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Scope of Electricity Efficiency Improvement in Switzerland until 2035

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ABSTRACT: This study uses Markowitz mean-variance portfolio theory with forecasted data for the years 2005 to 2035 to determine efficient electricity generating technology mixes for Switzerland. The SURE procedure has been applied to filter out the systematic components of the covariance matrix. Results indicate that risk-averse electricity users in 2035 gain in terms of higher expected return, less risk, more security of supply and a higher return-to-risk ratio compared to 2000 by adopting a feasible minimum variance (MV) technology mix containing 28 percent *Gas*, 20 percent *Run of river*, 13 percent *Storage hydro*, 9 percent *Nuclear*, and 5 percent each of *Solar*, *Smallhydro*, *Wind*, *Biomass*, *Incineration*, and *Biogas* respectively. However, this mix comes at the cost of higher CO_2 emissions.

Keywords: Efficiency Frontier, Herfindahl-Hirschman Index (HH), Power Generation, Mean-Variance Portfolio Theory, Seemingly Unrelated Regression Estimations (SURE), Shannon-Wiener Index (SW)

JEL: C32, G11, Q49, C23.

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1. Introduction

In this study, Markowitz mean-variance portfolio theory is applied to determine which electricity-generating technologies in Switzerland should be part of an efficient portfolio in 2035 in terms of maximizing expected return for any given level of risk or minimizing risk for any given level of expected return. By adopting a user view ("return" defined as kWh/CHF in levels), efficient technology mixes in 2035 are compared with the actual portfolio as of 2000 (AP2000) [1]. The gap between the two indicates the scope for efficiency improvement in terms of increasing expected return and/or reducing risk. In contrast, the European Union Energy Efficiency Action Plan (EEAP), which has been adopted in March 2007, uses a different efficiency improvement measure, viz. the maximum energy output for each unit of energy input. This approach, however, does not take any account of fluctuations in generation returns (risk), which arise due to volatile fuel costs and technological change. Therefore the adoption of a Markowitz mean-variance approach offers some additional insights.

Switzerland is expected to experience an electricity supply shortage between 20-40 percent by 2020, assuming a demand increase of 15-30 percent over 2000 (Gantner et al. 2000). As the government wishes to avoid an increased dependence on power imports, the options left are to generate more *Nuclear* electricity, introduce *Gas*-fired or new renewable technologies (such as *Solar*, *Smallhydro*, *Wind*, *Biomass*, and *Biogas*), or some mix of all these options. In fact, electricity suppliers such as Axpo and BKW but also organizations such as Avenir Suisse (an independent think tank for economic and social issues) in Switzerland are in favor of introducing new *Nuclear* power stations (see Meister, 2008), while *Gas* generated electricity (which has not been in use in Switzerland so far) also enjoys some support. Other technologies, that are expected to contribute to the 2035 electricity mix, but which hold shares of less than 1 percent in the 2000 electricity mix, are *Smallhydro*, *Wind*, *Biomass*, *Incineration*, and *Biogas*.

In this study, efficient portfolios such as the maximum expected return (MER), same variance (SV), same expected return (SER), and minimum variance (MV) are also evaluated in terms of supply security, using Shannon-Wiener and Herfindahl-Hirschman indices. In addition, to select the best efficient portfolio amongst the four choices the Sharpe ratio is calculated, which measures return-to-risk ratios. Several future scenarios are considered, placing some emphasis on what seems politically and geologically feasible. Finally, SURE-based portfolios will be compared with portfolios that were calculated with OLS.

Results indicate that the feasible minimum variance (MV) portfolio displays the highest return-to-risk ratio, and should therefore be preferred over all other efficient portfolios. Risk-averse

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[1] Some contributions in this field of research adopt an investor view following the lead of Humphreys and McClain (1998). An investor is concerned about *changes* in value over time, viz. the percentage increase of expected return.

users are thus best advised to adopt a future (MV) portfolio mix containing 9 percent *Nuclear*, 20 percent *Run of river*, 13 percent *Storage hydro*, 5 percent *Solar*, 28 percent *Gas*, and 5 percent each of *Smallhydro*, *Wind*, *Biomass*, *Incineration*, and *Biogas*. In addition, OLS-based econometric model specifications generate different expected return and risk values for the actual portfolio (AP2000) than the SURE-based procedure. This indicates that the adoption of the right model specification is important.

The paper is organized as follows. Section 2 presents literature dealing with multiple generating technology portfolios and introduces key concepts of Markowitz mean-variance portfolio theory. This is followed by section 3 that describes the econometric methodologies applied to time series of generation returns. The data is presented in section 4. Section 5 displays the main results and considers two measures of supply security, viz. Shannon-Wiener and Herfindahl-Hirschman indices. Conclusions are offered in section 6.

2 Measuring multiple electricity-generating technology portfolios

An increasing number of studies have been published in the field of multi technology electricity-generating portfolios over the last few years. These studies can be broadly separated in three groups, stochastic optimization, maximum diversity portfolios and a much wider branch of literature dealing with Markowitz mean-variance portfolio theory. This section presents two studies in the field of stochastic optimization and maximum diversity portfolios. Section 2.1 explains the concept of Markowitz mean-variance portfolio theory in more detail.

Roques et al. (2006) use stochastic optimization to model dynamic power investment choices in the U.K. They use long-run stochastic trends in electricity, gas, and carbon prices based on current projections, where expected parameters are based on historical data and British and U.S. forecasts. Random trajectories for the electricity, gas, and carbon prices were drawn from a series of Monte Carlo simulations. Stochastic optimization was then used to estimate the option value to the generating company of keeping open the choice between nuclear and gas technologies. Roques et al. conclude, that for the higher discount rates (10 percent real) that could be expected for most private new nuclear plant constructions, nuclear option value represents 9 percent of the expected net present value cost of a nuclear plant investment when there is no correlation between electricity, gas, and carbon prices, but that this value falls sharply with increasing correlation between these prices. The nuclear option value is close to zero for the correlations observed in the U.K. in early 2000. According to Roques et al. (2006) these results imply that there is little value to electricity-generating companies in retaining the nuclear option in risky

European electricity markets with the consequent high discount rates, given strong correlations between electricity, gas and carbon prices. Amongst others, Hlouskova et al. (2002) argue that stochastic optimization is very demanding in terms of computing with Roques et al. looking at only a 5-plant portfolio.

One way to overcome the computational limitations of stochastic optimization is to measure the best mix of electricity-generating technologies using so-called maximum-diversity portfolios as outlined by Stirling (1998). These portfolios take account of several performance criteria, disparity attributes, interactions, and constraints, where specific attributes such as political popularity are subjectively determined by the modeller. Performance criteria and disparity attributes are measured in ordinal categories (low, medium and high) which are again based on subjective opinions. In an application to the U.K. Stirling presents a maximum-diversity portfolio that suggests a mix containing a large share of gas, followed by coal and nuclear power. While the model appeals in terms of its complexity but ease of calculation, it clearly lacks in terms of objectivity. For example, Stirling claims that gas generated electricity in the U.K. is of high popularity to users, however, current market developments clearly speak against this view. In fact, sky-rocketing gas prices in the U.K. (an increase of more than 500 percent between January 2002 to January 2008, see Energy & Metals Consensus for Forecasts, 2008) underline the concern that the popularity of specific electricity generation technologies is subject to ongoing changes[2].

This paper therefore argues in favor of using Markowitz mean-variance portfolio theory, since it remedies all of the above-stated limitations, viz. it is straightforward to compute, takes account of all expected major generating technologies as of 2035, and covers the entire country's generation capacity using forecasted data.

