

# **Portfolio-Based Capacity Planning: How Renewables *Really* Impact Overall Generating Cost and Energy Security**

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**Tunis: Portfolio-Based Electricity Generation Planning**

*ANME – MEDREC – MinAmbienete*

*REEEP – UK-FCO – UNEP*

***April, 26 2005***

# SPRU Energy Group

## University of Sussex, UK

- **SPRU: One of the oldest & largest institutes for the study of science and technology policy**

- 50 faculty, 70 Ph.D. / 50 MSc students
- Science & Technology Policy, Technology and Sustainability

- **Energy Group Focus**

- The low-carbon transition
- Energy and Sustainability
- Climate Change Adaptation & Mitigation



# RETs Provide Important Portfolio Benefits Without Increasing Cost....

## But Lenders/Investors Cannot Capture These

Benefit	Policymaker Awareness
<ul style="list-style-type: none"> <li>● <b>Environmental Benefits</b></li> <li>- Widely understood—undervalued by regulators</li> </ul>	<b>HIGH</b>
<ul style="list-style-type: none"> <li>● <b>Help Mitigate Market Power</b></li> <li>- Help <i>Unlock</i> Benefits of Liberalization by Enhancing Competition along Power Network</li> <li>- Requires NO restructuring &amp; incentives</li> </ul>	<b>MOD</b>
<ul style="list-style-type: none"> <li>● <b>Security: <i>Mitigate/Diversify</i> Fossil Risk</b></li> <li>- <i>Reduce</i> overall electricity generating costs</li> <li>- <i>Minimize</i> exposure to macroeconomic fossil risk</li> </ul>	<b>LOW</b>

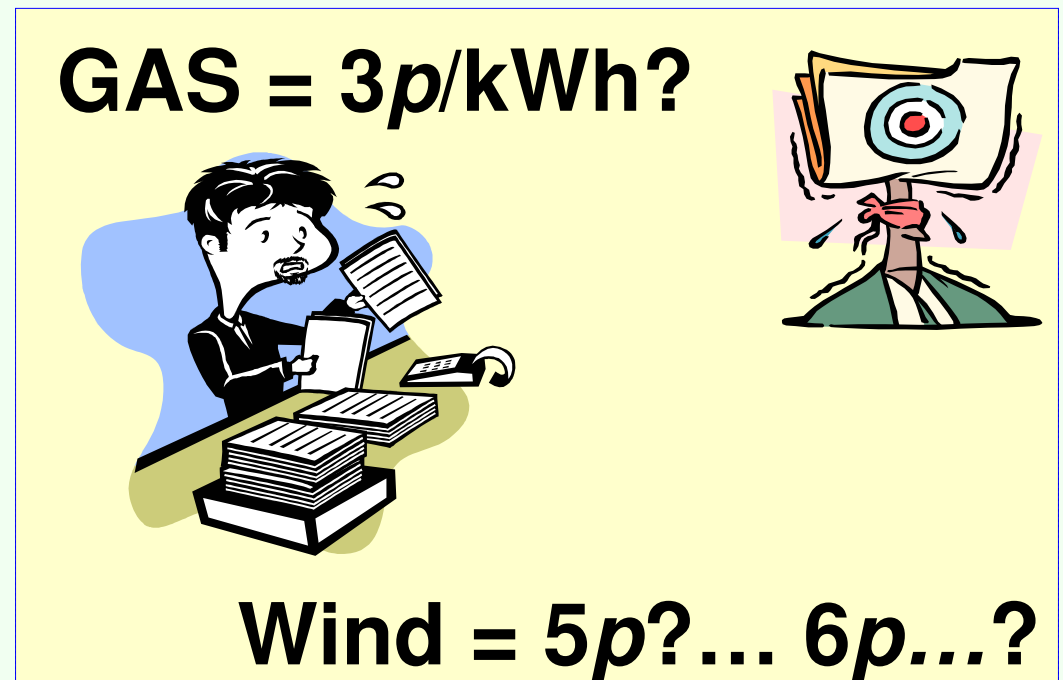
**Most significant aspect of energy security today**

# **REFLECTING MARKET RISK**

**Valuing Energy Technologies  
Necessarily Involves  
an Assessment of Financial Risk**

# Risk Directly Affects KWH Cost Estimates

- Risk affects *value* and economic *expectations*
  - Stock returns mean little without risk
  - Stock X vs. Stock Y
- Engineering kWh cost estimates use arbitrary discount rates
  - Have no economic interpretation

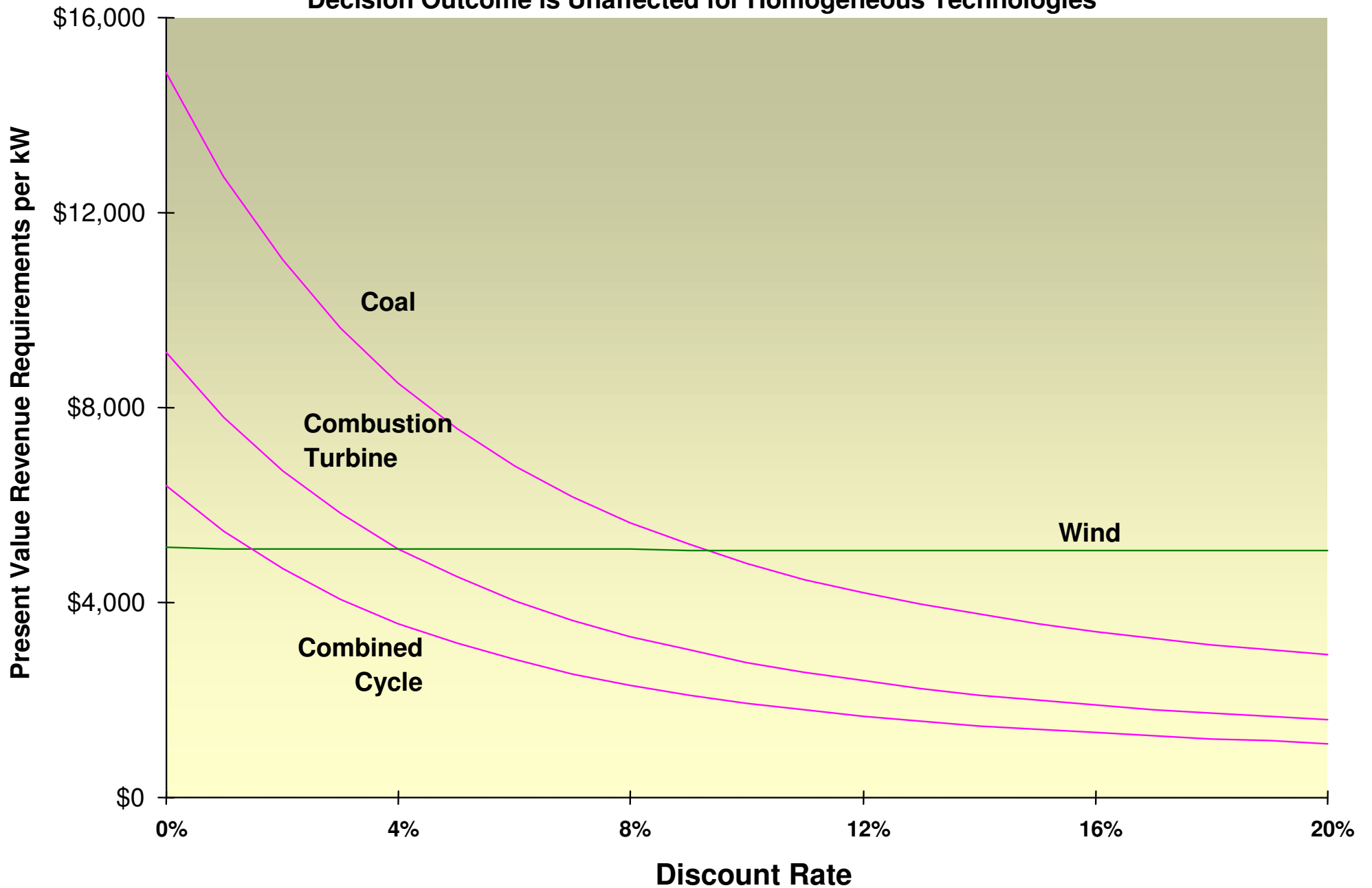


**Talking about kWh cost without also talking about risk is like watching a movie.....  
With the sound turned off!**

# Valuing Energy Technologies Requires an Assessment of Risky Future Cost Streams

- **Traditional cost-of-electricity models yield “rule of thumb” valuations**
  - Ignore risk differentials among technologies
  - Probably sufficed until very recently
  - Ignore effects of taxes
- **Fossil Fuel Prices Vary *Systematically* – non diversifiable risk**
- **Costs of passive/capital-intensive renewable technologies are *Systematically* Riskless (beta  $\approx 0$ )**
  - Financial properties mimic US Treasury obligations

**Ignoring Risk in Valuation:  
Present Values Using a Single Discount Rate for all Costs  
Decision Outcome is Unaffected for Homogeneous Technologies**



Based on NARUC [1990] Costs

# Arbitrary Discounting Produces Arbitrary Results

Valuing Two Bond Investments Using a Single Arbitrary Discount Rate		
	Junk Bond	Government Bond
	Tenet Hlth Care 7-3/8% due 2013	US Treasury 3-7/8% due 2013
	Yearly Proceeds	
2005	\$73.75	\$38.75
2006	\$73.75	\$38.75
2007	\$73.75	\$38.75
⋮	⋮	⋮
2013	\$1,073.75	\$1,038.75
<b>Present Value @ 5% Discount</b>	<b>But US-Treasury is Worth More!</b>	
	<b>\$1,154</b>	<b>\$927</b>

# Ignoring Risk-Differentials: Sensitivity Analysis Makes it Worse

<b>Sensitivity Analysis for Bond Investments With a Single Arbitrary Discount</b>				
	<b>Junk Bond</b>		<b>Government Bond</b>	
	<b>Tenet Hlth Care 7-3/8% due 2013</b>		<b>US Treasury 3-7/8% due 2013</b>	
<b>Sensitivity Range</b>	1.0	0.9	1.0	0.9
	<b>Yearly Proceeds</b>		<b>Yearly Proceeds</b>	
2005	(\$1,000)	(\$1,000)	(\$1,000)	(\$1,000)
2006	\$74	\$74	\$39	\$39
2007	\$74	\$74	\$39	\$39
2008	\$74	\$74	\$39	\$39
2009	\$74	\$74	\$39	\$39
2010	\$74	\$74	\$39	\$39
2011	\$74	\$74	\$39	\$39
2012	\$74	\$74	\$39	\$39
2013	\$1,074	\$966	\$1,039	\$935
<b>Net Present Value @5% Discount</b>	<b>\$146</b>	<b>\$77</b>	<b>(\$69)</b>	<b>(\$136)</b>
<b>Percent Change</b>	<b>0%</b>	<b>-47.3%</b>	<b>0%</b>	<b>-96.7%</b>

