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Efficient Investment Portfolios for the Swiss Electricity Supply Sector

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Abstract

In this paper, we investigate existing and possible future power generation capacities in Switzerland from a risk-return perspective, using the Mean-Variance Portfolio Theory of Markowitz (1952). The study covers power generation technologies currently in operation, such as nuclear power, storage hydro power and run-of-river hydro power plants, and two new renewable energy technologies (photovoltaics and wind). Additionally, natural gas combined cycle (NGCC) technology, a possible extension to the current Swiss portfolio, is assessed. The technology-specific risks considered include electricity spot market price, production capacity and reliability, fuel cost, funding liabilities, and operation and maintenance outlays. These factors are implemented in a Net Present Value (NPV) model and Monte Carlo simulations are applied to assess each investment alternative. The lifetime-adjusted average return, together with the return-specific variance, forms the basis for the portfolio optimization conducted in the second stage of the analysis. The minimum variance (or maximum return) optimization is performed separately for base-load and peak-load technology portfolios. By defining different scenarios for the upper and lower bound for each technology's share, we simulate different situations, enabling us both, to explain the risk-return profile of the current technology mix, and to make predictions for future portfolios. Our NPV calculations are in line with currently observed returns and, by imposing some reasonable restrictions, the model performs sufficiently well in terms of explaining past portfolio compositions. Moreover, our predicted optimal outcome matches quite nicely with the debated options for enlarging power production in Switzerland.

Key words: Portfolio optimization, Peak load demand, Electricity supply, Switzerland;
JEL Classification Nos.: G11, Q42

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1 Introduction

In 2005, electricity consumption in Switzerland rose by another 2.1%, while the economy grew at a rate of just below 2%. This development is in line with the correlation between the growing economy and the increased demand for electricity, as it has been observed since the 1970s. A trend break is not on the horizon yet. Rather, the 2005 electricity demand of 61'600 GWh was a new peak value, only slightly above the domestic power production output of 57'900 GWh. In contrast to power consumption, production in 2005 diminished by roughly 9% compared to 2004, mainly for reasons of unfavorable conditions in the hydroelectric power production park, and major repairs at one of the larger nuclear power plants in Switzerland (Leibstadt). As a consequence, the Swiss electricity balance was in deficit for the first time since national electricity statistics are being recorded and published (1910). On the production side, total electricity generating capacity has been roughly the same over the last twenty years: storage hydro and run-of-river power plants account for about 55%, nuclear power plants for about 40%, and conventional thermal power plants as well as alternative energy sources for the remaining 5%. This power production mix has so far enabled an exceptionally low electricity import dependence and a high level of supply security. Only the seasonal disparities between electricity demand and water flows (i.e. high water levels and thus large production capacities during summer and the contrary during the winter months) require some electricity imports, mainly from France.

The earlier mentioned first-time-ever electricity balance deficit is an indication that the Swiss utilities have reached the frontier of their current production capacities. Given the steady rise in power consumption, it is only a matter of time until current production possibilities will be insufficient to cover future electricity needs. However, the Swiss electric utilities face an even greater challenge due to the expiring long-term supply contracts with Electricité de France (EdF) for electricity, amounting to the production from two standard-sized nuclear power plants (1600 GWh each). This contracted amount of imported electricity will peter out, starting in 2020. Considering that Europe as a whole is expected to face a comparable power supply shortage around this period (VGB Powertech, 2003), it is rather unlikely that these contracts will be extended under the same conditions and volumes as in the past. Additionally, right around this time, the first nuclear power plants built in Switzerland (Mühleberg, Beznau I and II) will have to be shut down. Constructed in 1969 (Beznau I), 1971 (Beznau II) and 1972 (Mühleberg), respectively, their lifetime in 2020 will already have been extended far beyond the originally anticipated nuclear reactor lifetime of 40 years. Another so far only

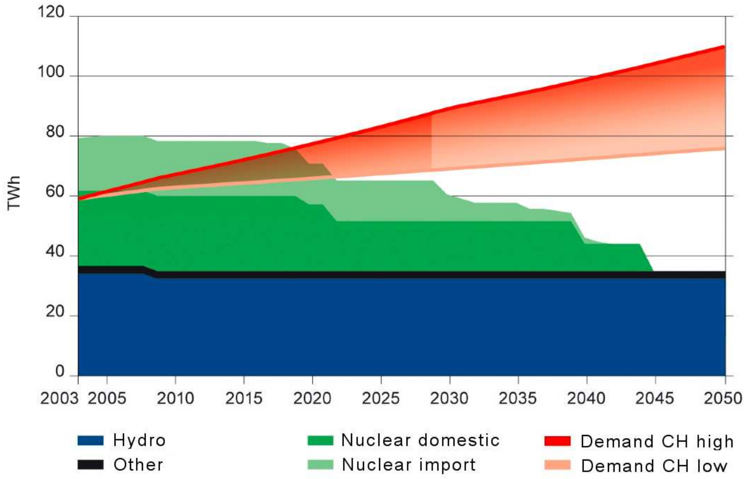


Figure 1: Electricity supply and demand projections for Switzerland (Axpo, 2006)

minor impact on the production of electricity is the changing climate. Due to less regular and in absolute numbers decreasing annual precipitation levels, run-of-river hydro plants will be unable to make use of the entire water flows that can be used, and storage hydro plants will not attain the same water volume levels as in past years. Depending on the further growth in electricity demand, all these aspects together will lead to an expected production gap of 10-30 TWh by 2030, or 15-33% of total power consumption (Axpo, 2006), compared to today's production capacities (figure 1).

As a result, regulators and utility companies will be confronted with a great challenge on how to overcome this emerging supply-demand gap, facing restrictions to operations that accrue from the speeding up of climate change, the commitment to the Kyoto Protocol, very volatile energy resource prices, and other factors.

The facts mentioned above indicate that large-scale investments in electricity production capacity will be inevitable in the coming years. These investments need to fulfill a number of requirements. They need to be adequate and brought on line in time to compensate for the phasing out of existing plants that are accepted by the public, economically attractive, and that suffice government and international regulations. In this paper we investigate the economic aspects of these investments, including some of the restrictions set by the electricity end-users (i.e. the amount of electricity that needs to be delivered) as well as the government (i.e. CO_2 taxes/certificates). Based on the existing portfolio of power generation plants, we evaluate how funds should be allocated in an optimal way for achieving the maximum expected return on investment for a chosen level of investment risk. The optimization is done from the point of view of a public electricity production corporation, facing the aggregate electricity demand of Switzerland. Microeconomic theory (Mas-Colell et al., 1995, p.148) tells us that in a competitive market, the profit maximization scheme remains the same, irrespective of whether the optimization is done in a decentralized way by many competing firms, or if it is done by a single, conglomerate firm[1]. This allows us to define our point of view either as being for the entire Swiss market (cf. Sections 4.5 to 4.7.4) or as being for a single company operating in that market (cf. Section 4.8).

It is very important at this point to keep in mind that the calculations that follow are based on data available at the time of writing. The results therefore only hold for investment decisions taken today, or in the not-too-distant future, since technological change and price movements can influence the expected returns markedly. As most power production facilities are owned by public limited companies, a trend that is likely to progress as liberalization proceeds, the focus of this study is on public corporations, and especially on one of the largest in Switzerland, Axpo.[2] Thus, the optimization problem described above is done from the point of view of a utility company optimizing its production capabilities, based on a production mandate and legal framework enacted by the government.

For estimating the expected returns from each electricity production technology for the utility company, one first has to take a closer look at the risks involved. The uncertainties that are most relevant include the development of the prices for fuel and CO_2[3], as well as the electricity price in a liberalized market and the technology-specific discount rate. After identifying the technology specific risks and adjusting for investment lifetime and construction lead time, we ran a Monte Carlo simulation (MCS) to obtain the expected means, variances and correlations of lifetime investment returns. In a final step, different portfolios for base-load and peak-load power are created, comprising all currently used technologies (i.e. storage

[1]The authors are aware that the price-taking behavior of a competitive market is a non-trivial assumption in the electricity market. In liberalized markets in particular one cannot completely dismiss a collusive behavior of electricity producers.

[2]Axpo AG is a holding company that comprises some of the largest electricity suppliers in Switzerland, such as the Nordostschweizerische Kraftwerke AG (NOK), Centralschweizerische Kraftwerke AG (CKW) and the Elektrizitäts-Gesellschaft Laufenburg AG (EGL).

[3]Unlike the European Union, the Swiss government has so far refrained from introducing a greenhouse gas emission trading scheme as a policy instrument for controlling greenhouse gas emissions. Instead, the Swiss government has decided to impose a levy on CO_2 emissions, starting in 2008 at a rate of CHF 35 per ton of CO_2 released. A special case applies for large electricity production facilities (CO_2 Act, art. 9), which are allowed to compensate their emissions by emission trading (of which at least 50-70% has to be effected in Switzerland itself). Due to a lack of reliable data on the cost of compensation, our computations are based on the fixed levy of CHF 35 per ton, which is in line with long-term estimates of compensation costs.

hydro, run-of-river hydro, nuclear, solar photovoltaics, and wind), as well as the natural gas combined cycle (NGCC) turbine technology, a potentially newly implemented option.

The optimization of the considered portfolios is subject to constraints set by the demand side and by the maximum possible output certain technologies are able to achieve in Switzerland. While the influence of the demand side is determined by current electricity consumption levels and their expected future growth, the production output constraint is to a large extent set by nature, especially concerning the renewable options such as wind, photovoltaics (PV) and hydropower.

A special characteristic of the diverse production technologies is their availability factor. While nuclear and run-of-river hydro power plants deliver base-load electricity, storage hydro and NGCC plants can rapidly be brought on line in case of additional peak-load demand. For the alternative energy technologies, such as wind or solar PV, the situation is more complicated. These technologies produce electricity whenever climate permits, and deliver their production output during base-load and peak-load times. Because their production output is hard to predict and cannot reliably be incorporated in a utilities' production plan, we assume in our model that the generated electricity is used to pump water into storage lakes. Furthermore, as storage hydro is mainly used for peak-load electricity production, we conclude that solar PV and wind power will ultimately be sold on the peak-load market.

The alternating demand cycles of base-load and peak-load is taken into account by constructing two portfolios. Specifically, we account for base-load periods where demand is mostly met by nuclear and run-of-river plants, complemented by NGCC and storage hydro if needed, while the peak-load portfolio covers peak-load production provided by hydro dams, NGCC plants as well as the two new renewable options, wind and solar PV.

The remainder of this paper is structured as follows: Section 2 provides an overview of the current literature and the main findings. Section 3 reports in detail on our portfolio approach for modeling the electricity production sector. Section 4 contains the results of the analysis, and Section 5 concludes.

2 Review of the literature

Since the scope of our analysis is restricted to the portfolio approach for finding an efficient power production mix, this short review of the literature is restricted to this specific application of portfolio theory. All of the research considered builds upon Harry Markowitz's well known Mean-Variance Portfolio (MVP) selection approach (Markowitz, 1952), first applied to the energy production business by Bar-Lev and Katz (1976). Concerned about the surging energy prices caused by the first oil crisis, they compared the historical price levels and volatilities of oil, coal and natural gas in an MVP approach, concluding that the utilities evaluated generally produce electricity close to the efficient frontier. Furthermore, they found that utilities prefer a high risk and high return portfolio, mainly caused by reassuring regulatory circumstances.

