Balancing Market Design and Opportunity Cost – The Swiss Case

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Abstract

The European energy systems are in transition. In the context of the energy transition also the balancing markets are adjusted in their design. The Swiss balancing market design changed in 2018 and is further adopted in the near future. In this paper, we have a look at the opportunity cost of hydropower for balancing provision under the past, current and future Swiss balancing market designs. Thereby, we use a hydropower operation model for a set of Swiss hydropower plants. Our results show that compared to the past balancing market design in Switzerland, significant cost savings can be achieved by adaptations in the balancing market design. In addition, we show how the opportunity cost dynamics may change in the future with an increasing share of variable renewable energies in the system.

1 Introduction

The European energy systems are in transition. In order to decrease CO2 emissions, many countries decided to increase their share of renewables energies (RES) while decreasing their share of fossil-fuel based technologies. In addition, countries like Germany or Switzerland decided after Fukushima to phase out from nuclear. With the energy transition, the system dynamics and requirements for security of supply change. With an increasing share of RES, energy production becomes less predictive, increasing the importance for ancillary services to secure a stable system operation. Out of these services, especially balancing is becoming more important to ensure that electricity demand and supply are equal in real time (Ocker et al., 2018a). Balancing power and energy are procured by the Transmission System Operators (TSOs) in the balancing markets. Today, balancing markets are mostly organized on national level and vary widely in their market design. Across Europe, no predominate balancing market design exist and market imperfections could be reveled in some countries in the past (Ocker et al., 2016). To remove market imperfections and to adjust to the energy transition balancing markets are changed in their designs in the last years and the near future. To harmonize national balancing market designs across Europe the European Commission (EC) published a guideline on electricity balancing. The guidelines by the EC aims at integrating national balancing markets in the future to increase competition and efficiency. In addition, the proposed changes in market design should enable market entry for new actors like variable renewable energies (vRES) or the demand side (European Commission, 2017).

The Swiss balancing market design has been adjusted in 2018 and is further adjusted in the next years. Thereby, the internalization of balancing markets, the price mechanism and market incentives, the synergies between products and the development of additional flexibility are addressed (Swissgrid, 2018a). In a previous paper (Schillinger and Weigt, 2019), we had a look at the past balancing market design[1] in Switzerland and showed that Swiss balancing market prices can be driven from the opportunity cost of hydropower. In this paper, we analyze the impact of the changes in the Swiss balancing market design on the opportunity cost of hydropower for providing balancing services. In addition, we have a look at future changes in the opportunity cost dynamics with an increasing share of vRES. To do so, we apply a hydropower operation model for a set of Swiss hydropower plants to derive their opportunity cost for balancing provision under the past, current and upcoming balancing market designs. Thereby, we use the Swiss market for secondary reserve (Sekundärregelleisung (SRL)) as an example for balancing markets while having a look only at balancing power and not energy. To analyze the future changes in the opportunity cost dynamics, we take into account future changes in the day-ahead market prices. Our results show that by changing the product design from symmetric to asymmetric products and from weekly to daily products, significant cost savings can be realized as compared to the past market design. Especially, the spring peak in the Swiss balancing market prices, which is

[1] In Schillinger and Weigt (2019), the Swiss balancing market design which was in place before June 2018 was taken into account.

driven by hydrological conditions, can be significantly reduced by adjusting the Swiss balancing market design. Our analysis of the future opportunity costs shows that the cost dynamics will change in the future due to an increasing share of vRES in the system.

The remainder of the paper is structured as follows: in section 2, we have a look into literature on balancing market design. In section 3, the changes in the Swiss balancing market design are shown. In section 4, the model and data used in this paper are explained. In section 5, the opportunity costs of hydropower for providing balancing power are illustrated. Section 6 concludes.

2 Literature Review

In literature many studies dealing with balancing markets. In this paper, we have a look at literature on balancing market design. In this regard, many studies having a look at balancing market design aspects of a specific country. Especially the German balancing markets are frequently considered in literature. Rammerstorfer and Wagner (2009) have a look at the minute reserves market in Germany and its reorganization in 2006. There results show that the reform, which included, e.g., an auction design based on a merit order or a reduction in the minimum bid quantity, lead to a decrease in level and volatility of the minute reserve prices. In addition, they show that the degree of integration between balancing and spot market has increased due to the reorganization of the market. Müsgens et al. (2012) analyze the timing of German balancing power markets. They show that shortening the length of the time period for which balancing power has to be provided increases the efficiency. Furthermore, holding auctions closer to the beginning of the bidding period can increase efficiency due to lower uncertainty in the spot prices. In a follow up study (Müsgens et al., 2014), the authors have a look at the scoring and settlement rule in the German balancing markets. They illustrate that a scoring rule based on capacity prices together with a settlement rule based on uniform pricing can lead to simultaneous efficiency on the spot and balancing markets. Hirth and Ziegenhagen (2015) also have a look at the German balancing market by reviewing the interaction between vRES and balancing. They show that while the capacity of vRES increased in the past years, the balancing requirements and cost decreased. Thus, balancing requirements are driven by a variety of factors and not just vRES forecast errors. In addition, the found that current balancing market design in Germany is not suitable for vRES participation and that the German imbalance settlement system does not provide enough incentives for accurate forecasts by vRES generators. Ocker et al. (2018b) analyze the bidding strategies under the German and Austrian balancing market design. By taking into account price expectations based on historic market outcomes in their game theoretic approach, they are able to identify bidding strategies which deviate from the optimal bidding strategies but which are observed in reality.

Beside the German balancing markets, also balancing markets of other countries like, e.g., Spain, Italy or Norway are studied in literature. Fernandes et al. (2016) study the participation of vRES under the Spanish balancing market design. Their study shows that the current Spanish market design may not be appropriate for the participation of vRES. The authors recommend to adopt the Spanish balancing market design in order to enable vRES participation. Main adaptations which are recommended are the separation of balancing power and energy products as well as up- and downward products. In addition, reducing the minimum bid quantity and shortening the product time resolution could reduce barriers for vRES participation. Gianfreda et al. (2018) analyze the impact of vRES on the Italian balancing market. They find that while balancing quantities decreased with an increase in vRES, balancing cost increased due to strategic behavior of conventional producers. While in Germany, balancing quantities and cost decreased with an increase in vRES, the authors explain the diverging observations in the German and Italian market by differences in the balancing market design. Aasgard and Roti (2016) analyze the cost of a hydropower system for delivering different types balancing reserves. By taking into account the Norwegian balancing market design, they determine the price of balancing reserves by the opportunity cost of hydropower in the day-ahead market. Their results show that spinning reserves are costly since they significantly change the day-ahead market production schedule. Furthermore, the symmetric nature of the primary reserves in the Norwegian market makes this type expensive.