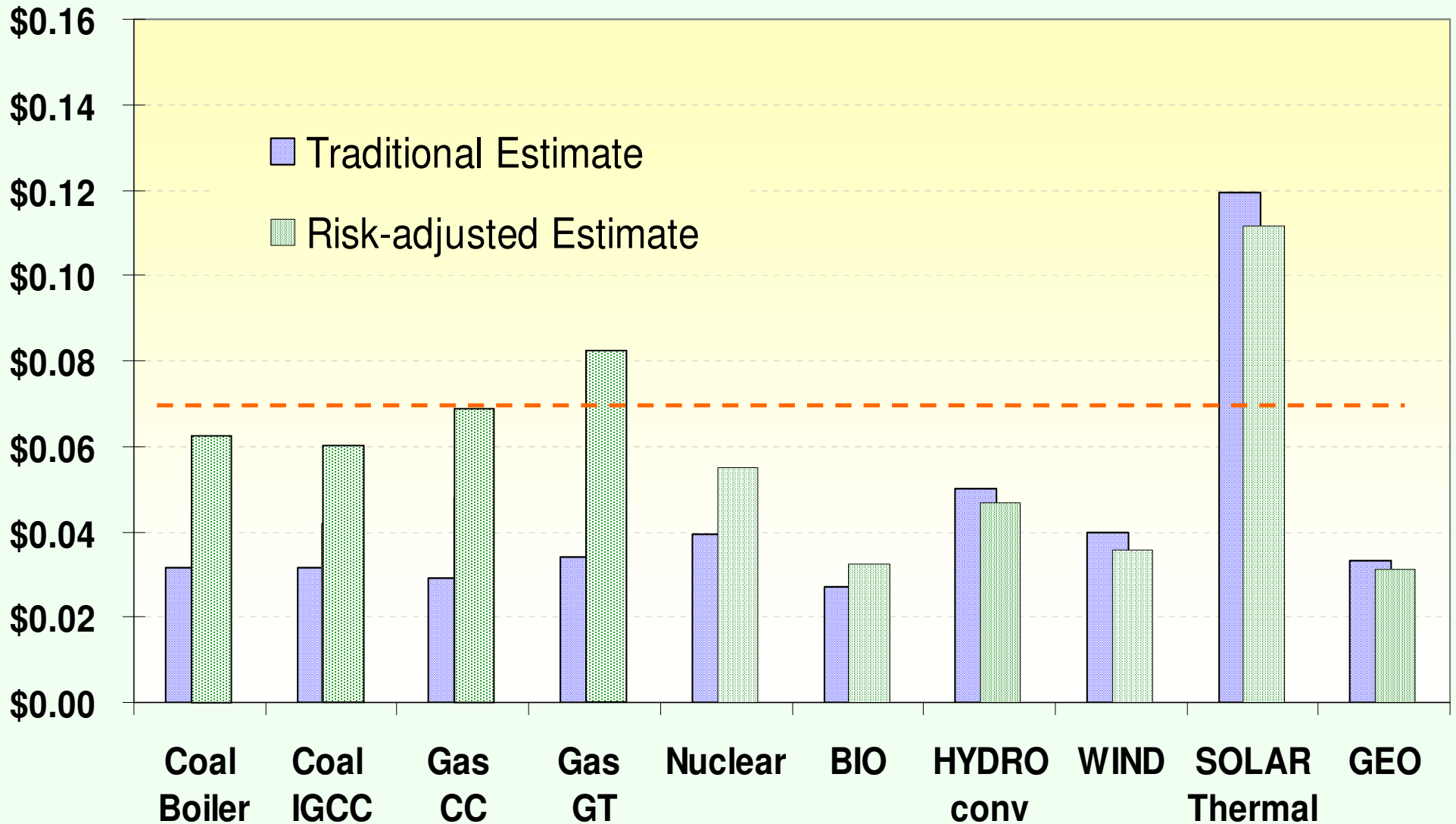
## How Standard Procedures Value Fixed & Variable Gas Prices

YEAR	Projected Annual Gas Outlays (Millions TND)	
	Projected Spot- Price Outlays	Fixed Price Riskless Contract (20% Premium)
2004	TND 1,000	TND 1,200
2005	1,200	1,440
2006	1,440	1,728
2007	1,728	2,074
2008	2,074	2,488
2009	2,488	2,986
2010	2,986	3,583
2011	3,583	4,300
2012	4,300	5,160
2013	5,160	6,192
2014	6,192	7,430

### Present Value of Gas Outlays

<b>WACC-</b>	<i>7.0%</i>	<i>7.0%</i>
<b>Based:</b>	<b>TND 19,461</b>	<b>TND 23,354</b>
<b>Market-</b>	<i>0.50%</i>	<i>4.0%</i>
<b>Based:</b>	<b>TND 30,941</b>	<b>TND 28,698</b>

# Traditional vs. Risk-Adjusted Levelized Cost-of-Electricity Estimates Historic Fossil Price Risk



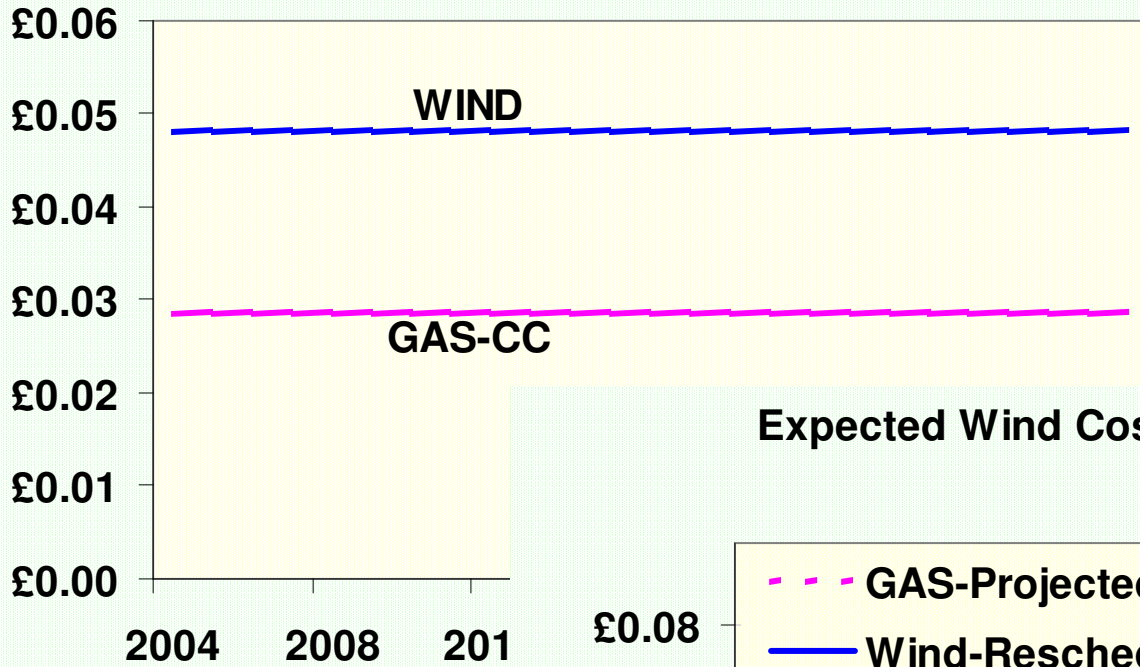
# What is *Levelized Cost* anyhow?

## What does it measure?

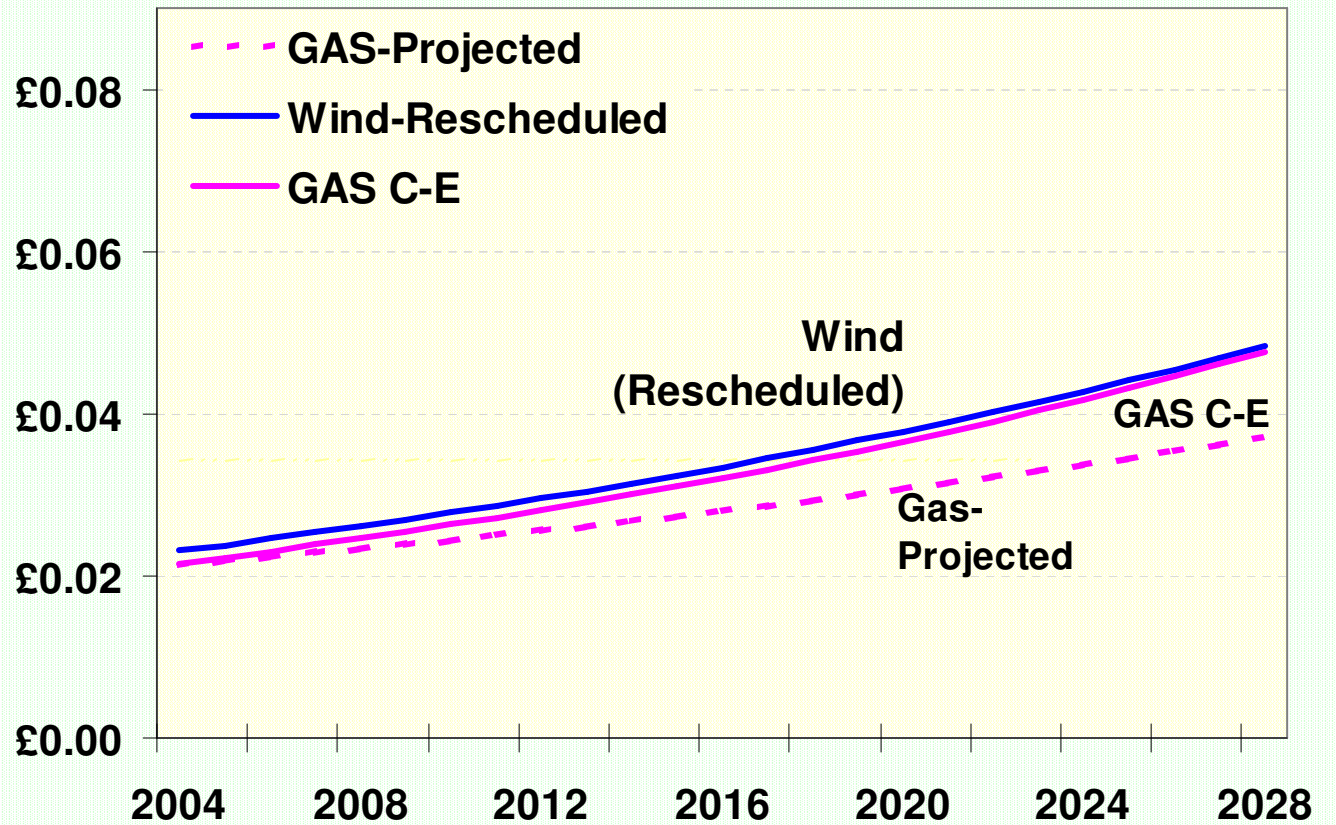
- **An *Imaginary Construct***
- **Cannot be compared to observed market prices**
- **Biases against capital-intensive alternatives especially with inflation**
- **Represents a *Time-Weighted-Average* of projected annual costs**



