short (ST) and Long Term (LT)



3.3 Results of the Workshop – Main Themes and Discussions

3.3.1 Climate Change

Climate change is mostly seen as a long-term issue. It is expected to have a major impact on HP, especially through changes in patterns of seasonality. According to representatives of the WSL (Swiss Federal Institute for Forest, Snow and Landscape), contemporary weather patterns have a large impact on the models used for improving the profitability of HP in the short term. Being considered as both an opportunity and a risk for HP, the impacts of climate change will most likely be site-specific. Climate change will particularly affect glaciers, and therefore mountain regions. But, it is also expected to impact the generation potential of run-of-river plants in the Central Plateau, as those plants will have lower water availability. However, regarding the short-term perspective, some participants raised concern about the over-estimation of the impacts of climate change on water catchments, which could potentially lead to an increase in regulations for the Swiss HP today (i.e., residual water restrictions).

3.3.2 Technical Change

In the discussion, it has been emphasized that technical factors are not considered as critical compared to the other aspects, since HP is largely seen as a mature technology with high technological standards. Only the flexibility of the Swiss HP plants is still recognized as an important issue with some technical problems remaining. However, this is considered to be less important compared to the other factors, since a high level of flexibility is already implemented in HP operations.

3.3.3 Legal Restrictions and Water Fees

According to some participants, the Swiss energy system tends to discriminate against large hydro plants, since the industry suffers from tight legal restrictions; i.e., residual water-flow restrictions that can potentially affect HP plant operations and therefore curtail beneficial opportunities. In addition, Swiss HP is subject to water fees (indirectly affecting operation costs and the returns on investment) and does not benefit from any subsidies.

The water fees, especially, are seen as discriminating against Swiss HP compared to other energy technologies and electricity imports from other countries. According to the participants, water fees account for approximately 35% of the operation costs of hydropower.[10] The resulting revenues currently go fully to the cantonal authorities (e.g., Ticino) or are shared between the cantonal authorities and the municipalities (e.g., Valais and Grisons), depending on the cantonal legislation. The cantons have the opportunity to set the amount of the fee, within the cap fixed by the Confederation. In this regard, some stakeholders emphasized that this is an important issue of

[10] The water fee in Switzerland is set on a yearly basis, and is calculated following the theoretical power of an installation. Therefore, as a fixed cost, it does not correspond to a direct operation cost (variable cost). The approximation of 35% of the operation costs represents therefore the total water fees of a specific year divided by the total amount of hydroelectricity produced in the same year that the fee accounts for.

governance. They raised the idea of restructuring the redistribution mechanism, either by reducing or eliminating the water fees and introducing, for example, a mechanism for auctioning concessions, or by reinvesting the revenues from water fees directly in the HP industry.

3.3.4 Investments Costs

An international comparison indicates that investments in Swiss HP may be more challenging, for two main reasons. First, the higher price level in Switzerland influences the relative costs of investments and HP technologies. The second point concerns safety and technological standards, which are perceived as higher in Switzerland than in other countries. This aspect is seen as increasing the cost of the required investments. Moreover, the issue of the amortization of large-scale HP infrastructure imposes a burden on current Swiss HP operations.

3.3.5 Market Constraints, Developments and Expectations

The current prices of electricity on the European market are largely seen as a major challenge for the promotion of HP in Switzerland. Indeed, the opinion is strongly supported, as voiced in the workshop, that the recent conjunction of relatively high HP costs (especially investment costs and water fees) and the recent collapse in electricity prices on the European market have made the Swiss HP industry relatively unprofitable. In this regard, several stakeholders have reported financial losses in recent years, as financial benefits from HP generation were too low to cover total costs. Some of them accordingly emphasized the importance of protecting Swiss HP from the fall in electricity market prices, as they are currently below the threshold of profitability for the Swiss HP industry.

Furthermore, electricity markets are characterized by uncertainty. The workshop participants perceived a high degree of uncertainty regarding future developments in the HP market, especially regarding the future of both electricity demand and market prices. However, while the participants envisage a positive relationship between increasing demand and increasing prices in the future, the uncertainty remaining in the market is expected to reduce future returns. Indeed, uncertainty increases the pressure on interest rates and returns on investment in the HP industry. Lastly, markets and especially market prices are not expected to change in the coming years.

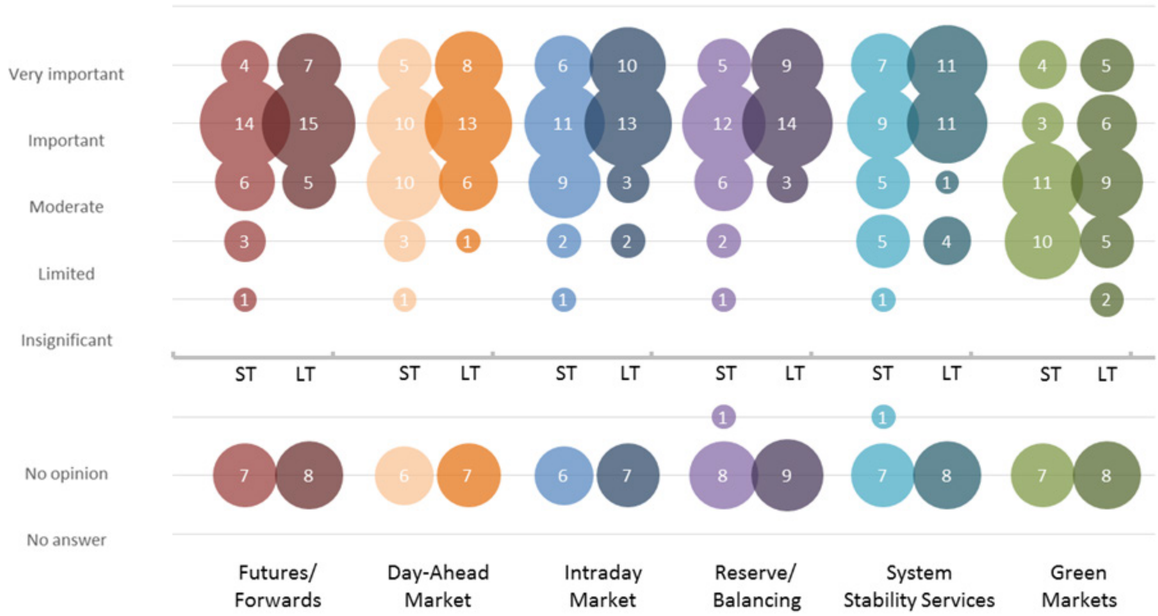
3.3.6 Market cycles and time constraints

The above issues (especially legal restrictions, investment costs and market constraints) result in a complex but intrinsic relationship between the markets prices and general costs of HP in Switzerland. The participants agreed that this is characterized by a cyclical pattern over time. Indeed, the current lack of profitability in the Swiss HP industry and the uncertainty on the market have led to a curtailment of investment in HP plants, even though a technical potential for HP capacity extension is acknowledged by the stakeholders. Moreover, the overcapacity on the electricity market, which partially results in low prices, reinforces the current situation in which no new capacity is needed, or encouraged. However, if new capacity is needed in the future (as the models indicate, by 2030) then prices will most likely rise and investments will be encouraged again. According to some participants, in such a case, new investments and their financing must be planned, or at least discussed, now. This is seen as a major problem that is likely to cause a delay between the acquisition of new investment, and the need to implement the new capacity.

3.3.7 Green Markets

In contrast to other markets, the green market issue was perceived differently (Figure 5). The current legal requirement that power producers provide a Guaranty of Origin (GoO; see Section 2.5) for the electricity generated by power plants with an output of 30kVA or more (Swissgrid 2014a) has created a market for green electricity. However, in the current Swiss context, the participants assessed that consumers are unwilling to pay a higher price for electricity from renewable sources such as HP. This is the reason why some stakeholders consider that demand-side regulation would be necessary to drive the green energy market.

Figure 5: Influence of Markets on the Future of Swiss HP in the Short (ST) and Long Term (LT)



3.3.8 Social Acceptance

On one hand, some NGO representatives emphasized during the workshop that the "negative picture" that NGOs tended to have about large-scale HP plants has decreased. Currently, NGOs adopt a broader scale of the issue, given the requirements of Switzerland's Energy Strategy 2050. In this framework, HP is seen as playing a major role. On the other hand, although small HP plants (<10 MW) seem to be politically more accepted. Several participants, however, assessed that numerous small HP plants are likely to produce a larger negative environmental impact than one comparable large-scale HP plant in terms of capacity.

The social acceptance of HP may affect the regulation of each site in Switzerland, as some reservoirs have a minimum storage requirement so that the lake remains attractive for tourism. Yet, from a more global perspective, its social acceptance is a double-sided problem. In the workshop, participants particularly emphasized that a higher implantation of renewable energies (RES), including HP, will make them subject to lower social acceptance. At the same time, the non-implementation of additional RES capacities also suffers from low social acceptance.