In more recent years, Awerbuch and Berger (2003) and Awerbuch (2006) applied MVP on the electricity generating mix of the European Union, using a more sophisticated model than Bar-Lev and Katz. Based on a cost approach they included additional variables to the basic resource costs, such as operation and maintenance (O&M) outlays, construction period expenses etc. They conclude that the current generating portfolios are slightly off the optimal track, lacking portfolio shares of fixed-cost technologies such as renewables.

Even more recently, Krey and Zweifel (2006) investigated the efficient electricity portfolios for Swiss and U.S.-American utilities, again using a cost-only approach. They calculated time series of total production cost per kWh, including fuel, O&M, capital and external costs. As in Awerbuch (2006), the decrease in total cost over a year was treated as expected return and then, together with its volatility, used to create portfolios. A new element of their study was the econometric approach adopted. Starting from the assumption that shocks in electricity generation costs are correlated, they used the seemingly unrelated regression (SUR) estimation to filter out the systematic component affecting the cost variation covariance matrix. The authors conclude that neither the American nor the Swiss electricity production is close to an optimum, both requiring major investments in coal or nuclear power plants for optimality. Finally, a series of papers by Roques and colleagues (Roques et al., 2006a) addresses the ongoing liberalization of the power supply market and, therefore, bases the MVP methodology not only on costs, but also on revenues, thus taking a closer look at the net present value (NPV) of the investments. Their research focused on UK's electricity supply sector and considered the three base-load energies nuclear, gas, and coal. By running a Monte Carlo simulation (MCS) of the investment-specific NPVs with the incorporated risks inherent to fuel, electricity and CO_2 price fluctuations, the required correlation and variance matrices were obtained and the efficient portfolio created. An important insight of their studies is that the dominance of gas-fueled power plants leads to a high correlation between electricity and gas prices, resulting in a reduced risk-return profile for this technology. Additionally, as NGCC plants will take an even larger share of the total electricity production, these correlation rises give such an investment an externality value. This externality value is gaining so much momentum that it makes investments in other technologies redundant when only the risk-return profile is considered. The authors conclude that the optimal portfolio of a UK-based utility company consists mainly of NGCC plants and only a few nuclear power plants (Roques et al., 2006b). Even though Roques and associates control for many cost and technical parameters, they do not put sufficient weight on the time value of these long-term investments. This is especially troublesome when the NPV is used as a target variable and the focus is on looking at the considerable differences in duration that invested capital is tied up for.

3 Construction of efficient portfolios

3.1 Mean Variance Portfolio Theory

MVP theory, introduced by Markowitz in the early 1950's (Markowitz, 1952), was initially designed and used for financial securities. The goal of every MVP analysis is to maximize the expected return, given a chosen amount of volatility or, alternatively, to minimize volatility given some desired expected return level. The basis for a successful application is expected returns and volatilities of the portfolio-forming investments, as well as their respective return-correlations. The expected return of the portfolio, in the following specified for the case of two securities, is generally composed of the expected return of each asset included, weighted by its share in the portfolio, i.e.

$$\mathrm{E}(\mu_{Portfolio}) = w_1 \cdot r_1 + w_2 \cdot r_2, \quad \text{with} \quad r_1 + r_2 = 1. \tag{1}$$

The portfolio's volatility can be determined in a somewhat more sophisticated manner, that is by including not only the volatility σ^2 of each investment with its squared weight w^2, but also the correlation ρ of each investment pair:

$$\sigma^2_{Portfolio} = w_1^2\sigma_1^2 + w_2^2\sigma_2^2 + 2(w_1 w_2 \rho_{12}\sigma_1\sigma_2). \tag{2}$$

Evidently, by adding more and more investments, the variance of each position becomes irrelevant when the squared weights approach zero. This leaves the portfolio volatility of a well diversified investor basically to be determined by the correlation. By definition, a correlation can only attain values between minus one and plus one, including the end points.

Thus, as long as two investments show a covariance smaller than one, the overall portfolio variance can be reduced by the construction of a basket that contains both securities.

MVP has a broad field of application in finance and enjoys a great popularity among people working in this field. However, there are some drawbacks to this methodology that need to be discussed. One that has become very prominent recently is that MVP reflects, as suggested by its name, only the first two moments of a distribution in its optimization. Fat tails or skewed distributions are therefore not considered to the extent that they should and hence the risk of very rare but devastating events is clearly underestimated. Such an event is for example the bursting of a dam, the leakage of a nuclear reactor, etc. A second, also widely discussed, caveat concerns the time dimension. MVP is a static methodology, heavily relying on past data. As a result a portfolio that is thought of as optimal today, might already be way off the efficient frontier tomorrow, depending on how the environment has changed. It is therefore a method that should only be considered within a very limited time frame.

3.2 Defining the MVP problem

For the effective construction of a portfolio, suitable measures for the variables included need to be defined. In our research, the objective variable is defined as the NPV of the investments, thus following an approach similar to the one used in Roques et al. (2008). A favorable property of the NPV approach is the allowance of a risk- and time-adjusted discounting, thus respecting the time value of different investments accordingly. This is an important point especially in the power supply industry, where investment horizons often span several decades. In the MVP approach adopted, the expected return variable is considered to be the NPV of each investment and the variance to be the respective volatility.

The power sector has received extended coverage in recent time because of its development from a government-regulated market towards a liberalized market. As a result, government subsidies and price guarantees are slowly fading out, forcing utility companies to become more concerned about costs, profits, and risks. Therefore, it is not only total cost that has to be minimized, as it was done in the past, but the investment as a whole has to yield the highest possible net profit. The answer to the new optimization problem, however, does not only consist of the share in total production each technology provides, but also of total production. The representative company, therefore, has to face the decision of how much spare capacity should be maintained in order to meet volatile electricity demand at any point in time.[4]

3.3 Investment consistency

In order to get an accurate revenue measure, it is important to include all the key elements that affect the profitability of the investment. In the literature, several sensitivity studies that focus on the main cost drivers of investments into different energy plants can be found (e.g. Roques et al., 2006a). These were taken as a guidance for defining the most important cost drivers in our research. In a first stage, all possible and reasonable investment alternatives for the Swiss electricity supply industry had to be defined. These alternatives are: (1) Run-of-river (RoR) hydro power plant (low pressure, LP; high pressure, HP); (2) Storage hydro (SH) power plant; (3) Nuclear power plant; (4) Natural gas combined cycle (NGCC) power plant; and (5) Alternative energy power plant (i.e. wind and solar PV).

As Switzerland produces a large proportion of its electricity needs by means of hydro power dams, the most profitable renewable energy facilities have already been built in the past. Remaining options to further develop this particular sector are sparse (e.g. Laufer et al., 2004), but there is additional production capacity which can be gained through refurbishment of existing hydro power plants. As these enhancement options can be expected to have more relevance in the near future than newly built hydro power plants, they were explicitly included in the portfolio selection menu. The specific enhancement options for hydro power production included in our analysis are: (1) Run-of-river hydro power plant, HP, new hardware (nh); (2) Run-of-river hydro power plant, LP, refurbished (ref); (3) Storage hydro power plant, new hardware; and (4) Storage hydro power plant, refurbished.[5]

[4] Note that the very specific topic of reserve capacity is beyond the scope of this paper and therefore not discussed further.

[5] The 'new hardware' and the 'refurbishment' electricity production enlargement options both focus on existing run-of-river and storage hydro electricity production facilities. Concerning the new hardware option, it is important to consider the age pattern of today's equipment. More than half of the current hydro electricity is produced by hydro power plants older than 40 years. By replacing the dated turbines and generators with more efficient and capacious new technology, additional electricity can be generated. The additional electricity output requires only little extra investment, as the hardware in use often needs replacement in the near future anyway. Another advantage of this hardware upgrade is the fact that there is essentially no additional adverse environmental impact. This is in contrast to the refurbishment option, which mainly consists either of increasing the height of the current dam or of dredging the held-up river/lake. Implementing this option is always impacting the surrounding environment, even though it only leads to serious consequences in very few cases. The overall gain in additional electricity production through a refurbishment of the hydro power plant is larger than through the application of new hardware. This is partly offset by the additionally required time that the refurbishment option needs to be realized, relative to the new hardware option. During the time of implementation, the hydro power plant is fully or at least partly off-line and thus unable to supply any electricity to the grid. Considering the hydro power enlargement options, one also has to keep in mind, that total improvement in electricity production capacity with these measures is very limited and unable to substitute for an entire new power plant. Finally, regulated minimum water flows of rivers and the residual

In our analysis we focus on the primary effects of investments in real assets and evaluate their portfolio behavior. This neglects the option of utilities to reduce part of their risk by using secondary markets (financial and commodity) to hedge partially against unfavorable conditions such as rising gas or uranium prices. However, this option only provides partial hedges and is not able to offset structural changes, which a primary hedge may be able to.

Another caveat concerns the real-option value which some technologies bear. Especially storage hydro power and NGCC plants carry additional value because of their flexibility of operation. When going through the analysis below one always has to bear in mind that these technologies may involve additional value for a utility company that is not reflected directly in our computations. Yet it also has to be argued here that the current overall production portfolio is just able to cover the entire national electricity demand, implying that the flexibility of the utilities to use their power plants to maximize profits is very limited.

Having defined the available investment options considered in our analysis, the power plant specific risks have to be taken into account in a next step. On the *revenue side*, the main risks concern the electricity spot price as well as the capacity factor of a power plant.

- **Electricity price:** The electricity spot price is a fairly new source of risk with a big impact on power plant investment profitability, as shown later. Recent experience shows that the bulk of electricity is traded on spot markets. Such trading has gained so much momentum that a new exchange, the European Electricity Exchange (EEX) (formerly only a small domestic German Electricity Exchange) has been established. In our research, the electricity price for base- and peak-load, as well as the respective volatilities, are based on time series data derived from the EEX[6]. Based on the price data we estimated the best fitting distribution, which in the case of both base- and peak-load prices was a lognormal distribution.[7] The underlying distribution parameters are shown in table 1.

  Based on findings of past research (Awerbuch and Berger, 2003; Roques et al., 2008)), we also estimated a correlation between fuel prices and the market price of electricity. The correlation coefficient for natural gas was estimated at 0.40 and the one for uranium at 0.13. The estimation was done based on monthly data (2005-2008) between the Swiss

water from hydro dams restrain the amount of water that can be used for hydro power production.

[6]Base-load: EEX - Phelix Base 16.06.2000 - 11.08.2008, daily
Peak-load: EEX - Phelix Peak 16.06.2000 - 11.08.2008, daily

[7]Parameter estimates:
Base-load: mean 76.45, sd. 41.41. Statistics: Anderson-Darling 8.7560, χ^2 125.43
Peak-load: mean 60.73, sd. 30.63. Statistics: Anderson-Darling 7.0878, χ^2 126.03

Table 1: Parameterization of the electricity price distribution (lognormal)

	Base-load CHF/MWh	Peak-load CHF/MWh
Likeliest	60.73	76.45
Scale	30.63	41.14

Electricity Price Index[8] and the price of natural gas and uranium respectively. For the entire simulation we assume that all technologies in the same portfolio (base- or peak-load) are subject to the same electricity market prices.