# DTI-UK Nominal Levelized kWh Costs

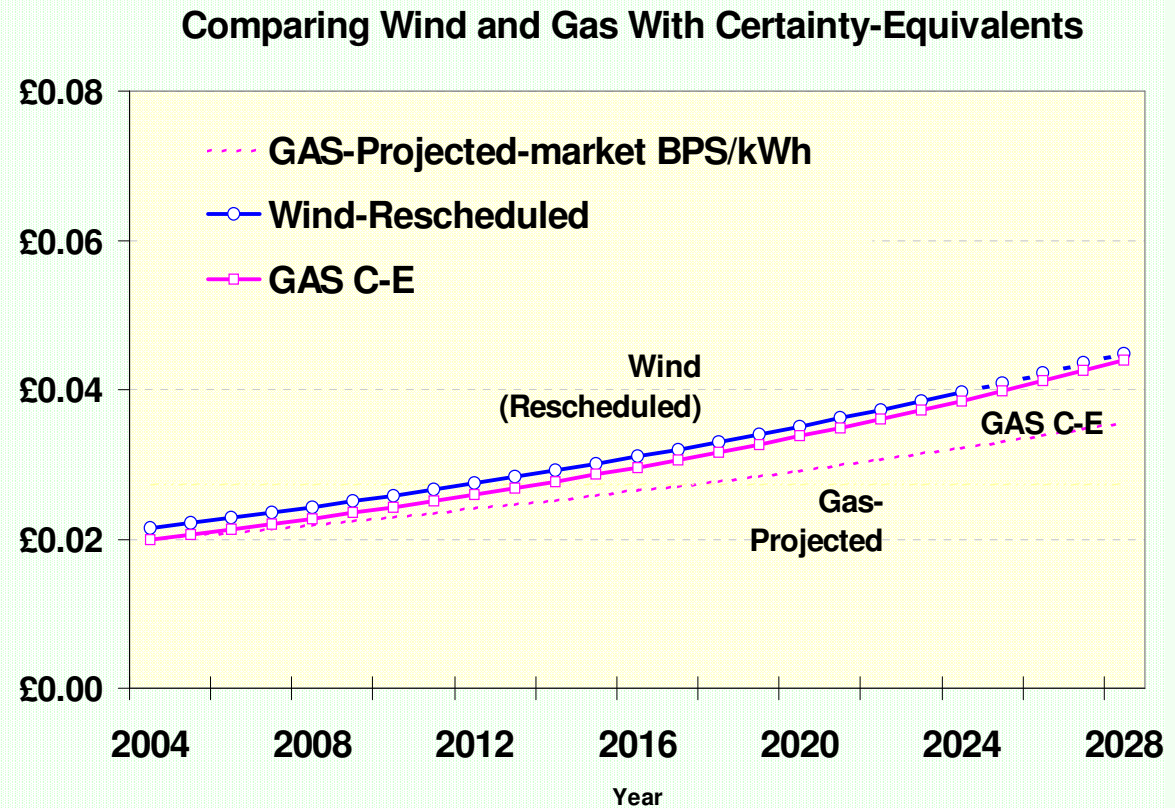


## Expected Wind Costs Compared to Gas Certainty-Equivalent



# Renewables Can Change the Legacy We Leave for Future Generations

- Fossil usage saddles future cohorts with rising fuel & environmental costs
- Back-loaded capital recovery for wind/PV may be a no-regrets means of hedging climate change risk



Should We Alter Our Compact With Future Generations?

**Portfolio Effect:  
The Only Free Lunch in  
Economics!**

**Astute Asset Combinations Reduce  
Cost at any Given Level of Risk**

# Portfolio-Theory: Renewables Will Not Raise Overall Cost

- A Generating Alternative's "Stand Alone" Cost Not Very Meaningful
- *Standard Portfolio Theory Predicts:*  
Adding Fixed-Cost Wind, Solar, etc. Generating Mix *Reduces* Overall Generating Cost at any Level of Risk..... Even if *stand-alone* costs are *higher*

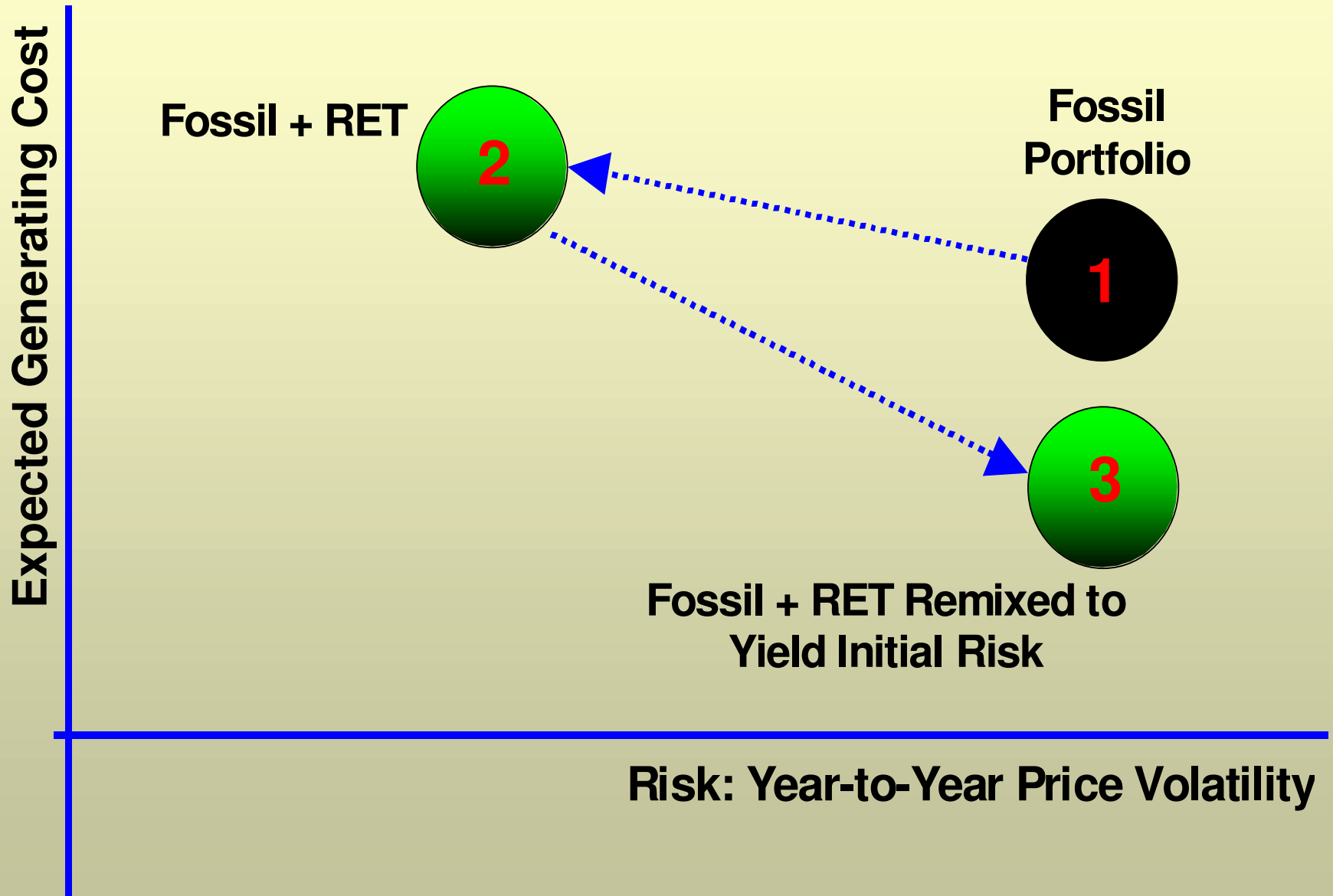


**Enhancing Energy Security  
Does Not Have to Raise Cost!**

# **Nobel Laureate Harry Markowitz Taught the World About Portfolios**

- **Portfolio of risky equity stocks  
expected yield = 10%**
- **Add risk-free government bonds  
with expected yield = 3%**
- **Resulting Overall Yield? ??**
- **Resulting yield will be  $>10\%$  at the same  
level of portfolio risk**