3.3.9 Contextual Issues

Most of the discussion and themes addressed during the workshop were set within the scope of the larger context of the Swiss HP industry. Most of the participants see the revival of HP as a major opportunity for the Swiss energy sector in the long term, especially regarding the decrease in installed capacity in Switzerland resulting from the nuclear phase-out. However, short-term limitations, ensuing from the specific current situation, are seen as a major risk for the development of those opportunities.

In order to promote large-scale HP plants, suggestions have been made regarding the redesign or further adjustment of existing markets, which have to be better tailored for large HP plants. Moreover, the idea of introducing the additional value of flexibility within existing markets has been raised. In this regard, a distinction needs to be made between run-of-river (RoR) and storage HP plants regarding their respective roles in the markets. Some restrictions particularly apply to specific plants, such as, for instance, current restrictions for RoR that make it mandatory to run at base load. These restrictions can partially limit some plants' participation in the market.

4 Interpretation

In this Section, we provide an interpretation of the insights gained from our literature survey, questionnaire and workshop. The aim is to clarify which challenges are perceived to be most important by Swiss HP companies, policy makers and scientists. Following the structure of the workshop, we will differentiate (1) short-term challenges -- namely the current mismatch between market conditions and Swiss HP production costs and the related effects -- and (2) long-term challenges -- namely uncertainties about long-term developments as well as the necessary adjustment processes with regard to governance.

4.1 Short Term Challenges

One main insight from the questionnaire and workshop is that the current mismatch between low market prices and high production costs is perceived as the most pressing challenge for Swiss HP. This is reflected in the ongoing discussion about the potential need for support mechanisms to help Swiss HP counter the current market conditions (cf. Alder 2015; Mijuk 2015; Müller 2015). In the following, we investigate the different drivers behind this key challenge, namely market and cost aspects, and identify potential starting points for a deeper discussion on whether or not Swiss HP should receive additional policy support.

4.1.1 Market Aspects

The Swiss electricity market is embedded in the European electricity system and thus affected by the general developments that occur in neighboring countries. The direct influence of Switzerland or of Swiss companies on this development is perceived as negligible by the stakeholders. Consequently, the market-side of this challenge has to be viewed as more or less static/stable for the near future of Swiss HP.

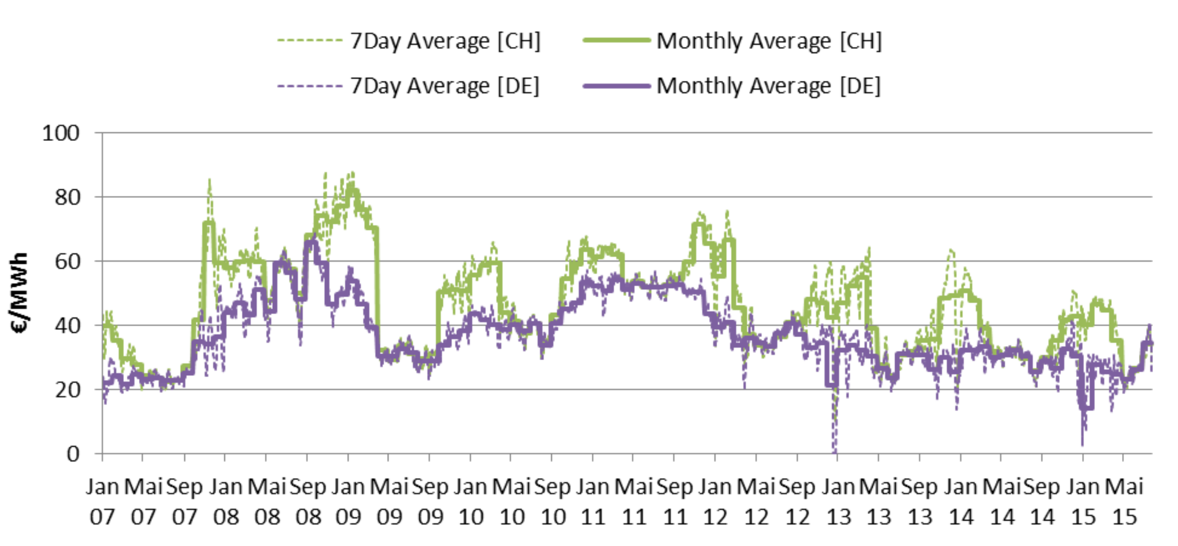
With the liberalization and restructuring of European electricity markets, wholesale prices have become increasingly important for electricity suppliers as this income source is used to refinance their power plant investments. Although the Swiss electricity market is not yet fully liberalized -- as small consumers are still subject to regulated tariffs -- the market price level is not only an important benchmark for Swiss HP companies, but also a major source of uncertainty. In the last decade, the Central European price level has experienced a rather volatile development. Following the economic crisis in 2008 and 2009, the previously high price level experienced a significant drop. Following an initial recovery, electricity prices have again been on the decline since 2011 and are consistently below 40€/MWh (see Figure 6).

There are two main reasons for this trend: First, emission permit prices have fallen from ca. 15€/t to about 5€/t since 2011, while at the same time coal prices have declined and natural gas prices remained rather stable. This has given German coal plants a cost advantage over gas-fired plants in Germany or in neighboring countries. Consequently, coal plants are the marginal units that determine the electricity wholesale price level keeping them at a low level. Second, the increased share of renewables leads to a general price decline on wholesale markets, the so called merit-order effect (see Cludius et al. (2014) for details and current estimates). At the same time, the increase in renewable generation is one reason why permit prices are so low (Böhringer and Rosendahl 2010).

These two developments have led to the price decline over the last years and are likely to persist over the coming years as well. The European Emission Trading System (ETS) faces an oversupply of permits due to the economic slowdown and increasing renewable shares. Although, the system could be adjusted to account for these developments by withdrawing permits and thereby increasing prices, the EU could only agree on backloading of permits to later years which would not alter the overall surplus (European Commission 2015). The share of renewable generation is also expected to further increase as most European states still have specific support mechanisms in place. This will prolong the current low price levels. Similarly, the already high share of solar generation will stabilize the moderate price spread between day and night and thereby reduce the potential revenues of PSP plants.

Even if prices are expected to change in the medium to long term, they are unlikely to change in the short term. As shown by the ‘Phelix Power Year Future’, electricity prices in 2016 will remain constant with current prices at around 40.5 €/MWh for the Phelix Peak Year Future and at around 32 €/MWh for the Phelix Base Year Future (EEX 2015c). Thus, in the short term, HP has to cope with low electricity price levels.

Figure 6: Average Spot Prices at the EEX



Data source: EEX prices retrieved via Bloomberg

Another important element of the current market challenges facing Swiss energy companies is the interaction between Switzerland and Europe. The goal of the European Union is to build an internal electricity market that includes all member states. To achieve this goal, several national electricity markets in the European Union have been linked in the last years in order to facilitate cross-border trade in electricity. In February 2014, the Nordic region and the Central Western European region were coupled with the United Kingdom and Ireland, the markets of the Czech Republic, Slovakia and Hungary were coupled, as well as Poland and Sweden, and Slovenia and Italy (European Commission 2014).

Regarding Switzerland, only the intra-day market is currently coupled with the German and French markets, while the other markets have not been coupled so far (Swissgrid 2014b). Due to the Swiss immigration referendum in February 2014, the negotiations about a preliminary bilateral electricity agreement between Switzerland and the EU were cancelled (see SRF 2015). If and when Switzerland will become part of the integrated European electricity market in the future is currently unclear. This increases uncertainty for Swiss generators, as the access to the EU market could be more difficult (e.g., participation in the explicit auctioning of transmission capacities) and costly compared to competing European companies.

The ongoing debate about capacity mechanisms is another current European development that impacts the Swiss market. It aims at creating a more certain environment for investments. Italy already introduced temporary capacity payments in 2004 as a reaction to a black-out in 2003 and currently debates whether the capacity payments should be replaced by reliability options. France is planning to implement capacity obligations to ensure security of supply. Germany introduced measures in 2012 to ensure security of supply by preventing unprofitable but system-relevant power plants from closure, and is therefore not opting for a capacity market. All this will have feedback effects on Swiss producers. If the capacity mechanisms allow cross-border participation, Swiss HP capacity could potentially benefit from additional payments (Thema Consulting Group et al. 2013). However, if cross-border participation is not an option, Swiss generators could have a disadvantage compared to generators in countries with capacity remuneration mechanisms, since Swiss investments would have to be financed over the energy-only markets.[11] The latter would, in turn, be negatively impacted by the capacity mechanisms that would keep generation capacities in the market and thus wholesale prices low.

