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The future of hydroelectric power in a changing market

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Abstract

Our paper outlines the future of hydropower in Switzerland, within the context of the European inter-connexion, taking into consideration all the factors that may affect its value in the long run. The complexity and uncertainties are taken into account. This type of analysis is very important to develop consistent policies and strategies. In this regard, we highlight the issues related to supply security, environmental protection and income creation.

We illustrate that high hydropower rents can be expected in the future. These rents may be used to modernize and retrofit (technically and environmentally) power plants. Hydropower is a renewable energy with highly acceptable levels of environmental impact compared to other sources and furthermore, through its water reservoirs, it provides electricity markets with the flexibility needed to stabilize networks, cover peak and super-peak loads and deal with intermittent energy sources, notably solar and wind power. Climate change and higher residual water flows may even increase hydropower's value, to the extent that such resources will become scarcer. However, reservoir management should be optimized according to changes in natural environment as well as markets.

Our conclusion is that hydropower represents a great opportunity for mountain regions. However, there are risks that should not be underestimated; risks linked to the policies adopted, possible new rules, as well as electricity market reconfiguration. The end of water concessions should be assessed from this perspective.

This article represents the first step in our research, as planned by the ACQWA project. The second step is an assessment of the impacts of hydrological changes on hydropower production and profitability, which will also include a Rhone Valley case study. In the third and final step, a synthesis will be carried out in collaboration with other groups involved in the assessment of the impacts of climate change on hydropower.

Key words: hydroelectric power, water concession, electric power market, climate change.

1. Introduction

The aim of this paper is to explore the future of hydroelectric power (in particular, hydropower plants with reservoirs) in Switzerland, within the context of the European inter-connexion, notably the "Continental Central-South area", which includes Austria, France, Germany, Italy, Slovenia and Switzerland. This problem is particularly relevant to public and private sector decision-makers concerned by electric power and its socio-economic and environmental implications, who must define long term policies and strategies. The preparation for water concession expiration and renewal[1] is particularly important in this perspective.

In this field, we are at the interface between the hydrological system and the electrical system. The management of hydropower plants and reservoirs should take into consideration water availability over the course of days, seasons and years, as well as price fluctuations on electricity markets. Water availability depends on climate change and on the implementation of new regulation, concerning residual flows in particular[2]. Price fluctuations are determined by wholesale electricity markets, which were opened to competition in the Nineties.

In the next point, we will briefly present our approach as well as the sources used. Then, we will present the results: first, the economic, environmental and energy stakes; second, hydropower's role within the electricity system; third, the scenarios until 2050; finally, the water concessions' expiration. Before the conclusions, we will discuss the future value of hydropower, and we will evoke the political and strategic issues.

[1] A "water concession", which is granted by a public body, is compulsory to build and exploit a hydropower plant.

[2] Residual flows depend on the volume of water diverted and turbined; a minimum residual flow can be fixed by the public authority.

2. Methodology and sources

In order to explore the future of hydroelectric power in a changing market, we carry out a synthesis which takes into consideration the different components of the electricity system, their interactions and their dynamics. On the one hand, we highlight the complexity of the electricity system and examine its critical components with respect to hydropower. In particular, we examine the electricity wholesale market, the balancing market, as well as green certificate markets. On the other hand, we examine several scenarios in order to anticipate the evolution of the main variables which influence hydropower plants and reservoirs' management as well as investment decisions. Uncertainties are highlighted. This approach allows us to discuss the options available to decision-makers in a complex and uncertain world.

Our research is based on a wide range of documents published by the European Union, the Swiss Government and several European and Swiss organizations (European Network of Transmission System Operators for Electricity, Union of the Electricity Industry, European Energy Exchange, Swissgrid, etc.). The main statistical sources were consulted to verify the availability of critical data. Relevant scientific literature was reviewed.

3. Results

3.1. The stakes: economics, energy and environment

3.1.1. Revenue maximization

In general, in a market that is open to competition, the primary objective of electricity companies (both private and public) is to maximize revenue within certain technical, social and environmental constraints. As stated by ENTSOE, "Generators are now maximizing their revenue under transmission constraints" (2010c, p. 39). Supply security at a national or regional level is the most important of these constraint. Environmental constraints are of an ever increasing level of importance.[3]

The average annual revenue generated by the Swiss electricity sector between 2005 and 2009 can be illustrated by the following figures, which are based on 90% of generating companies : CHF 2,484 million in profits; CHF 2,254 million in salaries; CHF 519 million in water royalties and CHF 558 million in taxes. International trade yielded an annual average of CHF 1,361 million (OFEN*,* 2010, p. 44 and 47).

3.1.2. Supply security

Supply security means "reliable and affordable supply" in terms of energy (kWh), power (kW) and money (Euro and CHF). Hydropower with reservoirs plays an important role. Through its flexibility, it provides power during peak and super-peak periods, as well as balancing energy. In general, generating costs are relatively low. In the future, hydropower may be of increasing importance due to the developments of PV and wind power, which are intermittent energy sources that require back-up capacity (IEA, 2005; OFEN, 2008).

In principle, the international electricity inter-connexion contributes to improving security and reducing costs as lower reserves are needed. There are very ambitious plans to develop high voltage lines on a continental and intercontinental scale. The primary objective is to link consumption centres to wind and solar parks situated (respectively) in the regions of the North and South of Europe (ENTSOE, 2010d).

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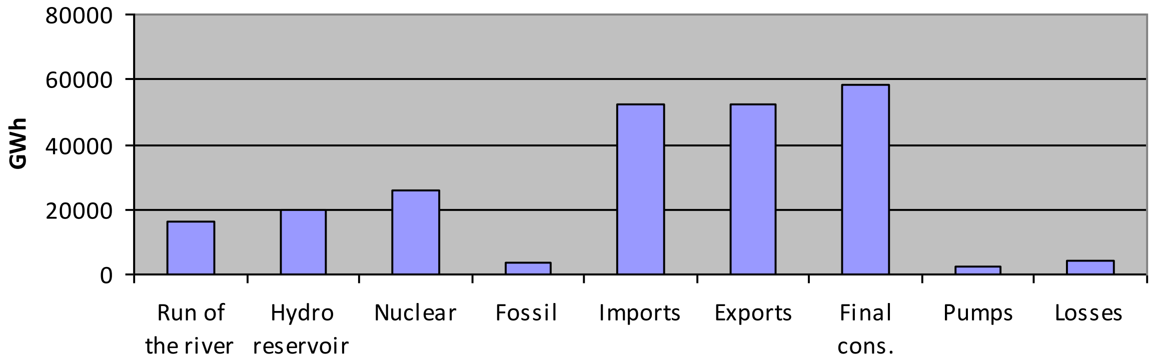
[3] The literature explores different variants: maximization of the "discounted present value of the revenues/profits"; "producer surpluses"; "producer and consumer surpluses". At a time of monopoly, we accepted the hypothesis of "minimization of the total costs" (Edwards, 2003, p. 54; Førsund, 2007, p. 116, 184 ; Kanamura and Ōhashi, 2007, p. 1023; Pérez-Díaz and Wilhelmi, 2010, p. 7963). If uncertainty is taken into consideration, one should maximize expected values and make a hypothesis concerning risk attitude (Førsund, 2007, p. 215 and 221). As a matter of fact, in a competitive market, the maximisation of revenue must be accompanied by risk management (EEX, *Annual Report 2009,* p. 72-74).