- **Capacity factor:** The output capacity factor measures the relation of produced electricity to installed capacity for each generating technology. Depending on the available data, different paths of approximation were chosen. The national energy statistic provides the capacity factor for the Swiss nuclear plants. The annual data for the period from 1992 to 2006 suggest that the capacity factor for nuclear is best approximated by a minimum extreme value distribution.[9] Due to a lack of data concerning capacity factors of NGCC plants in Switzerland, the same distribution as for nuclear power was assumed, with the parameter for the likeliest value adjusted to 0.62 (cf. Sättler et al., 2001). For hydro technologies, the capacity factor is largely dependent on the flow of water. The national energy statistic provides annual statistics for the production possibilities of hydro technologies. Again, based on the period from 1992 to 2006 estimates suggest that the hydro capacity factor follows a lognormal distribution with a standard deviation of 10% of the mean value.[10] Based on the average capacity factors for the different hydro technologies (cf. Laufer et al., 2004) this distribution was implemented. For the new renewable electricity options we could not rely on past data, as these technologies have experienced considerable growth in electricity output as well as technology improvement in recent years. This puts too much noise on a significant standard deviation estimate. We therefore approximated the variation of the annual capacity factor of the wind and solar PV technology with the data gained from the hydro technologies. An important point concerning capacity factors is the correlation that is present, especially in the case

[8]Already prior to the EEX launching their index (Phelius), two of Switzerland's utilities, Aare-Tessin AG für Elektrizität (Atel) and Elektrizitäts-Gesellschaft Laufenburg AG (EGL), initiated the Swiss Electricity Price Index (SWEP), a forward index established on March 10, 1998, that covers next day peak-load electricity prices.

[9]Parameters: Likeliest: 0.9, Scale: 0.0276. Test Statistics: Anderson-Darling 0.2116, χ^2 0.5

[10]Test Statistics: Anderson-Darling 0.3075, χ^2 0.4

of hydro technology. A year with above average precipitation clearly allows all hydro technologies to run with an increased capacity. We accounted for this by implementing correlations of 0.95 between similar hydro technology classes, i.e. storage hydro technology (new, new hardware, refurbishment) and run-of-river technology (HP, LP, new hardware, refurbishment). Data further suggests a correlation of 0.82 between these two technologies.

On the *expenditures side*, we considered fuel costs, the levy on the carbon dioxide emissions, other environmental costs (i.e. nuclear waste disposal), operation and maintenance (O&M) costs, and capital cost expenses which are closely tied to the (risk-adjusted) long-term interest rate.

- **Fuel cost:** The volatility incorporated in fuel cost can be obtained from time series data readily available. For the analyzed time period (natural gas 2005-2008, monthly data; uranium 2005-2008, monthly data). For natural gas this data suggests that prices follow a Gumbel distribution[11], while for uranium it is a Gamma distribution[12]. The time series to estimate the underlying distribution was chosen relatively short in order to account for the rising resource prices in recent years, which are given more weight this way. The use of water to generate electricity is taxed by governmental law at an average price of CHF 12 per MWh of electricity produced[13].

- **Environmental cost:** The Swiss CO_2 Act imposes a levy on the emittance of CO_2 of CHF 35 per ton. Waived from this tax are large CO_2 emitters, such as NGCC plants, which in turn have to fully compensate for their CO_2 output[14]. Due to a lack of reliable data on the cost of compensation, especially for Switzerland, the environmental costs are approximated by the fixed costs of CHF 35 per ton of emitted CO_2. Similar to the tax on CO_2 emissions are the charges for the disposal of nuclear waste. As the uranium used in nuclear reactors not only needs special treatment once the life-cycle of the fuel-rod reaches its end, but also requires a lot of resources to be obtained, we incorporated both outlays in 'fuel rod life-cycle costs'. Front-end expenditures are 4.71 CHF/MWh and cover all the refining processes uranium has to go through until it can

[11] Parameters: Likeliest 28.51, Scale 6.84. Statistics: Anderson-Darling 0.7308, χ^2 8.2791

[12] Parameters: Location 3.82, Standard Deviation 3.34, Shape 0.65; Statistics: Anderson-Darling 1.2787, χ^2 10.8525

[13] For a detailed account of the Swiss system of water taxes see Filippini et al. (2004).

[14] It is currently subject to discussion how this compensation has to be allocated. The two options either suggest that at least 50% (70%) of the compensation has to be conducted within Switzerland.

be burned as fuel rod in the plant, but do not cover the price of the basic resource itself. Back-end costs occur for nuclear waste disposal and account for about 1.48 CHF/MWh. However, the latter outlays only cover payments for final disposal of the nuclear waste and do not consider the possibility of fuel reprocessing and conditioning.

- **O & M cost:** Fixed and variable O&M costs are averaged over the entire lifetime of an investment and are tied to the annual electricity output of the plant. The cost estimates for a nuclear plant are based on an extensive report by the Paul Scherrer Institute (Hirschberg et al., 2005), for all hydro power plants on 'Ausbaupotential der Wasserkraft' (Laufer et al., 2004), for NGCC power plants on a report by Prognos (Sättler et al., 2001), and for the alternative energies on a study conducted by the OECD/IEA (IEA, 2005). Since this report did not cover alternative investments for Switzerland, we approximated the O&M costs from similar facilities in Germany and Austria. Additionally, similar to Awerbuch (2006) we assume the O&M costs to be volatile, following an underlying normal distribution with a standard deviation of 10% and an inter-technological correlation of 0.7.

- **Initial investment & depreciation:** The estimates for the average projected initial plant investments are based on the same studies as mentioned above. Past and current experience show that construction bears a large risk for utilities, sometimes going as far as putting them on the verge of bankruptcy. To incorporate this risk of cost overruns, the initial investment in each technology is modeled with a right-skewed distribution. This allows us to model the possibility of small, but highly probable as well as large and less likely investment outlay overruns.[15] Depreciation was calculated based on the assumption that technical lifetime equals economic lifetime of the investment. The level of depreciation depends on the value of the initial investment drawn from the above mentioned distribution.

- **Capital cost:** The level of the capital costs resulting from the power plant investment reflects the risk an equity provider has to bear during operation of the plant. An approximation of this risk can be obtained by estimating the demanded return for the invested funds. The expected rate of return is then used to calculate the interest

[15] Gamma distribution with location parameter equal to the expected initial investment costs and a shape parameter value of 2. The scale parameter varies with the size and technical difficulty of the investment: Nuclear and new hydro power have a scale parameter value of 20% of the location, all other technologies and hydro enhancements have a scale parameter value of 10%.

payments from initial investments. The financing criterion will receive an even heavier weight in liberalized electricity markets, since government subsidies or debt guarantees are no longer granted. As the process of liberalizing electricity markets has in many countries started just some years ago, there is only rudimentary experience in financing large power plant investments in this new, risky environment. For our estimates of appropriate discount rates we considered this current knowledge and also relied on past market data. The estimate for the global risk supplement on the discount rate was based on experiences in the already liberalized Californian energy market. There, the major part of the issued bonds that finance electricity generating plants received a BBB rating by Standard & Poor's (Veron and Iaconetti, 2001; Feldman, 2000; Stern, 1998). Based on a daily time series from 2000 to 2006, we approximated an average risk premium for this class of risk. The comparison was made between a ten-year Swiss government bond and a bond index for Swiss companies rated at BBB. In absolute numbers, this rating approximately equals a risk premium p of 2.48 percentage points. Furthermore, the long term average interest rate of a ten-year Swiss government bond is around 3.1%[16]. Therefore, the risk-adjusted discount rate for project financing in Switzerland is about 5.58%. Like depreciation, the amount of interest payment depends on the initial construction costs.

- **Time:** The time value of money is incorporated in this model through the discount rates which are equal to the interest rate the interest payments are based on. Additionally, it is considered that every investment has a lead time before operation can be picked up. The lead time consists largely of planning and construction processes and to a smaller extent of the time needed to obtain planning and operating permission. The estimates for these lead times are taken from the above-mentioned OECD report (IEA, 2005). As these lead times are based on best-case estimates, especially concerning licensing and public acceptance, we applied the same underlying uncertainty process as for initial investment[17].

An overview of the basic data used for the different technologies is given in table 2.

[16]Note that interest rates in Switzerland are usually below the Eurozone interest rate. A similar derivation for the discount rate on the European level would yield an interest rate about 1.5 percentage points above the Swiss rate.

[17]Gamma distribution with location parameter equal to the expected lead time and a shape parameter value of 2. The scale parameter varies with the technical difficulty and the political acceptance of the investment: Nuclear has a scale parameter value of 40%, NGCC and new hydro one of 30%, and all other technologies and hydro enhancements have a scale of 15% of the location parameter.

Table 2: Basic properties and assumptions

	Size MW_e	Utilization[9] % p.a.	O&M[3] costs TCHF[10] p.a.	Investment[4] CHF/kW	Fuel Costs CHF/MWh	Lifetime years	Leadtime[8] years
Nuc	1600	90.0 (2.8)[1]	95'308	2400 (20%)	3.8 (3.3)[5]	60	5 (2.0)
RoR (HP)	500	28.0 (2.8)[2]	12'900	4440 (20%)	12.0 (0.0)[6]	70	3 (0.9)
RoR (HP), nh	210	21.0 (2.1)[2]	5418	318 (10%)	12.0 (0.0)	70	1 (0.2)
RoR (LP)	420	52.0 (5.2)[2]	10'836	8143 (20%)	12.0 (0.0)	70	3 (0.9)
RoR (LP), ref	150	41.0 (4.1)[2]	3870	6480 (10%)	12.0 (0.0)	70	2 (0.3)
SH	1200	23.0 (2.3)[2]	30'960	6883 (20%)	12.0 (0.0)	70	6 (1.8)
SH, nh	120	34.0 (3.4)[2]	3096	300 (10%)	12.0 (0.0)	70	1 (0.2)
SH, ref	230	25.0 (2.5)[2]	5934	3130 (10%)	12.0 (0.0)	70	2 (0.3)
NGCC	400	62.0 (2.8)[1]	17'431	750 (10%)	26.3 (5.9)[7]	20	2 (0.6)
Solar PV	0.5	14.3 (1.4)[2]	30	6000 (10%)	0 (0)	25	1 (0.2)
Wind	1.75	15.0 (1.5)[2]	91	1850 (10%)	0 (0)	25	1 (0.2)

[1] Minimum extreme distribution: likeliest (scale)
[2] Lognormal distribution: mean (standard deviation)
[3] Normal distribution: mean with standard errors 10% of the mean value
[4] Gamma distribution (shape 2): location (scale)
[5] Gamma distribution (shape 0.65): mean (scale)
[6] Fixed tax for the use of water
[7] Maximum extreme distribution: likeliest (scale)
[8] Gamma distribution (shape 2): location (scale)
[9] Actual output as percentage of installed output capacity
[10] TCHF = 1000 CHF

4 Econometric conditioning

In order to be able to optimize a portfolio of power generation technologies, a correlation matrix of the calculated lifetime returns on investment is needed. To obtain such a correlation matrix, we conducted a Monte Carlo simulation (MCS). The procedure for successfully calculating the required data consists of the following four steps: First, to define the annual expected return model, including the underlying distribution parameters and inter-technological correlations for the uncertainty factors. Second, to perform an MCS for every technology to obtain the distribution parameters of annual expected returns. Third, to discount and sum up the annual expected returns over the investment-specific time horizon for obtaining the present value of lifetime return. Fourth, to calculate the correlation matrix of lifetime returns on investment in order to find efficient portfolios. These can either be conditional on minimizing risk or on maximizing expected return, by combining the different electricity producing technologies, accounting for imposed restrictions by the demand side.