2.1 Markowitz mean-variance portfolio theory

Mean-variance portfolio analysis, an established part of modern finance theory, is based on the pioneering work of Markowitz (1952), Varian (1993) and Fabozzi et al. (2002). In addition to its widespread use for financial portfolio optimization, mean-variance portfolio analysis has been applied to valuing offshore oil leases [Helfat (1988)], real asset portfolios in electricity generation [among others, Bar-Lev and Katz (1976), Adegbulugbe et al. (1989), Humphreys and McClain (1998), Awerbuch (2000), Awerbuch and Berger (2003), Berger (2003), Yu (2003), Awerbuch et al. (2004), Wenk and Madlener (2007), and Krey and Zweifel (2009)], and quantifying climate

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[2] Note, for example, that nuclear power after facing wide opposition for decades starts to enjoy an increasing popularity in Switzerland, which can be partly explained by increasing concerns about climate change, high fossil fuel and energy costs.

change mitigation risks [Springer (2003)]. This section outlines in more detail the theory of Markowitz mean-variance portfolio theory, and explains its use in this contribution.

In this study, mean-variance portfolio theory is used to locate efficient portfolios of electricity-generating technologies similar to Awerbuch et al. (2004). Risk is defined as the year-to-year variability (standard deviation) of expected return (kWh/CHF). Along the efficiency frontier, which will be explained in more detail in section 2.2, a Pareto improvement is not possible, since higher expected returns cannot be obtained without increasing the risk level, or, less risk cannot be generated without a reduction in expected returns. Efficient generating portfolios are thus defined by a twin property: they maximize expected return for any given level of risk or minimize expected risk for every level of expected return.

The following discussion of portfolio theory is based on a two-asset portfolio, presented in the context of portfolio return, viz. the inverse of generation costs.

Expected portfolio return $E(R_p)$ is the weighted average return of the generation mix components. For a two-technology generating mix, expected return is the weighted average of the individual expected returns of two technologies:

$$\text{Expected portfolio return: } E(R_p) = X_1 \cdot E(R_1) + X_2 \cdot E(R_2)\,, \tag{1}$$

where X_1 and X_2 are the shares[3] of the two technologies in the mix and $E(R_1)$ and $E(R_2)$ are their expected electricity-generating returns.

Portfolio risk, σ_p, is also a weighted average of the return variances of individual technologies:

$$\text{Portfolio risk: } \sigma_p = \sqrt{X_1^2\sigma_1^2 + X_2^2\sigma_2^2 + 2X_1X_2\rho_{12}\sigma_1\sigma_2}\,, \tag{2}$$

where X_1 and X_2 are the shares of the two technologies in the mix, σ_1 and σ_2 are the standard deviations of the expected return of the annual costs of technologies 1 and 2, and ρ_{12} is the correlation coefficient of technologies 1 and 2.

Correlation affects the degree of diversification and hence the portfolio's overall risk. As can be seen in equation (3), if the correlation ρ_{12} of the two technology example is zero, then expected total portfolio risk will always be lower than the same portfolio with identical technology shares and returns but with a positive correlation coefficient (see eq. 2). Obviously, once the correlation turns negative, risk can even be further reduced. In fact, if the correlation is -1, both technologies are perfectly negatively correlated, which implies that in a two technology portfolio where both technologies take the same shares, risk is completely diversified.

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[3] here, $X_1+X_2=1$.

$$\text{Portfolio risk: } \sigma_p = \sqrt{X_1^2\sigma_1^2 + X_2^2\sigma_2^2}\ ,\ \text{if } \rho_{12} = 0\,. \tag{3}$$

To estimate the expected portfolio return and risk one therefore needs the individual expected returns $E(R_i)$, the individual standard deviations σ_i, the correlation coefficients between two technologies ρ_{ij}, and finally the technology shares X_i of each individual technology in use. The individual expected returns and standard deviations on their own are not sufficient to determine their shares in the efficient portfolio. Therefore, technologies with low returns (viz. technologies with high costs[4]) can be part of an efficient mix if they diversify well.

2.2 Efficiency frontier

Figure 1 displays the theory as outlined in section 2.1, graphically (using data points based on the results presented in section 5). Expected return and risk of each generating technology are indicated by dots. For example, *Biogas* has a low expected return and low risk compared to *Nuclear*, which has a high expected return and high risk. Mean-variance portfolio theory is used to calculate the electricity-generating technology mix that is efficient. To do this all individual returns, standard deviations and their respective correlations between each technologies are taken into account (see eq. 1 and 2 for a two technologies example). There are infinite numbers of efficient portfolios, making up the efficiency frontier. Figure 1 displays a feasible efficiency frontier, feasible in the sense that no single technology can be the sole contributor to an efficient portfolio due to pre-defined constraints. It seems unrealistic from a technological, political, and supply security view to assume that one single technology is the sole contributor of electricity in Switzerland. Thus, *Nuclear* and *Biogas* are not part of the feasible efficiency frontier, although they generate the highest expected return or lowest risk, respectively, on a stand alone basis.

This study focuses on four efficient portfolios in particular, the maximum expected return (MER) portfolio, the same variance (SV) portfolio, the same expected return (SER) portfolio, and the minimum variance (MV) portfolio. These four efficient portfolios are chosen, because the risk preference of the Swiss population is unknown. As can be seen by the indifference curves, risk-neutral users opt for the MER portfolio, while risk-averse users would prefer the MV portfolio. In fact, there are an infinite amount of efficient portfolios located along the efficiency curve, but to simplify the analysis only MER, SV, SER, and MV portfolios are considered.

The MER portfolio in 2035 contains only those technologies that maximize expected return, while risk is relatively high. Note that the efficient MER mix in Figure 1 generates considerably more expected return than the AP2000, however, this comes with relatively more risk. The SV

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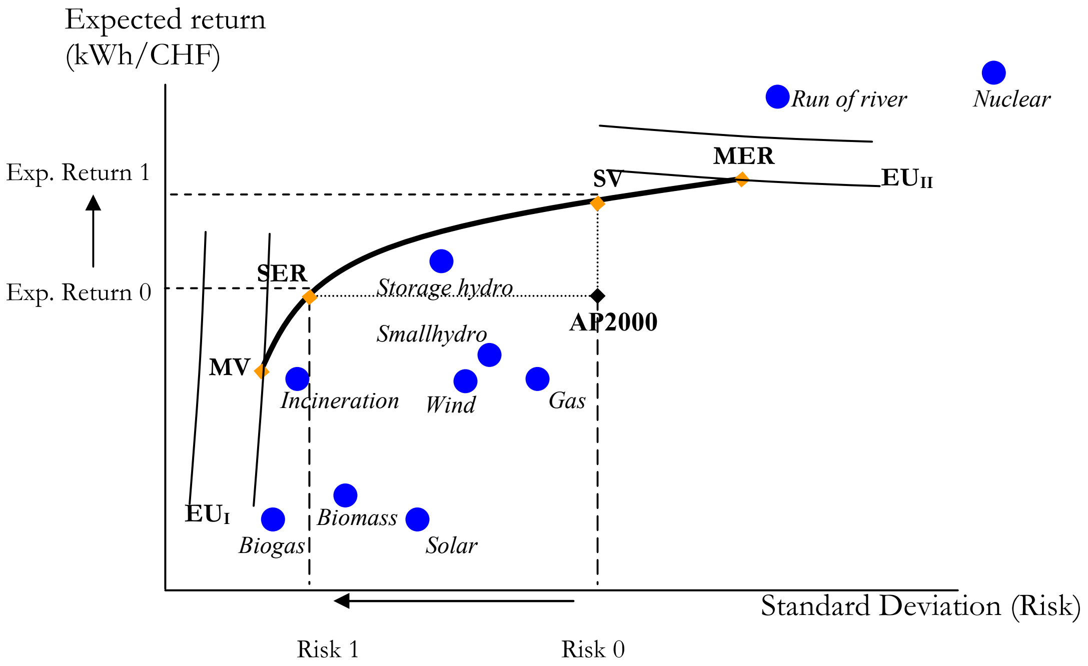
[4] Generation costs are the inverse of returns

portfolio in 2035 holds the technology mix that leads to the same risk as in 2000, but with more expected return (the gap between Exp. Return 0 and Exp. Return 1 on the vertical axis shows how much expected return can be gained by switching from the actual portfolio in 2000 to the efficient portfolio while holding the level of risk constant). The SER portfolio in 2035 generates the same expected return as in 2000, but with less risk (here the gap between Risk 0 and Risk 1 on the horizontal axis measures how much risk can be reduced if one switches from the actual generation mix to the efficient one while keeping expected returns constant).