Figure 1 provides a self explanatory breakdown of the Swiss electricity sector. One should stress that the phasing out of nuclear power by 2034, decided by the government in the aftermath of the Fukushima disaster, represents a challenge for the country (BFE, 2011b). International trade is very important due to the fact that Switzerland is a focal point in the European inter-connexion to which it is able to provide peak energy.

The average retail price is about 15 CHF/MWh in Switzerland and 10 EURO/MWh in Europe (OFEN, 2010, p. 46; EC, 2010c, p. 30). In general, it is assumed that the "value of the lost load" is 10'000 US$/MWh (Stoft, 2002, p. 155)[4]. Wholesale prices, which are very volatile, are analyzed below.

FIG. 1 - Electricity in Switzerland, Average 2005/06-2009/10



Source: OFEN, 2010, p. 10 and 16.

3.1.3. Environmental protection

In general, Alpine hydropower plants score quite highly in terms of their environmental impact when compared with other power generation systems. Sizeable disruptions to local and regional river ecosystems are however of concern (EAWAG, 2001). Installation upgrading provokes an increase in generation costs, but the production may acquire an ecological value. Green certificate markets may represent a new opportunity for hydropower plants; however, pumping energy is not recognized as renewable.

"Residual flows" depend on the volume of water diverted and turbined and can cause significant changes to the abiotic and biotic conditions in and around river systems. They represent the problem that attracted the greatest attention in Switzerland. Several measures have already been adopted in this respect, but important norms cannot be implemented until the end of the water concessions due to "vested rights".

One should also evoke "hydro peaking", which is provoked by the reservoirs' intermittent use and often causes rapid, very strong discharge fluctuations. Aquatic organisms are distressed because they do not have sufficient time to react. In the case of "bed load", aquatic life is disturbed by hydropower plants as they have an effect on the solid materials that are transported in a water stream. Flushing large reservoirs or sand traps can seriously affect rivers downstream.

3.2. Electrical system

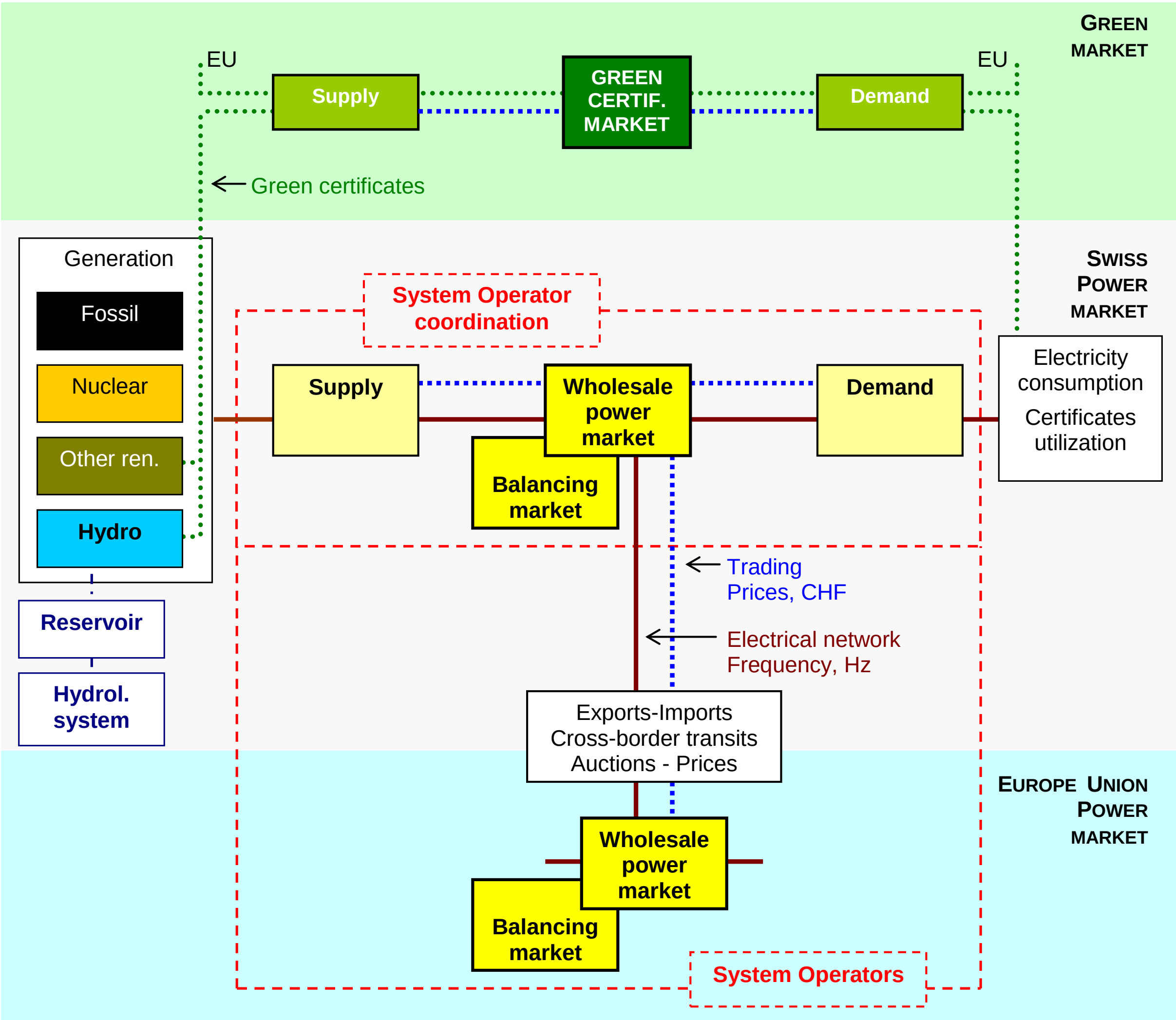
3.2.1. The Swiss electrical system and the European interconnexion

Figure 2 below represents an electrical system. By "system", one means a configuration of components connected together by a web of relationships. A system possesses its own dynamics and

[4] At the time of this article's publication (October 2010), the exchange rate between the Swiss Franc and the Euro was 0.8, and the Swiss Franc and the Dollar 1.1.

its own goals (for instance, revenue maximization). It may exchange with the environment. Feedback loops are important because they create non-linear relationships.[5]

FIG. 2 – Swiss electrical system, European inter-connexion



Source: Energy and policy group (ISE-UNIGE)

The Swiss electrical system is represented by the central part of figure 2. In a system open to competition, markets are "nevralgic centers", where generator supply meets consumer demand. Wholesale prices represent important signals for generators and market operators. Balancing markets provide ancillary services to the system operator, who is responsible for guaranteeing network stability, i.e. frequency levels close to 50 Hz. Hydropower reservoirs play a significant role in this respect.

The bottom part of figure 2 represents the European market, to which Switzerland is quite strongly integrated. Bottlenecks, which limit trading between countries, are increasingly auctioned among market players[6]. The top part of figure 2 shows the green certificates market that we will present below. We have also highlighted the hydrological system, because of this paper's focus on hydroelectric power.

[5] Ford, 1997; Olsina, Garcés and Haubrich, 2006; Wikipedia, "system dynamics", English and French (consulted 11.7.2011).
[6] There is a bottleneck when power flow reaches a certain threshold where transmission lines attain their physical limit.

Since the Nineties, European electricity systems have been opened to competition. Switzerland formalised this process with the Federal Electricity Supply Act of March 27, 2007, which also makes provision for new forms of regulation in the fields of public service, supply security and renewable energy. One should recall that networks were opened to competition by means of the “Third Party Access” principle, as they remain natural monopolies. The system operators are also natural monopolies. At present, the electricity reforms appear irreversible, but there remains the possibility that they may be challenged if the system fails in dealing with security and environmental problems (Romerio, 2007, p. 81-103).