4.1 The model

The previously specified and conditioned data now have to be arranged such that an annual expected return of operating a specific power plant can be obtained. The model on which our calculations are based is specified as follows:

$$\pi = p \cdot Q - om - fc - \delta - cc - Q \cdot \tau - Q \cdot n, \tag{3}$$

where π is the expected return per annum, p the price of electricity, Q the electricity output, fc the fuel costs, δ the annual depreciation, cc the annual capital cost, τ the CO_2 levy or the water tax, and n the nuclear life-cycle cost.

For each electricity generating technology, we specified this model with the appropriate figures and statistics and ran an MCS with 50,000 draws for each technology's expected return. The resulting revenues were analyzed and the parameters of the best fitting distribution function for each technology's payoff determined (in all cases, the standard normal distribution). Conditional to the differentiation between peak-load and base-load electricity, we assumed that technologies producing base-load only charge base-load energy prices, and vice versa. Although only of limited realism, this should not distract too much from creating the optimal portfolio, since every technology in the base-load environment is affected by this pricing rule to the same degree. The parameters (expected return μ and its standard deviation σ) of the annual earnings distributions for base-load and peak-load electricity are reported together with lifetime ROIs in table 3.

The results suggest significant differences in expected returns among the technologies, no matter if base-load or peak-load. Considering only newly built power plants, nuclear power is the one that yields the best outcome with a positive performance in about 50% of all draws. A moderately positive performing asset is the base-load environment NGCC plant, although only in approximately 15% of the time. For storage hydro plants, building new facilities basically always results in negative annual returns, making this option, from a return-only point of view, not worthwhile. On the other hand, hydro power plants bear the option of replacing the dated hardware of already existing plants with new, more efficient equipment. This upgrading yields positive earnings almost all the time, but is also a very limited option concerning electricity output enhancement. A refurbishment of run-of-river facilities allows for a larger increase in electricity output than the hardware upgrading option, but with higher costs entailed, it leads to negative expected returns almost all of the time, hence there does not seem to be a clear advantage of refurbishing a hydro facility if a new one can be built.

This leaves us with the technologies producing electricity during peak-load times. As said before, storage hydro plants produce most of their output during peak hours and, therefore, should be considered mainly as peak-load electricity suppliers, even though they also provide a fraction of their output as base-load electricity (reserve capacity). The returns from electricity sales during peak hours are about 20% higher, but even with this improved retailing condition all but one of the investments that yield a negative average payoff at base-load prices still have expected returns below zero at peak-load prices. The big winner of higher peak-load electricity prices is the NGCC technology. The negative average annual payoff for base-load electricity of CHF -59.4 million is about halved to a negative average yield of CHF 29.4 million p.a. with peak-load prices, and thus further earning non-negative expected returns in about 28% of the time. As for the new renewable energy technologies, solar PV and wind, it is shown that both technologies are so far not competitively taking part in the Swiss electricity market. With a zero probability of positive expected returns for solar PV and only about 1% for wind, these sources of electricity, at the current level of technology development, still need government subsidies, or the commitment of customers to pay extra for green energy, in order to overcome the otherwise negative expected returns.

4.2 Expected returns over time

The expected annual returns calculated now control for the major market risks as well as for some technology-specific variables. To enhance this model with the time dimension, we have to sum up all the expected returns an electricity generating technology yields during its lifetime. Of course, these expected returns have to be discounted with an appropriate discount rate. As the different technologies clearly bear different project risks considering time, it would not seem realistic to assume the same parameter values for all technologies. While alternative investments, such as solar photovoltaic panels or wind turbines, do not evoke a large public debate and can be set up at very short notice, projects such as new nuclear plants or hydro dams need a lot of public conviction, state concessions, and sometimes even a change in the current law. On top of that, they need a much longer time span to be built and commissioned. Additionally, some technologies are exposed to restrictive regulatory changes (nuclear moratorium, new climate protection laws etc.) or heavily fluctuating input prices, while other production possibilities generate electricity in a fairly stable legal environment. A differentiation can either be done by adjusting the discount rate or by varying the time needed for the construction of each technology. Our model is built on the latter assumption, as the general opinion on time is much clearer than on interest rate spreads.

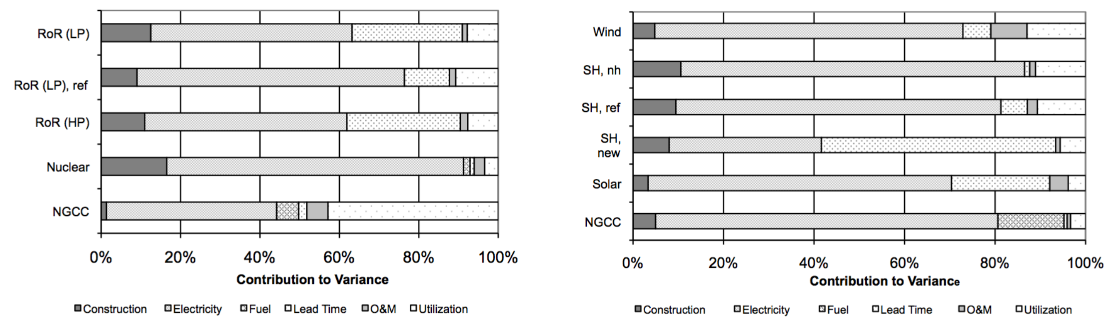
Discounting the expected annual investment returns over the specific lifetime of the power source yields the present value of a ready-to-produce power plant. Up to now we do not consider the time needed for construction and approval of the plant. During this time there are only cash outflows, which we consider on an annuity basis for the years of operation, but no cash inflows. We therefore use the calculated present value of the operation time span and discount it with the same risk-adjusted factor over the specific lead time period. These returns, adjusted for operation and construction period risk are then related to the initial investment to yield the lifetime return on investment. An overview is provided in table 3.

Table 3: Annual and lifetime returns

		Annual Returns CHF		Lifetime ROI %	
		μ	σ	μ	σ
Base-load	NGCC	-59.41	67.46	-0.28	1.66
	Nuc	80.11	390.37	0.14	0.60
	RoR (HP)	-175.12	58.98	-0.65	0.17
	RoR (HP), nh	7.63	12.05	1.52	2.40
	RoR (LP)	-260.18	90.79	-0.62	0.17
	RoR (LP), ref	-60.93	19.42	-0.73	0.21
Peak-load	SH	-704.25	194.91	-0.47	0.12
	SH, nh	16.85	14.96	6.19	5.56
	SH, ref	-35.12	22.33	-0.56	0.35
	NGCC	-29.38	87.47	0.49	2.13
	Solar PV	-0.40	0.06	-1.31	0.09
	Wind	-0.36	0.11	-1.11	0.31

4.3 Sensitivities

In a next step, we assessed the impact of the various input factors on a technology's lifetime ROI. Figure (2) shows the contribution of each input factor to the volatility of the lifetime ROI and thus allows to rank them according to their impact. The analyzed changes concern construction costs, price of electricity, fuel costs where applicable, lead time, O&M cost as well as utilization. The results clearly show that for all technologies the largest contributor to variance is the electricity market price ranging from about 30% for new storage hydro up to about 70% for peak-load NGCC plants. Changes in construction costs do not seem to impact the volatility of the lifetime return in a very significant manner. It is largest for nuclear power (about 18%) and storage hydro generally (about 10-15%). For all hydro technologies it can be observed that the lead time contributes about 25-45% of the volatility which is considerably larger than for the other technologies. However, this can be explained by the fact that hydro technologies do not have to bear any volatility from fuel prices, leaving the



(a) Base-load (b) Peak-load

Figure 2: Price sensitivity of expected returns, by technology

other factors of variance in a more prominent position. The results also show that O&M costs only have a minor impact on the variance of expected lifetime returns, ranging from a mere 1% or even less for nuclear or peak-load NGCC up to about 11% for wind. Fuel cost uncertainty only impacts NGCC and nuclear plants directly, but especially for latter plants this does not contribute more than 2% to total variance. This is different for NGCC plants where fuel costs are responsible for 10-25% of the lifetime return variance.

4.4 Portfolio definition

Based on the computed lifetime ROIs, we proceed by defining the correlation matrix for base-load and peak-load technologies. The data for this calculation is obtained from the MCS. The results are reported in tables 4 and 5.

Table 4: Correlation matrix, base-load technologies

	NGCC	Nuclear	RoR (HP)	RoR (LP), ref	RoR (LP)	RoR (HP), nh
NGCC	1					
Nuclear	0.90	1.00				
RoR (HP)	0.83	0.81	1.00			
RoR (HP), ref	0.92	0.89	0.86	1.00		
RoR (LP)	0.83	0.81	0.77	0.86	1.00	
RoR (HP), nh	0.93	0.90	0.87	0.96	0.87	1.00

Some of the given correlations are only added for completeness and do not have an interpretable meaning. This issue mainly concerns the hydro additions where it makes no sense to compare the addition to its base investment. The correlation matrices show how the returns of the different technologies vary relatively to each other. In the base-load portfolio we find

Table 5: Correlation matrix, peak-load technologies

	NGCC	Solar PV	SH	SH, ref	SH, nh	Wind
NGCC	1					
Solar PV	0.91	1.00				
SH	0.56	0.55	1.00			
SH, ref	0.94	0.92	0.58	1.00		
SH, nh	0.94	0.91	0.58	0.97	1.00	
Wind	0.93	0.91	0.56	0.93	0.93	1.00

a large correlation between the two hydro power options of refurbishment and new hardware which at the same time are also highly correlated with NGCC. Yet new run-of-river (HP and LP) installations seem to bear some diversification to NGCC and nuclear power. Interestingly, the two run-of-river technologies, HP and LP, have the lowest correlation coefficient of the whole base-load portfolio. The peak-load portfolio suggests that storage hydro power is only moving in the same directions as the other technologies return in about 50% of the time, thus offering some diversification potential.

4.5 Scenarios considered

Having all necessary data computed, we are now able to allocate the electricity production technologies in the portfolio. At this point, the *limitations* that some of the technologies face have to be considered. The extension options concerning the hydro power plants are technologically limited as only the already built dams and turbines can be upgraded. The improvement itself, therefore, cannot be viewed as an electricity source of its own as it always requires an already built hydro electricity unit to exert power. The other limitations concern the new renewable energy conversion technologies, wind and solar PV, whose production output is in both cases heavily dependent on the natural environment. Together with the irregular production output, which requires backup capacities, these technologies are only able to contribute a very limited amount to the total electricity output in Switzerland.
With these thoughts in mind, we look at the following four different scenarios, each representing a different base case. The limitations are calculated relative to the total energy consumption of the year 2005 (after the deduction of conduction loss), which was 57'300 GWh (Bundesamt für Energie, 2005). We did subdivide this amount into parts for base-load and peak-load according the assumptions made below (cf. Section 4.6). The following scenarios are considered:

- Scenario 1: No constraints and no hydro upgrades.