Other studies in literature do not focus on the balancing markets of a single country but have a look at the differences in balancing market design across countries. The European Network of Transmission System Operators for Electricity (Entsoe, 2016) undertake a survey on balancing market design throughout Europe. The survey results show a high diversity among design elements (e.g., time resolution, symmetrical products, minimum bid size or settlement rule) across Europe. Similarly, Ocker et al. (2016) empirically study the power market characteristics, the balancing power market characteristics and the balancing auction characteristics of 24 European countries. There results show that there is no predominant balancing market design in Europe but the share of vRES, short-term flexibility and market coupling are identified as key drivers for differences in the balancing market designs. Ocker (2017) analyzes the balancing markets of Austria, Germany, Portugal, Romania, Spain, Switzerland and the Netherlands. They illustrate differences in market structure and auction design and the resulting optimal theoretical bidding strategies in each market. By comparing the theoretical bidding calculus with the empirical auction results, they found strong deviations. For five of the balancing markets, theoretical predictions of the optimal bidding behavior do not match empirical observations. Borne et al. (2018) review barriers to entry in the balancing markets for distributed energy resources (DERs) using France, Germany, Denmark and the United Kingdom (UK) as case studies. They find that for DERs to participate in the balancing markets it is necessary to adapt the market design regarding the rules of aggregation of DERs, the definition of the market products and the definition of the payment scheme. Regarding the definition of the market products, the minimum bid size, the time definition of the products, the distance to real-time reservation and the symmetry of products are key parameters which can influence DERs participation ability.

Since there are many different balancing market designs in Europe, other studies in literature deal with the adaptation and harmonization in market design across Europe or the integration of balancing markets. Farahmand and Doorman (2012) analyze the integration of balancing markets in Northern Europe. By comparing the current situation with individual national balancing markets with a fully integrated balancing market, they show that less activation of balancing power due to imbalance netting and the use of cheaper balancing resources in an integrated market can lead to significant cost savings. Doorman and van der Veen (2013) analyze different design options for cross-border balancing markets. Their evaluation of market designs by performance criteria shows that solutions in which balancing providers trade with TSOs reduce welfare while designs which are based on a common merit order list perform well. Dallinger et al. (2018) study the impact of a harmonized common balancing capacity procurement among Austria, Germany, Belgium and the Netherlands. Their model results show that a common and asymmetric procurement of balancing power as well as a shorter timing and product length reduces costs of balancing and supports the integration of vRES and DER. Ocker et al. (2018a) analyze the current German and future harmonized European balancing market design as proposed by the EC from a game-theoretical and empirical perspective. They show that a switch from pay-as-bid to uniform pricing as proposed by the EC does not incentivize bidders to bid their true cost but to bid below their cost. Comparing the model outcomes to the German market results reveals non-competitive prices resulting from the regular repetition of the auction and an invariant supply side.

With this paper, we contribute to literature by having a look at the Swiss balancing market design. So far, not many studies analyzed the Swiss balancing markets. While most of the other studies focus on electricity systems which are dominated by fossil-fuel based technologies, we focus on a hydropower dominated electricity system by using Switzerland as a case study. The changes in the Swiss balancing market design are in line with the balancing guidelines for harmonization of the EC (Swissgrid, 2018a). Thus, by having a look at the changes in the Swiss balancing market design, we also contribute with this paper to the literature on balancing market harmonization.

3 Swiss Balancing Market Design

Driven by the transformation of the European energy systems and a corresponding increase in RES, national and European regulations like the Swiss Energy Strategy 2050, the European clean energy package or the electricity balancing guidelines by the EC as well as the increasing digitalization in the energy sector, the Swiss balancing market design has been adopted in 2018 and is further adopted in the next years. Thereby, the Swiss balancing markets should be developed in four directions: the internationalization of the balancing markets, pricing mechanisms and market incentives, the use of synergies between products and the development of additional flexibility. All types of balancing reserves and energy, primary, secondary and tertiary, are addressed by the adaptation of the Swiss balancing market design. While the procurement and the call up of balancing energy will be increasingly coordinated by international cooperation, balancing power is mostly procured on national level (Swissgrid, 2018a). In this paper, we focus on the adaptations regarding balancing power, more precisely the changes regarding secondary reserves. Adaptations regarding other balancing reserves and balancing energy are not considered in this paper.

In the SRL market, a first adaptation in market design was implemented in June 2018. Before June 2018, SRL was procured one week before the actual delivery period and awarded capacity had to be reserved for the length of one week. SRL capacity was tendered as a symmetric product, i.e., one product for up and downward regulation. The minimum bid size was 5MW and the maximum bid size per offer 50MW while stepwise offers were possible. Approximately 400MW of SRL capacity were requested by the Swiss TSO. Awarded capacity was remunerated by a pay-as-bid pricing mechanism while the market was cleared based on a cost minimization approach (Swissgrid, 2018a, 2017). With the adaptation of the SRL market design in June 2018 positive and negative SRL were split into individual products (i.e., asymmetric products). Thus, suppliers can now bid separately for positive and negative SRL. In addition, the maximum bid size per offer was increased to 100 MW and stepwise offers over both products are possible (Swissgrid, 2018a, 2018b). In 2019/ 2020 the Swiss SRL market design should be further adopted. While the procurement of asymmetric products is continued, daily products can be traded in addition to weekly products. Thus, it is possible to trade SRL the day before the actual delivery period. For how long SRL capacity has to be reserved by the suppliers in the daily SRL tenders is not yet defined. In this paper, we assume a reservation time of one day. In 2022, further changes in the Swiss SRL market design are envisaged. While most of the market and product structure will be analogous to the design in 2019/2020, the supply structure in the SRL market will be adopted to the "PICASSO" Project, an international platform for SRL procurement. In this context, the remuneration of awarded SRL capacity may change to a pay-as-cleared system instead of pay-as-bid (Swissgrid, 2018a).