3.2.2. Wholesale and balancing markets

Wholesale markets are made up of “over the counter” operations, where sellers and buyers trade directly; power exchanges, based on auctions, often called “spot markets”, which in fact are day-ahead markets; future markets, which allow buyers and sellers to hedge certain risks of trading power. All except real-time markets are financial markets, in so much as the delivery of power is optional and the seller’s only real obligation is financial. In general, real time markets, including the balancing market, are run by the system operators as they require central coordination in order to cash out imbalances.

Figure 3 shows that wholesale prices are determined by demand and supply. The supply curve reflects the marginal costs of the power plants, which are activated incrementally (“order of merit”). Depending on technology, they can be classified in function of their degree of flexibility. Nuclear power is extremely inflexible whereas gas turbines and hydropower plants with reservoirs are very flexible. Different demand curves may be considered, in particular peak and off-peak. One should recall that demand must always be equal to supply and electricity can’t be stored. Furthermore, one should stress that in short term demand elasticity is very low (Kanamura and Ōhashi, 2007).

Wholesale prices reflect the marginal cost of the last power plant brought into service, except when capacity limits are reached. In which case, prices soar. “Rationing prices” should limit demand to the quantity available. Even small variations in demand may provoke strong price fluctuations. In fact, spot prices are extremely volatile. This is an illustration of the non-linear relationship mentioned above.

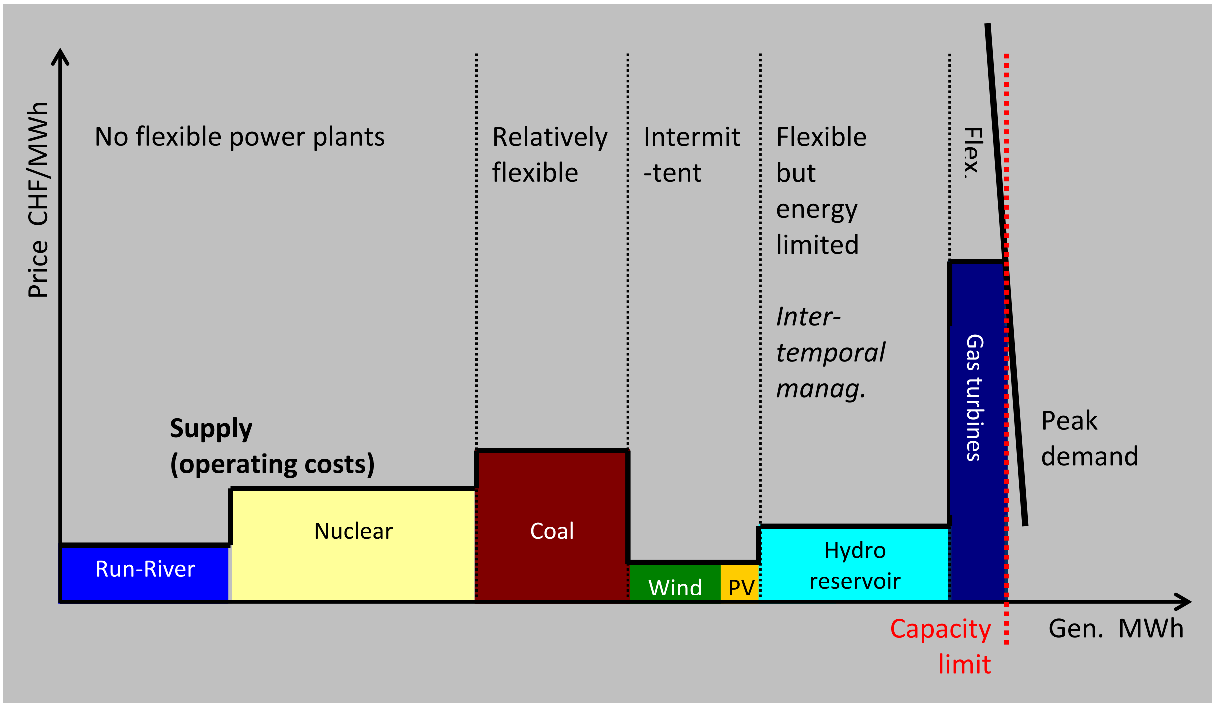
Hydropower plants with reservoirs require dynamic management because the amount of water available is limited by intakes and storage capacity. They cannot constantly generate at their maximum installed capacity. As shown by Massé, the value of the stored water in a reservoir is a probable value because it depends on the future evolution of certain variables. At the same time, it is a conditional value, because it depends on the entire series of future decisions taken by the company (1962, p. 320-337).

To prevent the use of hydro-storage when prices are low, one should take into consideration “opportunity cost”. The cost of emptying the reservoir today may be the benefit gained by using the water tomorrow.[7] The opportunity cost on various capacity constraints may serve as indications of the profitability of marginally increasing capacity, i.e. of a new investment.

Hydropower plants with reservoir are the most efficient source of ancillary service thanks to their high degree of flexibility. They may earn a substantial profit if balancing markets are competitive. As pointed out by Perekhodtsev and Lave, “the value of existing hydro generating plants operating in simultaneous markets for energy and ancillary services may be substantially higher than the value of hydro plants operating solely in energy markets” (2006, p. 21).

[7] Operational research models show that an “opportunity cost” or “shadow value” represents the change in the value of the “objective function” of a marginal change in the “constraint” (Førsund, 2007, p. 8, 15, 40).

FIG. 3 - Wholesale price formation model



Source: Energy and policy group (ISE-UNIGE)

Swissgrid (the Swiss system operator) does not own any power plants and must buy its ancillary services on the market. The so-called "service providers" are compensated for their reserved capacity, regardless of the balancing energy effectively supplied. The Swiss government stresses that "the most important costs [to Swissgrid] relate to reserved capacity and not to the effective supply of balancing energy", which is sold at market prices (Conseil fédéral, 2009, p. 13). Reserved capacity prices are influenced by the hydropower plant with reservoir's opportunity costs, which are significant according to the Swiss government, as well as by the spot price, alternative commercialisation prospects, planning of natural intakes and the effective capacity of the plant (Conseil fédéral, 2009, p. 14).

Following an enquiry by the regulatory authority, since July 2009 all regulation power has been procured following the "pay as bid" procedure, which means that the offer price is paid. A "price cap" was introduced at the same time. From its perspective, Swissgrid pointed out that "initial experience shows that pivotal companies are emerging in many tendering processes and that excess volumes are often very low" (Thoma and Niggli, 2010). Swissgrid is therefore seeking to attract more companies (both foreign and domestic) to the ancillary services market, in order to increase liquidity and boost competition amongst suppliers. Other countries, like Germany, are confronted by insufficiently competitive markets. For example, a suspected collusion in the German balancing market was documented by Platts (IEA, 2005, p. 44). In 2009, Swissgrid purchased ancillary services from electricity producers to the tune of around CHF 600 million in order to balance the transmission system (Swissgrid, *Annual Report 2009,* p. 49).