Figure 1: Efficiency Frontier for Switzerland



For a country like Switzerland, where inhabitants are widely regarded as being risk-averse (Szpiro, 1986), the MV mix might be of greatest interest. The MV portfolio contains those technologies that minimize the standard deviation of the expected return (risk). Along an indifference curve, expected utility (EU) is held constant. The more the preference gradient points towards the expected return and away from the risk axis, the more marked is the user's risk aversion. Therefore, a risk-averse user would prefer the MV portfolio (EU$_{\mathrm{I}}$), while a risk-neutral user would opt for the MER portfolio (EU$_{\mathrm{II}}$).

2.3 Measures of return-to-risk

The Sharpe ratio (*SR*) is a measure of return-to-risk and can be used as an additional criterion to choose the best portfolio mix, viz. the one with the highest return-to-risk ratio. In this study, the *SR* is used to determine the best efficient portfolio within specific scenarios (see section 5.2). The ratio is defined as

$$SR = ER_p / \sigma_p, \tag{4}$$

where ER_p is the expected return of the efficient portfolio (eq. 1) while σ_p represents the volatility (measured as standard deviation of the expected return) of the efficient portfolio (eq. 2). A higher value of the Sharpe ratio (*SR*) is preferred over a lower one.

3 Econometric analysis

One important criterion to calculate efficient portfolios is the estimation of a stable variance/covariance matrix. If this is not the case the measure of risk, which is a main component to calculate efficient portfolios, will be erroneous. OLS and SURE specifications have been tried in this study, however, only the latter appears suitable to estimate the expected returns and standard deviations for the future portfolios for 2035 and the actual portfolio in 2000 (AP2000). First, a simple OLS specification was used. Consider equation 5, where generation costs $Y_{i,t}$ are explained by a constant $\beta_{i,0}$, autoregressive dependent variables $Y_{i,t-j}$, a time trend $Trend_i$ and the disturbance term $u_{i,t}$

$$Y_{i,t} = \beta_{i,0} + \sum_{j=1}^{m} Y_{i,t-j}\beta_{i,j} + Trend_i + u_{i,t}. \tag{5}$$

Shocks $u_{i,t}$ causing volatility in $Y_{i,t}$ are correlated across technologies. As a consequence the error variance/covariance matrix of the generation technologies is not orthogonal, which leads to biased estimation results of risk σ^2 (Wooldridge, 2003, p. 335).

SURE therefore appears to be superior to OLS because it takes account of error spillovers across equations.

3.1 Seemingly unrelated regression estimation (SURE)

The SURE approach provides estimates of the covariance matrix that are time-invariant. In each time series of electricity generation returns this calls for the estimation of predicted values

$$\hat{R}_{i,t} = R_{i,t} - \hat{u}_{i,t}, \tag{6}$$

that do not contain a systematic shift. However, such values cannot be calculated from eq. 5, since shocks in $u_{i,t}$ causing volatility in $R_{i,t}$ are correlated across technologies. As found by Krey and Zweifel (2006), if error terms are correlated, SURE offers a method to improve the efficiency of the estimation. The set of equations making up SURE in a four technology example, such as the actual portfolio for the year 2000, reads

$$\begin{aligned} R_{1,t} &= a_0 + \sum_{j=1}^{m} a_{1,j} \cdot \mathrm{R}_{1,t-j} + u_{1,t} \\ R_{2,t} &= b_0 + \sum_{j=1}^{m} b_{2,j} \cdot \mathrm{R}_{2,t-j} + u_{2,t} \\ R_{3,t} &= c_0 + \sum_{j=1}^{m} c_{3,j} \cdot \mathrm{R}_{3,t-j} + u_{3,t} \\ R_{4,t} &= d_0 + \sum_{j=1}^{m} d_{4,j} \cdot \mathrm{R}_{4,t-j} + u_{4,t} \end{aligned} \quad , \tag{7}$$

where $R_{1,t}$ to $R_{4,t}$ are the returns for technologies i=1,2,3,4 in year t. a_0 to d_0 are their respective constants, $a_{1,j}$ to $d_{4,j}$ are the coefficients of returns lagged j years, $\mathrm{R}_{1,t-j}$ to $\mathrm{R}_{4,t-j}$ are the dependent explanatory variables lagged j years, and $u_{1,t}$ to $u_{4,t}$ are the error terms.

The crucial assumption that is specific to SURE is the non-diagonality assumption in the covariance matrix (see eq. 8), since it simultaneously estimates expected returns for all power generating technologies. This approach typically generates results that offer reliable estimates of the parameter $\beta_{i,j}$, residuals $u_{i,t}$, and hence of the σ_i and $\sigma_{i,j}$ (covariance matrix).

$$\mathbf{\Omega} = E(uu') = \begin{bmatrix} \sigma_{1,1}I & \sigma_{1,2}I & \sigma_{1,3}I & \sigma_{1,4}I \\ \sigma_{2,1}I & \sigma_{2,2}I & \sigma_{2,3}I & \sigma_{2,4}I \\ \sigma_{3,1}I & \sigma_{3,2}I & \sigma_{3,3}I & \sigma_{3,4}I \\ \sigma_{4,1}I & \sigma_{4,2}I & \sigma_{4,3}I & \sigma_{4,4}I \end{bmatrix} \tag{8}$$

3.2 Measures of supply security

Shannon-Wiener and Herfindahl-Hirschman indices are calculated to evaluate the degree of diversification that is predicted by the efficient power generating portfolios. These indices shed light on the question whether the future supply of the efficient power generating portfolio mix as of 2035 is secure. In addition, Shannon-Wiener and Herfindahl-Hirschman indices show the trade-off between efficiency and security of supply that might arise. A system that relies on only a few technologies is exposed to collusion and monopoly. One measure of diversity is entropy, and can be calculated by the Shannon-Wiener Index

$$SW = \sum_{i=1}^{m} - p_i \ln(p_i), \tag{9}$$

where p_i is the share of technology *i* in the efficient power generation portfolio. The weights of all technologies in the portfolio are considered (*i*=1,…,*m*). If the index exceeds the value of 1.00 the system is assumed to be well diversified and the risk of collusion or monopoly is low.

Alternatively, the Herfindahl-Hirschman index can be calculated. It is an alternative measure of security of supply and looks at the degree of concentration, in formal terms

$$HH = \sum_{i=1}^{m} P_i^2, \tag{10}$$

where P_i is the share (in percent) of technology *i* in the efficient portfolio (*i*=1,…,*m*). No concentration, and thus security of supply is assumed if the values of *HH*<1800 basis points (bps) (Grubb et al., 2005).