In this paper, we focus on two main adaptations in the Swiss SRL market design, namely the change from symmetric to asymmetric products and the change from weekly to daily products. All other adaptations are not considered in detail in this paper. Table 1 summarizes the main changes in the SRL market which are considered in this paper. Additional details on the SRL market, its adaptations and the adaptations regarding the other balancing product types and markets can be found in Swissgrid (2018a).

Table 1: Adaptations in the market for secondary reserves in Switzerland which are considered in this paper (Swissgrid, 2018a).

	Past	Current	Future
Time frame	Until end of May 2018	From June 2018	From approx. 2019/ 2020
Timing	Previous week, for one week	Previous week, for one week	Previous week, for one week AND Day before, for unclear duration
Supply structure	Symmetric (SRL+-)	Asymmetric (SRL+ and SRL-)	Asymmetric (SRL+ and SRL-

4 Modelling framework

4.1 Model

To analyze the impact of the adaptations in the Swiss SRL market design on the opportunity cost for hydropower for providing SRL, we use a hydropower operation model. The model and opportunity cost logic which are applied in this paper are described in Schillinger and Weigt (2019). Out of the models described in Schillinger and Weigt (2019), we rely on the simplified basic model in this paper. Thus, trading options beyond the day-ahead market, uncertainty or head effects are not considered in the analysis at hand. The model used is linear and deterministic. The objective of the plant operator is to maximize its revenue in the day-ahead market taking into account generation and storage constraints. While in Schillinger and Weigt (2019) the model has weekly time horizon, we assume a time horizon of one year. Thus, the storage at the beginning and end of the year is defined by hydrological conditions which is why water values can be ignored. The model is defined such that it can be applied for single hydropower plants as well as cascades with multiple plants and reservoirs. If the plant or the cascade is participating in the SRL market, the optimal generation schedule on the day-ahead market has to be adopted. In a symmetric balancing market, the plant has to be able to decrease its capacity which is why the plant has to be operated at least at the capacity level which was bid into the SRL market. At the same time, the plant has to keep enough capacity free to be able to increase its capacity by the SRL quantity. In an asymmetric market, the capacity is constrained only in one direction, either positive or negative. In addition to the capacity constraints, the plant needs to be able to deliver its SRL obligations in terms of energy if the TSO requires balancing energy to balance the system. Thus, if the plant participates in the SRL market it has to reserve enough water in the reservoir to be able to deliver balancing energy for the length of the bidding period (i.e., week or day). To derive the opportunity cost for providing SRL in a specific week or day, we first run a model where the plant or cascade is optimized on the day-ahead market only. Second, we run a model in which capacity is bid into the balancing market for one week or day of the year and the corresponding yearly generation schedule for the day-ahead market has to be adopted. By comparing the yearly revenue without and with balancing market participation in a specific week or day, we are able to calculate the opportunity costs of that week or day by the yearly revenue difference (Schillinger and Weigt, 2019).

4.2 Input data

To analyse the opportunity cost of hydropower for SRL under changing market designs, a set of Swiss hydropower cascades was chosen. The eight cascades which were selected should be representative for the whole population of Swiss storage hydropower plants, ranging from smaller plants with a simple topology to bigger cascades with a complex structure. While we focus on storage hydropower in this paper, the cascades which are considered here can include run-of-river (RoR) plants in addition to storage plants since pure storage hydropower cascades are rare. The hydropower plants and data used in this paper are the same as in Schillinger and Weigt (2019). The cascades differ, e.g., in the number of plants and reservoirs per cascade, the cascade structure or the turbine and storage capacity. In the results section, we focus on two of the cascades, a single site (cascade nr.3) which has a single plant and reservoir and a multi site (cascade nr.7) representing a bigger cascade with multiple plants and reservoirs. Table 2 summarizes the main characteristics of the single and multi site. Data and results on the other cascades can be found in the appendix.

Table 2: Data of selected hydropower cascades. Based on Balmer (2006), Garrison et al. (2018), Schlecht and Weigt (2014) and SFOE (2018).

	single site	multi site
Cascade Nr.	3	7
Turbine Capacity (MW)	60	397
Avg. Production (GWh/Year)	119	1036
Storage Capacity (Mio. m3)	40	204
Number of Plants	1	4
Number of Reservoirs	1	2

Beside hydropower data, price data are required as model input. Historic day-ahead market prices for Switzerland are based on EPEXSPOT (2019). Beside the year 2015, the years 2013 and 2014 are partly analyzed for some of the cascades (see appendix). In addition to historic years, day-ahead market prices for the years 2030 and 2050 are taken into account in order to derive potential changes in the SRL price dynamics in the future. Day-ahead market prices for 2030 and 2050 are simulated prices based on Schlecht and Weigt (2015). Figure 1 shows the day-ahead price dynamics for 2015, 2030 and 2050.