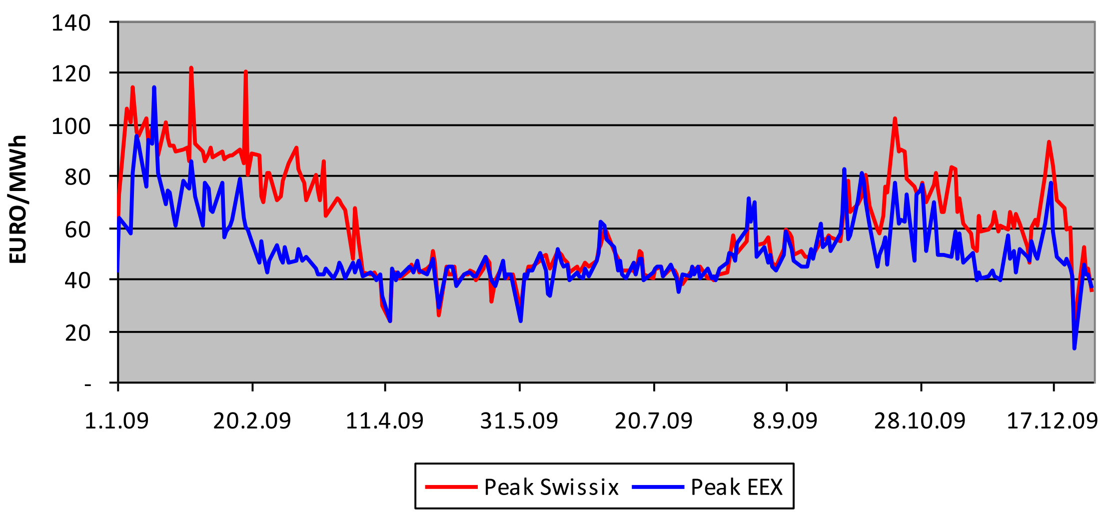
Anti-competitive behaviour is quite well known in electricity markets. So-called "market power" exists when a small number of dominant companies have the ability to provoke price spikes through certain forms of "strategic behaviours". When they control critical installations, for instance peak power plants, they are able to manipulate prices by withdrawing capacity. Electricity markets are particularly vulnerable to market power due to the inelasticity of demand and lack of storage capacity. Several studies were carried out in Europe and elsewhere on this topic[8]; we do not possess studies specific to Switzerland, with the exception of the analysis of balancing markets mentioned above.

Bushnell pointed out that “Hydro resources, with their ability to either smooth demand, or conversely, sharpen the peaks, provide their owners with the opportunity to greatly reduce or further increase the frequency and severity of market power” (2001, p. 12). He showed that in a perfect competitive market, hydropower companies transfer production from off-peak periods, when prices are low, to peak periods, when prices are high. Conversely, when generators have market power, they would tend to allocate relatively more hydro production to off-peak demand periods than to peak periods. By doing so, they reduce their own supply and push prices upwards.[9]

Figure 4 represents two series of wholesale electricity price indices, respectively for Germany and the Swiss market area. They are calculated by the European Energy Exchange (EEX), one of the leading trading platforms for energy and related products. One notices their strong volatility and the gap between them. In a perfectly integrated market, without the presence of bottlenecks, national prices tend to converge towards a single international price. In fact, at present, the electricity prices in different European market areas are often determined by German marginal power plants, primarily gas turbines (Percebois, 2009).

The gap between these prices and the average retail prices quoted above (15 CHF/MWh in Switzerland and 10 EURO/MWh in Europe) is due to the fact that only a small proportion of the electric power is traded on spot markets. The suppliers own production and bilateral agreements still represent the main source of supply. One should also point out that the opening of the markets to competition and physical unbundling have not yet been completed. Spot prices however represent very important “points of reference” for operators.

FIG. 4 - EEX and Swissix, 2009



By “peak” one means “at peak times from Monday to Friday, 8 am to 8 pm”.

Source: EEX.

[8] We will limit ourselves to citing the pioneering study by Green and Newbery (1992).

[9] On this issue, see also Førsund, 2007, p. 181 and 237; Rangel, 2008.

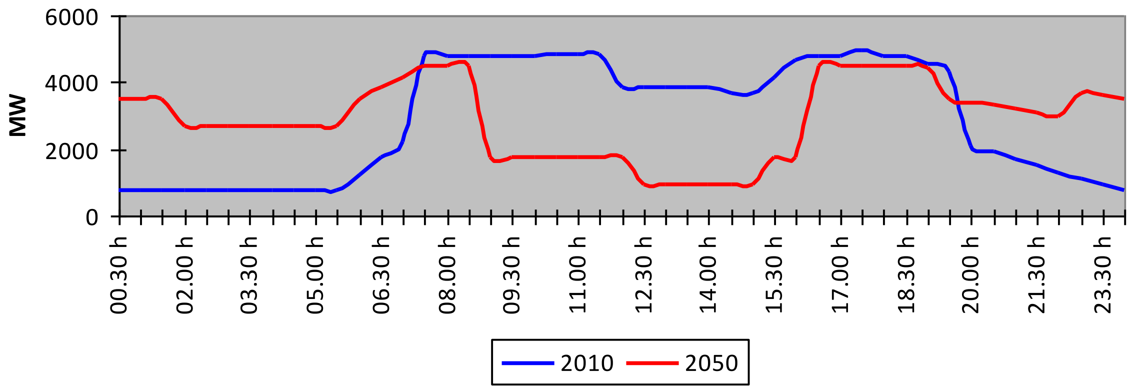
3.2.3. Short run management: generation

An electricity system must be sufficiently flexible to face fluctuations in consumption over the course of days and seasons. Flexibility may generate high returns because, by definition, it is available during price spikes. In terms of generation, flexibility is provided by hydropower plants with reservoirs, as well as gas turbines designed for peaking at a load factor of less than 5%. In this case, costs are high because of high heat rates and also low capacity factors (Hughes and Parece, 2002, 34). In terms of demand, a certain degree of flexibility is possible thanks to voltage reductions and DSM, which helps smooth out consumption peaks.

As stated by ENTSOE, "The development of renewables… will create significant challenges for balancing control, including the management of reserves" (2010c, p. 44). In the case of intermittent power plants (notably PV and wind farms), output is in fact determined directly by variations in energy input and more flexible capacity is needed. The integration between flexible and intermittent renewable energy represents a big stake for supply security in the future. Hydropower with reservoirs may provide power when PV or wind is not available; store PV or wind-generated energy when the market can't absorb them; save water when enough intermittent renewable energy is available.

Figure 5 illustrates the use of Swiss hydropower reservoirs during a typical day in 2010 and in 2050. In the future, turbines may be activated even during the night, due to the tension on the market at this moment in time, which is caused by the absence of wind. The curve for 2050 is an initial approximation that will be perfected by a model that we are developing, which will also allow us to simulate the effect of climate change on hydrology. To extrapolate the 2050 curve, we assume that the average annual rate of increase in electricity consumption is about 1% between 2010 and 2050; through DSM, peaks will be reduced; off-peak consumption will increase due to the diffusion of electric mobility; nuclear energy will be abandoned; new intermittent renewable energy will be developed according to the data provided by the SFOE (see point 3.3.3). It is assumed that the same amount of water is available in 2010 and in 2050. Imports and/or fossil generation (gas turbines and cogeneration) will be unavoidable. Exports are possible as far as one allows more imports and/or fossil generation. Lower water intakes in the reservoirs should be compensated in the same way.

FIG. 5 - Hydropower reservoirs' use



Source: Energy and policy group (ISE-UNIGE)

3.2.4. Long term management: investment

Competition in electricity markets, as well as new forms of regulation may jeopardize investment for several reasons. On the market side, one should quote wholesale electricity prices, which may not provide adequate revenues to attract investment in new generation. On the regulation side, one should mention price caps introduced by the Regulator, or reliability actions taken by the System operator, which may depress market prices and discourage investment.