In sum, in the short-term no major changes in the electricity market are expected that could lead to a significant upward shift in the market price level or provide additional revenue options for Swiss HP. However, this is a problem for most conventional generators in Europe and not a predominantly HP-related issue. Addressing the initial causes of the current price decline would, on the one hand, require a change in the ETS to provide a proper internalization of the externalities of greenhouse gas emissions, and, on the other hand, require a mechanism to address the interaction between subsidized generation via market prices and the refinancing of non-subsidized generation. The former would require, first, that Switzerland joins the ETS, and, second, that it can convince the EU member states to adjust the mechanism. The later course of action would require, first, that Switzerland is able to identify if and how the interaction could be addressed, and, then, quantify how this interaction is impacted by the renewable energy support in the different European countries in order to design an adequate counter mechanism. Both of these requirements are rather unlikely scenarios.

4.1.2 Cost Aspects

The second side of this problem relates to the cost level that Swiss HP producers face. For large HP plants, the total production costs and the cost structures vary and are reported in the range between 3 to 10 Rp./kWh, with an average of 7 Rp./kWh, according to information provided by the Swiss Association of Energy producers (VSE 2014)[12], while the Swiss Federal Office of Energy (SFOE) reports an average of 5.6 Rp./kWh (SFOE 2014b). The data of the SFOE report is based on 58 power plants, provided by cantons and companies for the period from 2011 to 2013. Although the numbers are highly site-specific, it is obvious that for a large fraction of Swiss HP companies, the total cost level is above the current market price level (Table 1). However, it remains unclear how the reported costs of HP are calculated.

A more detailed HP costs discussion can be found in the final report of the cost structure and cost efficiency of Swiss HP provided by Filippini and Geissmann (2014). Using a broad database of annual reports over a period from 2000 to 2013 and different considerations about how to compute the costs of HP, the average costs structure is derived (Figure 7) with total cost levels ranging between 5 and 6 Rp./kWh.

[11] Switzerland could initiate its own capacity market to compensate such effects.

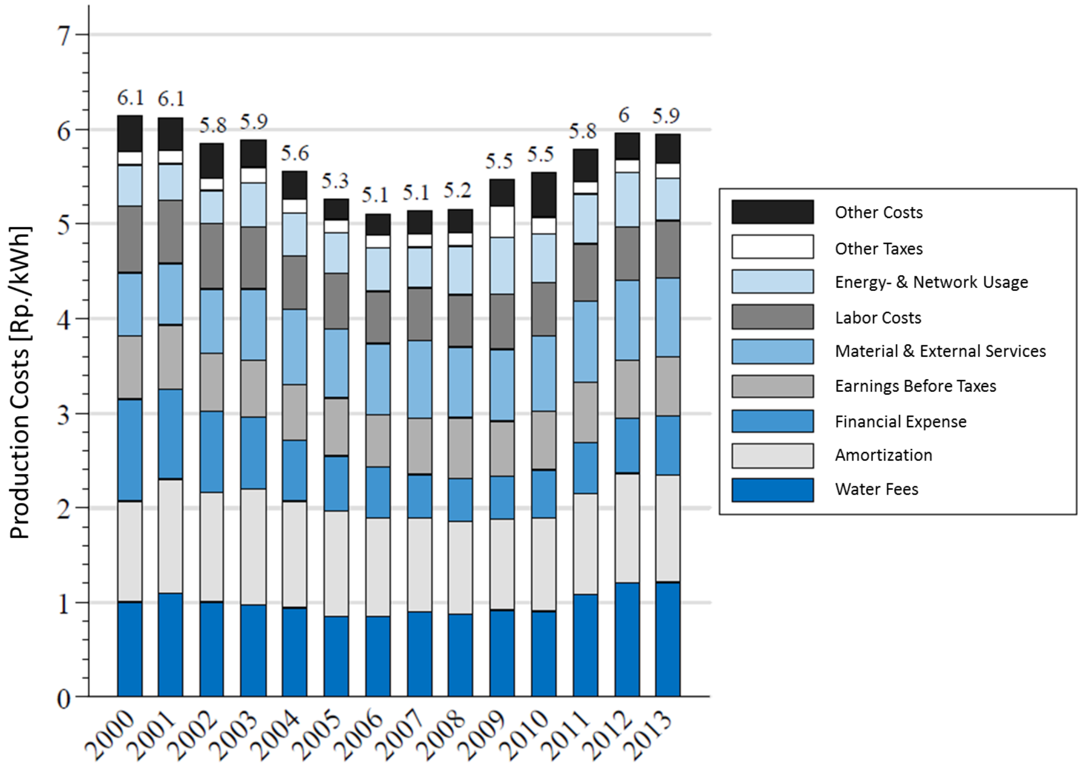
[12] These numbers date back to a survey conducted in 2009 (Ernst Basler + Partner 2009) and therefore do not necessarily hold anymore under the current market conditions.

Table 1: Costs per plant type in Rp./kWh

	All	RoR	Storage	Pumped Storage
Average	5.6	4.5	5.9	6.4
Min	2.1	2.1	3.9	4.8
Max	17.6	17.6	10.3	8.3

Data source: SFOE (2014b).

Figure 7: Average Cash-Based Costs



Source: Filippini and Geissmann (2014).

As indicated above, the cost spread of Swiss HP can be quite large, even though it can be expected that the costs depend on the type of plant. Next, we provide a more detailed evaluation based on a sample of Swiss plants. For each of the three main types (RoR, storage, and PSP), we have chosen one 'Partnerwerk' as a characteristic company and have analyzed the respective annual reports for 2012 and 2013.[13] The chosen companies are mainly influenced by one type of HP power production. For RoR plants, we choose the Rheinkraftwerke Säckingen AG. They have 15 full-time equivalents (FTE) and run a single plant on the river Rhine. Its stakeholders are German and Swiss electricity companies. For the storage power plant, we have chosen Maggia Kraftwerke AG. It has ten production sites and about 132 FTEs for the reported periods. For the PSP, we have chosen KWO Grimselstrom. The company has nine production sites, but about 350 FTEs. Their high personnel expenses can be

[13] We have chosen only Partnerwerke as they sell the energy they produce to companies that hold their shares, and these companies have a particular interest to obtain this energy for a low price. Thus, the interest rates on their equity are often lower than for plants which are integrated within a bigger company. This observation has been confirmed in SFOE (2014b).

explained, as they also maintain railways and hotels. We have tried to correct this anomaly by adjusting personnel expenses for our analysis by assuming that on average 15 people are needed per site. This corresponds to the figure for the single RoR plant reported here, and is above the value reported for Maggia Kraftwerke, who have 13,2 people per production site. Based on this assumption, the company would need 135 FTEs to operate their HP production, which is about 38% of their employees. We have corrected the reported personnel expenses by this percentage as calculated for each period.

Table 2 shows the comparison of the main cost blocks for the different companies.[14] For the RoR plant, the overall cost level is below the current market price level, and the three cost components (production, fees, financial costs) split nearly equally. The total costs of the storage plant are significantly higher than those of the RoR plant, while the relative share of fees is also higher and the share of production costs slightly lower. The PSP shows slightly higher costs than the RoR plant, but with a relatively similar cost structure as the storage plant.

Table 2: Costs per plant type in Rp./kWh

	RoR Rheinkraftwerke Säckingen		**Storage** Maggia Kraftwerke		**Pumped Storage** KWO Grimselstrom	
	2012	2013	2012	2013	2012	2013
Production Expenses	0.70	0.71	1.45	1.28	1.83	1.58
Fees	0.80	0.82	2.34	2.02	2.42	2.43
Financial Costs	0.70	0.80	1.70	1.57	1.75	1.97
Total Costs	2.20	2.33	5.48	4.87	5.99	5.98

Source: company reports

In total, our examples are within the range of SFOE (2014b) and Filippini and Geissmann (2014). As a simplification, it could be stated that the production costs of electric energy by HP are about 30% of what is generally reported as total costs, financial costs are in the same range, while fees represent about 40% of the total costs. This breakdown is often not well-reflected in the current discussions, as often only total costs are mentioned. Furthermore, it remains to be determined whether the costs which are not associated with production, such as dividends, as well as water fees and taxes, should be included in the calculation of the costs for HP. This is particularly relevant when it comes to the marginal cost and pricing.

By closely inspecting the above cost blocks, specific challenges can be identified: First, within the production costs of HP plants, personnel expenses typically represent a rather large block. Given the high salary level in Switzerland compared to its neighbors, this can present a competitive disadvantage that needs to be addressed by organization or management approaches or higher cost efficiency in other segments. Second, the high capital costs (namely for financing debt and capital depreciation) are mainly an effect of given regulations and management decisions. Due to the high initial investment

[14] A synthesis of the full cost reports is provided in Appendix A.

costs, large parts of the investments have been made using debt financing. This causes relatively high interest payments, even though the sites have already been in operation for several decades. Similar aspects can be observed for the depreciations. In all examples, depreciations are calculated linearly over the entire period of the concession; i.e., plants which have been in operation for 40 years, will still have 50% of their initial investment costs as liabilities (long-term borrowings) on their balance sheets. Due to the low electricity prices, companies have to make additional extraordinary depreciations, as their production sites still have higher values than the current value of their expected production capacities. Alpiq, for instance, had extraordinary depreciations in 2014 of about CHF 732 million, causing the company's negative result of about CHF 902 million (Alpiq 2014). Finally, the fees to be paid by HP companies for water usage have been designed in a regulated energy system and may need to be adjusted to address the challenges imposed by a volatile market environment (see Section 4.2.).