- Scenario 2: Maximum restrictions on alternative energies as well as on all hydro power plants and minimal requirements, equal to the current production level, on hydro power plants. Additionally, we also consider hydro power plant upgrades and leave nuclear and NGCC power plants unrestrained.
- Scenario 3: Maximum restrictions on alternative energies as well as on all hydro power facilities and no consideration of hydro power upgrades.
- Scenarios 4a+b: Minimum constraints equal to the current production portfolio plus maximum restrictions on all sources including upgrades.

For each of the above scenarios, we calculated the portfolios yielding global maximum expected return or global minimum variance. Furthermore, we evaluated the current Swiss portfolio and calculated the return-maximizing as well as the variance minimizing portfolio given the actual portfolio variance or demanded market return (5.58% p.a.), respectively. In order to keep the focus of this paper on current and future developments, we only discuss Scenarios 3 and 4 in more detail.[18].

4.6 Current portfolio

In order to find some improvement over the current situation on how electricity is produced we have to first define the actual portfolio. Looking at the entire electricity production, Switzerland produces about 40% by nuclear, 25% by run-of-river, 30% by storage hydro and the remaining 5% with other technologies. In order to consistently estimate possible improvements, the technologies have to be either assigned to the base-load or the peak-load technologies. We therefore considered nuclear and run-of-river as base-load technologies, while storage hydro and other technologies (in our case the new renewable ones) produce peak-load electricity[19]. Table 6 shows the allocation as well as the risk-return parameters for the current portfolio.

4.6.1 Scenarios 1 & 2

Scenario 1 was calculated to evaluate how a power plant portfolio could look like if none of the geophysical and political restrictions are imposed and with now currently available energy

[18] A more detailed analysis of all scenarios and further interpretation can be found in (Wenk and Madlener, 2007).

[19] We allocate the technologies according to their major field of production and thus abstract from the fact that storage hydro also produces a minor share of base-load electricity.

Table 6: Current[1] Swiss Portfolio

	Nuclear	RoR[3]	SH	Solar	Wind	μ	σ
Base-load[2]	59.0%	41.0%				-18.01%	41.25%
Peak-load			85.0%	7.5%	7.5%	-58.10%	12.12%

[1] Accounting only for technologies covered in this study.
[2] Technologies allocated to environment where they produce the bulk-load of their electricity.
[3] Run-of-river contains both technologies, high- and low-pressure, in equal parts.

infrastructure. The second portfolio basically looks at the current situation in Switzerland, with the restriction that hydro infrastructure is not reduced. Given this very likely restriction, it is possible to evaluate the efficiency of the power producers currently in the market. Two tables (base- and peak-load) containing the restrictions to this and all other scenarios can be found in the Appendix.

4.6.2 Scenario 3 (hydro and alternatives constrained, excl. hydro upgrades)

This scenario reflects a situation in which the Swiss electricity production portfolio would have to be built completely new from scratch. The environmental restrictions imposed on wind, solar PV, storage and run-of-river power are considered as binding. As discussed before, the caps evolve for reasons of unfavorable environmental circumstances as well as lacking profitability, thus arising either from the very limited number of possible sites where wind turbines can be run with positive expected returns, as shown in our calculations, or from the still very expensive solar PV panels combined with the limited hours of sunshine. The storage hydro plants are said to have reached an almost 100% saturation level, meaning that new dams can only be built if major interference with environmental and public issues can be solved. From today's point of view, it does not seem plausible to extend storage hydro capacity beyond the additional output of 2360 GWh (Laufer et al., 2004) and, therefore, new construction options are only considered up to this level. Another way to enlarge capacity from storage hydro power is by upgrading the applied technologies in order to reach an improved level of production efficiency. However, hydro electricity enhancements were not considered because it is not possible to define the amount of upgradable hydro power in the portfolio from an *ex-ante* point of view. From the earlier mentioned research commissioned by BFE (Laufer et al., 2004) on hydro power facilities, as well as the report by the Paul Scherrer Institute (Hirschberg et al., 2005) on renewable energies in Switzerland, it is assumed that the caps listed in table 7 and table 8 (cf. Appendix A) are indeed binding.

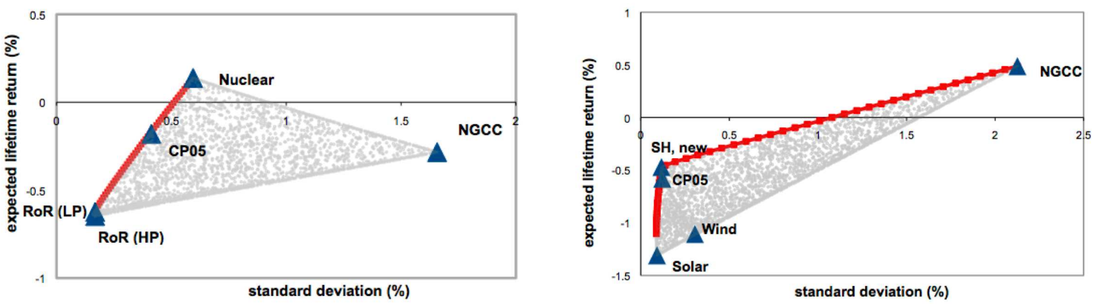
4.6.3 Scenario 4 (minimum constraints on current production)

In this scenario, we take the current electricity production portfolio as given and concentrate on the supply-demand gap that will arise eventually if production capacities are not extended. A recently conducted study by Axpo (Axpo, 2006) suggests that by 2020, electricity demand will be between 62,700 GWh and 72,000 GWh, depending on the growth scenario assumed.[20] This would lead to an additional electricity demand of 5400 GWh or 14,700 GWh, respectively. Again these figures are calculated on an annual demand basis only, thus not differentiating between base-load and peak-load. We considered the remaining production possibilities to generate the additionally demanded electricity, setting the upper bounds with respect to the output gap in the high and low electricity demand growth scenario. For wind power and solar PV, we set the maximum bounds to the projected output volume in 2035 (Hirschberg et al., 2005) and, therefore, neglect the comparably tiny electricity output already generated today. The resulting portfolio is particularly interesting because it shows how the current electricity production facilities should be complemented as electricity demand rises. The considered bounds are again listed in table 7 and table 8 (Appendix A).

4.7 Portfolio evaluation

In this subsection, we present the results from the optimization and show the portfolio compositions evolving from the different scenarios. Basically, we are interested in two specific portfolios, one that yields the highest expected profit given its variance equal to the current Swiss portfolio, and the other one with the lowest expected return variance given that the current demanded return of 5.58% p.a. can be achieved. These portfolios are especially worth considering when looking at Scenarios 2 and 3, which best reflect the current portfolio, as they show possible improvements to the current situation. When considering Scenarios 4a and 4b it makes more sense to look at the global portfolios, either with the lowest possible variance or the highest possible yield, as the goal of these scenarios is to provide guidance for future investment. These portfolios set the outer extrema, with the real portfolio lying somewhere in between, depending on how the utility is positioning itself. Under a strict regulation by the government, electricity suppliers are primarily forced to follow the path of minimal variance, hence providing electricity with the highest possible supply security. The loss in profitability that emerges from this strict goal has to be covered by the government.

[20]Scenario 'high' ('low') assumes an annual electricity demand growth of 2% (1%) until 2010 and afterwards one of 1.5% (0.5%).



(a) Base-load (b) Peak-load

Figure 3: Efficient frontiers

In a more liberalized market the electricity companies have more freedom of choice when it comes to a market strategy, so they choose their portfolio somewhere in between the highest possible profit and the lowest possible variance. For Scenario 4, the most realistic one, the portfolio that yields the risk-adjusted market return, which we used for discounting, was also provided. A complete overview of all the portfolios considered is provided in the Appendix.

4.7.1 General observations

Before actually looking at the different scenarios, we first evaluate the unconstrained efficient frontier containing only new power plants (no extensions), as seen in figures 3(a) and 3(b)). Annual and lifetime returns were already reported above in Section 4.2, table 3. In the following figures, the dots represent different portfolio compositions, the triangles show how the single technologies are positioned and the dark line represents the efficient frontier which covers the best set of portfolios from a risk-return point of view.

In both figure some extraordinarily high expected returns immediately catch the eye. The expected base-load lifetime returns on investment of approximately 152% and 306% for a hardware upgrade in a run-of-river and storage hydro power plant, respectively, are even higher if peak-load electricity prices are considered (only for the storage hydro option). An explanation for these skyrocketing expected returns can certainly be found in their very low investment costs. The hardware upgrading option needs already existing run-of-river or storage hydro power plants to be effectively implemented and, therefore, the low investment costs mask much of the true outlays that once had to be made. Nevertheless, for already existing dams this investment alternative seems quite interesting even though the very high volatility of expected lifetime returns also have to be considered. For the following scenarios it will also be important to notice that these high yield investments only provide comparably little additional energy and thus the overall impact on expected portfolio returns is very limited.

4.7.2 Evaluation of Scenarios 1 & 2

The first scenario suggests a rising share of nuclear power for the base-load portfolio. In order to obtain the currently demanded market return of 5.58%, the share of nuclear power should rise to 89.2% (+28.2%[21]), while the production with run-of-river power plants is focussed all together on the low pressure (LP) option. Thus, the lowest risk (measured in terms of standard deviation) at which this return can be achieved is 54.5%. The portfolio which maximizes return while keeping the risk at the same level as the current portfolio is very close to the actual allocation. Nuclear (+0.9%) and low pressure run-of-river (38%) produce a return, which is still negative, but improved by 0.8 percentage points while keeping the risk at 42.15%. Storage hydro is even more prominent in the peak-load portfolio, taking a share of 45.1% in the variance minimizing and one of even 99.7% in the return maximizing portfolio. By increasing the share of storage hydro it is therefore possible to improve the peak-load portfolio's return by more than 10%-points while keeping the risk at the same level. Of the alternative technologies, wind is not considered at all, while solar PV makes up for three quarters of the global minimum variance portfolio.

For Scenario 2 it is not possible to find a base-load portfolio with a lower variance as the current portfolio given the demanded market return as well as the imposed restrictions. Additionally, the restrictions make it also impossible to find a portfolio with an improvement in return, given the current risk. However, is possible to reduce the risk by 7.2%-points (at the expense of a 12%-points reduced ROI) by lowering nuclear to 45.5% (ca. -5.5%) while extending the run-of-river technologies to their full extent and furthermore refurbishing the low-pressure dams. In the peak-load portfolio it is possible to improve expected return, even though still negative, by 12%-points while keeping the variance at the current level.

4.7.3 Evaluation of Scenario 3

In a first, step we evaluate the risk minimizing portfolio that yields the demanded market return. Considering only run-of-river technologies together with nuclear for base-load we find a portfolio which has a higher volatility (55% instead of 41%), instead of a -18% return, and that yields a positive return of 5.6% p.a. Thus, by increasing nuclear power by 30%-

[21]The percentage changes are relative to the share of this technology in the current Swiss portfolio.

points and producing all run-of-river electricity with low pressure technology a considerable improvement in return can be achieved. On the other hand, it is possible to improve the return by one percentage point while keeping the volatility at the current level. To achieve this nuclear power has to be kept at the current level and half of the electricity produced with high-pressure run-of-river has to be shifted to low-pressure.