# RENEWABLE TECHNOLOGIES HELP THE GENERATING MIX RISK AND COST OF GENERATING PORTFOLIOS

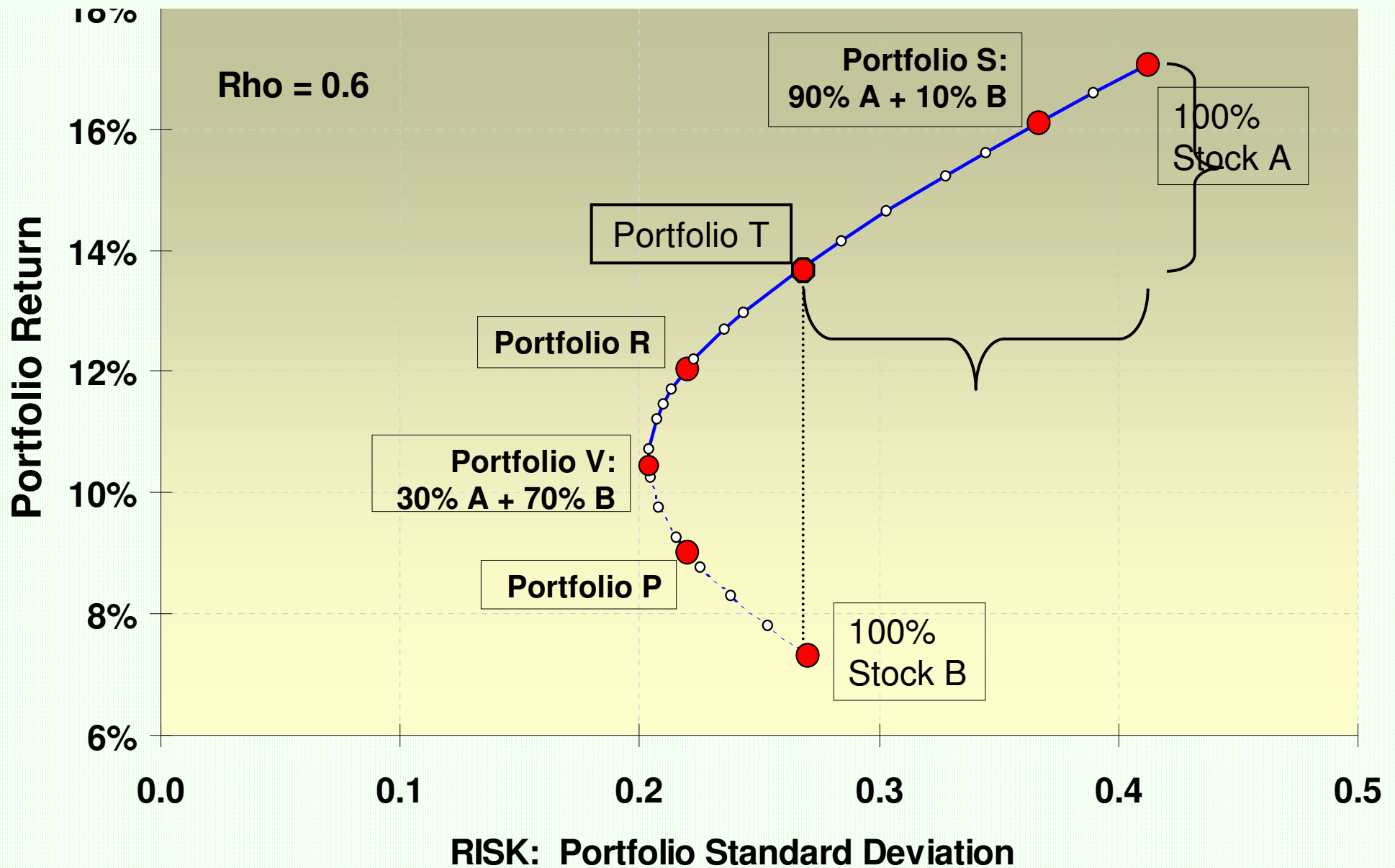


# **Portfolio Diversity and Security: REITs Provide Important but Poorly Recognized Energy Security Benefits**

- **Mitigate fossil price volatility - intuitive**
- **Provide Important *Counter-cyclical* Benefits:  
a form of “national insurance”**
  - (R. C. Lind & Nobel Laureate J. Kenneth Arrow, 1984)
- **Payoff occurs when economy is doing poorly**

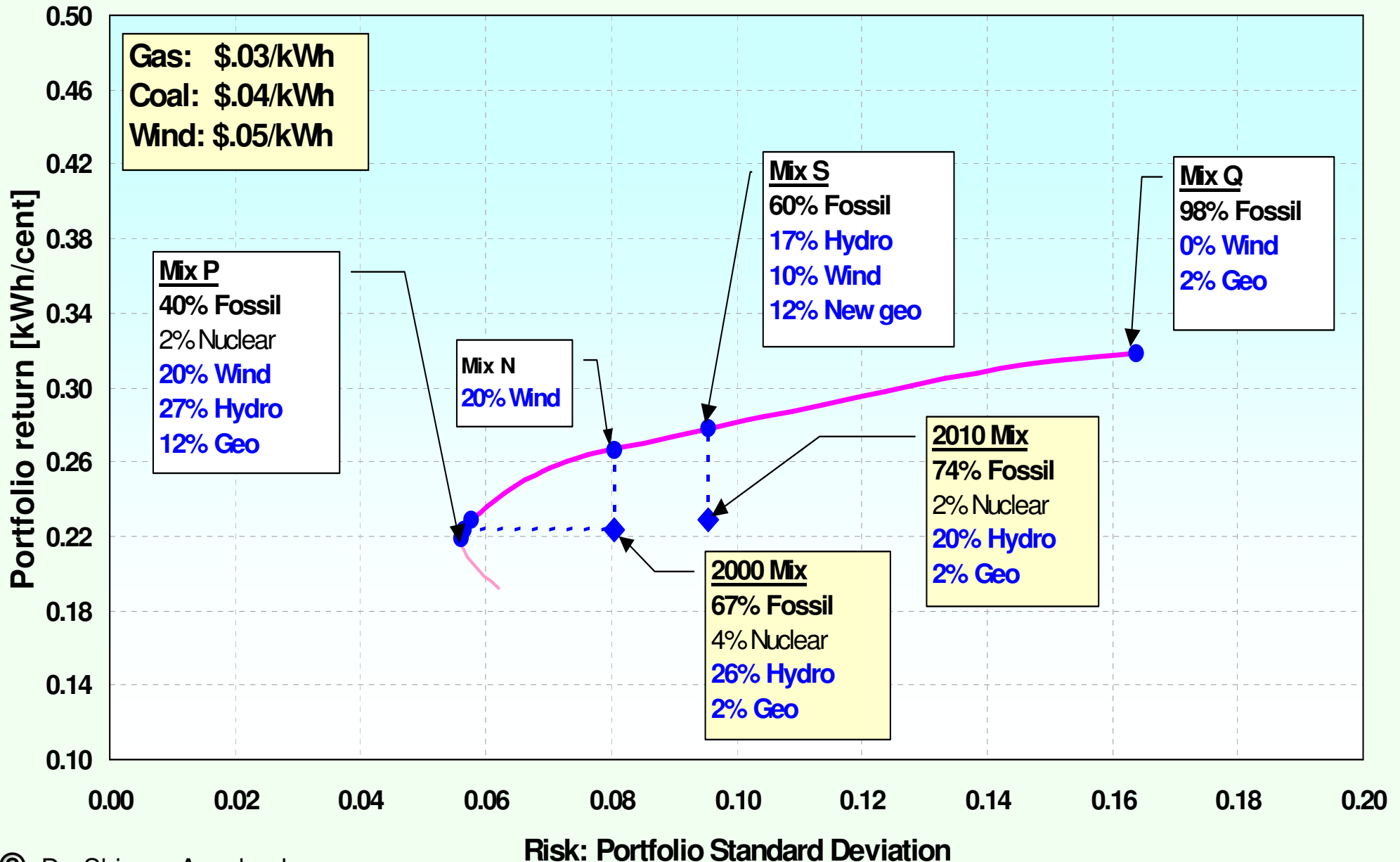
**Energy security is reduced when nations  
hold inefficient portfolios that are  
needlessly exposed to fossil risk**