In sum, in the short term many of the Swiss HP companies have a total cost level that is higher than obtainable electricity prices on the wholesale market. While operational and financing cost elements can be impacted by management decisions and efficiency improvements, the impact of fees and concession structures would require a change in the current political and legal regulations for Swiss HP. Nevertheless, all measures require time to be implemented. From an economic perspective, none of the cost aspects represents a classic market failure that would be warrant direct support for Swiss HP via subsidies or other means; however, an adjustment of current regulatory requirements with respect to fees seems advisable.

Finally, it has to be considered that accounting-cost calculations are not identical to expenses. Therefore, comparing costs and market prices from a short-term perspective does not provide a picture that is economically correct, since the earnings covering imputed costs, which do not affect cash-flow, are available to the company for future investments. In fact, this is one of the objectives of depreciation. On the one hand, depreciation represents the decreasing value of existing assets, while, on the other hand, it allows the company to build resources for future investments.

4.2 Long-Term Challenges

Although the market conditions are considered the most pressing challenge for Swiss HP right now, there are also longer-term developments that require Swiss HP companies to reconsider their strategy. As the questionnaire and workshop highlighted, the future legal and regulatory framework is seen as the second big challenge for Swiss HP. This is strongly related to the market challenge, as part of the solution is seen in adopting a different regulatory framework. A current trend even seems to oppose market liberalization and calls for electricity companies to strengthen their vertical integration in order to protect HP, while addressing other goals, such as energy efficiency or public services. However, it is doubtful whether such a strategy could produce the expected or desired results. In contrast, long-term uncertainties stemming from natural or technical developments do not present immanent threats that need immediate action. In the long run, technical changes in the electricity sector may be very relevant and are recognized as important challenges. In the following sub-sections, we highlight the perception of long-term uncertainties and discuss some governance aspects.

4.2.1 Uncertainty and Long-Term Developments

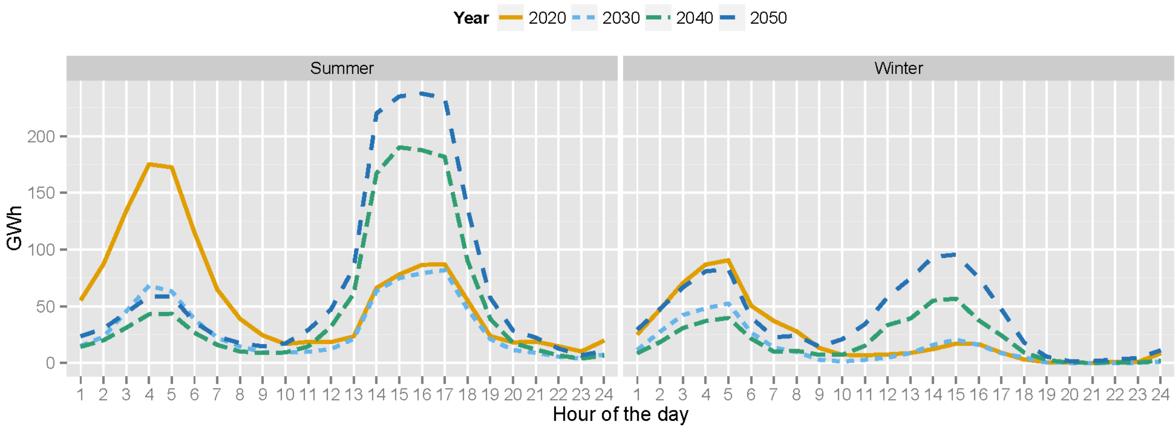
With the liberalization of the electricity market and the ongoing energy and environmental policy interventions, the market framework has shifted from being a relatively low-risk regulated framework to being a quite competitive environment with a high degree of uncertainty. This shift is naturally a challenge which will have to be faced by Swiss HP companies and Swiss electricity markets in the coming decades. Most electricity markets in Europe (including Switzerland) are in a phase of transition. In particular, the merit-order of competing energy technologies in the European Union as well as in the Swiss electricity market will undergo alteration until 2050, due to the announced nuclear phase-out of some countries, the envisioned shift away from carbon-intensive generation, and the increase in intermittent renewable energies.

On the one hand, the nuclear phase-out, a more stringent emission restriction, and economic growth could lead to higher electricity prices, as assumed in studies such as Frontier Economics and SwissQuant (2013) and SFOE (2013b). On the other hand, the further integration of renewables with zero or low variable costs is likely to keep spot prices low in the long run. Switzerland proposes to replace its nuclear plants with solar, wind, biomass, geothermal, and waste-fired generation as well as imports (SFOE 2013c; Swiss Federal Council 2013). Similarly, Germany proposes its future electricity supply to be based on renewable energies, which should cover 80% of its electricity demand in 2050 (BMWi 2015). Such changes in the merit-order will increase the volatility in prices and alter the daily production profile of HP. Schlecht and Weigt's (2015) model simulations, for instance, predict a significant shift in the pattern of pump storage usage up until 2050 (see Figure 8).

Beside the supply side, also electricity demand is likely to change in the medium and long term. On the one hand, electricity consumption per capita is expected to decline; e.g., by realizing energy efficiency potentials.[15] On the other hand, electricity demand may become more elastic in the future; e.g., due to smart metering which makes customers more price sensitive (SFOE 2013c; Swiss Federal Council 2013). This will also reduce the spread between peak- and off-peak prices. Thus, although the long-term market trend is clearly moving in the direction of a predominantly renewable electricity market, it is unclear what this transition will mean for HP in detail.

[15] According to the 'Botschaft zum ersten Massnahmenpaket der Energiestrategie 2050' (Dispatch regarding the first package of measures for Energy Strategy 2050) the average electricity consumption per capita and year should decrease by 3% by 2020 compared to the benchmark of 2000 (Swiss Federal Council 2013).

Figure 8: Daily Pump Storage Profile, 2020 to 2050



Source: Schlecht and Weigt (2015)

In addition to the long-term trends of the electricity market transition, the liberalization process is likely to lead to a more cyclical price pattern (Ford 1999). In an economic environment where investments are driven by volatile market prices instead of regulated tariffs, one can expect the classical model of the business cycle to occur with alternating phases of high and low prices that are matched by phases of over- and underinvestment. This will encourage HP companies, which in general face high investment costs and long-lived tangible and intangible assets, to develop proper financing strategies for a competitive and uncertain market environment.

However, so far, the whole market development is heavily impacted by policy interventions. As highlighted by the ongoing capacity market debate, there is a high degree of uncertainty in the actual design of future electricity markets. It is possible that existing markets might be adjusted in future to account for flexibility issues and thereby provide a competitive advantage for HP. Since storage HP plants, in particular, have a high degree of flexibility, they could benefit from changes in market design, such as the introduction of more flexible bid adjustments, reductions in the length of the bidding intervals or by allowing trade closer to delivery. The need to increase the flexibility of generation technologies was also a major concern of the HP stakeholders in our workshop. Moreover, new markets may become more important, such as the currently unattractive green markets; e.g., if customers become more conscientious about environmental issues or if green markets become more mandatory. In the National Electricity Market of Australia for example, tradable green certificates provide additional income streams for renewable energies and are thus an important driver for investments in new projects (MacGill 2010). However, the ‘greenness’ of HP is also debated (e.g., Bratrich and Truffer 2001).

Related to future market developments is the question of competing technologies and substitution possibilities. In the current market, HP is the cheapest generation technology to offer a high level of flexibility and thereby provide the needed counterpart for intermittent renewable generation. But this position may be challenged by developments of other sources of flexibility, e.g. storage technology, demand-side management, dispatched power plants and interconnection extensions (IEA 2011b). HP itself is a mature technology, and further improvements are likely to be minor. Innovation in other technologies, however, will reduce the current comparative advantage of HP and reinforce uncertainty in the long run. Moreover, new technologies may have a higher managerial flexibility than HP. This can become important in highly volatile markets.

In addition to market developments, climate change has direct impacts on HP, particularly through changes in precipitation, seasonal run-offs, and extreme events. The workshop participants were mostly concerned about the impact on seasonality, while most scientific studies focus on annual runoff and inter-annual variability. Given that hydro reservoirs directly help to manage the seasonal availability of water through their storage function, a research focus on the interplay between climate-induced changes in water availability and the resulting impact on seasonal hydro operation could be beneficial. In general, the impact of climate change is highly site-specific. However, many workshop participants expect that the changes in water availability will have a negative impact on production, especially for RoR plants.

4.2.2 Governance and Policy Adjustments

As highlighted in Figures 3 and 4 political, legal and social aspects are seen by the Swiss HP stakeholders as important, both for the short- and long-term development of Swiss HP. Furthermore, numerous challenges are related to the general governance framework of Swiss HP, as either new support mechanisms or adjustments to existing regulations are proposed as a solution.