In a next step the analysis is done for the global minimum variance portfolio emerging from this scenario. We find that hydro power plants generally involve a lower return volatility, producing in a much more stable environment. Therefore, all the hydro power plants produce up to their maximum capacity, reflecting not only the current stock of hydro storage plants, but also including possible enlargements through refurbishments. This results in a run-of-river power plant composition of 25.5% (HP) and 27.5% (LP), respectively. Furthermore, refurbishments make up for about 1.5% and nuclear energy takes a 45.5% share. This clearly shows that utilities in Switzerland currently are not producing electricity with the goal to minimize return volatility, but rather take a good share of risk to increase return, yet as shown above, they could do even better.

A similar behavior as for base-load can be seen in the peak-load composition. The portfolio which delivers the expected market return and thus a return that is larger by 63%-points consists to a large extent of NGCC (54.9%), and is supplemented only by new storage hydro (45.1%). This large increase in return comes at a cost of a considerably risen standard deviation of the return, now being at 120% (up from 12%). This clearly shows that NGCC plants are a valid investment for utilities if they plan to increase return and are willing to take the risk of increased volatility. On the other hand, it is possible to reduce the current risk by 12%-points by simply increasing the share of storage hydro to 99.6% with the remaining half percent being produced with NGCC. A lower variance (11.4%) can only be achieved if storage hydro is complemented by solar PV (3.4%). As the peak demand in Switzerland has so far been successfully covered with storage hydro and alternative energies, there was no need to build any NGCC plants so far. However, this could change rapidly in the years to come; according to Axpo, a shortage in peak-load power might arise as soon as 2012. Based on these results the raising demand should either be covered with NGCC if the main goal is improvement in return,while an increase in storage hydro is the way to go if the return volatility should be kept as low as possible.

Only of partial interest is the global maximum expected return portfolio for Scenario 3. For base-load it yields 15.3% p.a., with a risk of 61.1%, and consists to 99% of nuclear power with the remaining 1% being upgraded hardware of run-of-river plants. For peak-load the only technology which should produce electricity is NGCC, with a return of 48.8% p.a. and a risk of 213%. This implies that if the current Swiss electricity production portfolio is supposed to generate higher expected returns, new nuclear plants should be added to the base-load production mix and new NGCC plants to the peak-load one.

4.7.4 Evaluation of Scenario 4

Scenario 4a

The portfolios for Scenarios 4a and 4b should look very similar, but the small differences could be of great interest. Depending on the credibility assigned to each prediction, low or high demand growth, investment decisions could look differently.

We first consider the global minimum variance portfolio for the lower demand growth scenario where all the additional demand can be covered with investment in run-of-river power plants. New run-of-river facilities should be built up to their maximum possible level, 54.8% for low-pressure and 34.6% for high-pressure, and the current low-pressure installations should be refurbished to make up for the remaining 10.57%. This composition keeps the risk at a low 16.2% with a negative return of 64.3%. None of the other technologies (NGCC and nuclear) are included. This changes if the global maximum return portfolio is considered. It suggests that 88.8% of the additional energy demand is covered with new nuclear energy and 11.2% with a full hardware upgrade of the high-pressure run-of-river facilities. Relative to the global minimum variance portfolio, the expected portfolio return raises by about 90%-points to 29.4% p.a. while risk raises to 78%. These two portfolios should set the upper and lower bound from a risk-return point of view. It can further be analyzed how future demand should be covered, given the requirement that risk has to be kept at current levels. With this restriction, the most profitable base-load portfolio yields a return of -17% p.a. and is composed of 59.4% nuclear and 40.6% low-pressure run-of-river. If a utility is willing to take more risk with future investments, it is possible to attain the required market return by providing the additional electricity with 89.2% nuclear and 10.8% run-of-river (LP). As the ongoing privatization increases the pressure on utilities to produce profitably, it is likely that the investments for new facilities follow the scheme of the latter portfolio. A first indication for this is the recent effort of some of the largest Swiss utilities to get permissions for new nuclear plants.

The global minimum variance peak-load portfolio in the low growth scenario follows the expectations one has after the calculations of the previous scenarios. The generation possibilities given for solar PV are implemented to its full extent (36.2%), with the remaining electricity provided by new storage hydro (63.8%). This portfolio yields a negative return of -77.36% with a standard deviation as low as 9.7% (-1.4%-points). This clearly does not seem like a feasible way to go for any utility company as the negative returns are too heavy a burden. Furthermore, as already mentioned in the introduction of this section, a minor caveat has to be added here. The maximum output limits imposed on solar PV and wind power are taken from a prediction level for the year 2035, while the expected additional demand is calculated for the year 2020. We allowed for that with the thought in mind that even with an overestimated share of alternative power plants, the relative composition of the portfolio will stay about the same, as additionally demanded peak electricity will not equal total additional demand.

If the goal is set on maximizing expected returns, peak-load power is generated mainly by NGCC power plants, accounting for 82.4%, along with new hardware for storage hydro dams (18.6%). The highest achievable expected return is 155.1% p.a., with a standard deviation of 272.5%. As before, this clearly is also a portfolio that utilities want to avoid, as a return volatility with this magnitude is clearly undesirable. Thus if the goal of a company is again to provide the additional energy at the current level of risk, the demand should be covered mainly by new storage hydro (99.9%) and a hardware upgrade (0.1%). With this composition it is not only possible to produce at the same level of risk as with the current portfolio, but the return, even though it remains negative, can also be improved (existing portfolio -58% p.a., new additions -46%). From a market-based view that requires a minimum return of 5.58% p.a., the portfolio would have to be constructed with a 92.1% share of new storage hydro while new hardware produces the residual amount of 7.9%. This competitive return comes at a cost of an increase in risk to 50.9%. Again, as the market-based view will gain more and more momentum in the foreseeable future, it is likely that projects concerning the construction of new storage hydro are launched. This again fits in well with the current project development of some of the larger utilities in Switzerland.

Scenario 4b

We now take a closer look at the higher expected demand growth scenario and especially focus on differences to Scenario 4a. For the base-load global minimum variance case, we are confronted with a completely different picture. Because of the larger electricity demand growth, new run-of-river facilities are only able to cover a partial amount of what they did in the previous scenario (HP: 12.7%, compared to 34.6%; LP: 20.1%, compared to 54.8%; refurbishment: 5.72%, compared to 10.57%). As all the hydro power plants including their extension options run on their upper bound, nuclear power plants (61.4%) have to provide the supplemental demand. This results in an expected return of -16.5% p.a. and a global minimum standard deviation of 42.1%. Thus the newly added technologies not only take care of the rising demand, but also render the portfolio more profitable (compared to a negative expected return of -64.3% p.a. in the low growth scenario).

From the risk involved in the global minimum variance portfolio (42.1%) it can be concluded that it is not possible to produce the additional electricity demand at a risk that is equal to the one of the current portfolio (41.2%).

The relative shares of the portfolio which yields the market return remain exactly equal and only scale up in an absolute manner. Hence, the portfolio consists of 89.2% nuclear and 18.8% run-of-river (LP) power plants.

Similar argumentation as in the base-load scenario can be applied for peak-load global minimum variance. As additional electricity demand gets higher, hydro power can only cover it to an ever smaller percentage. Instead, NGCC plants and alternative energy sources jump in to provide the necessary energy. NGCC covers up to 22.9% of the supplemental demand, while a new hydro storage plant in combination with new hardware extensions provide around 52.4% and the alternative power plants, solar PV and wind, provide 13.3% and 11.4%, respectively. This results in a return of -44.2% p.a. (up from -77.4% p.a. in the low-growth scenario) with risk of 58.6% (up from 9.7%). Hence, a larger growth of electricity demand necessarily requires the utilities to bear a larger risk, but at the same time also earns them a better rate of return.

The risk involved in the global minimum variance portfolio (58.6%) suggests again that it is not possible to produce the additional electricity at a risk equal to the current portfolio.

The peak-load market return portfolio follows the same scheme. While in the low-growth scenario additional demand was covered for a major part by new storage hydro, the high-growth scenario is much more diversified. As new storage hydro, together with refurbishment and new hardware for existing plants, is only able to cover 59.3%, wind (11.4%), solar PV (7.3%) and NGCC (22%) cover the residual demand. Even though the demanded market return can be provided, it is only possible at an increased risk of 93.1%, up from 50.9%.

The global maximum expected return portfolio behaves exactly the same in the low and high growth case, i.e. the new hardware option on high pressure run-of-river is fully implemented, while the additional energy is produced in nuclear reactors. The only difference lies in the shares the hydro options have in the total portfolio. In Scenario 4b their proportion shrinks, making nuclear power (95.9% compared to 88.8% before) even more dominant. This implies a lower expected return of 19.5% (down from 29.4% p.a.), and a reduced standard deviation of now 66.1% (down from 78.0%). Exactly the same line of thought applies for the peak-load portfolio maximizing expected return. The already prominent NGCC power is gaining additional quota and now provides electricity in 93.2% of the time, leaving the remaining 6.8% to the new hardware option for storage hydro dams. The expected return is now 87.8%, with a standard deviation of 234.1%.

4.8 The case of Axpo

In the introduction it was mentioned that the optimization conducted above can be applied either for Switzerland as a whole, i.e. the aggregate production of all electricity supply companies, or for a single company. Given the computed possibilities for improvements in the current electricity production portfolio, we now like to assess if the proposed strategy of one of the largest Swiss utilities, Axpo AG, is in line with our findings. The subsequent report on analogies or discrepancies to our calculations is based on the recently provided, detailed overview of Axpo's perceived future in the electricity production sector (cf. Axpo, 2006).

The aggregated electricity generating portfolio for Axpo as of 2004 contained only nuclear power (74%) and hydro power (26%). As this portfolio represents total electricity production, we have to break it up into a base-load and a peak-load portfolio in order to make it comparable to our Scenario 3 electricity production portfolio. Due to a lack of exact figures, we had to approximate the Axpo electricity portfolios for their Swiss-based operations. We assume that the base-load portfolio of Axpo is predominantly compiled of nuclear power, together with a small amount of hydro power generated by run-of-river power plants. The peak-load electricity production is almost altogether done by storage hydro dams, supported only by a very small fraction of alternative electricity sources.