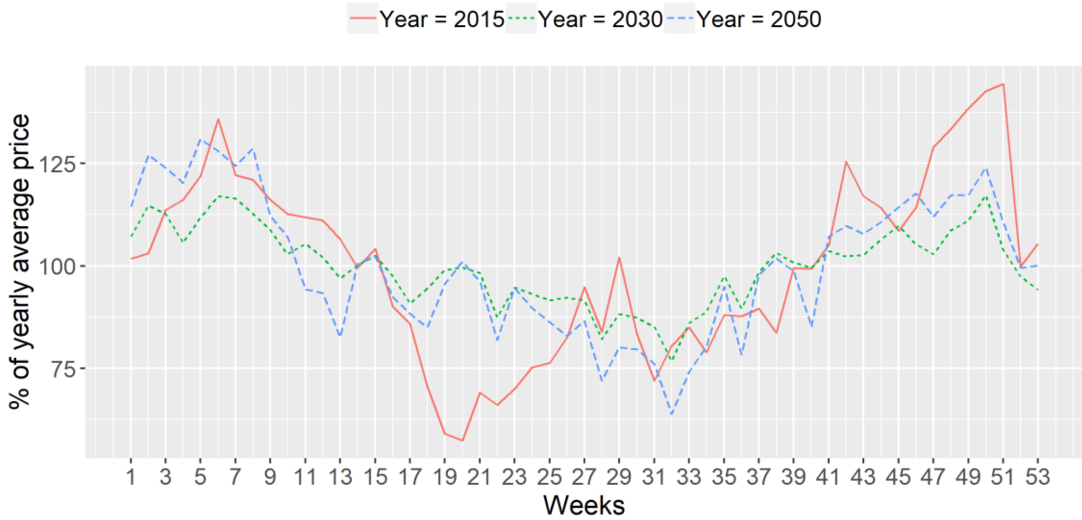

Figure 1: Day-ahead price by week relative to yearly average day-ahead price. Prices for 2015 are from EPEXSPOT (2019), prices for 2030 and 2050 are based on Schlecht and Weigt (2015).

As illustrated in Figure 1, day-ahead price dynamics will change in 2030 and 2050 driven by a significant increase in vRES and a decrease in fossil-fuel based technologies in Europe. While the Swiss prices in 2015 are more defined by hydrological conditions (i.e., minimum in May when the inflows are high), future price dynamics are more influenced by the infeed of Wind and Solar in Europe. Especially the increase in Solar will decrease prices in summer (i.e., minimum prices in 2030 and 2050 in August when Solar infeed is high).

5 Results

In the results section, we first have a look at the impact of a change from symmetric to asymmetric products on the opportunity cost of hydropower for providing SRL. Afterwards, the introduction of daily SRL products is analysed. These results are illustrated under historic conditions taking the year 2015 as example. After the historic analysis, future changes in the opportunity cost dynamics under the future SRL market design (i.e., asymmetric weekly and daily SRL products) are illustrated. In the results section, only the results for two cascades, a single and a multi site, are presented. Furthermore, we focus on the results for a SRL bid size of 30MW except in the illustration of the yearly costs. Results on additional historic years (2013 and 2014 for cascade nr. 3 and 7), additional cascades and SRL bid sizes can be found in the appendix.

5.1 Historic

5.1.1 Symmetric vs. asymmetric products

In June 2018, asymmetric weekly SRL products were introduced in the Swiss SRL market. Compared to before, firms or plants can now bid separately for positive or negative SRL. This shift from symmetric to asymmetric products has an impact on the cost of hydropower for providing these products. Figure 2 compares the yearly opportunity cost for separate bids for positive and negative SRL with the cost for symmetric SRL bids. Relative costs are illustrated for different SRL bid sizes and sites for the year 2015.

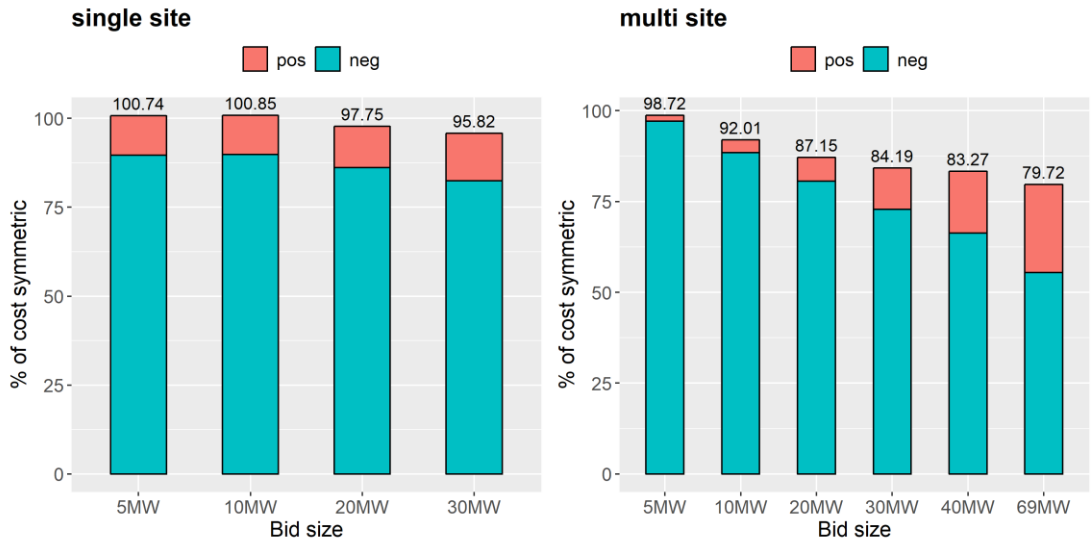

Figure 2: Cost per year for asymmetric weekly SRL relative to symmetric weekly SRL by bid size and cascade.

As shown in Figure 2, bidding separately for positive and negative SRL can reduce cost for hydropower plants or cascades to provide these products compared to a symmetric SRL provision. While at lower SRL bid sizes, cost for symmetric or asymmetric SRL provision are similar, cost reduction can be realized at higher SRL bid sizes. At low SRL bid sizes, SRL provision has only a limited impact on the day-ahead generation schedule. However, at higher bid sizes significant changes in the day-ahead generation schedule occur when providing SRL. Thus, cost reductions, which can be achieved by the introduction of asymmetric SRL products, increase with the increase in the SRL bid size. Comparing positive and negative SRL, the provision of negative SRL comes at a high cost for storage hydro power plants. While a storage hydropower plant would only produce in a few high price hours if just active on the day-ahead market, it has to run baseload at the offered capacity level for the whole week if participating in the negative SRL market. Such a change in the day-ahead market schedule would limit its possibility to benefit from high prices hours of the year since the water availability in the reservoir is reduced. For the provision of positive SRL, mostly the capacity level which can be bid into the day-ahead market is limited. Thus, the provision of positive SRL has a smaller impact on the day-ahead generation schedule which is why it can be provided at lower cost. However, comparing single to multi sites, it seems that at higher SRL bid sizes, the cost for providing positive SRL increase in the total cost share for multi sites. At higher bid sizes, also the provision of positive SRL becomes more constraining for the day-ahead generation schedule. At the same time, cost reductions in negative SRL are increasing for multi sites with higher SRL bid sizes. While the provision of negative SRL can be costly for storage hydropower plants, it can be provided at lower cost for RoR plants which are running baseload anyway. Since cascades can be bid as a portfolio of plants into the SRL market and mostly include RoR plants in addition to storage plants, multi sites can provide negative SRL at lower cost. In addition, multi sites have a higher flexibility in general, since they are able to coordinate their SRL obligations among the plants and reservoirs of the cascade (see also Schillinger and Weigt (2019)). By introducing asymmetric SRL products, multi sites can achieve higher cost reduction compared to single sites.