Wholesale prices may rise dramatically when markets are stretched. It is during this time that generators should collect revenues high enough to cover fixed costs and realise new investment. In other words, the profitability of new investment depends upon the "scarcity rent", which is equal to the difference between market prices and marginal costs. If the rent is not high enough, one faces the so-called "missing money problem", which could represent a deterrent to investment in new generating capacity (Joskow, 2006, p. 58). The problem is particularly noteworthy in the case of reserve equipment[10] that is put to use as little as a few hundred hours a year. One may anticipate cyclical movements, with periods of overinvestment and periods of underinvestment, linked respectively to periods of high and low prices (Ford, 1999). The construction time (including approval) should also be taken into consideration.

In the case of Switzerland, the opening of markets to competition did not have a negative effect on investment. This is illustrated by the fact that shortly before the Fukushima disaster one was seeking authorisation to construct new nuclear facilities, and one is currently in the process of developing new pumped-storage hydroelectric power stations. This can be explained by different factors: the market is not yet entirely competitive; spot markets only represent a small proportion of a company's trade; electricity companies possess medium and long term strategies; they are not guided solely by short term fluctuations. As stated by Newbery, "… large irreversible investment decisions are based on analysing market fundamentals, not just current trading views…" (2005, p. 10).

3.2.5. Green markets

The top part of figure 2 represents the green certificates market, which is particularly relevant to the future of hydropower. Green certificates are completely delinked from the physical flows of electricity. Each MWh of green electricity produced in eligible plants yields one certificate. Certificates are used to enable many types of support schemes, whether voluntary (such as green labels), or mandatory (such as supply obligations, portfolio standards and feed-in systems) (Söderholm, 2008).

A standardised system of "Guarantee of Origin" (GO) was designed to stimulate cross border trade in the European market for green certificates and to increase renewable energy production and competition. The EU has two different systems that provide GO: the "European Energy Certificate System" (EECS) and the "Renewable Energy Certificate System" (RECS). The intention is that EECS and RECS are merged to form one system in the future (AIB and RECS's annual report 2009).

GOs were introduced in 2001 by the European Parliament and Council, whereas RECS started as an initiative of European companies to create a voluntary market for green energy. The minimum specifications of a GO are the amount of electricity from renewable sources that has been injected into the public grid, the type of renewable energy source used, the date and place of production, and, in the case of hydroelectric installations, the capacity of the power plant.

Switzerland is member of the AIB and participates in the European energy certificate market. Proof of the method of production and the origin of electricity (GO) is regulated in Ordinance 730.010.1, which has been in force since December 2006. However, participation is very low, despite the "strategy aimed at actively utilising the comparative advantages of hydraulic energy", evoked by the SFOE (OFEN, 2008, p. 11).

About 200 TWh of EECS certificates were issued in 2009; 150 TWh cancelled. Almost 80% of them were of hydro origin (AIB, *Annual Report 2009,* p. 6-7). The RECS market is relatively similar: almost

[10] Operating reserves (to face short term disturbances) and planning reserves (to maintain system adequacy by meeting annual demand peaks)

180 TWh issued; 150 TWh cancelled; about 90% of them of hydro origin (RECS, *Annual Report 2009,* p. 8-9). A major shortfall in these markets is the lack of any electronic platform or published price index.

One should stress that green certificates are not labels. They possess no further ecological quality than that it originates from a renewable source. A well known label which imposes stringent requirements regarding ecological sustainability is “Naturemade star” (EAWAG, 2001, p. 112). According to Pricewaterhouse Coopers Ltd, with the exception of “Naturemade star”, “criteria regarding hydropower [taken into consideration by other labels] are not very strict and well developed”. This is “a surprising fact considering that hydropower amounts to up to 80% of renewable electricity worldwide” (2009, p. 21)

Renewable energy sources include hydropower, wind, solar, geothermal, wave, tidal, biomass, landfill gas, sewage treatment plant gas and biogases. On the other hand, the power generated by pumped-storage hydropower stations is not considered as renewable energy, as fossil or nuclear energy can be used for pumping (BFE, 2008). This is almost a paradox as one needs flexibility to develop intermittent renewable energy and this is a rare resource.

3.3. Scenarios for the future

3.3.1. Introduction

Scenarios include objectives, measures, whose aim it is to realize the objectives, as well as assumptions, for instance on technological innovation or on international oil price developments. Often, they represent political or strategic documents carried out to support the aims of a government, an organization or a company. Some scenarios are tainted by “wishful thinking” and the degree of transparency is quite low (Romerio, 2007, p. 45-50).

Most of the time, radical changes are discarded. For instance, in the scenarios published in 2007, the SFOE stated that “It would be too costly and unwise to base energy policy on the worst possible scenario or on an unexpected technological breakthrough” (OFEN, 2007, p. R1). There was however the Fukushima disaster that provoked a sudden u-turn in Swiss electricity policy.

In the case of the European Union, we review the scenarios published by EURELECTRIC and Greenpeace, because they highlight the contrasts between two organizations that possess very different “visions” concerning society and energy (EURELECTRIC, 2010; Greenpeace, 2011). Furthermore, these scenarios have the advantage of considering a 2050 horizon, whereas most other scenarios look no further than 2030, not least those published to date by the European Commission (EC, 2010c). We have also taken into consideration the reports published by the EC and ENTSOE which are quoted in the references. In the case of Switzerland, we present the scenarios published by the SFOE in the aftermath of the Fukushima disaster (BFE, 2011a and b). The Eurelectric and Greenpeace scenarios were published before.

We focus on certain key electricity market variables. Data on demand and supply is relatively abundant. Price evolution estimates, on the other hand, are rare. This is quite a paradox in markets open to competition. Data is provided on an annual (occasionally seasonal) basis; unfortunately though, rarely on a daily basis.

3.3.2. European Union

EURELECTRIC defined two scenarios for the EU’s 27 countries: the “baseline scenario”, which in fact is one of “business as usual”, and the “power choices” scenario, which sets a 75% reduction target for greenhouse gases. The simulations are based on the “PRIMES energy model”, developed by professors Capros and Mantzos at Athens Technical University (Capros and Mantzos, 2005). They assumed an annual GDP rate of growth of 1.65% leading up to 2050, whereas the oil barrel prices would rise from $72 to 127.

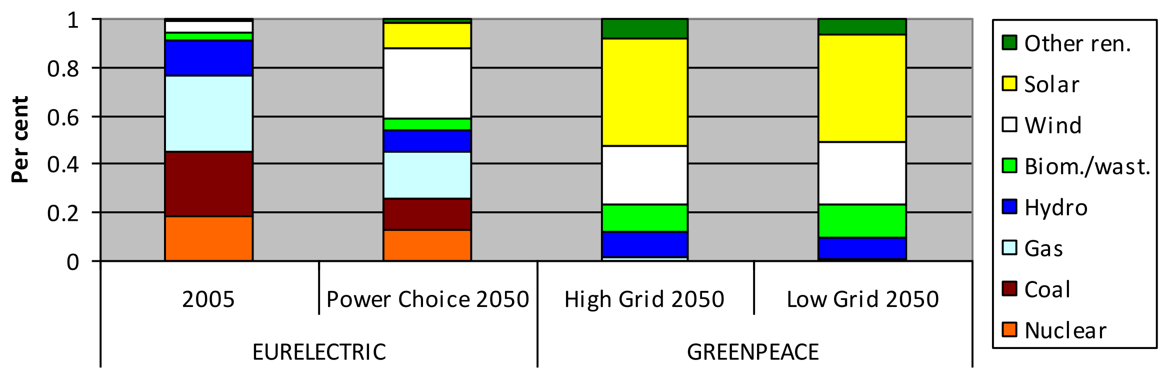
For its part, Greenpeace takes into consideration a “high grid” and a “low grid” scenario for the EU’s 27 countries, Switzerland, Norway and non-EU Balkan States. The former assumes the realization of an inter-connexion with North Africa, where solar parks would be built, whereas the latter supposes that more renewable energy resources will be developed closer to consumption centres. The scenarios were developed by Energynautics GmbH. They accepted the hypotheses made by the 2009 edition of “World energy outlook” (IEA, 2009, p. 58-68), probably to be in line with a recognized international organization.