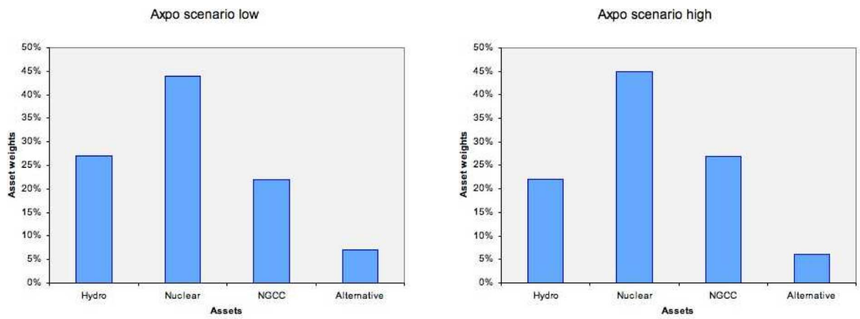
4.8.1 Comparison with Scenario 3

With these assumptions made, a comparison to the Scenario 3 electric power generation portfolio is now possible. Scenario 3 was chosen in a first step because it depicts best the environment in which Axpo currently competes, at least with their Swiss-based operations. The intuition behind this argument is that the large storage hydro and run-of-river facilities were financed a long time ago and have mostly been amortized by today. Thus, it is not an efficient option to stop producing electricity through these hydro facilities as long as positive profits are possible. Moreover, the hydro technologies produce clean electricity and therefore receive large support by politics and the public. Consequently, the only limiting boundaries in Axpo's national portfolio allocation are set by governmental law as well as by environmentally determined factors. Axpo's large share of nuclear power indicates that the base-load electricity portfolio is driven largely by a profitability objective. The run-of-river hydro power share of the base-load portfolio causes only little diversification, but is certainly decreasing the volatility implied by nuclear power. As mentioned above, the major part of the hydro power portfolio share is essentially used for peak-load electricity production. Since NGCC power plants are so far not in operation in Switzerland, this fits in well with the Scenario 3 peak-load minimum variance portfolio.

Overall, it can be said that the Axpo portfolio contains a highly profitable, but at the same time very volatile base-load electricity production share, while the peak-load portion produces electricity in a very stable, though not very profitable environment. The small base-load diversification in hydro power plants helps to lower the return variance, but at the same time also reduces the expected rate of return. Considering that Axpo has to deliver both base-load and peak-load electricity, this portfolio seems to be made up of a well balanced mix of high yield and low volatility technologies, whereas the high yield base-load technologies clearly outweigh the low volatility peak-load technologies.

For the decades to come, Axpo plan to diversify their portfolio by adding NGCC electric power and additional alternative energy technologies to it. Moreover, they are considering the import of electricity provided by NGCC or coal power plants of neighboring countries. From a report conducted by Prognos (Sättler et al., 2001), it can be assumed that importing electricity will cost just as much as the production through a newly built, domestic NGCC power plant. We therefore added the share of imported electricity to their portion of new gas-fired power plants planned to be constructed in Switzerland. Taking this into account, the Axpo electricity production portfolios forecasted for the year 2030 (and dependent on the assumed growth scenario) look as depicted in figure 4.

Again, Axpo only provide information on total load portfolios, leaving us with assumptions on how to allocate resources to the peak-load and base-load portfolio. As before, we believe that the base-load electricity portfolio is made up of nuclear power for the most part and complemented by run-of-river hydro power. The NGCC power plants offer great flexibil-



(a) Low growth (b) High growth

Figure 4: Anticipated Axpo portfolios by 2030, total load

ity in electricity production as they can easily be put into or out of operation. In the case of Switzerland, we think that NGCC power plants are mostly used for producing peak-load electricity. This is because of several reasons; first, the CO_2 balance is heavily stressed by electricity production through NGCC power plants, and thus has to be kept at the minimum possible level, secondly the price for natural gas is quite volatile, making it hard to predict future business and thirdly, from the public point of view, the acceptance of CO_2-emitting NGCC power plants is falling, the longer the discussion about global warming keeps going. Furthermore, this assumption is also in line with the calculated expected investment return of NGCC power plants as they can be run a lot more profitably by covering peak-load electricity demand, and thus will apparently be in operation during this period. As for the alternative energies, we add them to the peak-load portfolio, as assumed during the whole study, but keeping in mind that they follow a stochastic electricity production process.

4.8.2 Comparison with Scenario 4

In order to compare the predicted Axpo portfolio to our Scenario 4 portfolios, we have to take a closer look at the changes that will take place in the Axpo portfolio until 2030. We start this analysis with the lower growth portfolio equal to our Scenario 4a. What can be seen immediately is the diversification that takes place in the Axpo portfolio. The technologies in operation by 2004, nuclear and hydro, are extended by NGCC and alternative power sources. The relative share of hydro powers stays about the same in the Axpo portfolio (2004: 26%, 2030: 27%), but gains in absolute terms. This increase is accomplished through the new hardware and the refurbishment hydro option as well as some new run-of-river facilities. A big drop can be seen in the portfolio share of nuclear power, namely from 74% in 2004 to 44% in 2030. As this reduction of nuclear power is made up for by additional hydro power only to a minor extent, we have in a first step to conclude that the NGCC power plants cover for the rest and thus are, against our assumptions, part of the base-load electricity portfolio. In our point of view, this change in portfolio composition can only be explained to a limited degree. The fact that the hydro enhancement option of new hardware only bears limited additional potential for electricity production and that nuclear power is reduced, suggest similarities to the minimum variance portfolio of Scenario 4a. The rise in the share of electricity from NGCC power plants cannot be explained by our base-load portfolio. Neither the minimum variance nor the maximum expected return portfolio contains a roughly equal amount of this technology. A possible explanation can be seen in the context of alternative powers. As they produce electricity on an irregular basis, they need backup power plants that can fill the gap in case of suspended electricity production. With the above-mentioned flexibility, NGCC power plants are highly qualified for this task. On top of this, it might also be the case that Axpo value the flexibility option of NGCC power plants to such an extent that they are willing to trade off expected investment return for it. As these are factors that are not modeled in our investment return calculation, we can only speculate on that point. However, by taking a second look at the Scenario 4a base-load minimum variance portfolio, one can also suspect that Axpo are reorganizing their hydro power facilities. By trading part of their storage hydro capacities for run-of-river facilities and additionally extending their run-of-river installations, the share of NGCC power plants in the base-load portfolio can be reduced profoundly. The only deviation to our calculated minimum variance portfolio 4a is found in new storage hydro facilities. If there really is a shift in focus inside the hydro powers, it is very unlikely that new storage hydro dams are being built and, on top of that, our analysis made it quite clear that new storage hydro power facilities are almost impossible to earn positive expected returns. Thus, it is more realistic to assume that the additionally demanded base-load electricity is provided by alternative energies, making up for an ambitious 7% of the portfolio, with NGCC power plants as a backup. As alternative energies bear only a little investment return volatility, it would fit in quite well with our assumption of Axpo following the minimum variance option for their base-load electricity portfolio. Compared to their 2004 portfolio Axpo are mainly diversifying their peak-load electricity production. Taken the assumption that the hydro powers are being shifted away from peak-load electricity production, it becomes obvious that now most of the demanded peak-load electricity comes from NGCC power plants. This constitutes a big shift in the peak-load portfolio of Axpo, away from hydro power and towards natural gas technology. Relating this to our Scenario 4a portfolio, it can be seen that this investment strategy by Axpo closely follows the path of maximizing expected return. This leaves us with the conclusion that, in the low growth scenario, Axpo assembles its base-load electricity portfolio by following the goal of keeping down the invested return volatility, thus providing the electricity through nuclear, run-of-river and alternative power plants with NGCC facilities as backup power. The peak-load electricity portfolio, on the other hand, clearly follows a strategy of maximizing expected return. This is done by investing heavily in NGCC power plants and keeping some of the already owned storage hydro facilities.

We now take a look at Axpo's high growth scenario. The portfolio composition changes only slightly, thus the above made argumentation can also be adopted for this scenario. Compared to the low growth scenario, nuclear power is now providing a larger portion of electricity to the base-load portfolio, both in relative and absolute numbers. The drop in hydro powers of 5% of the portfolio share equals only a very small decline in absolute hydro electricity output, the same being true for the alternative technologies. It can therefore be concluded that the additional electricity demand growth is tackled by additional output of nuclear power plants for base-load electricity demand and of NGCC power plants for peak-load electricity demand. Again, this fits in perfectly well with our Scenario 4b portfolios. Again, base-load electricity is produced by a portfolio composed with the goal of minimizing return volatility, while the peak-load electricity portfolio follows the strategy of maximizing expected investment return. As the two technologies used to cover additional electricity demand of the high growth scenario, nuclear and NGCC, both rise expected investment return, it can be concluded that the entire Axpo portfolio for the high growth scenario is most likely to yield a higher expected return on investment than the low growth scenario. However, this rise in investment yield is not for free, but is accompanied by a larger volatility in return, thus chances of either having a very good or a very bad expected return on investment increase.

If we consider the fact that Axpo as well as most other electricity producing companies are still linked one way or the other to governmental institutions, the concern about return volatility is assumed not to be first priority. In fact, the strive for an increased expected investment return is probably receiving more attention from the management of these companies. Together with the above-mentioned conclusions for Scenario 4b, one can now think about the behavior of the electricity production company. Since the main focus is set on expected return on investment, the electricity company welcomes additional electricity demand, as this rising need for electricity can be covered by technologies that yield exactly the aspired expected return. In other words, the electricity production companies have the incentive to make their customers consume as much electricity as possible in order to raise their expected return on investment. However, this would only be the case were the public and the government to allow the companies to build the needed power plants.

5 Conclusions

In this study, real data from the past and qualitative future estimates on the development and production of electricity in Switzerland are brought together in order to analyze the current electricity production portfolio and to show possible alternatives facing upcoming challenges.

In a first step, where each technology was examined on its own, we found that there exist large discrepancies in return probabilities. While some technologies or technology enhancement options, such as the implementation of new hardware for hydro power stations and new nuclear plants, earn positive expected profits in more than 50% of the time, other technologies, like new hydro storage or solar PV facilities, basically always yield negative expected returns. In a sensitivity analysis, we have shown that some of the more profitable technologies, for example new nuclear power or NGCC power plants, react a lot more sensitively to changes in key variables, such as electricity sales prices or fuel prices, than the above-mentioned negative expected return investments. Through a combination of these technologies it is possible to achieve an attractive expected investment return, while at the same time keeping volatility at an acceptable level.

The evaluation of such combinations was done in the last part, where the portfolios following different scenarios and different investor objectives (expected return vs. minimum variance) were optimized. This allowed eventually to examine the current and future portfolio of a typical Swiss electricity production company such as Axpo. In this case it was shown that the current Axpo portfolio is almost strictly focusing on expected return, controlling only little for return volatility. This drawback has been noticed by the company and the future portfolio is planned to be much more diversified. The investment in various technologies will lower return variance, but at the same time also diminish profits. In Axpo's prospected future portfolio, this diminution of expected returns is kept as small as possible. This can be achieved by following a minimal variance strategy for base-load on the one hand, while trying to optimize the peak-load portfolio for maximum profitability on the other hand.

For the case of Switzerland as a whole, we have shown that the current national production portfolio for base-load is very close to the efficient frontier leaving only little room for optimization. On the other hand, the peak-load portfolio sill allows for some improvement, depending on the focus the national utility companies take. For future perspectives it seems inevitable that new electric power plants are to be built. With an ongoing rise in electricity demand and the petering out of contracts for electricity imports, new ways of electricity supply have to be found. We have shown that parts of the electricity supply gap can be covered either by refurbishing already existing hydro power plants, or by enhancing their efficiency through new hardware installations. Even if the additional environmentally possible capacity concerning storage hydro and run-of-river power is fully utilized, a shortage in electricity supply is only a matter of time. The same is true for peak-load power. The alternative energies have very limited, nature-dependent capabilities of providing electricity, and on top of that rely on a production environment that follows a stochastic process. Peak-load production through storage hydro plants has a limited extension potential and will be a big environmental issue if it comes to new constructions.