Among the multitude of regulatory elements, the specification of water concessions and water fees are often the first mentioned in the ongoing debate. For Swiss HP companies, water fees represent an important segment of cost (see Section 4.1.2) and are seen by workshop participants as having a discriminatory effect on Swiss HP compared to other energy technologies and imports from other countries. In contrast, the resulting revenues substantially contribute to cantonal and municipal budgets.

Potential ideas suggested for reforming the water fee mechanism include reducing or even completely eliminating the fees, auctioning concessions, reinvesting revenues from water fees directly into the HP industry, or introducing fees based on resource rents. Naturally, the change will have an impact on the parties involved. Gaudard (2015) shows that the more flexible the concessions become, the more they increase in value. The potential change in the level or mechanism will require agreements at a federal, cantonal and local level and will involve a complicated political decision process that is likely to materialize within a long time frame, only. An important issue in this respect is the fairness between cantons, as any adjustment will involve potential budget reallocations between federal, cantonal and local authorities.

Beside the concessions and fees, the whole corporate structure of Swiss HP may change. The current structure, based on the so-called 'joint-venture' ('Partnerwerke') approach, defines how profits and costs are allocated between the hydro plants and the actual companies selling the energy on the market. A reform of water fees towards a revenue-based method could mean that a hydro plant which transfers its energy to a trading company at cost would not pay any fees, while a plant which was directly active in the market would have to pay the fees. The fact that Swiss HP covers about 60% of Swiss electricity generation presents a further challenge, as the future of HP largely defines the future of the entire Swiss electricity sector.

In general, the specific regulations in Switzerland regarding HP as well as companies' internal guidelines and interdependencies may indeed present a competitive challenge in the European context. While fees are perceived as a disadvantage from a company perspective, the long duration of Swiss concessions may present an advantage to the European market by providing long-term planning security, while the impact of the 'joint-venture' structure on competitiveness is rather unclear. We have no detailed assessments of these issues, which presents an opportunity for further research.

Another important regulatory aspect of HP concerns the ecological constraints that this technology faces. As explained in Section 2, restrictions on water levels and water flows are incorporated in new or renewed concessions and therefore highly interlinked with the ongoing debate about the potential reform of the concession mechanism. Given the higher renewable shares might result in an increased volatility of the electricity system, it may also incentivize HP plants to operate in a more fluctuating manner; e.g, with more frequent switches between full-load and no-load/low-load conditions. This in turn could lead to further ecological impacts that need to be addressed by new regulations; e.g., more specific requirements on artificial flooding or temperature peaking restrictions. Consequently, a better understanding of the ecological aspects of HP and the linkage between HP usage and environmental services will be needed to cope with these developments.

Finally, the social acceptance of HP seems to be decreasing. In the past, HP was accepted in the peripheral mountain regions thanks to the revenues and the jobs that it brought to these regions (Romerio 2008). However, in recent years energy infrastructure has been facing local opposition in many regions of Europe. While this is often related to conventional power plants and network investments, it currently encompasses renewable production, including HP as well. At the same time, changes towards renewable energy generation are generally supported, but lead to a mismatch between global and local acceptance (Kontogianni et al. 2014).

At the workshop some NGO representatives emphasized that the 'negative picture' which NGOs tended to have of large-scale hydropower plants has improved somewhat. In contrast, small HP plants (<10 MW) seem to be better accepted politically. However, several participants assessed that numerous small HP plants are likely to have a larger negative environmental impact than a large-scale hydro plant with the same output capacity. There is even no scientific consensus on this issue, especially because the impacts are site specific.

The social acceptance of HP has further consequences, as it is related to competing and synergetic uses of land and water between HP, tourism/recreation, agriculture and municipal/industrial uses. It can impose further operational restrictions; e.g., additional minimum storage requirements to provide an attractive lake panorama for tourism. Enhanced stakeholder involvement (participation) can foster a critical dialogue and improve regional acceptance of particular HP projects, and provide better grounds for comprehensive, flexible and transdisciplinary evaluations.

To conclude, in the long term, Swiss HP will face multiple market and environmental uncertainties. While generally recognized, most of these uncertainties are not perceived as pressing compared to the regulatory aspects of Swiss HP and their interplay with the short-term market challenges. Especially, the role of water concessions and fees plays a major role in the ongoing debate and is likely to have the largest impact on the long-term development of Swiss hydropower, the refinancing of existing plants, and investment in new plants. Devising a suitable new regulatory framework and determining how to adequately integrate the different stakeholder perspectives in its conception will be a major challenge both for scientists, the Swiss HP community, and Swiss politicians.

5 Summary and Conclusion

In this paper, we highlight the current status and future prospects of Swiss HP. Given the importance of HP for the Swiss electricity supply and consequently for the success of the envisioned Energy Strategy 2050, the current developments and uncertainties that HP has to face constitute a potential threat to the involved stakeholders. By reviewing the influencing factors that affect both the current and the future development of Swiss HP and discussing them with Swiss stakeholders, via a questionnaire and workshop, we are able to identify which challenges they consider should take precedence in being tackled by companies, policy makers and scientists.

Although there is a vast array of specificities to account for, the different concerns can be clustered into two main aspects: First, the market-imposed challenges, and second, the political and legal framework. Naturally, both aspects are highly interlinked as the market-driven aspects are partly a result of the current regulatory framework for Swiss HP, and potential solutions for these market challenges are considered to be issues of governance that stem from the political sphere. In contrast, natural and technical aspects are recognized, but are not considered pressing. In other words, while the relevant aspects of HP are holistic in nature, ranging from ecological, to technical, economic and social dimensions, the main concerns, as currently perceived, are predominantly socio-economic.

Regarding the market challenges, the general consensus is that neither Swiss energy companies nor Swiss energy politics has much influence on the underlying developments. The driving force behind the current low price levels are the increased share of renewable generation in Europe and low carbon prices, both of which are not likely to change in the coming years and are not under control of Swiss industry and politics. Naturally, the companies need to adopt as well as possible to the new circumstances by improving their performance, reducing costs, and potentially adjusting their financing and accounting structures. Similarly, the regulatory framework for energy companies and HP in particular needs to be adjusted to the new market realities. This translates into the second challenge regarding energy politics. The current regulations -- especially, water fees and concessions -- have been designed for a completely different market and policy environment. Thus, the Swiss authorities will need to account for the new realities of electricity markets which are now characterized by high volatility and uncertainty. It seems advisable that with the higher flexibility of the market environment, also the legal elements should become more flexible.

The adjustment of governance and policies is at least a medium-term process and involves a high level of uncertainty. The related changes are not likely to provide remedies for the current plight of Swiss HP. However, it still has to be investigated whether there is a justification for providing Swiss HP companies with direct additional help, above and beyond the general adjustments that are needed to cope with a risky market environment, and what form this support should take,.

Finally, an important issue in the whole discussion is the relationship between Switzerland and Europe. While the European market developments are the main driver of those market aspects that condition the future of Swiss HP, the continuing uncertainty about the integration of the Swiss electricity market in the ongoing process of European market coupling as well as Swiss HP's general access to the European market adds to the complexity of the issue. In addition, the stakeholders consider the differences in HP-specific regulations between Switzerland and European countries to be very important. But, this issue requires a thorough investigation.

In conclusion, we can say that the next steps that are necessary to provide answers to the threats and uncertainties identified above will have to focus on improving the performance and flexibility of HP, developing approaches to deal with high levels of uncertainty, adjusting the company internal and external regulatory framework, and investigating the interplay between Switzerland and Europe. Especially, the third and fourth point will require a comprehensive stakeholder process, as changes in the concession and fee regulations, in particular, will have significant impacts on revenue distributions between companies, federal, cantonal and local stakeholders. In other words, the issue of governance must be addressed and carefully investigated.

1 References

AEV (2009), *Volkswirtschaftliche Bedeutung der Wasserkraftwerke in Graubünden*, Amt für Energie und Verkehr Graubünden, Chur.

AG Wasserkraft (2011), *Strategie Wasserkraft Kanton Wallis*, Departement für Volkswirtschaft, Energie und Raumentwicklung des Kantons Wallis, Sion.

Alder, K. (2015), "Quotenmodell für Wasserkraft? Staatlich verordneter Strom aus Wasser", *NZZ am Sonntag*, 24.5.2015 (http://www.nzz.ch/nzzas/nzz-am-sonntag/staatlich-verordneter-strom-aus-wasser-1.18548268).

Alpiq (2014), *Alpiq Berichte: Geschäftsbericht 2014*, available at: http://www.alpiq.com/de/investoren/publikationen/publications.jsp.

ASAE (2012), *Potentiel de la force hydrolique en Suisse*, Fiche d'information, Juillet 2012, available at: http://www.swv.ch/fr/Downloads.