In general, hydropower is influenced by hydrological conditions throughout the year. Thus, also the opportunity cost for providing SRL and consequently the SRL prices are driven by hydrological conditions throughout the year. Therefore, Figure 3 shows the opportunity cost for 30 MW of SRL by site and SRL product in weekly time resolution.

Figure 3: Opportunity cost for 30 MW of weekly symmetric and asymmetric SRL by cascade.

As illustrated in Figure 3, opportunity cost for SRL and thus the SRL prices especially peak in spring. Since the storage reservoirs are empty at that time and the snow melt has not begun yet, water availability and consequently the flexibility of hydropower plants are low.

Providing SRL at that time comes at a high cost. Since the low runoff in spring does not just influence storage power plants but also RoR plants, bigger cascades have high opportunity cost during spring as well (see also Schillinger and Weigt (2019)). With the introduction of asymmetric SRL products, the spring peak still persists but at a lower level. Since the opportunity cost for positive and negative SRL are in sum (pos+neg) similar to the opportunity cost for symmetric SRL in all other weeks of the year, the reductions in the yearly cost as discussed before (Figure 2) can be traced back to a reduction in the opportunity cost in spring. This is also true for other SRL bid sizes (see appendix). Having a look at the individual products, not just the cost for negative SRL are relatively high in spring but also the cost for positive SRL. However, as discussed before, providing negative SRL is more costly for storage hydropower plants than the provision of positive SRL. As illustrated for the single site, especially for pure storage power plants, the provision of negative SRL is cheaper in times when the day-ahead market prices are high. If prices are high, the plant is producing in the day-ahead market and does not have to be started up just for the provision of negative SRL. At the same time, positive SRL is more costly if the prices are high, since the storage power plant cannot use its full capacity in the day-ahead market (see, e.g., week 6 and 50 and prices in chapter 4). For the multi site, the price impact is less obvious, since the cascade includes also RoR plants for which the generation is defined by inflows but not prices.

5.1.2 Daily products

In 2019/ 2020 daily asymmetric SRL products will be introduced in the Swiss SRL market. While the actual contract length (i.e., for how long capacity has to be reserved) is not yet defined, we assume a contract length of one day in this analysis. How the yearly opportunity cost change by the introduction of daily asymmetric products compared to symmetric weekly products is illustrated in Figure 4.

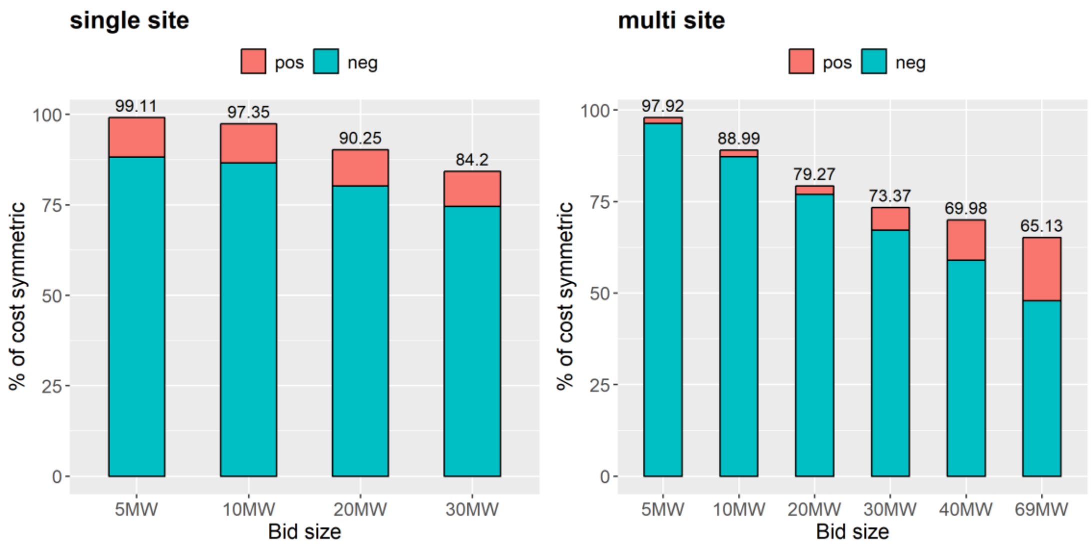

Figure 4: Cost per year for asymmetric daily SRL relative to symmetric weekly SRL by bid size and cascade.

By the introduction of daily SRL products, further cost reductions can be realized. Especially at higher SRL bid sizes, significant cost reductions are possible. At a bid size of 30MW for example, cost are approximately 15% (single site) respectively 25% (multi site) lower as compared to the cost of symmetric SRL products. Compared to weekly asymmetric SRL products, this is an additional reduction in cost by approximately 10%. By shortening the SRL contract length, SRL provision becomes less restrictive for hydropower. Compared to weekly SRL products, less loss in flexibility and less changes in the optimal generation schedule have to be accepted when providing SRL on daily basis.

Figure 5 shows the weekly opportunity cost for the single site for a bid size of 30MW by SRL product design. The daily opportunity cost for daily SRL products are illustrated as weekly average values.