What is left is the currently exercised option of importing electricity to help domestic electricity production meeting excess demand. This option can turn out to be a very costly and unreliable one, as Europe as a whole will be facing shortages of supply similar to Switzerland. This leaves us with new nuclear and NGCC power plants to cover the demand gap, but these technologies find only little public acceptance so far. In the longer run though, it will be inevitable to decide in favor of at least one of the mentioned technologies. Additional nuclear power would help, in a profitable way, to cover base-load electricity needs. If enough output can be produced with nuclear power, some of the storage hydro dams that are now producing medium-load power will be freed and available to supply additional peak-load power. Alternatively, NGCC power plants could be installed to produce either base-load or peak-load power. Due to their flexible production capabilities and short construction lead times, their installation can turn out to be indispensable. For electricity production companies, NGCC power plants bear great opportunities but also risks. Because of their comparably low investment volume they are easier to finance and through their flexibility in production they can be operated highly profitable. The main two drawbacks are the volatile price of natural gas and the unknown development of the CO_2 compensation costs, i.e. the market development for CO_2 certificates. For the country itself, NGCC power plants, being very sensitive to market price movements, will undoubtedly bring a raising volatility in electricity market prices. A major point concerning this technology is clearly the CO_2 emission. If the supply gap has to be filled mainly with electricity from NGCC power plants, not only one plant, but many more will have to be built in order to meet rising electricity demands. In current times this will inevitably lead to major disagreements with the public opinion and will also make it harder to comply with the Swiss greenhouse gas mitigation goals under the CO_2 Act and the Kyoto Protocol. But if energy efficiency cannot be raised to a much higher level, and we thus face a steadily growing demand for electricity, NGCC power plants for peak-load power will likely be as inescapable as nuclear power will be for base-load electricity. However, decisions will have to be made soon in favor of one or the other technology. Unless these decisions are made in a timely manner, the portfolio will be supplemented by the kind of facilities that can be constructed and put into operation the quickest, leaving no room for argumentation and decisions that are optimal in the long run.

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A Portfolio bounds

Table 7: Output bounds by technology and scenario; base-load portfolio

	NGCC	Nuclear	RoR (HP)	RoR (LP), ref	RoR (LP)	RoR (HP), nh
Scenario 1	100%	100%	100%	0%	100%	0%
	0%	0%	0%	0%	0%	0%
Scenario 2	100.00%	100.00%	25.55%	1.47%	27.46%	1.06%
	0.00%	0.00%	22.29%	0.00%	22.29%	0.00%
Scenario 3	100.00%	100.00%	25.55%	1.47%	27.46%	1.06%
	0%	0%	0%	0%	0%	0%
Scenario 4a	100.00%	100.00%	34.62%	15.58%	54.81%	11.25%
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Scenario 4b	100.00%	100.00%	12.72%	5.72%	20.13%	4.13%
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 8: Output bounds by technology and scenario; peak-load portfolio

	NGCC	Solar PV	SH	SH, ref	SH, nh	Wind
Scenario 1	100.00%	100.00%	100.00%	0.00%	0.00%	100.00%
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Scenario 2	100.00%	3.41%	100.00%	1.95%	0.63%	1.05%
	0.00%	0.00%	91.63%	0.00%	0.00%	0.00%
Scenario 3	100%	3.41%	100.00%	0.00%	0.00%	2.92%
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Scenario 4a	100.00%	36.00%	100.00%	21.00%	19.00%	31.00%
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Scenario 4b	100.00%	13.00%	45.00%	8.00%	7.00%	11.00%
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

B Portfolio compositions

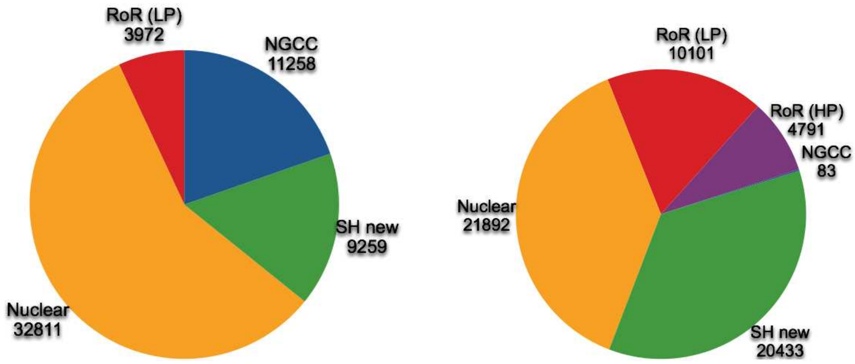
Table 9: Summary table, base-load technology portfolios

		NGCC	Nuclear	RoR (HP)	RoR (LP), ref	RoR (LP)	RoR (HP), nh	Return	Risk
Scenario 1	Global Min Var	0.00%	0.00%	50.08%	0.00%	49.92%	0.00%	-63.56%	15.82%
	Min Var	0.00%	89.20%	0.00%	0.00%	10.80%	0.00%	5.58%	54.49%
	Max Ret	0.00%	61.96%	0.00%	0.00%	38.04%	0.00%	-15.17%	42.15%
	Global Max Ret	0.00%	54.36%	22.29%	0.00%	22.29%	1.06%	-19.22%	40.89%
Scenario 2	Global Min Var	0.00%	45.52%	25.55%	1.47%	27.46%	0.00%	-28.45%	34.79%
	Min Var	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Max Ret	0.00%	54.36%	22.29%	0.00%	22.29%	1.06%	-19.22%	40.89%
	Global Max Ret	0.00%	54.36%	22.29%	0.00%	22.29%	1.06%	-19.22%	40.89%
Scenario 3	Global Min Var	0.00%	45.52%	25.55%	1.47%	27.46%	0.00%	-28.45%	34.79%
	Min Var	0.00%	89.20%	0.00%	0.00%	10.80%	0.00%	5.58%	54.49%
	Max Ret	0.00%	59.51%	13.03%	0.00%	27.46%	0.00%	-17.34%	42.15%
	Global Max Ret	0.00%	98.94%	0.00%	0.00%	0.00%	1.06%	15.27%	61.12%
Scenario 4a	Global Min Var	0.00%	0.00%	34.62%	10.57%	54.81%	0.00%	-64.28%	16.21%
	Min Var	0.00%	89.20%	0.00%	0.00%	10.80%	0.00%	5.58%	54.49%
	Max Ret	0.00%	59.39%	0.00%	0.00%	40.61%	0.00%	-17.12%	42.15%
	Global Max Ret	0.00%	88.75%	0.00%	0.00%	0.00%	11.25%	29.37%	78.03%
Scenario 4b	Global Min Var	0.00%	61.43%	12.72%	5.72%	20.13%	0.00%	-16.47%	42.15%
	Min Var	0.00%	89.20%	0.00%	0.00%	10.80%	0.00%	5.58%	54.49%
	Max Ret	0.00%	61.47%	12.72%	5.68%	20.13%	0.00%	-16.44%	42.15%
	Global Max Ret	0.00%	95.87%	0.00%	0.00%	0.00%	4.13%	19.52%	66.09%

Table 10: Summary table, peak-load technology portfolios

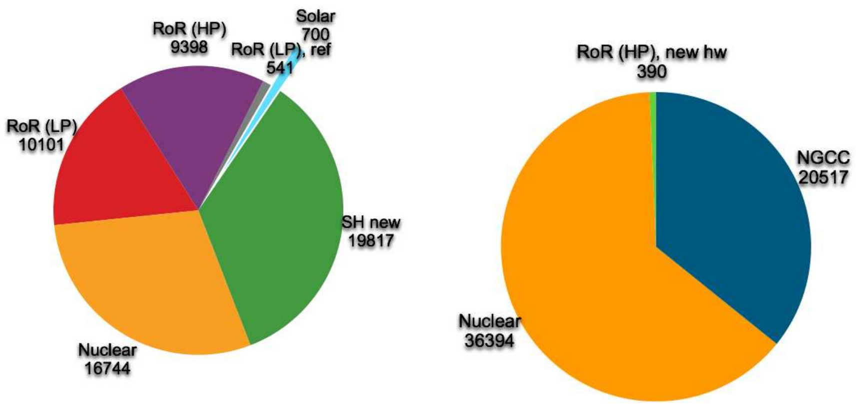
		NGCC	Solar	SH new	SH ref	SH new hw	Wind	Return	Risk
Scenario 1	Global Min Var	0.00%	75.41%	24.59%	0.00%	0.00%	0.00%	-110.26%	8.80%
	Min Var	54.87%	0.00%	45.13%	0.00%	0.00%	0.00%	5.58%	119.69%
	Max Ret	0.30%	0.00%	99.70%	0.00%	0.00%	0.00%	-46.69%	12.00%
	Global Max Ret	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	48.81%	212.62%
Scenario 2	Global Min Var	0.00%	3.41%	96.59%	0.00%	0.00%	0.00%	-49.85%	11.44%
	Min Var	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Max Ret	0.00%	0.00%	99.86%	0.00%	0.14%	0.00%	-46.04%	12.12%
	Global Max Ret	7.74%	0.00%	91.63%	0.00%	0.63%	0.00%	-35.37%	27.30%
Scenario 3	Global Min Var	0.00%	3.41%	96.59%	0.00%	0.00%	0.00%	-49.85%	11.44%
	Min Var	54.87%	0.00%	45.13%	0.00%	0.00%	0.00%	5.58%	119.69%
	Max Ret	0.41%	0.00%	99.59%	0.00%	0.00%	0.00%	-46.59%	12.12%
	Global Max Ret	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	48.81%	212.62%
Scenario 4a	Global Min Var	0.00%	36.20%	63.80%	0.00%	0.00%	0.00%	-77.36%	9.66%
	Min Var	0.00%	0.00%	92.11%	0.00%	7.89%	0.00%	5.58%	50.85%
	Max Ret	0.00%	0.00%	99.86%	0.00%	0.14%	0.00%	-46.04%	12.12%
	Global Max Ret	81.38%	0.00%	0.00%	0.00%	18.62%	0.00%	155.05%	272.51%
Scenario 4b	Global Min Var	22.86%	13.30%	44.84%	7.60%	0.00%	11.40%	-44.21%	58.62%
	Min Var	22.01%	7.31%	44.84%	7.60%	6.84%	11.40%	5.58%	93.15%
	Max Ret	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Global Max Ret	93.16%	0.00%	0.00%	0.00%	6.84%	0.00%	87.84%	234.11%

C Total-load portfolios



(a) Minimum variance portfolio (b) Maximum return portfolio

Figure 5: Contribution to total load (GWh)



(a) Global minimum variance portfolio (b) Global maximum return portfolio

Figure 6: Contribution to total load (GWh)

List of FCN Working Papers

2008

Madlener R., Gao W., Neustadt I., Zweifel P. (2008). Promoting Renewable Electricity Generation in Imperfect Markets: Price vs. Quantity Policies, FCN Working Paper No. 2/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Madlener R., Wenk C. (2008). Efficient Investment Portfolios for the Swiss Electricity Supply Sector, FCN Working Paper No. 1/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

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