4 The data

This study uses observed and predicted annual generation cost data[5], covering the periods 1991 to 2000 (to calculate the AP2000) and 2005 to 2035 (to estimate all future portfolios). Data were mainly obtained from Hirschberg (1999, 2005) and Oettli (2004) and relate to the returns of *Nuclear*[6], *Run of river*[7], *Storage hydro*[8], *Solar power*[9], which were used to estimate the AP2000 and the future efficiency frontier, and *Gas*[10], *Biogas*, *Biomass*, *Incineration*, *Smallhydro* and *Wind* as additional technologies for the future[11] efficiency frontier estimation. All observations of electricity generation returns (kWh/CHF) are measured in levels (user view). Throughout, expected returns (the inverse of generation costs) comprise (i) fuel costs, (ii) costs of current operations, and (iii) capital user costs including depreciation. In the case of *Nuclear*, estimated decommissioning and waste disposal costs are also included. Externality surcharges are included since electricity

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[5] To obtain annual data, cubic spline interpolation was applied where necessary (Ingersoll, 1987).

[6] Data sources: KKL (2005), KKG (2005), Hirschberg (2005, ch. 7) and Hirschberg and Jakob (1999, pp. 2-19).

[7] Data sources: personal correspondence, Hirschberg et al. (2005, ch. 4) and Hirschberg and Jakob (1999, pp. 2-19).

[8] Data sources: personal correspondence, Hirschberg et al.(2005, ch. 4) and Hirschberg and Jakob (1999, pp. 2-19).

[9] RWE Schott Solar (2005); The average exchange rate of 2000 was used to convert Euro into CHF (source: SNB). RWE Schott solar data from Germany is used as a proxy for Swiss solar electricity, since solar generation technologies are similar.

[10] At present Switzerland does not generate electricity with gas.

[11] By Infras, see Oettli et al. (2004).

generation causes hazards and environmental damage. Generation cost data for the period 1991 to 2000 is based on observed costs, and covers about 80 percent of all *Nuclear* power, and more than 60 percent of hydro power (*Run of river* and *Storage hydro*) capacities in Switzerland.

The data set for the period 2005 to 2035 was computed by Infras and is based on several assumptions, such as a constant population of 7.4 million people in Switzerland, economic growth of 1.5 – 2 percent per annum, a convergence of Swiss wages with the European average by 2025, and a real interest for capital costs of 2.5 percent (see Oettli et al., 2004). Generation costs, the inverse of expected returns, are predicted by using different scenarios[12] to estimate cost components such as fuel and fixed costs (including capital user costs). If different scenarios led to different cost predications, the higher priced generation cost components were chosen (conservative approach). Concerns may be raised about the predicted real interest rate for capital, since minor variations lead to great fluctuations in generation costs. The data set takes account of learning curve effects thus new-renewable technologies such as *Smallhydro* and *Wind* generate increasingly more expected return over time.

External costs are included and relate to health and global warming, which were obtained from Hirschberg and Jakob (1999). However, no data are available for some other categories, such as costs related to agriculture, forestry, and emission trading.

5 Portfolio estimation and discussion

This section presents the econometric results and predicted efficient electricity portfolios for Switzerland in 2035. For brevity, only the econometric results for the future portfolios are shown. Correlation tables and regression results of the AP2000 estimation are presented in the appendix. The analysis compares the risk-return properties of the de facto 2000 generation mix to a set of efficient portfolios in 2035 using different scenarios. First, the discussion focuses on those portfolios that used correlations and a stable variance/covariance matrix estimated by SURE. Later, some results are compared with generated portfolios using correlations, expected returns and risk estimates obtained from OLS to see whether different model specifications lead to different efficient portfolio returns and risks and therefore generating technology shares.

5.1 Preliminary testing and SURE results

The augmented Dickey-Fuller (ADF) test confirms at the one percent significance level that all time series of returns are stationary (for both, the future and actual portfolio estimations). The correct lag order for the SURE regressions were obtained by using the following tests: Akaike's

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[12] Scenarios looked at different degrees of electricity demand and electricity generation.

information criterion, Hannan & Quinn's information criterion, Schwarz's Bayesian information criterion and the likelihood ratio test (for details see Al-Sabaihi, 2002 and Liew, 2004). Table 3 further below displays the chosen lag orders for each technology in the future portfolio, Table A3 in the appendix shows the equivalent for the actual portfolio in 2000.

As mentioned before, SURE increases the efficiency of estimation by accounting for correlations in unobserved shocks. Table 1 provides evidence that supports this notion, which displays partial correlation coefficients that relate to returns (kWh/CHF).

Table 1: Partial correlation coefficients (2005 – 2035)

Technology	*Nuclear*	*ROR*	*Hydro Sto.*	*Solar*	*Gas*
Nuclear	1.0000	-0.9165	0.1614	0.9628	-0.9463
Run of river	-0.9165	1.0000	-0.4685	-0.9820	0.9636
Storage hydro	0.1614	-0.4685	1.0000	0.3847	-0.3794
Solar	0.9628	-0.9820	0.3847	1.0000	-0.9752
Gas	-0.9463	0.9636	-0.3794	-0.9752	1.0000
Smallhydro	0.8673	-0.9931	0.5620	0.9593	-0.9411
Wind	0.8668	-0.9930	0.5626	0.9590	-0.9408
Biomass	0.9675	-0.9872	0.3684	0.9970	-0.9772
Incineration	0.7199	-0.9345	0.6740	0.8620	-0.8416
Biogas	0.8597	-0.9915	0.5662	0.9559	-0.9374

Technology	*Smallhydro*	*Wind*	*Biomass*	*Incin*	*Biogas*
Nuclear	0.8673	0.8668	0.9675	0.7199	0.8597
Run of river	-0.9931	-0.9930	-0.9872	-0.9345	-0.9915
Storage hydro	0.5620	0.5626	0.3684	0.6740	0.5662
Solar	0.9593	0.9590	0.9970	0.8620	0.9559
Gas	-0.9411	-0.9408	-0.9772	-0.8416	-0.9374
Smallhydro	1.0000	0.9999	0.9641	0.9664	0.9995
Wind	0.9999	1.0000	0.9638	0.9666	0.9995
Biomass	0.9641	0.9638	1.0000	0.8691	0.9603
Incineration	0.9664	0.9666	0.8691	1.0000	0.9713
Biogas	0.9995	0.9995	0.9603	0.9713	1.0000

The coefficients indicate strong correlations. For example, *Incineration* and *Nuclear* exhibit a correlation of 0.7199. A very strong and negative correlation can be seen between *Run of river* and *Biogas* (-0.9915). Here, a one percent increase in returns for *Run of river* is matched by an almost identical drop in *Biogas*. Both technologies therefore diversify very well. A comparison of the same technologies for the time periods 1991-2000 (appendix, Table A1) and 2005-2035 (Table 1) reveals that *Nuclear* continues to diversify well with *Run of river* (in both time periods the coefficient stays negative). A strong negative correlation between these technologies seems intuitive, since a reduction in *Run of river* generated electricity (for example during a heat period) will be compensated by an increase in *Nuclear* generated power (*Nuclear* does not run on full capacity, and therefore has the ability to increase production capacity during times of electricity shortages). According to the forecasted data, this effect is expected to increase more than twice as much from -0.4945 for the time period 1991-2000 to -0.9165 between 2005-2035.

Table 2 contains the correlations of $u_{i,t}$, i.e. the residuals of eq. (7), which represent the components due to unobserved shocks. Correlation coefficients remain high, with no changes in signs. For instance, the correlation across the equations of *Incineration* and *Nuclear* is 0.7578. Partial correlations for the period 1991-2000 clearly differ (appendix, Table A2), here none of the coefficients are negative, and all exceed 0.95.