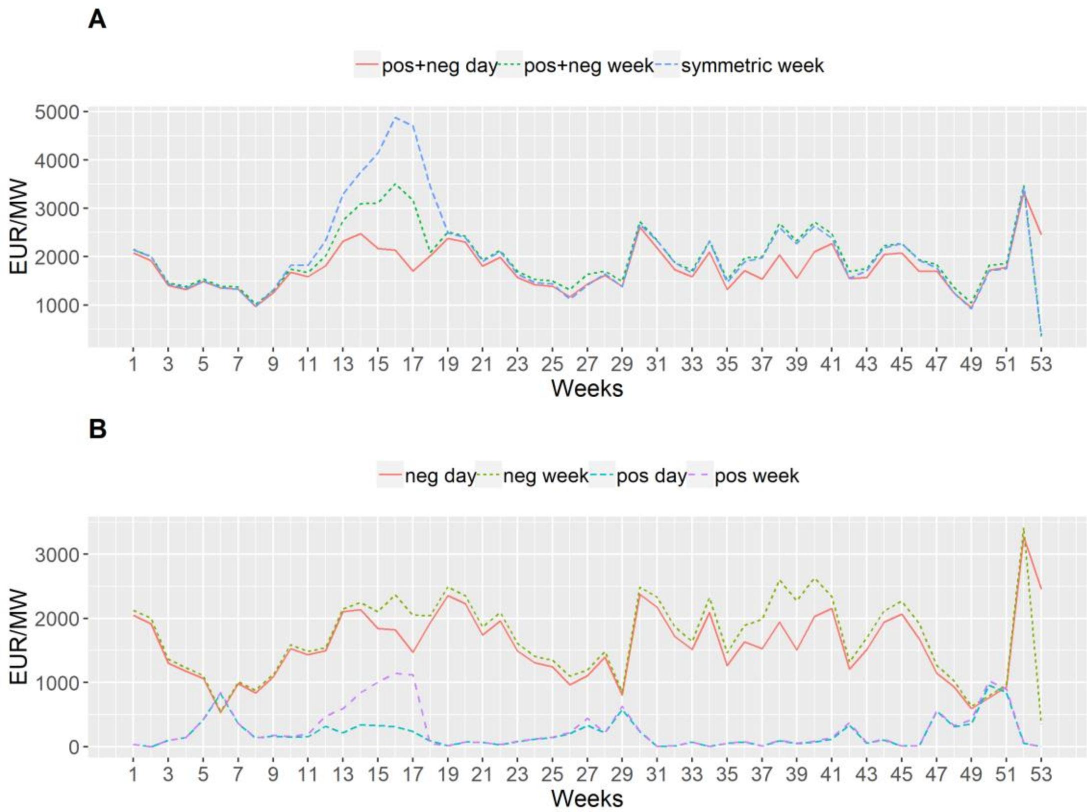

Figure 5: Opportunity costs for 30 MW of symmetric and asymmetric SRL by duration for single site plant. (A) shows the sum over positive and negative products, (B) is split up by direction. Opportunity cost for daily SRL are illustrated as weekly average values.

As shown in Figure 5A, the spring peak in the total opportunity costs (i.e., the sum of costs for positive and negative SRL) disappears for the single site by the introduction of daily SRL products. Since water has to be reserved just for a day instead of a week, costs for providing SRL at that time are much lower. In addition to the cost reductions in spring, the opportunity cost in other weeks of the year can be reduced as well. Especially in early fall, further cost reductions by daily asymmetric SRL products can be realized. As shown in Figure 5B, the disappearance of the spring peak results from a reduction in the opportunity costs for positive and negative SRL. The reduction in the opportunity cost in fall, however, is driven by a reduction in the costs for negative SRL. If the plant would be active just on the day-ahead market at that time, generation would be rather low due to unfavorable market prices. If the plant bids into the weekly symmetric or asymmetric SRL market, generation has to be significantly increased during that time in order to provide negative SRL. If the plant bids for daily SRL, generation also has to be increased but since the capacity and the water has to be reserved just on a daily basis, the plant is able to operate closer to the optimal day-ahead generation schedule. Thus, providing SRL in early Fall comes at a lower cost if provided on daily instead of a weekly basis.

Figure 6 shows the weekly opportunity cost for the multi site for a bid size of 30MW by SRL product design.