# Risk and Return for A Portfolio of Risky Assets



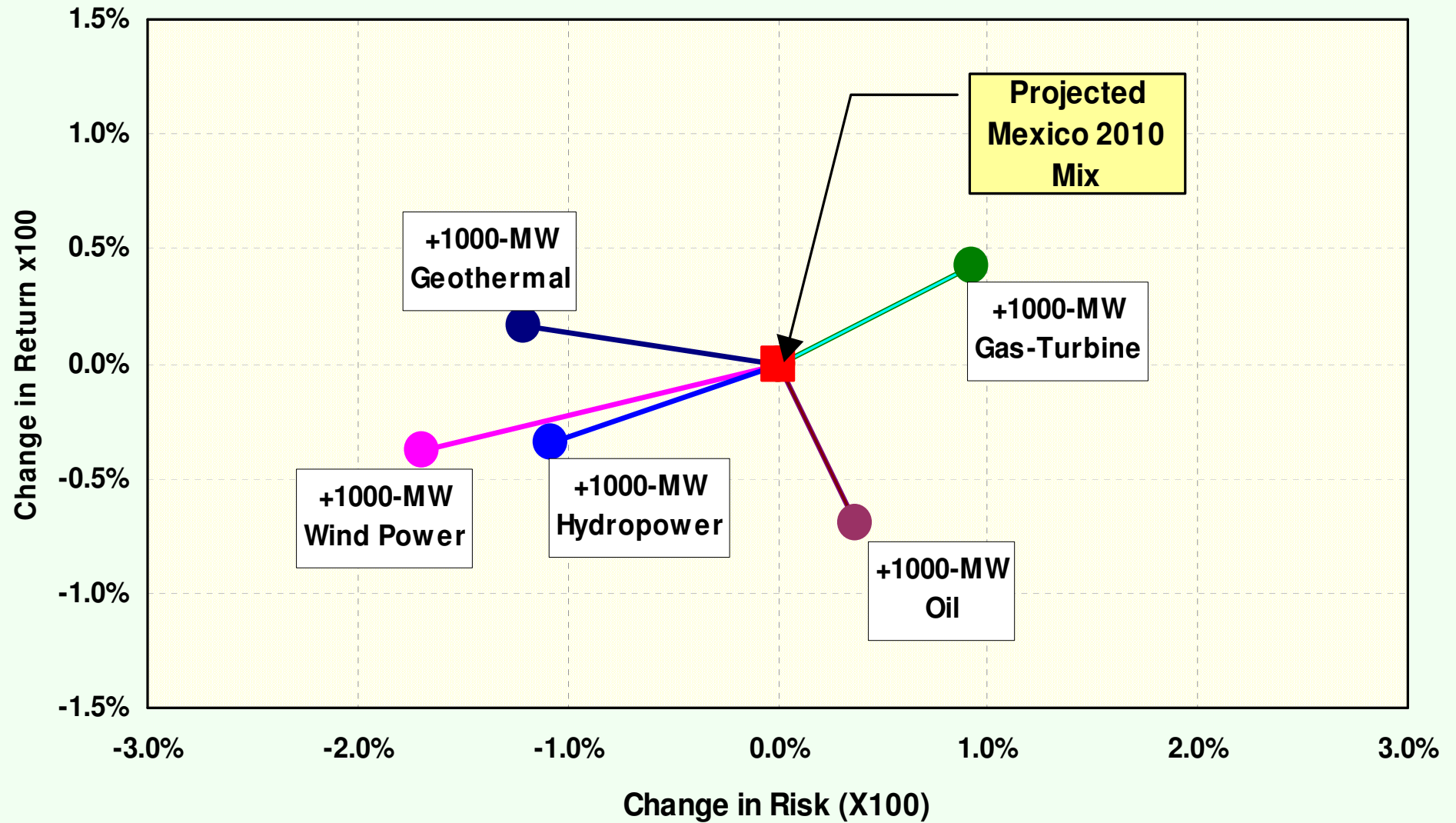
# Wind/RE Lowers Mexico Generating Cost

## Mexico Generating Portfolio Risk/Return

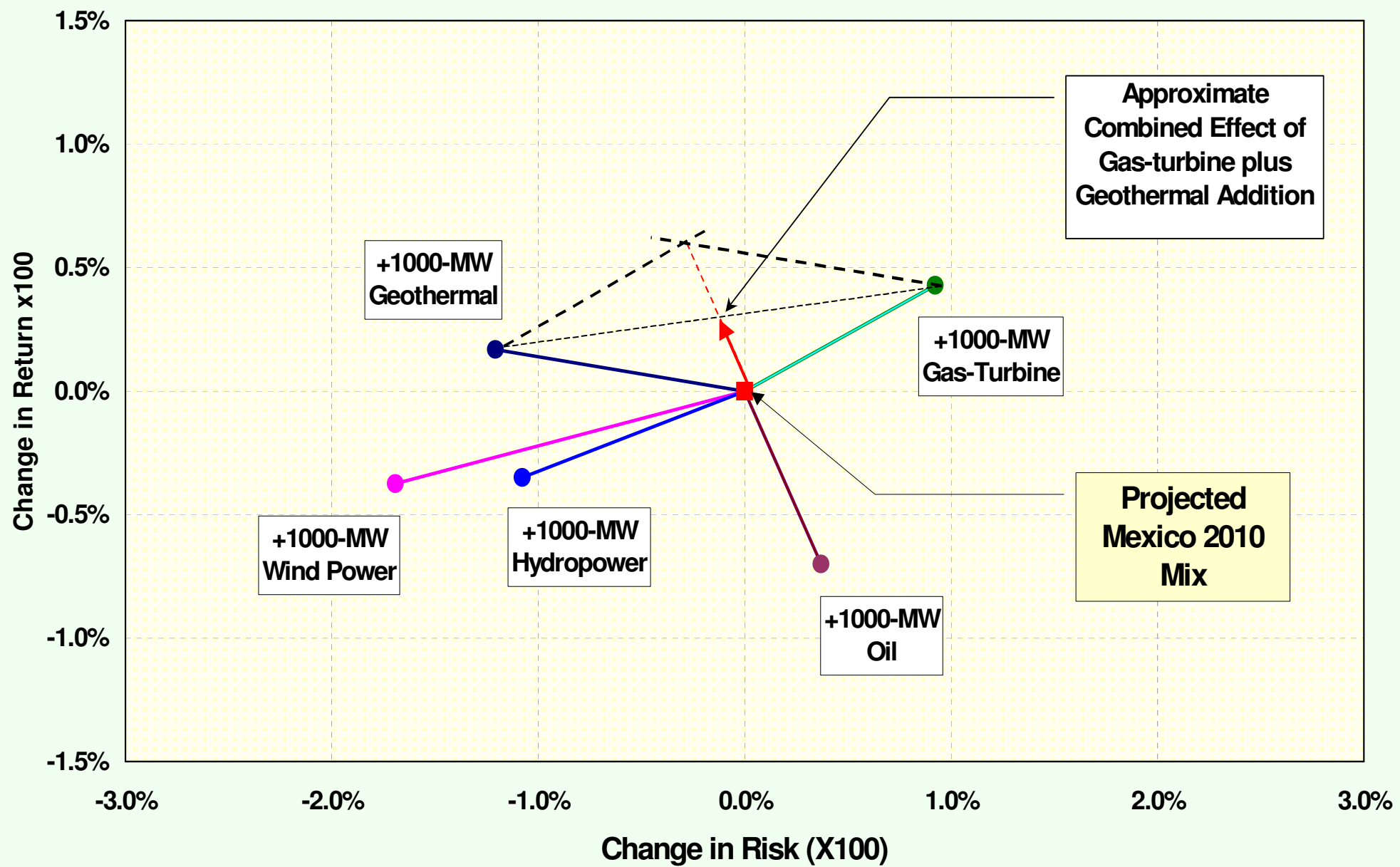


# One-Step Analysis for Planners

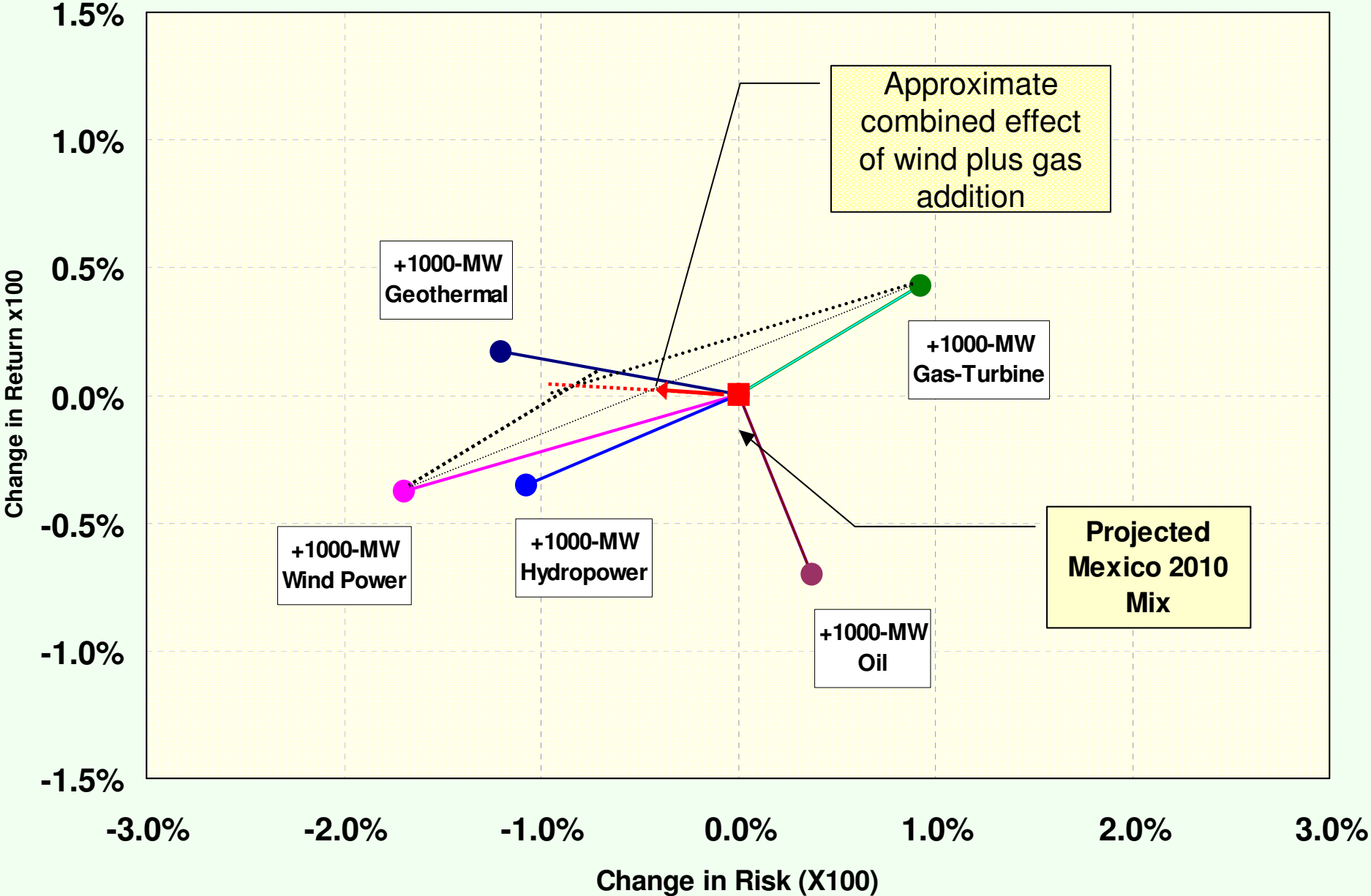
Mexico: Risk-Return Sensitivity of Projected Mexico 2010 Mix  
to 1000-MW Additions of Various Technologies



# Graphic One-Step Vector Diagram: Risk-Cost Addition for Multiple Small Project Additions



# Graphic One-Step Diagram: Risk-Cost Change for Wind-Gas Additions



# **Tunisia**

## **Portfolio Optimization:**

### **Electricity Generation and Solar Water Heating**

# **Tunisia Portfolio Optimization: Generating Mix + WH**

- **Portfolio optimization locates generating mixes with lowest-expected cost at every level of risk**
  - Risk is the year-to-year variability in technology generating costs
- **STEG projected target generating mixes serve as a benchmark or starting point**
- **The optimal results suggest that compared to the target mix:**
  - There exist generating mixes with larger renewables shares, with the same or lower cost and risk

# Portfolio Optimization

- **Locates lowest cost portfolio at every level of risk**
- **These optimal (*efficient*) portfolios lie on *Efficient Frontier* (EF)**
- **Portfolio cost = weighted average cost of generating mix components**
- **For a two-technology generating mix:**
  - Expected portfolio cost is the weighted average of individual expected costs of the two technologies:  
**Expected Portfolio Cost =  $E(C_p) = X_1 \cdot E(C_1) + X_2 \cdot E(C_2)$**
  - Where:  $X_1$ ,  $X_2$  are the shares of the two technologies and  $E(C_1)$ ,  $E(C_2)$  are expected generating costs for those technologies

# Portfolio Optimization (Continued)

- **Expected Portfolio risk = weighted average of individual technology cost variances, tempered by their co-variances:**

$$\text{Expected Portfolio Risk} = \sigma_p = \sqrt{X_1^2 \sigma_1^2 + X_2^2 \sigma_2^2 + 2X_1 X_2 \rho_{12} \sigma_1 \sigma_2}$$

- $\sigma_1, \sigma_2$  = Std. Dev. of annual costs of technologies 1 and 2
- $\rho_{12}$  = their correlation coefficient

- **Correlation is a measure of diversity. Lower correlation among portfolio cost components increases diversity, which reduces portfolio risk and enables cost reductions**
- **Adding a fixed-cost technology to a risky generating mix *lowers* expected portfolio cost at any level of risk**
  - Pure fixed-cost technology has  $\sigma_i = 0$ . Yields a straight-line *EF* and lowers portfolio risk since two terms in the equation reduce to zero