Table 2: Partial correlation coefficients for $u_{i,t}$ residuals from eq. (7) (2005 – 2035)

Technology	***Nuclear***	***ROR***	***Hydro Sto.***	***Solar***	***Gas***
Nuclear	1.0000	-0.9398	0.0123	0.9690	-0.9589
Run of river	-0.9398	1.0000	-0.2844	-0.9848	0.9834
Storage hydro	0.0123	-0.2844	1.0000	0.2171	-0.2376
Solar	0.9690	-0.9848	0.2171	1.0000	-0.9854
Gas	-0.9589	0.9834	-0.2376	-0.9854	1.0000
Smallhydro	0.8915	-0.9914	0.4017	0.9622	-0.9644
Wind	0.8912	-0.9913	0.4024	0.9620	-0.9642
Biomass	0.9784	-0.9891	0.1883	0.9962	-0.9886
Incineration	0.7578	-0.9326	0.5666	0.8746	-0.8785
Biogas	0.8907	-0.9914	0.4016	0.9639	-0.9649

Technology	***Smallhydro***	***Wind***	***Biomass***	***Incin***	***Biogas***
Nuclear	0.8915	0.8912	0.9784	0.7578	0.8907
Run of river	-0.9914	-0.9913	-0.9891	-0.9326	-0.9914
Storage hydro	0.4017	0.4024	0.1883	0.5666	0.4016
Solar	0.9622	0.9620	0.9962	0.8746	0.9639
Gas	-0.9644	-0.9642	-0.9886	-0.8785	-0.9649
Smallhydro	1.0000	0.9990	0.9645	0.9704	0.9996
Wind	0.9990	1.0000	0.9643	0.9706	0.9996
Biomass	0.9645	0.9643	1.0000	0.8736	0.9647
Incineration	0.9704	0.9706	0.8736	1.0000	0.9703
Biogas	0.9996	0.9996	0.9647	0.9703	1.0000

Table 3 displays the SURE regression results. As can be seen from the column denoted Exp. Return, *Nuclear* has the largest expected return, amounting to 25.7 kWh/CHF, while *Biogas* has the smallest expected return, at a mere 2.6 kWh/CHF. The standard deviations of all technologies vary widely, with *Biogas* being the least volatile (0.1) and *Nuclear* the most (4.7). Every regression includes a time trend, reflecting technological change, which is positive and significant for *Nuclear*, *Storage hydro*, *Smallhydro*, and *Wind*. These technologies are expected to continue to gain from technological progress (particularly learning effects), which lead to increases in expected returns over time. However, most of the coefficients are close to zero, indicating a slow rate of progress. The coefficients of determination R^2 all exceed 0.89 thus offering some confidence in the SURE results.

Table 3: Results of SURE regressions, Switzerland (2005 – 2035)

Technology	**Exp. Return**	**Std. dev**	**b_0**	**b_1**	**b_2**	**b_3**	**b_4**	***Trend***	**Obs**	**R^2**
Nuclear	25.7	4.7	-0.2***	2.8***	-2.8***	0.9***	-	0.001***	27	0.90
Run of river	25.6	1.6	1.3**	2.6***	-2.3***	0.7***	-	-0.01**	27	0.89
Storage hydro	18.4	0.8	0.5***	3.2***	-4.3***	2.7***	-0.7***	0.001**	27	0.89
Solar	3.1	1.2	-0.003	3.1***	-3.7***	2.0***	-0.4***	-0.0005	27	0.91
Gas	11.8	1.3	4.7***	0.7***	-	-	-	-0.06***	27	0.90
Smallhydro	12.7	1.3	1.6***	-	-0.8***	0.2	0.004***	0.3***	27	0.90
Wind	12.5	1.1	0.2***	1.7***	-0.2	-0.75**	0.2	0.003***	27	0.92
Biomass	4.6	0.8	-0.02***	2.7***	-2.5***	0.8***	-	-0.0002	27	0.99
Incineration	13.2	0.2	0.1	1.4***	-0.4***	-	-	-0.001***	27	0.89
Biogas	2.6	0.1	-0.05	1.3***	-0.25**	-	-	-0.001**	27	0.95

*Significant at 10 percent level, ** significant at 5 percent level, *** significant at 1 percent level

As can be seen in the appendix (Table A3), *Run of river* and *Storage hydro* generate higher expected returns in 2000 than *Nuclear* power (30.1 and 15.1 vs. 14.4 kWh/CHF). One explanation for this is the inclusion of external costs (see section 4) that are higher for *Nuclear* power and thus lead to lower expected returns. In addition, decommissioning and waste disposal further reduce expected return for *Nuclear*. In addition, *Run of river* is the most volatile technology (2.7), which is due to seasonal variations in the quantity of water that is needed for power generation. The trend variable indicates that all four technologies in 2000 face increasing returns over time. With the exception of *Run of river* all R^2 results are comfortably high (all exceed 0.65).

5.2 Efficient portfolio shares for different scenarios using SURE

Three different future scenarios are examined, reflecting different degrees of feasibility constraints. Scenario SI contains no constraints, and therefore tends to generate concentrated technology portfolio mixes (see section 2.2). Along the efficiency frontier more diversified generation mixes are located, as will be seen in the cases of SV and SER portfolios. In scenario SII the shares of *Nuclear* and *Gas* are set to zero (reflecting a strict aversion to *Nuclear* power and *Gas* fuel dependency), while the shares of *Run of river* and *Storage hydro* cannot exceed 24 and 32 percent, respectively (this restriction is based on Laufer et al. (2004) who claim that larger shares of *Run of river* and *Storage hydro* are unlikely in the future due to technical and geological restrictions). Finally, scenario SIII presents a technologically feasible generation mix in accordance to studies by the Swiss Federal Office of Energy (SFoE, 2005) and Laufer et al. (2004). Here *Solar*, *Smallhydro*, *Wind*, *Biomass*, *Incineration* and *Biogas* are constrained to take a minimum share of 5 percent each, while *Nuclear*, *Run of river* and *Storage hydro* are constrained at maximum shares of 40 percent, 24 percent and 32 percent, respectively. The latter three technology constraints reflect the status quo view, where shares are kept the same in 2035 as in early 2000.

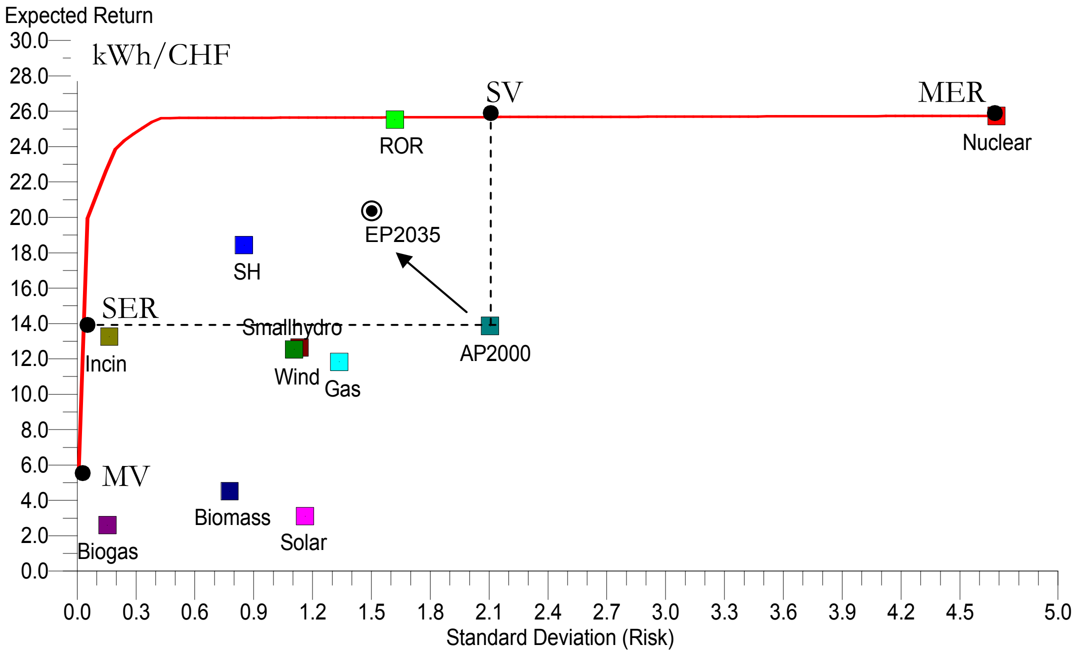
5.2.1 Scenario SI: No constraints imposed

