Least-cost approaches have been the mainstay of electricity planning in most western countries for at least a half century. The underlying idea is that by adding “least-cost” incremental capacities, planners will maintain a minimum cost generating system. Least cost probably worked sufficiently well in a previous technological era, marked by relative certainty, low rates of technological progress, homogeneous generating alternatives and stable energy prices. Today’s electricity planner, by contrast, faces a broadly diverse range of technological and institutional options for generating electricity and a future that is highly dynamic, complex, and uncertain. In such an environment attempting to identify long-lived “least-cost” alternatives is nearly impossible. Clearly, more powerful techniques are required if we are to develop robust generating strategies that remain economical under a variety of possible future outcomes.

Financial investors are used to dealing with uncertainty. They have learned that a portfolio of assets provides the best means of hedging possible future outcomes. Investors would not conceive of investing all their funds in a single a stock on the basis of 30-year forecasts of market conditions and stock performance. Yet this is what least-cost procedures imply. Given the rapidly changing environment, it makes sense to shift our energy policy from its current emphasis of evaluating alternative technologies, to evaluating alternative generating portfolios and strategies.

Portfolio theory, an established part of modern finance theory, is based on the pioneering work of Nobel Laureate Harry Markowitz nearly 50 years ago. Portfolio theory has been applied to capital budgeting and project valuation,\(^3\) valuing offshore oil leases,\(^4\) and quantifying climate change mitigation risks.\(^5\) Recently, the approach was used to value generating alternatives and energy diversity and security objectives.

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5 Urs Springer and Harri Laurikka, “Quantifying risks and risk correlations of investments in Climate Change Mitigation,” IWOe Discussion paper No. 101, University of St. Gallen
Applying Portfolio Theory to Renewables Valuation and Energy Security Issues

In Europe and the US policy makers are considering or have already implemented renewables targets or portfolio standards. Underlying these targets is the widespread belief that their adoption will increase overall generation costs since renewables "cost more" on a stand-alone basis. However, portfolio-based analyses in the US indicate that adding PV, wind and other fixed-cost renewable technologies (RETs) to a fossil generating portfolio serves to lower overall generating cost and risk, even though these alternatives may cost more on a stand-alone basis. This counter-intuitive result stems from the portfolio effect, which, in part, implies that all efficient (i.e. optimal) generating portfolios must contain some portion of fixed-cost renewable generation.

More recently, the present authors evaluated the EU renewables targets and energy security objectives by comparing the risk-return properties of EU generating mixes to a set of optimal portfolios that minimize risk at any given overall generating cost level. The results indicate that EU generating mixes are sub-optimal in the sense that portfolios with lower cost and risk can be developed by including greater shares of wind or other fixed-cost renewables and by adjusting the conventional mix. This reduces cost while enhancing energy security.

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Figure 1: Adding 12-cent/kwh renewable to US generating mix reduces cost and risk.

Risk and "Return" for Three-Technology US Generating Portfolio
Assumed Cost for Riskless Renewable: $.12/kWh

Cost and Risk of EU Business-as-usual generating mixes can be reduced by adding wind.

Illustrative Evaluation of the Mexican Generating Mix

Figure 3, 4, 5, 6 present some preliminary, illustrative results that, with refinement, could help policy makers evaluate existing and projected Mexican generating mixes. Figure 3 shows the risk and return (the inverse of cost) of various generating alternatives and portfolios of alternatives as well as the unconstrained Efficient Frontier. This is the location of all optimal portfolios, when no renewable resource constraints are imposed.

Observe that Mexico’s Business-as-usual (BAU) 2010 mix (ME-2010) costs the same as the 2000 mix, but has moved to the right indicating that expected year-to-year generating costs become riskier or more volatile. Both the ME-2000 and the ME-2010 mixes are inefficient in the sense that there exist virtually an infinite number of portfolio combinations that lie to the left and above these mixes. Any of these portfolios will exhibit higher returns (i.e. lower generating costs) and lower expected cost volatilities.

For example, though not technically feasible, Portfolio N, consisting of 80% wind, plus small quantities of hydro nuclear and coal, exhibits significantly reduced volatility as compared to the BAU ME-2010 mix although expected cost is the same. By comparison,
costs for Portfolio S, which consists of about 25% wind, 20% geothermal, and 50% oil and gas, are lower than ME-2010 and so is their risk.

Figure 3
Risk-Return for current and projected Mexico Generating Mixes
Showing “Unconstrained” Efficient Frontier
Figure 4 shows the *Technically Feasible Efficient Frontier*, which reflects practical Mexican resource constraints for wind and other renewables. Along this line lie all *technically feasible*, optimal generating mixes. The feasible portfolios are riskier and costlier than the unconstrained possibilities suggesting that greater emphasis on locating and expanding renewable resources, which would allow additional wind, geothermal and other capacity additions by 2010, could serve to reduce generating cost and risk. This idea is also reflected in Figure 5.

Finally, Figure 6 shows the optimal transition: the particular capacity additions that should be made to move from the current ME-2000 generating mix, to an optimal portfolio such as the one represented by *Portfolio N* (in Figure 4), which exhibits the same expected cost as ME-2010, but with lower volatility.
Figure 5: Changes in the optimal Mix Along the Efficient Frontier: Most RETs are Resource Constrained. Lower Cost/Higher Risk mixes contain more gas and less hydro.
Comparison of capacity mixes
RES are constrained by their technical potentials

**Figure 6:**
Optimal Capacity additions to shift from the Mexico-2000 Mix to an efficient portfolio