The greatest convergence between EURELECTRIC and Greenpeace related to electricity consumption increases resulting from developments in electric mobility and heat pumps. Both organizations also accept that natural gas will play an important role for a certain period, in particular to provide backup capacity to compensate for new renewable energy intermittency. The divergences concern mainly nuclear and coal power plants, which should be shut down by 2030 according to Greenpeace, whereas according to EURELECTRIC they will remain part of the electricity mix beyond 2050.

More specifically, the annual rate of growth in electricity consumption up to 2050 is about 1% in the different scenarios considered in this review. An increase in electricity consumption is also anticipated by the EC and ENTSOE (EC, 2010b, p. 6; EC, 2010d, p. 12). ENTSOE points out that this is due to improved living standards as well as end-users switching from oil and gas to electricity (2010d, p. 12).

Figure 6 shows the installed capacity based on technology in 2005 and 2050. The situation in 2005 is directly comparable with the EURELECTRIC “power choices” scenario. The Greenpeace scenarios, on the other hand, are not directly comparable because of the different geographical area taken into consideration. This highlights in particular the significant increase of new renewable energy’s share in the electricity mix.

FIG. 6 - Capacity (GW) according to the technology



Sources: EURELECTRIC, 2010, p. 63; Greenpeace, 2011, p. 29.

According to EURELECTRIC, gas-based generation will play an important role in the provision of balancing and back-up services, which are needed to manage the increase in power generation from intermittent resources. According to Greenpeace, natural gas may play a role up to 2030, but then should be replaced by dispatchable renewable energy “such as hydro, geothermal, concentrated solar power and biomass” (2011, p. 5). The prediction that in the future gas will play an important role from this point of view is generally accepted (see for instance EC, 2010c, p. 43).

According to EURELECTRIC, high utilisation rates will be achieved in nuclear and coal power plants (equipped with CCS) compared to gas turbines. This is not Greenpeace’s “vision”, which seeks greater penetration of intermittent new renewable energy in the electricity system at the expense of nuclear and coal power plants. In other words, the electricity grid needs less and less base-load capacity, and more flexible installations capable of filling the fluctuating gap between consumption and intermittent generation.

Greenpeace doesn't provide price estimates, whereas the EURELECTRIC scenarios show that retail prices see a rise of approximately 38% between 2005 and 2030, driven by fossil fuel price increases, carbon prices, as well as the additional costs of power generation induced by CO2 emission reductions and new renewable energy promotion. The EC predicts a similar price rise, which is not surprising as they use the same models (2010c, p. 30 and 45).

Before considering the case of Switzerland, one should evoke the EC and ENTSOE's projects to further increase cross-border capacity through the Alps and even redesign the European grid, because they may have important implications for hydropower plants with reservoirs (EC, 2010b, p. 10; ENSOE, 2010d, p. 73). Furthermore, this corresponds to the Greenpeace "high grid" scenario. As stated by ENTSOE, "A strong central-European North-South transmission corridor will allow a better integration of the intermittent sources by combining the wind farm generation in the North with the pumping storage in the Alps, thus, helping to achieve real central-European power balancing" (ENSOE, 2010d, p. 73).

3.3.3. Switzerland

In the aftermath of the Fukushima disaster, the Swiss government decided to phase out nuclear power by 2034[11]. The decision was approved by the Federal Assembly. Energy efficiency and the promotion of renewable energy sources (hydropower included) are key features in recent energy policy, which is based on the concept of the "2'000 Watt Society".[12]

As pointed out by the SFOE, "To achieve these objectives, Switzerland should adopt […] a very interventionist approach" (BFE, 2011b, p. i). A prerequisite is that energy policy instruments are internationally harmonized. Assumptions are an annual GDP growth rate of 1.2% and a doubling of end user energy prices by 2050.

The New Energy Policy scenario (NEP) predicts a rate of growth in electricity consumption of minus 0.2% per annum, whereas in the Business as Usual scenario (BaU) this rate is plus 0.6%. Without new investment, the shortfall will be respectively 30.37 TWh and 54.81 TWh in 2050[13] (BFE, 2011a, p. 1-5). To fill the gap, alongside renewable energy development, three options are considered, combined-cycle gas turbines, cogeneration (combined heat and power) and imports.

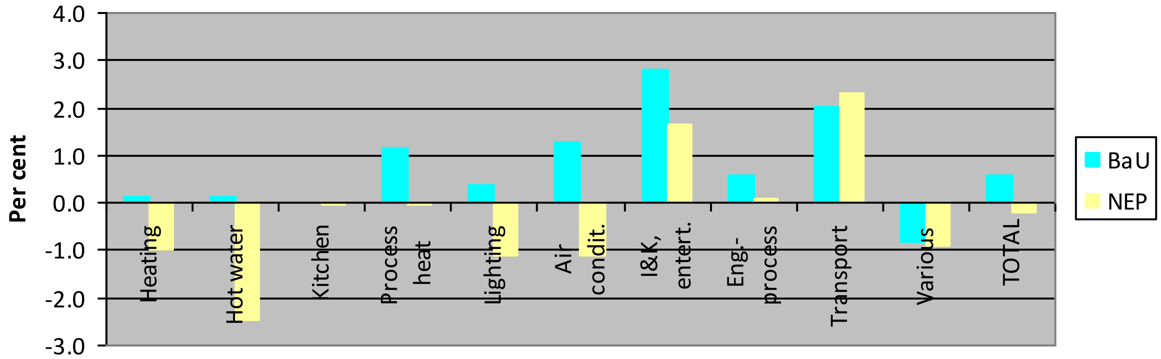
Figure 7 represents the power consumption's annual rate of growth between 2009 and 2050. In the BaU scenario, energy efficiency measures are partially cancelled out by the adoption of new applications and the duplication of household appliances. In the NEP scenario, the rates of growth are much lower, except for "transport". The following consumption categories have a seasonal or daily pattern: heating, air conditioning and lighting. Cars may store electricity during the night.

[11] *Cf.* Federal Council, 2011 and Press release "Federal Council decides to gradually phase out nuclear energy as part of its new energy strategy", (http://www.bfe.admin.ch/energie/00588/00589/00644/index.html?lang=en&msg-id=39337, consulted May 2011).

[12] The vision of a "2'000 Watt Society" considers primary energy consumption levels no greater than the equivalent of an average continuous power of 2'000 Watt per capita (about 63 GJ per capita and year). According to Schulz *et al.*, the transition of the current energy system to a 2'000 W society should be seen as a long term, highly ambitious, goal (2008, p. 1303 and 1315).

[13] 6 TWh required operating the pump storage power plants which will be built between 2015 and 2020 are included.