Banfi, S. and Fetz, A. (2006), "Regionale und volkswirtschaftliche Bedeutung der Wasserkraftnutzung im Kanton Graubünden", in Ramming, F. (Ed.), *Politische, rechtliche und wirtschaftliche Aspekte der hundertjährigen Wasserkraftnutzung in Graubünden*, Verlag Bündner Monatsblatt, Chur, pp. 139–159.

Banfi, S., Filippini, M. and Mueller, A. (2005), "An estimation of the Swiss hydropower rent", *Energy Policy*, Vol. 33 No. 7, pp. 927–937.

Banfi, S., Filippini, M., Luchsingr, C. and Mueller, A. (2004), *Bedeutung der Wasserzinse in der Schweiz und Möglichkeiten einer Flexibilisierung*, vdf Hochschulverlag, Zürich.

Beniston, M. (2012), "Impacts of climatic change on water and associated economic activities in the Swiss Alps", *Journal of Hydrology*, 412-413, pp. 291–296.

BMWi (2015), "Erneuerbare Energien: Sonne, Wind & Co.", available at: http://www.bmwi.de/DE/Themen/Energie/Erneuerbare-Energien/sonne-wind-und-co.html (accessed 22 July 2015).

Böhringer, C. and Rosendahl, K.E. (2010), "Green promotes the dirtiest: On the interaction between black and green quotas in energy markets", *Journal of Regulatory Economics*, Vol. 37 No. 3, pp. 316–325.

Bond, A., Morrison-Saunders, A. and Pope, J. (2012), "Sustainability assessment: The state of the art", *Impact Assessment and Project Appraisal*, Vol. 30 No. 1, pp. 53–62.

Bratrich C. and Truffer B. (2001), *Green Electricity Certification for Hydropower Plants: Concept, Procedure, Criteria,* Green Power Publications 7.

Breeze, P.A. (2014), *Power generation technologies,* Second edition, Newnes, Oxford.

CH2014-Impacts (2014), *Toward Quantitative Scenarios of Climate Change Impacts in Switzerland*, OCCR, FOEN, MeteoSwiss, C2SM, Agroscope and ProClim, Bern.

Cheng, C., Shen, J., Wu, X. and Chau, K. (2012), "Short-Term Hydroscheduling with Discrepant Objectives Using Multi-Step Progressive Optimality Algorithm", *Journal of the American Water Resources Association*, Vol. 48 No. 3, pp. 464–479.

Cludius, J., Hermann, H., Matthes, F.C. and Graichen, V. (2014), "The merit order effect of wind and photovoltaic electricity generation in Germany 2008–2016: Estimation and distributional implications", *Energy Economics*, Vol. 44, pp. 302–313.

CommGAP (2009), *Multi-Stakeholder Dialogue*, Communication for Governance & Accountability Program, World Bank, Washington DC.

Cuppen, E. (2012), "Diversity and constructive conflict in stakeholder dialogue: Considerations for design and methods", *Policy Sciences*, Vol. 45 No. 1, pp. 23–46.

EAWAG (2011), "Wasserkraft und Ökologie - Faktenblatt", available at: http://www.eawag.ch/de/beratung/wissens-und-technologietransfer/publikationen-fuer-die-praxis/.

EEX (2015a), "Strom Terminmarkt", available at: http://www.eex.com/de/produkte/energie/strom/power-terminmarkt (accessed 23 July 2015).

EEX (2015b), "Herkunftsnachweise für Grünstrom", available at: http://www.eex.com/de/produkte/umweltprodukte/herkunftsnachweise/handel (accessed 22 July 2015).

EEX (2015c), "Phelix Power Futures-EEX Power Derivatives", available at: https://www.eex.com/de/marktdaten/strom/terminmarkt/phelix-futures#!/2015/04/30 (accessed 3 June 2015).

Elbatran, A.H., Yaakob, O.B., Ahmed, Y.M. and Shabara, H.M. (2015), "Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: A review", *Renewable and Sustainable Energy Reviews*, Vol. 43, pp. 40–50.

ElCom (2014), "Europäischer Markt für die Schweiz wichtig", available at: https://www.news.admin.ch/message/index.html?lang=de&msg-id=55212 (accessed 23 July 2015).

EPEX SPOT (2015a), "European Power Exchange Price List.", available at: http://static.epexspot.com/document/31018/EPEX%20SPOT%20Price%20List%20January%202015.pdf (accessed 13 April 2015).

EPEX SPOT (2015b), "Day-ahead-Auktion mit Lieferung in der Schweizer Regelzone", available at: http://www.epexspot.com/de/produkte/auktionshandel/schweiz (accessed 20 June 2015).

EPEX SPOT (2015c), "Intraday Markt mit Lieferung in der Schweizer Regelzone", available at: http://www.epexspot.com/de/produkte/intradaycontinuous/schweiz (accessed 22 June 2015).

EPEX SPOT (2015d), "Marktdaten Kontinuierlicher Intraday-Handel.", available at: http://www.epexspot.com/de/marktdaten/intradaycontinuous/intraday-table/-/CH (accessed 14 April 2015).

EPEX SPOT (2015e), "Marktdaten Day-Ahead-Auktion", available at: http://www.epexspot.com/de/marktdaten/dayaheadauktion (accessed 14 April 2015).

EPEX SPOT (2015f), "Marktkopplung ELIX: Einem einzigen europäischen Marktpreis entgegen.", available at: https://www.epexspot.com/de/Marktkopplung/elix_einemeinzigen_europaeischen_marktpreis_entgegen (accessed 15 April 2015).

Ernst Basler + Partner (2009), *Überblick finanzielle Kenngrössen der Schweizer Wasserwirtschaft*, Federal Office for the Environment, Bern.

European Commission (2014), *EU Energy Markets in 2014*, Publications Office of the European Union, Luxembourg.

European Commission (2015), "Structural reform of the European carbon market", available at: http://ec.europa.eu/clima/policies/ets/reform/index\textunderscore en.htm (accessed 24 July 2015).

Filippini, M. and Geissmann, T. (2014), *Kostenstruktur und Kosteneffizienz der Schweizer Wasserkraft*, Swiss Federal Office of Energy, Centre for Energy Policy and Economics, Zürich.

Fleten, S.-E. and Kristoffersen, T.K. (2008), "Short-term hydropower production planning by stochastic programming", *Computers & Operations Research*, Vol. 35 No. 8, pp. 2656–2671.

FOEN (2013a), "Restwasser", available at: http://www.bafu.admin.ch/wasser/13465/13486/14117/index.html?lang=de (accessed 9 April 2015).

FOEN (2013b), "Restwassersanierung", available at: http://www.bafu.admin.ch/gewaesserschutz/01284/01290/index.html?lang=de (accessed 9 April 2015).

FOEN (2013c), "Schwall- und Sunkbetrieb", available at: http://www.bafu.admin.ch/gewaesserschutz/04851/index.html?lang=de (accessed 9 April 2015).

FOEN (2014a), *Schweizer Klimapolitik auf einen Blick: Stand und Perspektiven auf Grundlage des Berichts 2014 der Schweiz an das UNO-Klimasekretariat*, Federal Office for the Environment, Bern.

FOEN (2014b), "Hydrologisches Jahrbuch der Schweiz 2013", *Umwelt-Zustand No.* 1411, p. 32.

FOEN, SFOE and ARE (2011), *Empfehlung zur Erarbeitung kantonaler Schutz- und Nutzungsstrategien im Bereich Kleinwasserkraftwerke*, Federal Office for the Environment, Swiss Federal Office of Energy and Federal Office for Spatial Development, Bern.

Ford A. (1999). Cycles in competitive electricity markets: A simulation study of the western United States. *Energy Policy* 27, 637-658.

Frontier Economics and SwissQuant (2013), *Bewertung von Pumpspeicherkraftwerken in der Schweiz im Rahmen der Energiestrategie 2050: Studie für das Bundesamt für Energie (BFE)*, Swiss Federal Office of Energy, Bern.

Gaudard, L. (2015), "Pumped-storage project: A short to long term investment analysis including climate change", *Renewable and Sustainable Energy Reviews*, Vol. 49, pp. 91–99.

Gaudard, L. and Romerio, F. (2014), "The future of hydropower in Europe: Interconnecting climate, markets and policies", *Environmental Science & Policy*, Vol. 37, pp. 172–181.

Gaudard, L., Gilli, M. and Romerio, F. (2013), "Climate Change Impacts on Hydropower Management", *Water Resources Management*, Vol. 27, pp. 5143–5156.

Gaudard, L., Romerio, F., Dalla Valle, F., Gorret, R., Maran, S., Ravazzani, G., Stoffel, M. and Volonterio, M. (2014), "Climate change impacts on hydropower in the Swiss and Italian Alps", *Science of The Total Environment*, Vol. 493, pp. 1211–1221.

Georg, J., Holik, H., Ramsauer, D., Rohrer, D. and Wolter, H. (2013), *Markt- und Wettbewerbsanalyse für den Bericht des BFE zu den Massnahmen des StromVG und der Strom VV nach Art 27 Abs. 3 StromVV*, BET Dynamo Suisse, Zofingen.