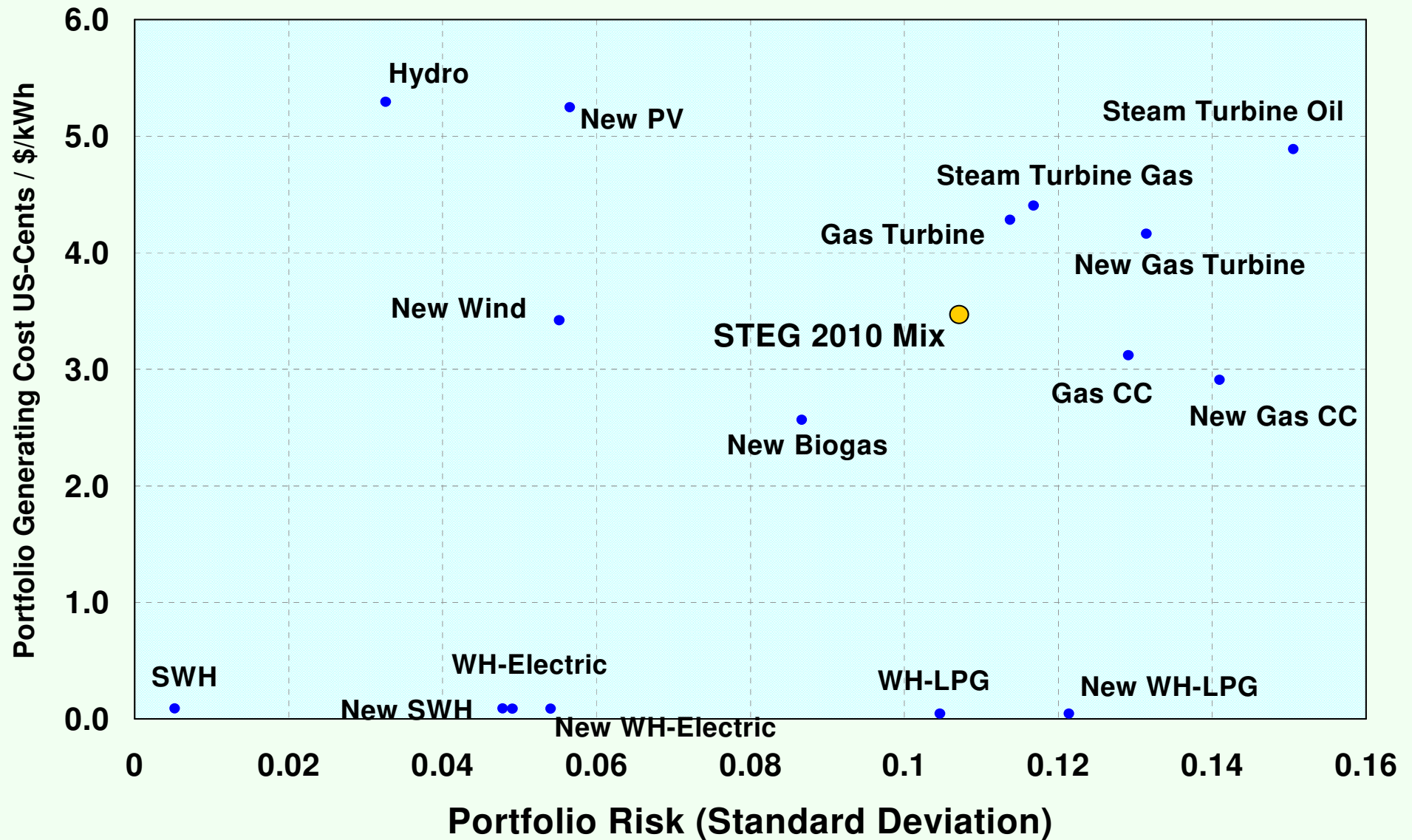
## Tunisia 2010 Technology Performance Data

Technology	Cost (US-Cents/kWh)				Capacity (MW)	Energy (GWH)
	Initial Outlay	Fuel	Fix OM	Var OM		
Gas-CC New	0.855	1.70	0.150	0.201	500	3250
Gas-CC	0.986	1.77	0.150	0.214	836	5434
Steam Turb-Oil	1.600	2.74	0.240	0.310	226	1250
Steam Turb-Gas	1.600	2.25	0.240	0.310	734	4054
Gas Turbine - New	1.600	2.01	0.240	0.310	600	1800
Gas Turbine	1.600	2.13	0.240	0.310	738	1742
Hydro	4.432	-0-	0.863	-0-	21	67
Wind - New	2.879	-0-	0.543	-0-	310	775
Photovoltaic - New	4.340	-0-	0.909	-0-	4	6
Biogas - New	2.016	0.17	0.380	-0-	30	180
SWH	0.085	-0-	0.005	-0-	1	26
WH-LPG	0.018	0.02	0.008	-0-	1	1118
WH-Electric	0.019	0.06	0.008	-0-	1	156
SWH - New	0.085	-0-	0.005	-0-	0	0
WH-LPG - New	0.018	0.02	0.008	-0-	0	0
WH-Electric - New	0.019	0.06	0.008	-0-	0	0
					4,001	19,858

# Understanding Risk

- **Portfolio optimization locates generating mixes with minimum expected cost and risk**
- **For each technology, risk is the year-to-year variability (standard deviation) of the generating cost inputs: fuel, O&M and construction period risk**
  - Fossil fuel standard deviations are estimated from historic data
  - Standard deviations for capital and O&M are estimated using proxy procedures (Awerbuch and Berger, IEA, 2003)
- **Construction period risk for embedded technologies is 0.0**
- **‘New’ technologies are therefore riskier than embedded ones - e.g. new gas is riskier than ‘old’ gas**

# Tunisia - 2010 Projected Technology Cost-Risk



## Assumed Risk (Standard Deviation) for Technology Cost Streams

Technology	Construction Period */	Fuel	Variable OM	Fix OM
Gas CC	0.15	0.23	0.2	0.087
Steam Turbine Oil	0.00	0.27	0.2	0.087
Steam Turbine Gas	0.00	0.23	0.2	0.087
Gas Turbine	0.18	0.23	0.2	0.087
Hydro	0.00	0	0.2	0.087
Wind	0.05	0	0.2	0.087
Photovoltaic	0.05	0	0.2	0.087
Biogas	0.10	0	0.2	0.087
SWH	0.05	0	0.2	0.087
WH / LPG	0.15	0.24	0.2	0.087
WH / Electric	0.10	0.07	0.2	0.087

\*/ Construction Period Risk for Existing Technologies = 0

## Estimated Tunisian Fuel Correlation Factors and Standard Deviations

Fuel	Gas	Oil	Renewable	LPG	Electricity	Standard Deviation of Annual Fuel Outlays
Gas	1	0.5745	0	0.46	<u>0.7</u>	0.2262
Oil	0.5745	1	0	<u>0.8</u>	0.3	0.2676
Renewable	0	0	1	0	0	0
LPG	0.46	<u>0.8</u>	0	1	0.24	0.24084
Electricity	<u>0.7</u>	0.3	0	0.24	1	0.07

### Assumed Correlations:

LPG-Oil = 0.8

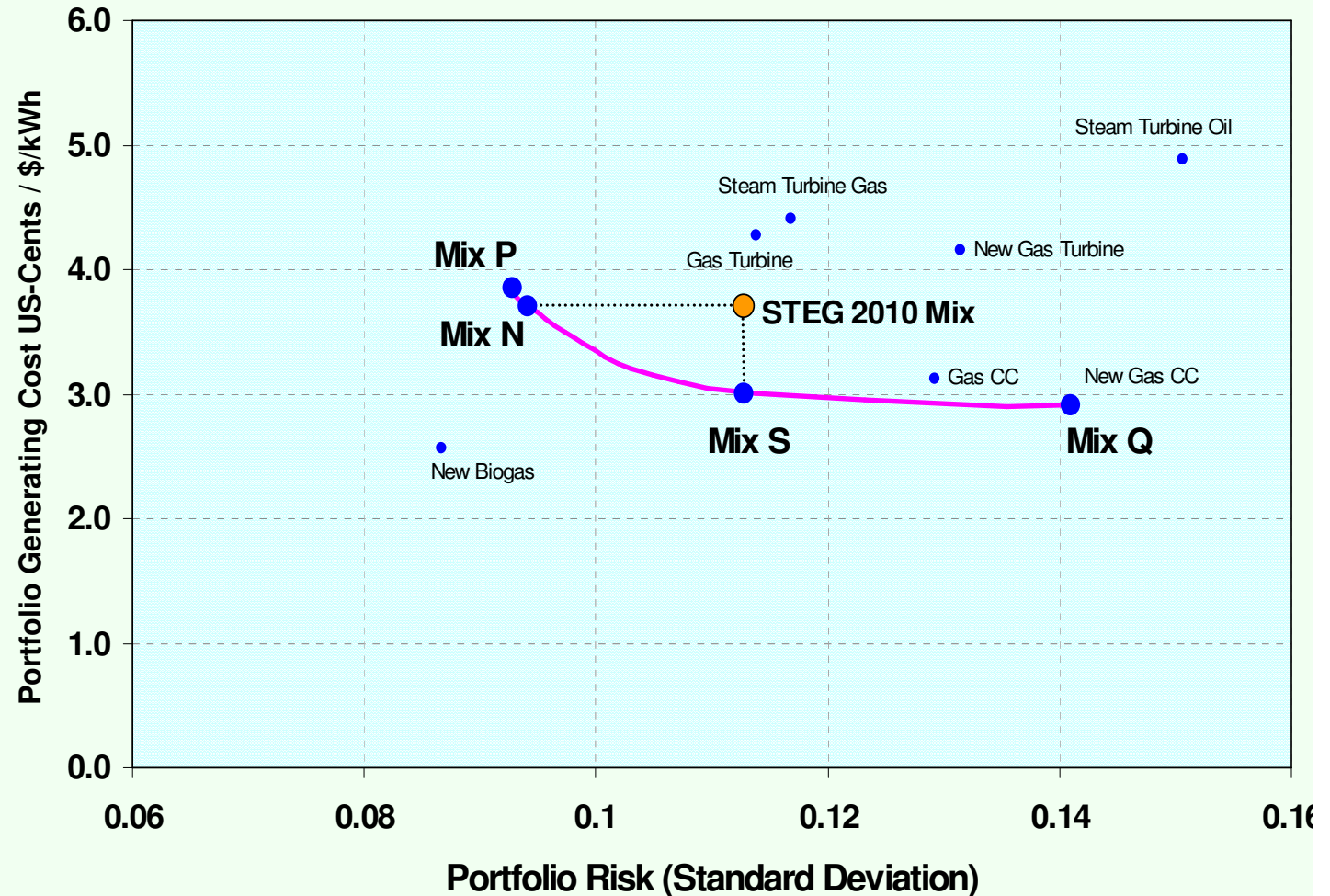
Electric-Gas = 0.7

## Non-Fuel Correlation Factors

		Technology A		
		Construction Period	Variable OM	Fixed OM
Technology B	Construction Period	0.7	0.1	0.1
	Variable OM	0.1	0.7	0.1
	Fixed OM	0.1	0.1	0.7