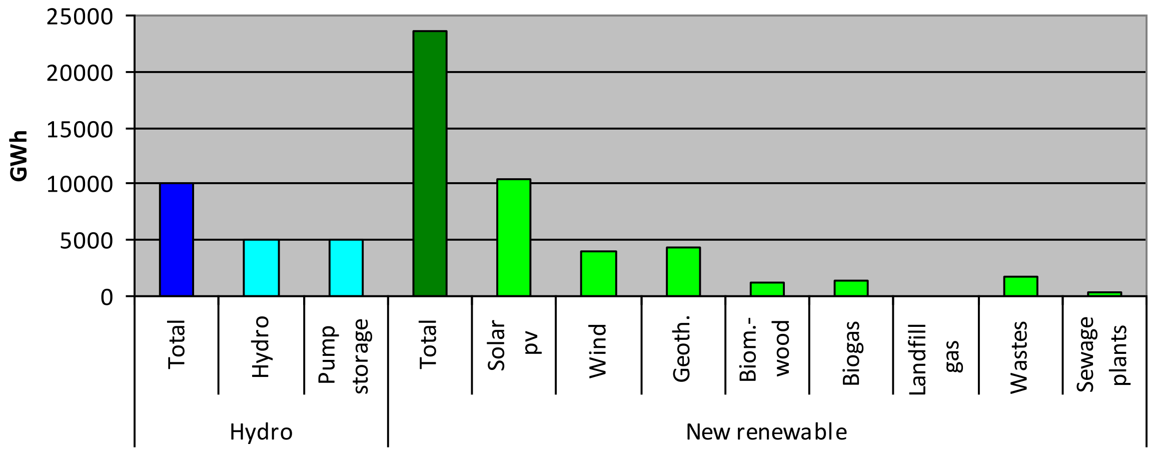
FIG. 7 - Power consumption's annual rate of growth, Switzerland 2009-2050



Source: BFE, 2011b, p. xiii.

Figure 8 shows the potential planned development of renewable energy. It shows that 10'000 GWh are hydro, of which 5'000 are generated by new pumped storage plants. In fact, the Swiss electricity sector is assessing several projects of this kind, which may reinforce its position in the European grid, although the availability of the pumping energy may be jeopardized by the decision to abandon nuclear energy. The projects of Nant-de-Drance, in Valais (600 MW, 3.3 GWh in winter, 5.7 GWh in summer) and Limmern, in Glaris (1'000 MW, 6.4 GWh in winter, 1.4 GWh in summer), both under construction, warrant a mention.

FIG. 8 - Potential planned construction (by 2050)



Source : BFE, 2011b, p. xviii.

Hydroelectric power's potential should equally be assessed in light of environmental changes as well as in terms of the creation and application of new rules. The most important regulatory changes concern "residual flows". The Federal water protection act of January 24, 1991 determines the minimal residual flows (art. 31), that can be increased or decreased by the executing authorities under certain conditions (art. 32 and 33). These norms will not take effect until the existing water concessions have expired, because of the "vested rights", which are protected by law and by the Federal Constitution. Certain remedial measures have been provided in the interim (art. 80). There are no precise estimates as to the impact of increased residual water flows on hydro generation. The SFOE proposes the figure of 700 GWh/year by 2050 (BFE, 2011a, p. 2).

Climate change may also have a significant impact on hydro generation. The IPCC states that "By the 2070s, hydropower potential for the whole of Europe is expected to decline by 6%, with strong regional variations from a 20-50% decrease in the Mediterranean region to a 15-30% increase in northern and eastern Europe" (2008, p. 129). The SFOE estimates that the loss of production in Switzerland will be of 2'000 GWh/year by 2050, which represents about 6% of the present average output (BFE, 2011a, p. 2). In anticipation of the results from the ACQWA and FUGE[14] research projects, one should quote a document published in September 2011 by the Swiss commission on hydrology, focussing on certain hydropower installations situated in Valais (p. 22-26). A small decrease in hydropower production is expected by 2035, which can reach 4-8% of present output by 2085. In extreme cases, losses would be less than 20%. These results, which remain tainted by significant uncertainties, cannot be generalized to the entire Swiss hydroelectric system.

The effect on hydropower generation of sedimentation, hydro-peaking management, as well as the use of water reservoirs to attenuate the flood peaks' effects downstream cannot be taken into consideration in our assessment, because of the lack of studies allowing even preliminary generalizations in this respect.

3.4. Water concessions

To build and operate a hydropower plant in Switzerland, one needs a water concession. In the current system, it is awarded by cantons or communes. Article 2 of the Federal hydropower act of December 22, 1916, states that "cantonal legislation decides the community (canton, district, commune or corporation), that has the right to use public water power". Article 3 affirms that "the community… can use it itself or grant it to third parties".

According to Federal law, the concession must define the concessionary's rights and obligations in terms of environment, construction, management, taxes, etc. Vested rights are guaranteed by article 43 of the Federal hydropower act, which states that "once granted, the right of use cannot be rescinded or restricted except for reasons of public utility and upon indemnification". Concessions have a maximum duration of 80 years. Upon expiration, the conceding community has the right to reclaim the "wet parts" of the installation (reservoir, pressure pipes, hydraulic engines and buildings which shelter them) at no cost, as well as to take back the energy generation and transportation equipment in return for an equitable payment.

It is not possible here to present water concession systems in other alpine countries. The French case should however be evoked, because it highlights the orientation taken by the European Union (Cheseaux, 2011, p. 17). Hydropower exploitation in France is governed by the act on hydroelectric power's use of October 16, 1919. Article 1 states that "nobody can use the energy […] of a water course without concession or authorisation". The "preferential right" granted to Electricité de France in relation to the renewal of water concessions was however retracted following a decision by the European Commission to refer France to the Court of Justice, in light of the fact that it created a discrimination against other European operators.[15] Nowadays, the market is open to competition and several European companies (the Swiss Alpiq included) have already expressed their interest in acquiring hydropower concessions in France.

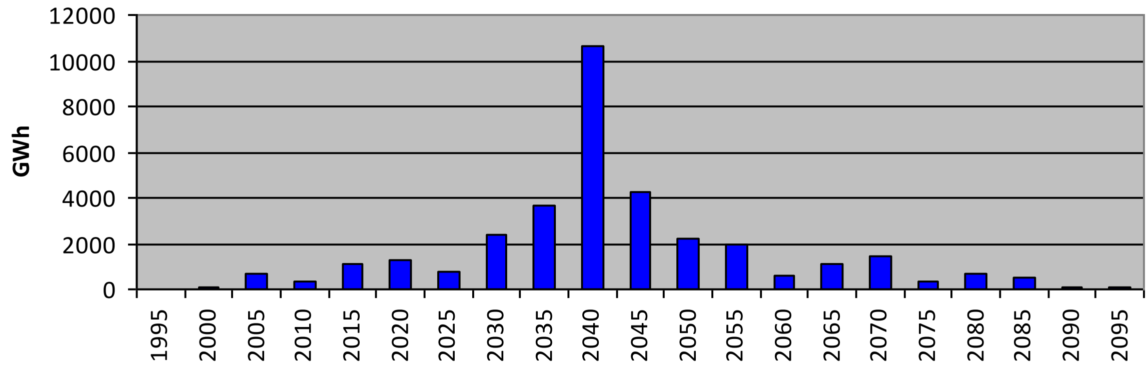
In Switzerland, water concessions were granted to public and private electricity companies, most of which have their headquarters in urban cantons. In order to build installations and to exploit power plants, so called "partner companies" were often formed. Each partner is entitled to a proportion of production relative to their equity share, for which they pay the generating cost. Production is destined for the partners' markets, which include final consumers as well as national and international trade (Romerio, 2008b).

[14] FUGE=Future glacier evolution and consequences for the hydrology and the potential for glacier hazards in Switzerland (www.nfp61.ch/F/projets/cluster-hydrologie/recul-glaciers).