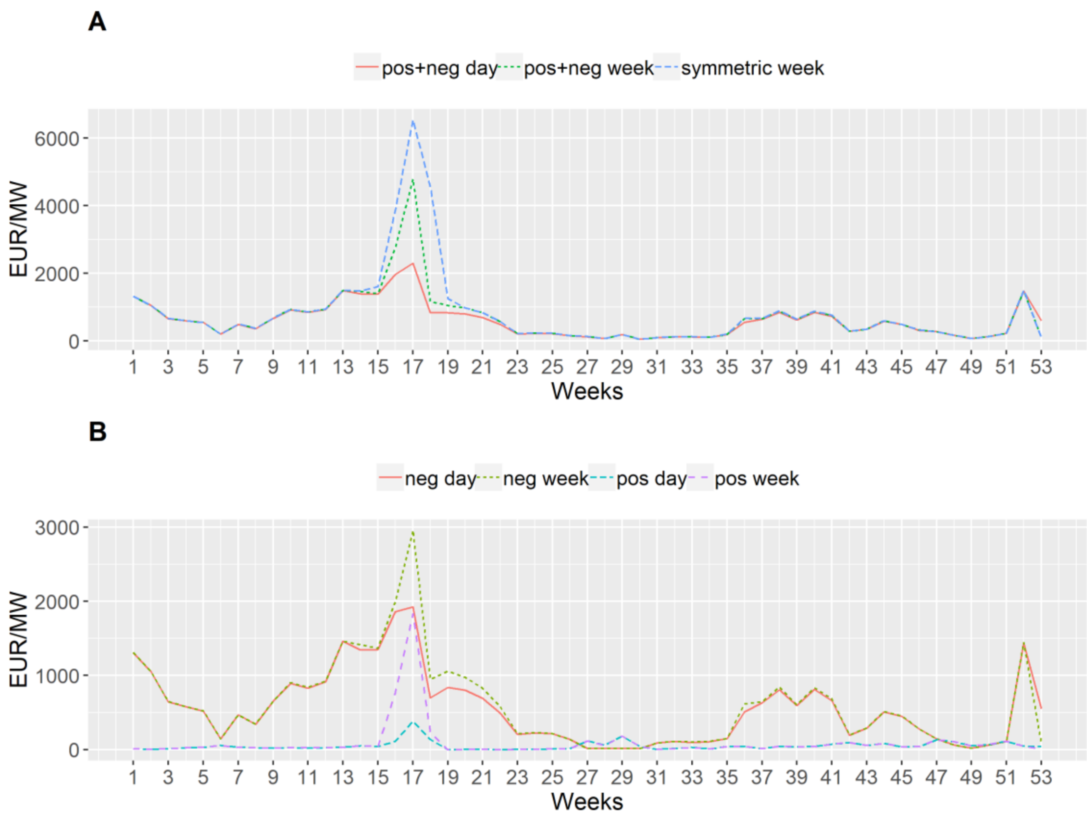

Figure 6: Opportunity costs for 30 MW of symmetric and asymmetric SRL by duration for multi site plant. (A) shows the sum over positive and negative products, (B) is split up by direction. Opportunity cost for daily SRL are illustrated as weekly average values.

As for the single site, the spring peak in the opportunity costs for the multi site is further reduced by the introduction of daily asymmetric SRL products (see Figure 6A). However, for the multi site highest opportunity cost of the year still occur in spring but on a much lower level as compared to weekly products. While the opportunity cost are reduced in spring by the introduction of daily SRL products, the opportunity costs in the other weeks of the year remain unchanged. As illustrated in Figure 6B, the cost reductions in spring results from lower costs in both, positive and negative daily SRL. Especially the cost for positive SRL are significantly reduced.

5.2 Future

With the increase in vRES in Europe, the day-ahead market price dynamics will change in the future (see prices in chapter 4). If the day-ahead market price dynamics change, also the opportunity cost and SRL price dynamics will change. The change in the opportunity cost dynamics in 2030 and 2050 compared to 2015 under the future SRL market design (i.e., weekly and daily asymmetric SRL products) for the single site are illustrated in Figure 7. Thereby, opportunity cost are illustrated as the sum over positive and negative opportunity costs. In Figure 7A, the cost dynamics for weekly products are shown, Figure 7B shows the cost dynamics for daily products.

Figure 7: Changes in opportunity cost dynamics by 2030 and 2050 for 30MW of weekly (A) and daily (B) asymmetric SRL for single site plant. Opportunity costs are the sum over positive and negative opportunity costs. Changes for daily SRL are illustrated as weekly average values.

In the future analysis, inflow values for 2030 and 2050 are equal to the inflows in 2015. Thus, hydrological conditions are the same and all changes in the opportunity costs dynamics in

2030 and 2050 can be traced back to changes in the day-ahead market dynamics. In 2015, Swiss day-ahead market prices are defined by hydrology. In winter when the runoff is low and thus hydropower availability reduced, prices are high. With the snow melt in spring, runoff and hydropower availability are high and prices are low (e.g., minimum day-ahead prices in 2015 in May). In 2030 and 2050, the low price period shifts to summer when the infeed of Solar is high in Europe (e.g., minimum prices in 2030 and 2050 in August). The high price hours, however, still occur in winter due to the low hydropower availability and a lower infeed by Solar. With changes in the day-ahead price dynamics in the future, also the day-ahead generation schedules of the hydropower plants change. Depending on the day-ahead price level and if storage hydropower plants would produce at that price level it can be costly or not to provide SRL. With lower day-ahead market prices in summer in 2030 and 2050, generation of storage hydropower plants is reduced in that season. If generation is low, opportunity costs for providing SRL (i.e., negative SRL) are high since major adaptation in the day-ahead generation schedule are necessary to provide SRL. As illustrated in Figure 7, providing SRL in summer comes at a higher cost in the future. In many weeks in spring, prices in 2030 and 2050 are higher as in 2015 which is why generation of storage plants in 2030 and 2050 is also higher during that time. With a higher generation, especially negative SRL can be provided at lower cost since the plant is running in more hours and does not have to be started up for SRL provision. At the beginning of spring, prices in 2030 and 2050 are less favorable for storage hydropower plants as in 2015. Consequently, generation is lower at that time and opportunity costs are higher. Comparing 2030 to 2050, the change in the opportunity cost dynamics is similar. However, since the share of vRES is further increased between 2030 and 2050, day-ahead prices in 2030 and 2050 differ. In general, day-ahead prices in 2050 are higher in winter and lower in summer as compared to 2030. With differences in prices also day-ahead generation schedules and consequently the opportunity cost for SRL slightly differ in 2030 and 2050. Comparing Figure 7A and 7B, similar changes in the opportunity costs can be observed for weekly and daily SRL products in the future. However, while changes in the opportunity costs for daily and weekly products are similar in summer, opportunity cost for daily SRL are generally lower in spring.

How the change in the opportunity cost dynamics in 2030 and 2050 compared to 2015 under the future SRL market design for the multi site looks like is illustrated in Figure 8.