A look at Figure 2 reveals that the actual portfolio (AP2000) is far off the efficiency frontier, implying that the AP2000 mix is inefficient if no constraints are imposed (Scenario SI). As expected, the MER portfolio is heavily concentrated, containing 100 percent *Nuclear*, see Table 4. Expected return is almost twice the size of the AP2000 (25.74 kWh/CHF vs 13.82 kWh/CHF). Keeping risk the same (SV), a shift towards *Nuclear* (58 percent) and *Run of river* (42 percent) also improves expected returns to 25.67 kWh/CHF, which is only marginally less than the MER portfolio. On the other hand, the SER portfolio reveals how much risk can be reduced by keeping the expected return the same as in 2000. Using more *Run of river* (48 percent, up from 27 percent in AP2000) and *Smallyhdro* (42 percent, which has not been used before), while reducing the shares of *Nuclear* (7 percent, down from 38 percent) and *Storage hydro* (3 percent, down from 31 percent) decreases risk to a mere 0.05 (down from 2.10 in AP2000). Finally, the MV portfolio, containing a share of 88 percent *Biogas*, generates the lowest level of risk (0.01).

Shannon-Wiener and Herfindahl-Hirschman indices show that the inefficient AP2000 mix diversifies better than all four efficient portfolios. The *SW* index exceeds 1.00, which indicates that the risk of collusion is low. However, the *HH* index being more than 1800 bps signifies some concentration. With the exception of SER, all other portfolios are concentrated, with the MER taking the maximum possible *HH* index of 10000 bps, since the portfolio contains only one technology. According to the Sharpe ratio, the MV mix offers the best return-to-risk relationship, which is more than seventy times bigger than the AP2000 (529.00 vs. 7.00). Therefore, users are best advised to adopt the MV portfolio if they want a generating mix that offers the lowest risk and the highest return-to-risk ratio compared to the AP2000 and all other efficient portfolios.

If the same technology shares as in the AP2000 are adopted for the predicted year 2035 data set, then the portfolio shifts closer to the efficiency frontier as shown by portfolio EP2035 (see Figure 2). Here expected return increases from 13.82 in the AP2000 to 21.56 in EP2035. In addition, volatilities in returns are expected to decline from 2.10 as in AP2000 to 1.57 in EP2035. This shift could be explained by technological progress particularly due to learning curve effects (for example, expected return of *Solar* increases almost three times from 1.1 kWh/CHF in 2000 to 3.1 kWh/CHF in 2035, see Tables A3 and 3). However, this could also be due to the smoothing, which is inherent in forecasts.

Figure 2: Efficient portfolio for Switzerland using SURE procedure in scenario SI



However, because the EP2035 is based on the same technology shares as the AP2000 it can only be achieved if electricity consumption stays the same between 2000 and 2035, or if an increase in electricity demand is proportionately matched by an increase in all technologies. Both cases seem unlikely, because demand is expected to increase by at least 15 percent by 2020 (see section 1), and hydro generated electricity is already being fully utilized (Laufer et al. 2004).

Table 4: Efficient Portfolio shares in Scenario SI

	MER	SV	SER	MV	AP2000	EP2035
Nuclear	100%	58%	7%	1%	38%	38%
Run of river		42%	48%	10%	27%	27%
Storage hydro			3%		31%	31%
Solar					4%	4%
Gas				1%		
Smallhydro			42%			
Wind						
Biomass						
Incineration						
Biogas				88%		
Exp. Return	25.74	25.67	13.82	5.29	13.82	21.56
Std.Dev.	4.69	2.10	0.05	0.01	2.10	1.57
SW	0.00	0.68	1.01	0.44	1.21	1.21
HH	10000	5138	4130	7814	3150	3150
Sharpe	5.49	12.22	276.41	529.00	7.00	14.00

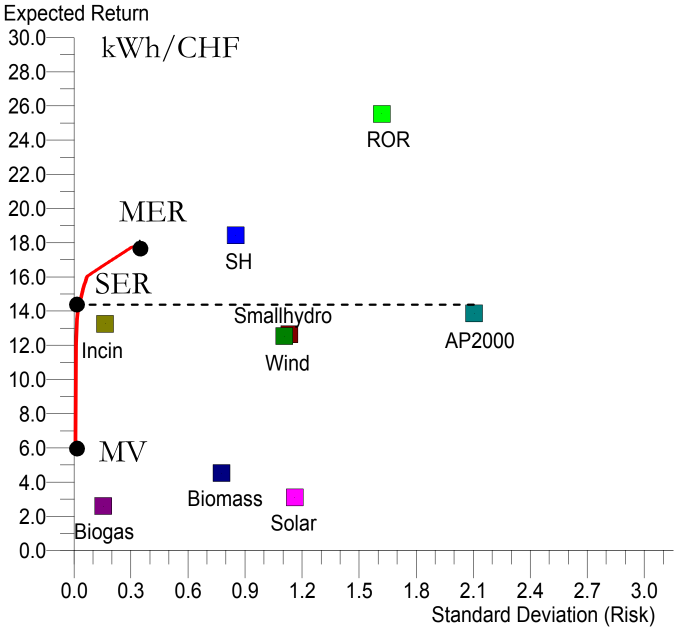
Critics may also express their concern that scenario SI is generally unrealistic. In particular *Nuclear* and *Biogas* taking shares of 100 and 88 percent in the MER and MV portfolios, respectively, and

Run of river exceeding 40 percent in the SER and SV portfolios are deemed unrealistic. Therefore the next two subsections discuss two additional scenarios, where so-called feasibility constraints are applied.

5.2.2 Scenario SII: No nuclear and gas, restricted shares for hydro power

In scenario SII neither *Nuclear* nor *Gas* contribute towards an efficient electricity mix. Users that dislike *Nuclear* power and who strongly oppose any form of *Gas* dependency opt for this alternative. In addition, both hydro technologies are constrained to their technically feasible generation shares as predicted by Laufer et al. (2004). As can be seen in Figure 3, the efficiency frontier shrinks in size as compared to Figure 2 in 5.2.1[13], while the AP2000 is still far off the efficiency frontier. Table 5 shows that MER is much less concentrated than in the previous section. *Run of river* and *Storage hydro* take their binding shares, 24 and 32 percent, respectively. In addition, *Incineration* plays an important role (44 percent). Both expected return and standard deviation (risk) speak in favor of MER, since both values are better than the AP2000 ones, where expected return is 4 percentage points lower, and risk almost 2 percentage points higher. The efficiency frontier shrunk in size due to the imposed constraints.