[15] http://ec.europa.eu/internal_market/smn/smn51/docs/infringements_fr.pdf

Figure 9 illustrates water concession expiration and its relative importance based on power plants' average production. One notices for instance that between 2040 and 2045, water concessions corresponding to about 11'000 GWh/year will expire. This will represent a turning point for the electricity sector as well as for public bodies. In principle, new concessions could be granted to the incumbent company, to another company, or to a company totally or partially controlled by the canton and/or the communes. Based upon past experience, the decision is likely to be politically charged. There does however remain the possibility that new rules will be introduced, as in France, and that public bodies will be forced to carry out a form of auction, based on predefined specifications.

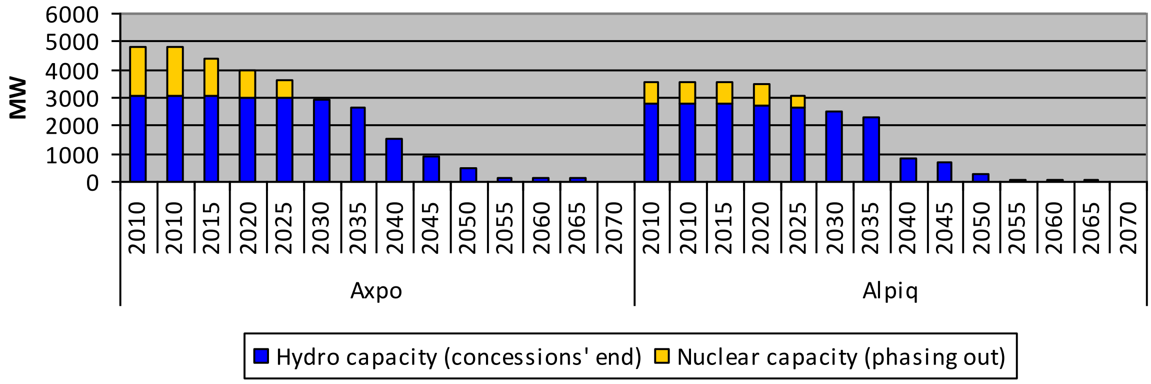
FIG. 9 - End of water concessions, Switzerland



Source: OFEN, 2011, table 14.

Figure 10 represents the impact of the water concessions' expiration, as well as the abandon of nuclear power, on the assets of Alpiq and Axpo, the two main Swiss electric groups. The histograms highlight the challenges that the Swiss electricity groups will face in the future.

FIG. 10 - Assets situated in Switzerand



Sources: OFEN 2011;
http://www.alpiq.com/fr/ce-que-nous-offrons/nos-actifs/our-assets.jsp;
http://www.axpo.ch/axpo/fr/hydroenergie/wissen/kraftwerke.html;
http://www.ckw.ch/internet/ckw/de/ueber_uns/energieproduktion/wasserkraft.html;
http://www.egl.eu/eglch/en/home/competencies/assets/powergeneration.html (consulted October 2011).

4. Discussion

The value of the water stored in hydropower reservoirs depends upon electricity market prices. In other words, the return that a hydropower plant can generate is given by the wholesale or balancing market price minus operating costs. Part of this return, which in fact represents a "rent" [16], may be used to carry out new investments or to retrofit (technically and environmentally) existing installations.

Our analysis shows that the electrical system will require an increasing amount of flexible energy in order to deal with the intermittent nature of new renewable energy in addition to consumption peaks. DSM measures can help reduce these peaks, as well as the effects of consumption increases resulting from the diffusion of electric mobility. Peaks in Mediterranean countries during summer months, due to the use of air-conditioning, represent however a recent phenomenon which goes in the opposite sense. Increasing intermittency represents an irreversible trend due to the desire to phase out coal and nuclear power plants.

Hydro returns are likely to increase in the future due to tight markets and price spikes. It is worth remembering that the only alternative to hydropower plants with reservoirs is gas turbines. Green markets may represent another opportunity for hydropower, as long as renewable energy is used to pump water. During a period of transition, the use of fossil fuels for this purpose should not be penalised, as the development of new renewable energy relies on the availability of flexible energy.

Further research should be carried out to determine the effects on international trade, in particular for countries like Switzerland that have historically benefited from exports during peak and super-peak periods. In this respect, one should note that important amounts of balancing energy may be required by the grid if the "electricity highways" connecting the renewable parks situated in the North and South of Europe, crossing the Alps, are developed.

Climate change, sedimentation and higher residual flows don't necessarily lead to a decrease in hydro returns. In fact, a shift in the supply curve will lead to a price increase which may result in increased revenues for hydropower companies.[17] This hypothesis warrants further analysis, which will be carried out when more information on the impact of climate change is available.

An important point is that the development of intermittent new renewable energy will impact on daily reservoir management. Variations can also be expected on a monthly and seasonal basis, due to temporal changes in renewable energy availability as well as in peak consumption. In order to assess the future of hydroelectric power, the complete range of factors affecting the electrical system should be considered, which are both environmental and techno-economical in nature.

These problems should be analyzed in light of electricity sector reorganisation, which is far from complete. More specifically, one should consider the evolution of relationships between company owners (cantons, communes and private owners), spheres of activity (generation, trading, supply...), as well as the assets, as illustrated by figure 10. The fate of partner companies is particularly important for the hydropower sector[18]. The policy that will be developed in view of the water concessions' expiration, as well as the new rules that could be adopted in this respect, are of course extremely important for the hydropower sector's future.

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[16] One should make a distinction between the "scarcity" and the "differential" rent. The former is brought about by the fact that supply is limited in relation to demand; the latter is linked to the fact that power plants have different generating costs (Rothman, 2000 ; Romerio, 2008a, p. 91).

[17] For an analysis on the effect of dry weather on wholesale electricity prices in Europe see Lise, Hobbs and Hers, 2008.

[18] For instance, the Swiss federal council points out that partner companies' ability to provide ancillary systems as well as their efficient operation "largely depends on the partnership model to which they adhere" (Conseil fédéral, 2009, p. 13-14)

5. Conclusion

The academic relevance of this article is in its analysis of the electrical system as a whole, particularly suited to address complex problems, as well as the identification of the most probable scenarios, representing a useful approach to deal with uncertainty. Furthermore, the Swiss case study, viewed in the context of the European interconnexion, provides interesting insight into the future of hydropower, in a country which has to deal with important medium and long term changes in energy and environment.

The practical interest stems from the information provided to decision-makers in the perspective of water concession expiration. The options available to public bodies and electricity companies are highlighted and key variables outlined. Despite uncertainties and the overall complexity, we show that hydroelectric power still represents a great opportunity for the mountain regions and their electricity companies. However, there are risks that should not be underestimated, linked to the policies adopted, possible new rules, as well as electricity market's reconfiguration.

This article represents the first step in our research, as planned by the ACQWA project. The second step is an assessment of the impacts of hydrological changes on hydropower production and profitability, which will also include a Rhone Valley case study. In this perspective, we are building a simulation model for water reservoir management, as well as an investment model particularly suited to hydropower plant modernization. In the third and final step, a synthesis will be carried out in collaboration with other groups involved in the assessment of the impacts of climate change on hydropower.

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Acronyms

AIB	Association of Issuing Bodies
BFE	Bundesamt für Energie
CCS	Carbon capture & storage
EAWAG	Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz
EC	European Commission
EEX	European Energy Exchange
ENTSOE	European Network of Transmission System Operators for Electricity
EU	European Union
EURELECTRIC	Union of the Electricity Industry
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change

OFEN	Office fédéral de l’énergie
RECS	Renewable Energy Certificate System
SFOE	Swiss Federal Office of Energy