Glachant, J.-M., Saguan, M., Rious, V., Douguet, S. and Gentzoglanis, E. (2014), *Regimes for granting rights to use hydropower in Europe*, European University Institute, Florence.

Grijalva, S. and Tariq, M.U. (2011), "Prosumer-based smart grid architecture enables a flat, sustainable electricity industry", *Innovative Smart Grid Technologies (ISGT), 2011 IEEE PES*, pp. 1–6.

Hediger, W. (2010), "Welfare and capital-theoretic foundations of corporate social responsibility and corporate sustainability", *The Journal of Socio-Economics*, Vol. 39 No. 4, pp. 518–526 [reprinted in "Economics of Corporate Social Responsibility", McWilliams A. (ed.), The International Library of Critical Writings in Economics, Edward Elgar, Cheltenham, UK].

Hernández, J.G., Schleiss, A. and Boillat, J.L. (2011), "The Decision Support Tool MINDS for Flood management in the Upper Rhone River", *Proceedings of the 34th IAHR World Congress*, pp. 1929–1936.

Hill Clarvis M., Fatichi, S., Allan, A., Fuhrer, J., Stoffel, M., Romerio, F., Gaudard, L., Burlando, P., Beniston, M., Xoplaki, E. and Toreti, A. (2014), "Governing and managing water resources under changing hydro-climatic contexts: The case of the upper Rhone basin", *Environmental Science & Policy*, Vol. 43, pp. 56–67.

IEA (2002), *Environmental and health impacts of electricity generation: A Comparison of the Environmental Impacts of Hydropower with those of Other Generation Technologies*, International Energy Agency, Paris.

IEA (2011a), *Harnessing Variable Renewables: A guide to balancing challenge*, International Energy Agency, Paris.

IEA (2011b), *Technology Roadmap: Smart Grids*, International Energy Agency, Paris.

IEA (2012), "Technology Roadmap Hydropower", available at: http://www.iea.org/roadmaps/ (accessed 14 October 2014).

IfnE (2007), *Ermittlung des Stromgroßhandelspreises im Schweizer Strommarkt: Untersuchung im Auftrag des Bundesamtes für Energie*, Swiss Federal Office of Energy, Bern.

IHA (2010), *Hydropower Sustainability Assessment Protocol*, International Hydropower Association, London.

Joskow, P.L. (2008), "Capacity payments in imperfect electricity markets: Need and design", *Utilities Policy*, Vol. 16 No. 3, pp. 159–170.

Kaptein, M. and van Tulder, R. (2003), “Toward Effective Stakeholder Dialogue”, *Business and Society Review*, Vol. 108 No. 2, pp. 203–224.

Kontogianni, A., Tourkolias, C., Skourtos, M., and Damigos, D. (2014), “Planning globally, protesting locally: Patterns in community perceptions towards the installation of wind farms“, *Renewable Energy*, Vol. 66, pp. 170-177.

Kt. Graubünden (2012), *Bericht über die Strompolitik des Kantons Graubünden: Botschaft der Regierung an den Grossen Rat* Heft Nr. 6/2012-2013, Chur.

Kumar, A., Schei, T., Ahenkorah, A., Caceres Rodriguez, R., Devernay, J.-M., Freitas, M., Hall, D., Killingtveit, Å. and Liu, Z. (2011), “Hydropower”, in Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S. and Stechow, C.v. (Eds.), *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*, Cambridge University Press, Cambridge, New York, pp. 437–496.

Labadie, J.W. (2004), “Optimal Operation of Multireservoir Systems: State-of-the-Art Review”, *Journal of Water Resources Planning and Management*, Vol. 130 No. 2, pp. 93–111.

Lehner, B., Czisch, G. and Vassolo, S. (2005), “The impact of global change on the hydropower potential of Europe: A model-based analysis”, *Energy Policy*, Vol. 33 No. 7, pp. 839–855.

Lueken, R. and Apt, J. (2014), “The effects of bulk electricity storage on the PJM market”, *Energy Systems*, Vol. 5 No. 4, pp. 677–704.

MacGill, I. (2010), “Electricity market design for facilitating the integration of wind energy: Experience and prospects with the Australian National Electricity Market”, *Energy Policy*, Vol. 38 No. 7, pp. 3180–3191.

Meister, U. (2012), “Anliegen einer internationalen und marktlichen Energiestrategie”, *Die Volkswirtschaft* 11-2012, pp. 27–31.

Mijuk, G. (2015), “Schweizer Wasserkraft: Im Subventionsfieber“, *NZZ am Sonntag*, 13.4.2015 (http://www.nzz.ch/nzzas/nzz-am-sonntag/schweizer-wasserkraft-im-subventionsfieber-1.18520447).

MIT (2011), *The future of the Electric Grid: An interdisciplinary MIT study*, Massachusetts Institute of Technology, Cambridge.

Müller, G.V. (2015), “Ungenügende Rentabilität: Wasserkraft unter Reformdruck“, *NZZ*, 20.6.2015 (http://www.nzz.ch/meinung/kommentare/systemrelevante-wasserkraft-1.18565846).

Müller, L. (2001), *Handbuch der Elektrizitätswirtschaft: Technische, wirtschaftliche und rechtliche Grundlagen,* Second edition, Springer, [S.l.].

Müller, M. and Schleiss, A. (2010), *Méthodes d’observation et de prévision de l’alluvionnement des rete- nues des aménagements de pompage-turbinage*, Office fédéral de l’énergie, Berne.

Okot, D.K. (2013), “Review of small hydropower technology”, *Renewable and Sustainable Energy Reviews*, Vol. 26, pp. 515–520.

Ott, W., Staub, C. and Leimbacher, J. (2008), *Grundlagen Wasserzinspolitik: Ökonomische Überlegungen: Schlussbericht 28. Oktober 2008*, Bern.

Peizhen, Z., Molnar, P. and Downs, W.R. (2001), “Increased sedimentation rates and grain sizes 2-4 Myr ago due to the influence of climate change on erosion rates”, *Nature*, Vol. 410 No. 6831, pp. 891–897.

Pérez-Díaz, J.I., Wilhelmi, J.R. and Sánchez-Fernández, J.Á. (2010), “Short-term operation scheduling of a hydropower plant in the day-ahead electricity market”, *Electric Power Systems Research*, Vol. 80 No. 12, pp. 1535–1542.

Pfammatter, R. (2012), “Neue Kompromisse braucht das Land”, *Pusch, Thema Umwelt*, 1/2012, pp. 10–11.

Pfammatter, R. and Piot, M. (2014), “Situation und Perspektiven der Schweizer Wasserkraft”, *Wasser Energie Luft*, Vol. 106 No. 1, pp. 1–11.

Pfaundler, M. and Keusen, M. (2007), “Veränderungen von Schwall-Sunk: Hydrologische Datenanalyse zur Charakterisierung von Schwall-Sunk Phänomenen in der Schweiz”, *Umwelt-Wissen No.* 0712, p. 110.

Plaz, P. and Hanser, C. (2008), *Strom - Bündner Exportprodukt mit Zukunft*, Wirtschaftsforum Graubünden, Chur.

Plaz, P. and Rütimann, M. (2010), *Elektrizitätswirtschaft Graubünden: Analyse der Wertschöpfungsflüsse*, Wirtschaftsforum Graubünden, Chur.

Rieder, P. and Caviezel, F. (2006), “Regionalwirtschaftliche Analyse zur Wasserkraftnutzung im Kanton Graubünden;”, in Ramming, F. (Ed.), *Politische, rechtliche und wirtschaftliche Aspekte der hundertjährigen Wasserkraftnutzung in Graubünden*, Verlag Bündner Monatsblatt, Chur, pp. 119–138.

Romerio, F. (2008), “Regional policy and hydroelectric resources: The case of a Swiss Mountain Canton”, *Journal of Alpine Research*, Vol. 96, pp. 79–89.

Scheidegger, E. (2012), “Wenn der Weg nicht das Ziel ist”, *Die Volkswirtschaft* 11-2012, p. 3.

Schlange, L.E. (2009), “Stakeholder Identification in Sustainability Entrepreneurship: The Role of Managerial and Organisational Cognition”, *Greener Management International*, Vol. 55, pp. 13–32.

Schlecht, I. and Weigt, H. (2015), “Linking Europe: The Role of the Swiss Electricity Transmission Grid until 2050”, *Swiss Journal of Economics and Statistics*, Vol. 151 No. 2, pp. 125–165.

Schleiss, A.J. (2013), “Reservoir sedimentation endangers the sustainable use of hydropower”, in Bobrowsky, P.T. (Ed.), *Encyclopaedia of Natural Hazards*, Springer, New York, pp. 901–905.

Schröder, A., Kunz, F., Meiss, J., Mendelevitch, R. and Hirschhausen, C.v. (2013), “Current and Prospective Costs of Electricity Generation until 2050”, *DIW Data Documentation*, Vol. 68, p. 104.