Figure 3: Efficient portfolio for Switzerland using SURE in scenario SII



For that reason the SV portfolio could not be estimated. The SER portfolio mix contains 24 percent *Run of river* (binding share, down from 27 percent in the AP2000), and 12 percent *Smallhydro*, 26 percent *Biomass*, and 38 percent *Incineration*, which are all technologies, that if aggregated made up less than one percent before 2000. As before in scenario SI, the MV mix

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[13] due to the imposed feasibility constraints

places a strong weight on *Biogas* (almost 80 percent), which helps to reduce risk to a mere 0.01. As can be seen by the Shannon-Wiener and Herfindahl-Hirschman indices, the SER portfolio displays some remarkable features: although *Nuclear* and *Gas* are not part of the efficient portfolio, the mix is very well diversified, much better than the inefficient AP2000 and all other efficient portfolio mixes. The same applies to the Sharpe ratio, no other portfolio in scenario SII exceeds 691.00. Therefore, in terms of expected return, *SW*, *HH* and the Sharpe ratio no other portfolio provides better results than the SER mix.

Table 5: Efficient portfolio shares in scenario SII

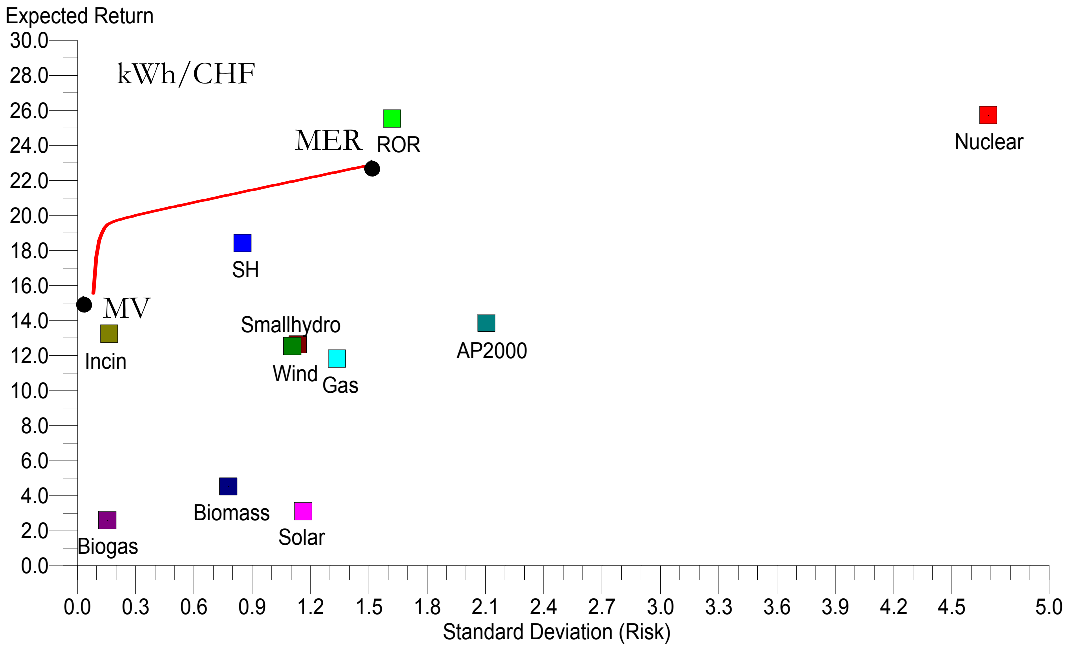
	MER	SV	SER	MV	AP2000
Nuclear					38%
Run of river	24%		24%	12%	27%
Storage hydro	32%				31%
Solar					4%
Gas					
Smallhydro			12%		
Wind					
Biomass			26%	12%	
Incineration	44%		38%		
Biogas				76%	
Exp. Return	17.85		13.82	5.70	13.82
Std.Dev.	0.37		0.02	0.01	2.10
SW	1.07		1.31	0.72	1.21
HH	3536		2862	6067	3150
Sharpe	48.24		691.00	570.00	7.00

5.2.3 Scenario SIII: Restricted shares for nuclear, hydro power, and new-renewables

In scenario SIII *Solar*, *Smallhydro*, *Wind*, *Biomass*, *Incineration* and *Biogas* take a minimum share of 5 percent each, while *Nuclear*, *Run of river* and *Storage hydro* are constrained to maximum shares of 40 percent, 24 percent and 32 percent, respectively. Figure 4 displays the efficiency frontier, which as before in Scenario SII shrunk in size, due to imposed feasibility constraints. As in the previous two scenarios, the AP2000 is off the efficiency frontier, indicating that an efficiency improvement is possible.

Table 6 shows, that the MER portfolio contains *Nuclear* (40 percent, constraint binding), *Run of river* (24 percent, constraint binding), *Storage hydro* (32 percent, constraint binding), and *Incineration* (4 percent). Like in section 5.2.2, the MER portfolio generates higher expected returns and less risk than the actual portfolio (AP2000). Due to the imposed constraints, both SV and SER portfolios are not part of the efficiency frontier, since the frontier shrunk in size. The MV portfolio contains all ten generating technologies, where *Gas*, *Run of river*, and *Storage hydro* contribute the largest shares, with 28 percent, 20 percent, and 13 percent, respectively. Both, expected returns and risk are more favorable in the MV portfolio than in AP2000.

Figure 4: Efficient portfolio for Switzerland using SURE in scenario SIII



As expected, the Shannon-Wiener index of the MV portfolio not only exceeds those of AP2000 and the efficient MER portfolio, but also those of all other *SW* indices that were previously calculated and displayed in Tables 4 and 5.

Table 6: Efficient portfolio shares in scenario SIII

	MER	**SV**	**SER**	**MV**	**AP2000**
Nuclear	40%			9%	38%
Run of river	24%			20%	27%
Storage hydro	32%			13%	31%
Solar				5%	4%
Gas				28%	
Smallhydro				5%	
Wind				5%	
Biomass				5%	
Incineration	4%			5%	
Biogas				5%	
Exp. Return	22.86			15.56	13.82
Std.Dev.	1.53			0.08	2.10
SW	1.20			2.06	1.21
HH	3216			1570	3150
Sharpe	14.94			194.50	7.00

The *HH* is below 1800 bps (the first, and only time in this study), indicating that this portfolio mix is secure and diverse. The Sharpe ratio is more than ten times larger than the MER, indicating that the return-to-risk relationship is best utilized with the MV portfolio. Therefore users in scenario SIII are best advised to adopt the MV portfolio, since it offers the highest expected return, the lowest risk, the best indices for security of supply and the highest return-to-risk ratio, relative to the inefficient AP2000 and the efficient MER portfolio.

5.3 Comparing OLS-based portfolios with SURE in scenario SIII

This section compares efficient portfolio technology shares that were determined by using different econometric specifications for scenario SIII. Although OLS estimates do not control for error spillovers across equations (see section 3) maximum expected return portfolios that are calculated by OLS (see Table 7) are the same as in scenario SIII where SURE is used (see Table 6).

Table 7: OLS-based scenario SIII

	MER	**SV**	**SER**	**MV**	**AP2000**
Nuclear	40%			10%	38%
Run of river	24%			22%	27%
Storage hydro	32%			13%	31%
Solar				5%	4%
Gas				25%	
Smallhydro				5%	
Wind				5%	
Biomass				5%	
Incineration	4%			5%	
Biogas				5%	
Exp. Return	22.86			15.93	14.19
Std.Dev.	1.53			0.08	2.31
SW	1.20			2.07	1.21
HH	3216			1545	3150
Sharpe	14.94			200	6.14

Differences arise in the MV portfolio, where in SIII with SURE more weight is placed on *Gas* and less on *Run of river* as compared to OLS-based shares. Comparing expected returns of the AP2000 portfolios amongst SURE- and OLS-based portfolios reveals some striking differences. SURE-based AP2000 displays less expected return than OLS (13.82 vs. 14.19). The same holds true for the standard deviation, where SURE results are lower than OLS (2.10 vs. 2.31). The differences show that OLS-based portfolios tend to underestimate the scope of efficiency improvement, since differences between the future portfolios and the AP2000 are much smaller as compared to SURE-based portfolios. Therefore, controlling for the econometric methodology is important since correlated shocks in the disturbance term affect estimates of expected return and standard deviation.