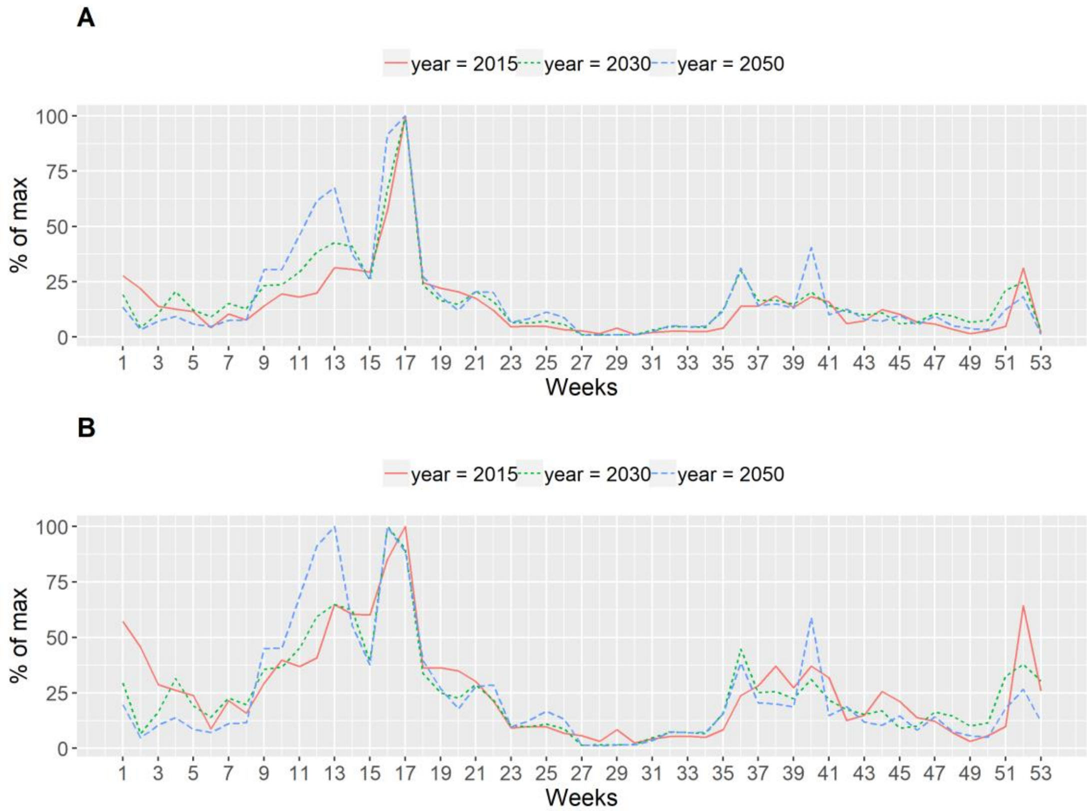

Figure 8: Changes in opportunity cost dynamics by 2030 and 2050 for 30MW of weekly (A) and daily (B) asymmetric SRL for multi site plant. Opportunity costs are the sum over positive and negative opportunity costs. Changes for daily SRL are illustrated as weekly average values.

For the multi site opportunity costs for weekly (Figure 8A) and daily (Figure 8B) asymmetric SRL products in 2030 and 2050 increase much less in summer because of the less price dependent RoR generation of the cascade. However, in late summer and the beginning of Fall increases in the opportunity costs can be observed due to a lower day-ahead prices and a lower day-ahead generation at that time as compared to 2015. In addition, opportunity costs significantly increase at the beginning of spring. In that time, generation of the cascade is more price dependent since inflows and RoR generation are low. Thus, as for the single site, changes in the day-ahead price dynamics in 2030 and 2050 lead to significant increases in the opportunity costs during that time of the year for the multi site. Overall, the opportunity cost dynamics of the multi site show less changes in the future as compared to the single site. Since the RoR generation of the multi site is dependent on inflows and not on market prices, less adaptations to changes in the day-ahead market dynamics can be observed.

6 Conclusion

With the energy transition in Europe, also the balancing markets are adapted in their design. The Swiss balancing market design has been adjusted in 2018 and is further adjusted in the next years. In this paper, we analysed the impact of the adaptations in the Swiss balancing market design on the opportunity cost of hydropower for providing balancing services. Therefore, we used a hydropower operation model and a set of Swiss hydropower plants and cascades. Our results show that a change from symmetric to asymmetric and from weekly to daily balancing products can significantly reduce the cost of balancing power. In the Swiss system, especially the spring peak in the balancing prices can be reduced by changing the balancing market design. In addition, we showed that the opportunity cost dynamics may change in the future with an increasing share of vRES. Our findings on the impact of the adaptations in the balancing market design are in line with previous studies. As Aasgard and Roti (2016) or Dallinger et al. (2018) we found that by asymmetric balancing products cost reductions can be realized as compared to symmetric balancing products. As Müsgens et al. (2012) or Dallinger et al. (2018) we showed that shortening the length of the time period for which balancing power has to be provided can significantly decrease costs. The adaptations in the Swiss balancing market design are in line with the proposed harmonization in the European balancing markets by the European Commission (2017). As our results show, the propositions by the EC are promising regaining efficiency gains, at least for a hydropower dominated electricity system like Switzerland. With the adaptations in the balancing markets in Switzerland and other countries, also the barriers for the participation of other actors like vRES, DERs or the demand side are reduced. If additional actors participate in the market, additional efficiency gains may be possible (Borne et al., 2018; Fernandes et al., 2016). In addition, by adapting the Swiss balancing market design to the European one, a future integration of Switzerland into a European market would be possible. In an integrated balancing market further cost savings are possible (Dallinger et al., 2018; Farahmand and Doorman, 2012). In this paper, we only had a look at the market design of the SRL market. However, also the other Swiss balancing markets (i.e., primary and tertiary) will be adopted in their design in the near future and the activation of balancing energy will increasingly coordinated by international cooperation (Swissgrid, 2018a). What the effect of the adaptations in the market design in the other balancing markets and the increasing cooperation will be should be addressed in future studies.

Our analysis in this paper is not without limitations. First of all, we use a simplified linear and deterministic hydropower operation model to derive the opportunity costs under various market designs. Taking into account uncertainty as well as non-linear hydropower plant characteristics may change the opportunity costs of hydropower for providing balancing power (see also Schillinger and Weigt (2019)). In addition, we only take into account a set of Swiss hydropower plants while this set should be representative for the whole fleet of Swiss storage hydropower plants. However, in reality each hydropower plant and cascade is unique in its characteristics. In addition, more detailed data on Swiss hydropower could lead to more precise results. In this paper for example, we use inflow data with a monthly time resolution. However, inflow dynamics within months have an impact on the generation schedules of hydropower plants as well.

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Appendix

A1 Data

Table A 1: Data of selected hydropower cascades. Based on Balmer (2006), Garrison et al. (2018), Schlecht and Weigt (2014) and SFOE (2018).

Cascade Nr.	Capacity (MW)	Avg. Production (GWh)	Storage (Mio. m3)	Number Plants	Number Reservoirs
1	54	72	50	1	1
2	56	214	20	2	2
3	60	119	40	1	1
4	104	318	6	3	2
5	109	227	86	2	1
6	201	702	62	5	3
7	397	1’036	204	4	2
8	439	925	111	3	3