# Portfolio Optimization: Interpreting the Results

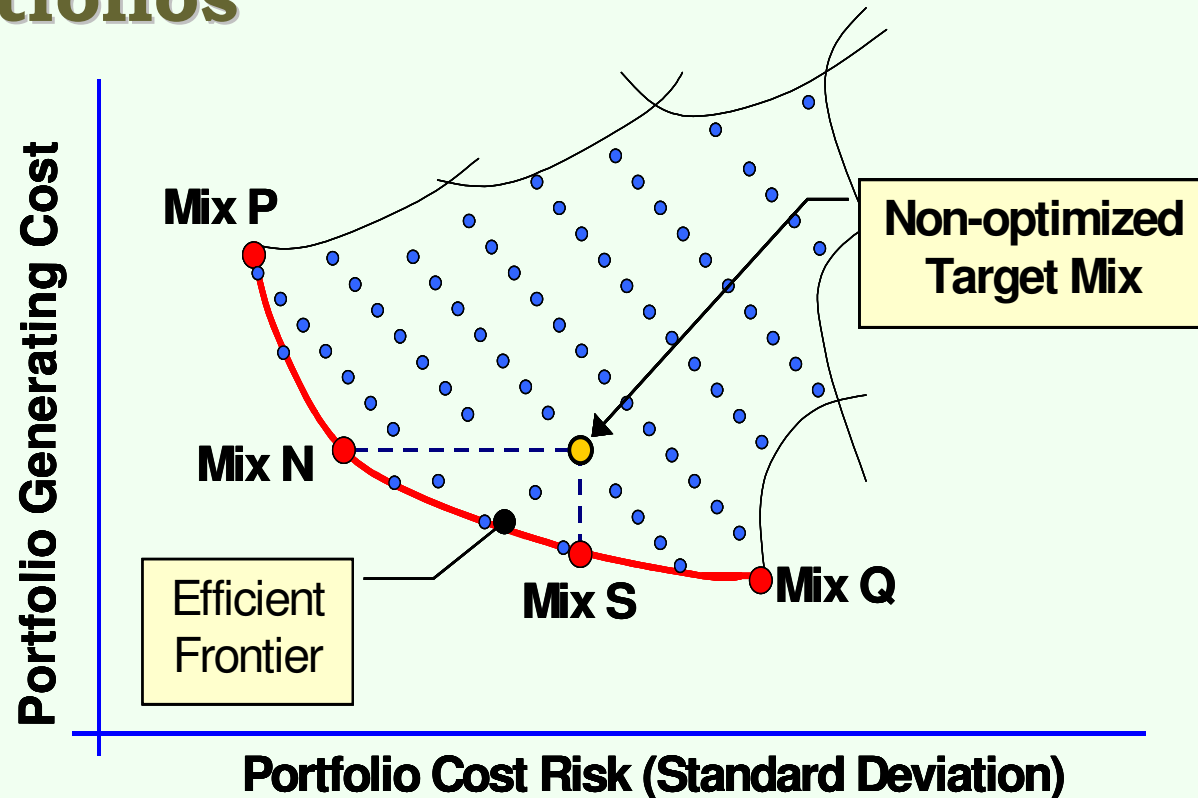
- Charts Show Generating Portfolio Cost and Risk
- *Efficient Frontier* shows all optimal mixes
- Along the EF, cost reductions attained only at higher risk
- Infinite solutions exist
- We locate the following *typical* mixes:



- *Mix P*: Lowest-risk/highest-cost feasible optimal mix; usually most diverse
- *Mix N*: Equal-cost mix: *Minimum-risk* mix with cost = Target-Mix cost
- *Mix S*: Equal-risk mix: *Minimum-cost* mix with risk = Target-Mix risk
- *Mix Q*: Lowest-cost/highest-risk feasible optimal mix; usually least diverse

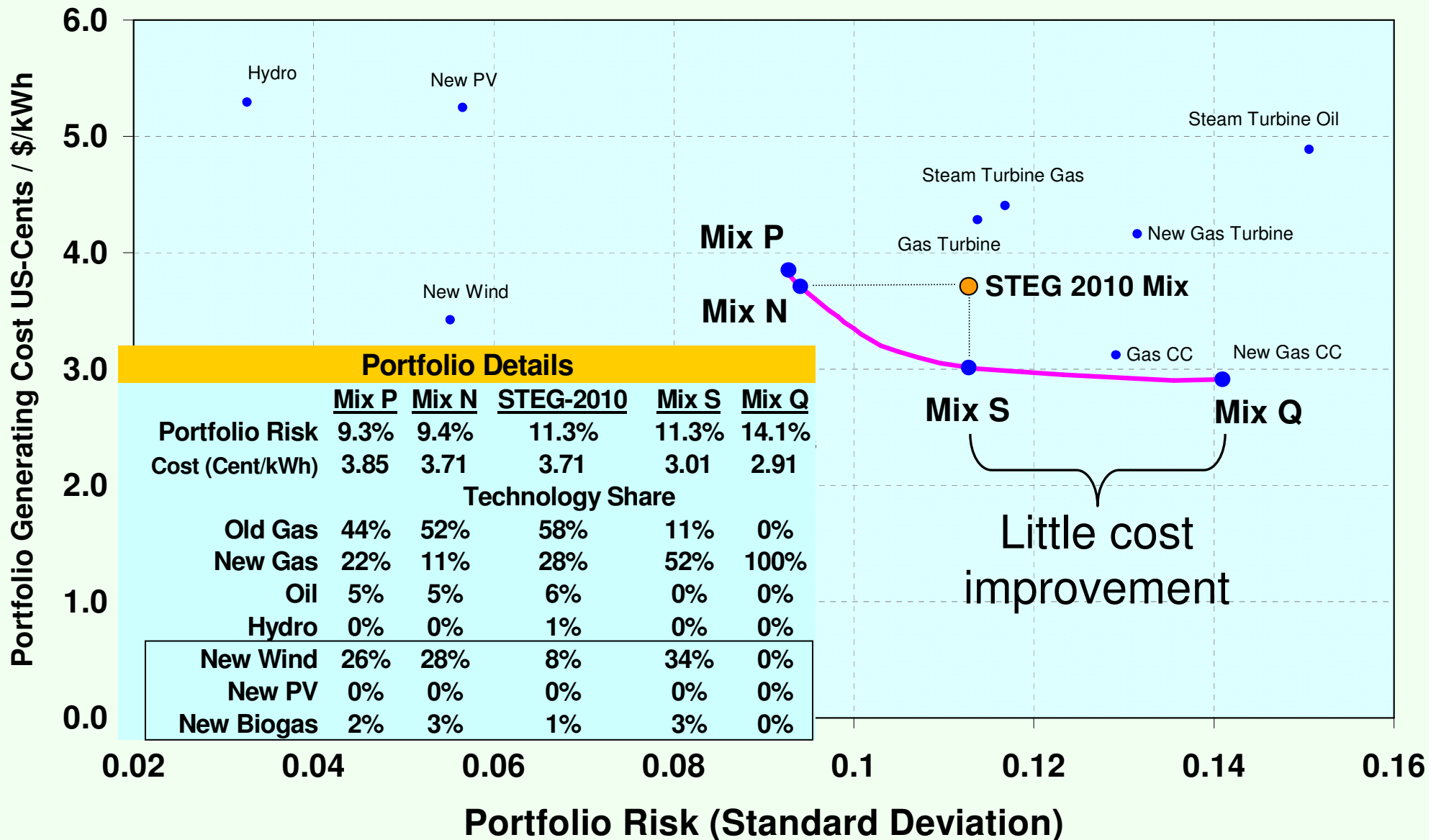
# Feasible Region and Efficient Frontier For Multi-Asset Portfolios

- Feasible region contains infinite number of mixes
- Radically different mixes can have very similar cost-risk
- Internal mixes are inefficient



- EF is the locus of all optimal mixes
  - Cannot reduce cost further without accepting more risk
  - There are no feasible mixes below the EF
- Infinite mixes along the EF. We show only P,N,S,Q