6 Concluding comments

This study applied Markowitz mean-variance portfolio theory to determine efficient electricity-generating portfolios in Switzerland for 2035. These efficient portfolios were compared with the actual portfolio as of the year 2000 (AP2000). The gap between the AP2000 and the future efficient portfolios indicated the scope of efficiency improvement. OLS- and SURE-based econometric procedures were used to estimate a stable covariance/variance matrix of the technologies disturbance term. This is important to be able to obtain adequate expected returns and to derive reliable standard deviations, which are used to calculate efficient portfolios. However, OLS failed to account for error spillovers across equations, which has been remedied by using a Seemingly Unrelated Regression Estimation (SURE).

Three scenarios were analyzed, with feasibility constraints of different degrees of restrictiveness. According to the Sharpe ratio, viz. return-to-risk ratio, the MV portfolios score best in Scenarios SI (without constraints) and SIII (where constraints are imposed on *Nuclear*, *Run of river*, *Storage hydro*, and all new-renewables). In scenario SII (where both *Nuclear* and *Gas* generated electricity technology shares are set to zero, while both hydro technologies are restricted to feasible shares) the Sharpe ratio scored best with the same expected return (SER) portfolio, containing 24 percent *Run of river*, 12 percent *Smallhydro*, 26 percent *Biomass*, and 39 percent *Incineration.* This mix would suit users who dislike *Nuclear* power and any form of *Gas* fuel dependency.

According to Szpiro (1986) the Swiss population is best described as being risk-averse, therefore risk-averse (MV) power portfolio holders in 2035 (who do not oppose *Nuclear* and *Gas*) would be advised to adopt a feasible technology mix containing 28 percent *Gas*, 20 percent *Run of river*, 13 percent *Storage hydro*, 9 percent *Nuclear*, and 5 percent each of *Solar*, *Smallhydro*, *Wind*, *Biomass*, *Incineration*, and *Biogas*, respectively. This portfolio mix improves expected returns by more than 12 percent, while keeping risk more than 90 percent lower than the actual portfolio in 2000. The Shannon-Wiener and Herfindahl-Hirschman indices suggest that this mix is both secure and well diversified, and the Sharpe ratio is almost thirty times larger than that of the actual portfolio in 2000.

However, a share of 28 percent *Gas*, 5 percent *Biomass*, 5 percent *Incineration* and 5 percent *Biogas*, which move users closer to the efficiency frontier, entails additional CO_2 emissions.

Therefore, if Switzerland is able to reposition its Kyoto emission reductions more towards transport fuels and away from electricity generation, this portfolio appears feasible.

The Energy Research Centre of the Netherlands (ECN) commissioned a similar application of portfolio analysis to the Dutch generating mix for 2030 (Jansen et al., 2006). Although the authors did not control for correlated shocks, their results point into the same direction as this study. Risk-averse electricity-generating technology portfolio holders in the Netherlands should adopt a mix in 2030 that contains 33 percent new-renewable technologies, such as *Wind* and *Biomass* (up from 6 percent in 2000). This mix comes at the expense of less *Nuclear* power (down to 0 percent from 5 percent in 2000), less *Coal* (down to 12 percent from 29 percent in 2000), and less *Gas* (down to 55 percent from 60 percent in 2000). Therefore, both countries, Switzerland and the Netherlands are advised to put more weight on new renewable technologies for at least two reasons: first, it reduces risk. Second, the generation portfolio is more diversified and thus serves well to ensure supply security.

One limitation of this study concerns the narrow focus on electricity-generating technologies. A wider perspective should include data on transportation and long-distance heating, which all play an important role in achieving a more efficient use of energy rather than only electricity. However, this study shows that Switzerland has scope for electricity-generating efficiency improvements by employing a more diversified portfolio mix containing *Nuclear* and *Gas*, combined with new-renewables.

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Appendix

Table A1: Partial correlation coefficients (1991 – 2000)

Technology	*Nuclear*	*ROR*	*Hydro Sto.*	*Solar*
Nuclear	1.0000	-0.4945	-0.1488	0.9843
Run of river	-0.4945	1.0000	0.5170	-0.3856
Storage hydro	-0.1488	0.5170	1.0000	0.0169
Solar	0.9843	-0.3856	0.0169	1.0000

Table A2: Partial correlation coefficients for u_{it} residuals (1991 – 2000)

Technology	*Nuclear*	*ROR*	*Hydro Sto.*	*Solar*
Nuclear	1.0000	0.9641	0.9812	0.9987
Run of river	0.9641	1.0000	0.9542	0.9532
Storage hydro	0.9812	0.9542	1.0000	0.9797
Solar	0.9987	0.9532	0.9797	1.0000

Table A3: Results of SURE regressions, Switzerland (1991 – 2000)

Technology	Exp. Return	Std. dev	b_0	b_1	b_2	b_3	*Trend*	Obs	R^2
Nuclear	14.4	2.2	4.8**	0.3	-	-	0.36	10	0.75
Run of river	30.1	2.7	10.2	-0.2	0.2	0.1	1.10**	10	0.44
Storage hydro	15.1	1.8	8.3***	-0.4**	0.001	-0.2	0.94***	10	0.68
Solar	1.1	0.2	0.02	0.4	-	-	0.04**	10	0.99

*Significant at 10 percent level, ** significant at 5 percent level, *** significant at 1 percent level

Table A4: Partial correlation coefficients (2005 – 2035) using OLS

Technology	*Nuclear*	*ROR*	*Hydro Sto.*	*Solar*	*Gas*
Nuclear	1.0000	-0.9399	0.0112	0.9689	-0.9599
Run of river	-0.9399	1.0000	-0.2842	-0.9853	0.9778
Storage hydro	0.0112	-0.2842	1.0000	0.2167	-0.2239
Solar	0.9689	-0.9853	0.2167	1.0000	-0.9829
Gas	-0.9599	0.9778	-0.2239	-0.9829	1.0000
Smallhydro	0.8916	-0.9914	0.4018	0.9628	-0.9567
Wind	0.8912	-0.9912	0.4025	0.9626	-0.9565
Biomass	0.9784	-0.9892	0.1876	0.9963	-0.9858
Incineration	0.7593	-0.9334	0.5662	0.8766	-0.8675
Biogas	0.8912	-0.9915	0.4012	0.9647	-0.9577

Technology	*Smallhydro*	*Wind*	*Biomass*	*Incin*	*Biogas*
Nuclear	0.8916	0.8912	0.9784	0.7593	0.8912
Run of river	-0.9914	-0.9912	-0.9892	-0.9334	0.9915
Storage hydro	0.4018	0.4025	0.1876	0.5662	0.4012
Solar	0.9628	0.9626	0.9963	0.8766	0.9647
Gas	-0.9567	-0.9565	-0.9858	-0.8675	-0.9575
Smallhydro	1.0000	0.9988	0.9646	0.9710	0.9996
Wind	0.9988	1.0000	0.9643	0.9712	0.9996
Biomass	0.9646	0.9643	1.0000	0.8748	0.9650
Incineration	0.9710	0.9712	0.8748	1.0000	0.9706
Biogas	0.9996	0.9996	0.9650	0.9706	1.0000

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