Scrieciu, S.S. (2007), “The inherent dangers of using computable general equilibrium models as a single integrated modelling framework for sustainability impact assessment. A critical note on Böhringer and Löschel (2006)”, *Ecological Economics*, Vol. 60 No. 4, pp. 678–684.

SFOE (2007), *Die Energieperspektiven 2035: Band 4 Exkurse*, Swiss Federal Office of Energy, Bern.

SFOE (2008), *Strategie Wasserkraftnutzung Schweiz*, Swiss Federal Office of Energy, Bern.

SFOE (2012a), *Wasserkraftpotenzial der Schweiz: Abschätzung des Ausbaupotenzials der Wasserkraftnutzung im Rahmen der Energiestrategie 2050*, Swiss Federal Office of Energy, Bern.

SFOE (2012b), *Schweizerische Elektrizitätsstatistik 2012*, Swiss Federal Office of Energy, Bern.

SFOE (2013a), *Schweizerische Elektrizitätsstatistik 2013*, Swiss Federal Office of Energy, Bern.

SFOE (2013b), *Perspektiven für die Grosswasserkraft in der Schweiz: Wirtschaftlichkeit von Projekten für grosse Laufwasser- und Speicherkraftwerke und mögliche Instrumente zur Förderung der Grosswasserkraft*, Swiss Federal Office of Energy, Bern.

SFOE (2013c), *Energieperspektiven 2050: Zusammenfassung*, Swiss Federal Office of Energy, Bern.

SFOE (2014a), *Potentiale zur Erzielung von Deckungsbeiträgen für Pumpspeicherkraftwerke in der Schweiz, Österreich und Deutschland*, Swiss Federal Office of Energy, Bern

SFOE (2014b), *Rentabilität der bestehenden Wasserkraft: Bericht zuhanden der UREK-N*, Swiss Federal Office of Energy, Bern.

SFOE (2015), *Wochenbericht: Speicherinhalt*, Swiss Federal Office of Energy, Bern.

Sigg, R. and Röthlisberger, W. (2002), *Der Wasserzins - die wichtigste Abgabe auf der Wasserkraftnutzung in der Schweiz, Berichte des BWG, Serie Wasser*, Vol. 3, Bundesamt für Wasser und Geologie, Bern.

SRF (2015), "EU gewährt Schweiz keinen Strom-Kompromiss", *SRF4 News*, 27.4.2015 (http://www.srf.ch/news/schweiz/eu-gewaehrt-schweiz-keinen-strom-kompromiss; last accessed on 14.08.2015).

Swiss Federal Council (2012), *Sustainable Development Strategy 2012-2015*, Bern.

Swiss Federal Council (2013), *Botschaft zum ersten Massnahmenpaket der Energiestrategie 2050 (Revision des Energierechts) und zur Volksinitiative 'Für den geordneten Ausstieg aus der Atomenergie (Atomausstiegsinitiative)'*, Bern.

Swissgrid (2014a), "Herkunftsnachweise und Stromkennzeichnung", available at: http://www.swissgrid.ch/swissgrid/de/home/experts/topics/goo.html (accessed 22 October 2014).

Swissgrid (2014b), "Engpassmanagement", available at: http://www.swissgrid.ch/swissgrid/de/home/experts/topics/congestion\textunderscore management.html (accessed 22 October 2014).

Swissgrid (2014c), "Regelpooling", available at: https://www.swissgrid.ch/swissgrid/de/home/reliability/power_market/control_pooling.html (accessed 22 October 2014).

Swissgrid (2015a), *Systemdienstleistungen*, Swissgrid AG, Frick.

Swissgrid (2015b), *Grundlagen Systemdienstleistungsprodukte*, Swissgrid AG, Frick.

Swissgrid (2015c), “Ausschreibungen”, available at: https://www.swissgrid.ch/swissgrid/de/home/experts/topics/ancillary_services/tenders.html (accessed 13 April 2015).

Swissgrid (2015d), “Active power losses”, available at: https://www.swissgrid.ch/swissgrid/de/home/experts/topics/ancillary_services/tenders/active-power-losses.html (accessed 14 April 2015).

SWV (2012a), *Sind Stauseen schädlich für das Klima?, Faktenblatt Juni 2012*, Schweizerische Wasserwirtschaftsverband.

SWV (2012b), *Heimfall und Neukonzessionierung von Wasserkraftwerken, Faktenblatt November 2012*, Schweizerische Wasserwirtschaftsverband.

Thema Consulting Group, E3M-Lab and COWI (2013), *Capacity Mechanisms in individual markets within the IEM*, European Commission, Brussels.

Toman, M.A., Lile, R. and King, D. (1998), *Assessing Sustainability: Conceptual and Empirical Challenges, Discussion Paper*, 98-42, Resources for the Future, Washington DC.

Voegeli, G., Baur, P., Giuliani, G., and Hediger, W. (2015), *Sustainability Assessment: State of the Arte and Propects for Hydropower Evaluation*, Center for Economic Policy Research, HTW Chur, Chur (forthcoming).

VSE (2012), *Beiträge der Erzeugungstechnologien zur Stromversorgung und Stabilität des elektrischen Systems*, Verband Schweizerischer Elektrizitätsunternehmen, Aarau.

VSE (2014), *Grosswasserkraft*, Verband Schweizerischer Elektrizitätsunternehmen, Aarau.

Wheeler, D. and Sillanpää, M. (1998), “Including the stakeholders: The business case”, *Long Range Planning*, Vol. 31 No. 2, pp. 201–210.

Wüest, A. (2012), *Potenzial und Grenzen der Wasserkraft, Eawag News*, Vol. 72, Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz.

Wyer, H. (2008), *Die Nutzung der Wasserkraft im Wallis: Geschichte, Recht, Heimfall*, Rotten-Verlag, Visp.

Zhang, X.-M., Wang, L.-P., Li, J.-W. and Zhang, Y.-K. (2013), “Self-Optimization Simulation Model of Short-Term Cascaded Hydroelectric System Dispatching Based on the Daily Load Curve”, *Water Resources Management*, Vol. 27, pp. 5045–5067.

Zheng, Y., Fu, X. and Wei, J. (2013), “Evaluation of Power Generation Efficiency of Cascade Hydropower Plants: A Case Study”, *Energies*, Vol. 6 No. 2, pp. 1165–1177.

Zhu, Y.-M., Lu, X.X. and Zhou, Y. (2008), “Sediment flux sensitivity to climate change: A case study in the Longchuanjiang catchment of the upper Yangtze River, China”, *Global and Planetary Change*, Vol. 60 3-4, pp. 429–442.

Appendix A: Synthesis of Company Balance Sheets

	Rheinkraftwerke Säckingen AG		Maggia Kraftwerke AG		KWO Grimselstrom [with adjusted personal]	
	2013	2012	2013/14	2013/12	2013	2012
Production [GWh]	431,6	437,1	1.495,6	1.346.8	2.255	2.312
Turnaround [mn CHF]	8,990	9,249	69,843	61,510	134,083	144,154
Average price [Rp/kWh]	**2,08**	**2,12**	**4,67**	**4,57**	**5,95**	**6,24**
Production [mn CHF]						
Material expenses	0,566	0,580	4,162	4,750	13,844	19,720
Staff expenses	1,708	1,796	13,673	13,386	14,601	14,271
Other expenses	0,778	0,676	1,255	1,355	7,212	8,299
Total expenses	3,054	3,054	19,090	19,492	35,658	42,291
Production [Rp/kWh]	**0,71**	**0,70**	**1,28**	**1,45**	**1,58**	**1,83**
Fees [mn CHF]						
Net fees			11,332	12,651	30,471	31,190
Public fees	3,538	3,494	18,936	18,836	24,334	24,697
Total fees	3,538	3,494	30,269	31,487	54,806	55,887
Fees [Rp/kWh]	**0,82**	**0,80**	**2,02**	**2,34**	**2,43**	**2,42**
Financial						
Depreciation	1,968	1,969	15,610	15,101	30,295	28,529
Negative financial result	1,483	1,095	7,923	7,747	14,138	11,838
Total financial	3,451	3,064	23,534	22,849	44,434	40,367
Financial costs [Rp/kWh]	**0,80**	**0,70**	**1,57**	**1,70**	**1,97**	**1,75**
Total Costs [Rp/kWh]	**2,33**	**2,20**	**4,87**	**5,48**	**5,98**	**5,99**
Taxes on profit [mn CHF]	0,285	0,225	6,177	6,100	1,966	1,932
others expenses [mn CHF]	0,013	0,013	0,048			
other earnings [mn CHF]	1,712	0,962	13,217	22,369	33,323	27,605
Balance sheet profit [mn CHF]	**0,360**	**0,360**	**3,941**	**3,950**	**30,541**	**31,279**
Balance sheet profit [Rp/kWh]	**0,08**	**0,08**	**0,26**	**0,29**	**1,35**	**1,35**

Source: company reports