# Tunisia: 2010 Portfolio Optimization - Electricity Only -



# 2010 Electricity Portfolio Optimization Results

## ● STEG-2010 mix

- Generating Cost: 3.71 us-¢/kWh
- Wind+Bio+PV: 9%

## ● Optimization reveals other alternatives:

### 1. Mix P:

- Cost: 3.85 us-¢/kWh
- Wind+Bio+PV: 28%

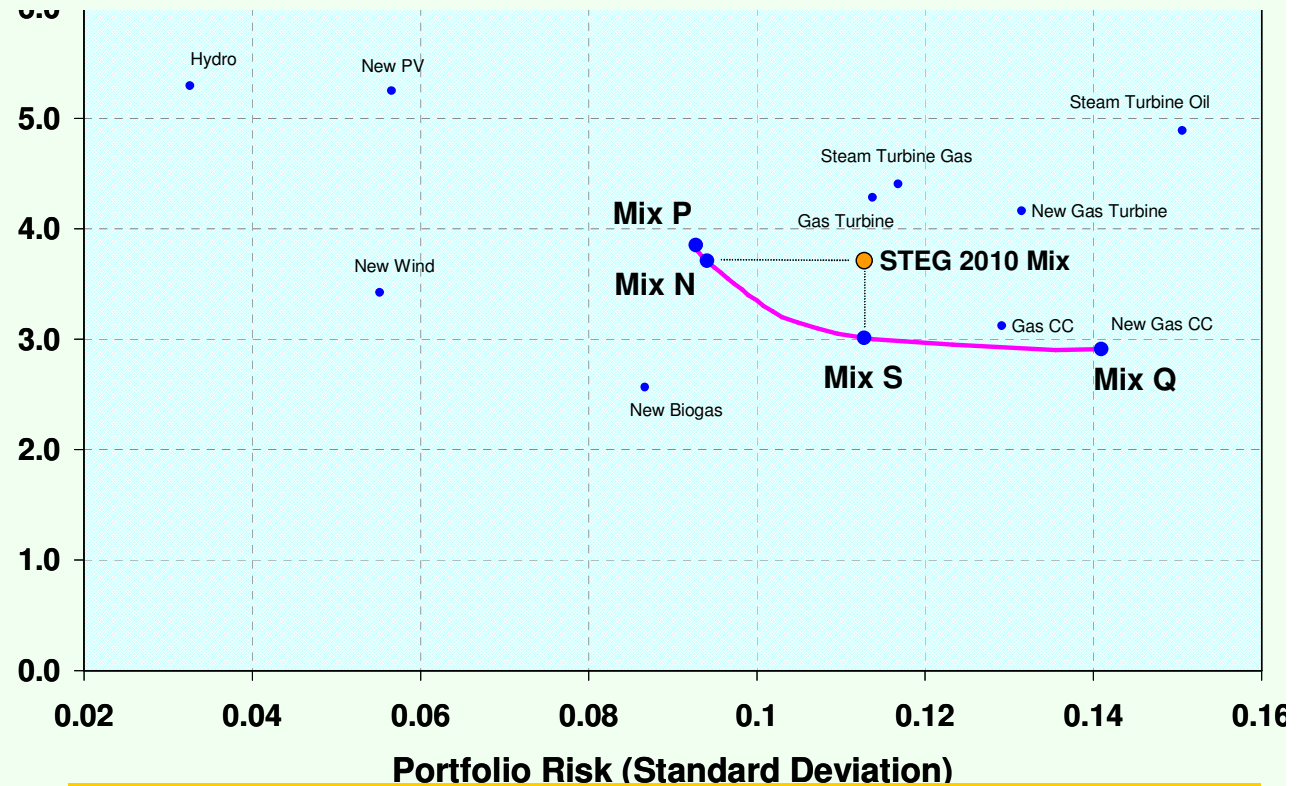
### 2. Mix N:

- Cost: 3.71 us-¢/kWh
- Wind+Bio+PV: 31%

### 3. Mix S:

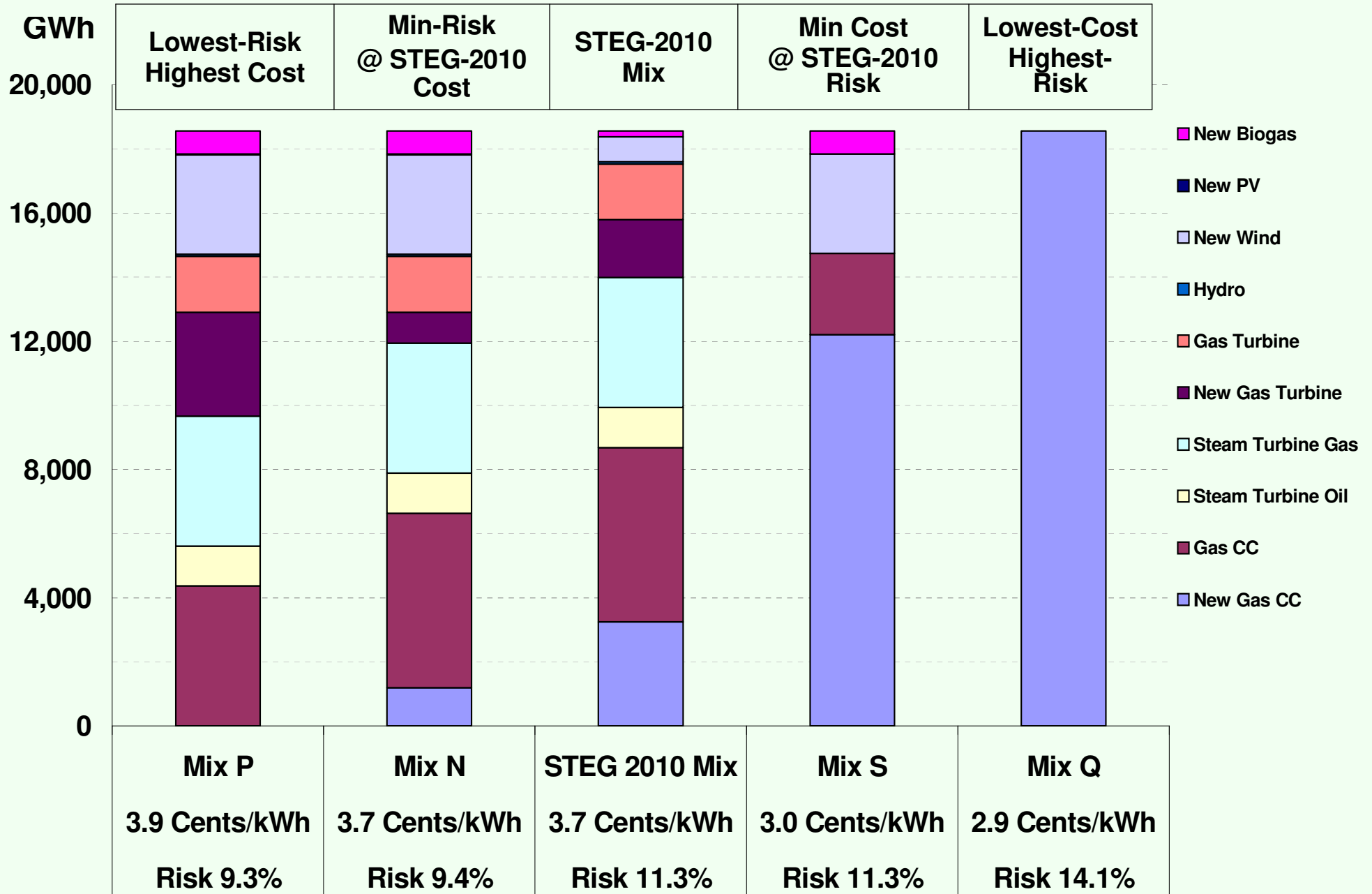
- Costs: 3.01 ¢/kWh
- Wind+Bio+PV: 37%

### 4. Infinite other solutions exist

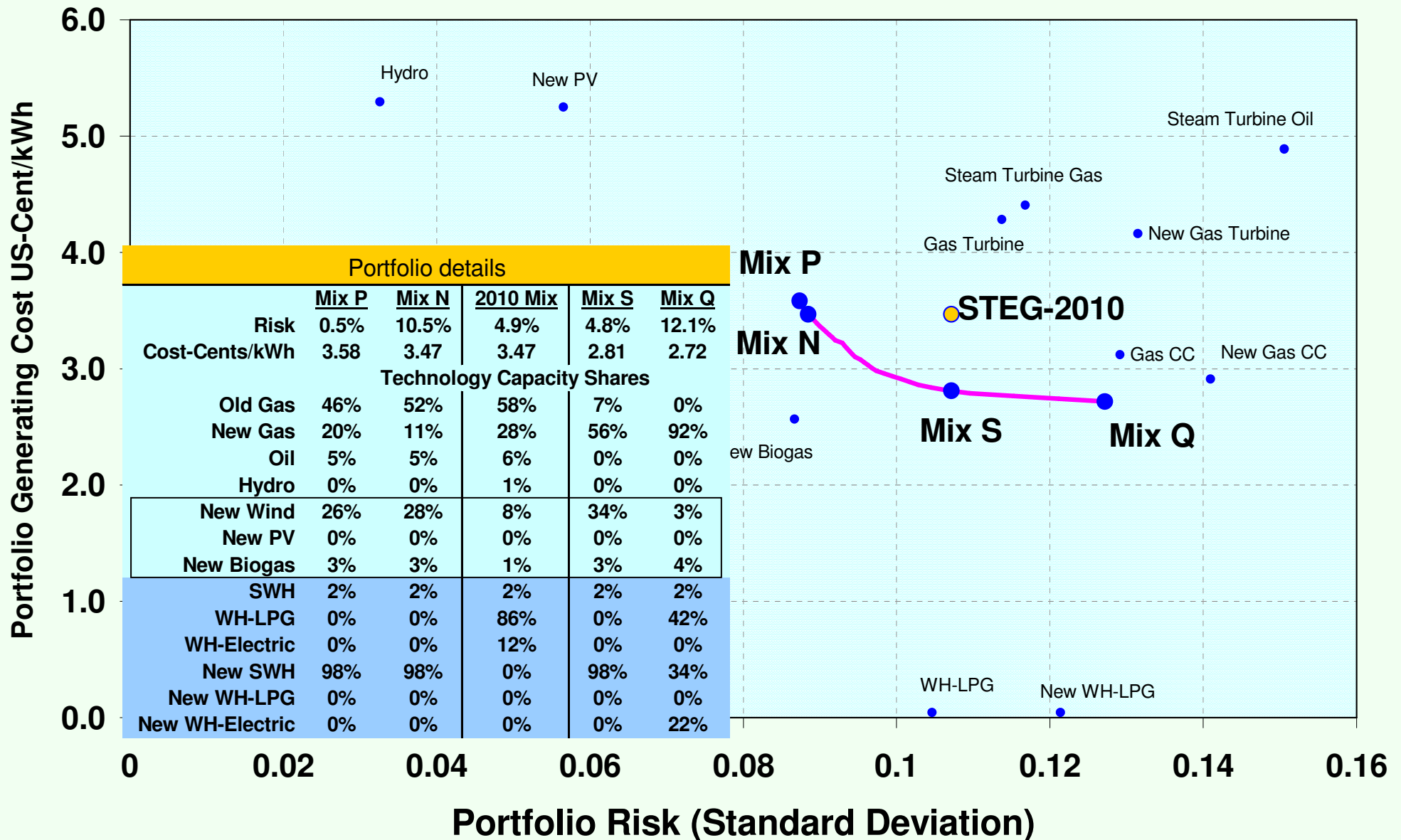


Portfolio Details					
	Mix P	Mix N	STEG-2010	Mix S	Mix Q
Portfolio Risk	9.3%	9.4%	11.3%	11.3%	14.1%
Cost (Cent/kWh)	3.85	3.71	3.71	3.01	2.91
Technology Share					
Old Gas	44%	52%	58%	11%	0%
New Gas	22%	11%	28%	52%	100%
Oil	5%	5%	6%	0%	0%
Hydro	0%	0%	1%	0%	0%
New Wind	26%	28%	8%	34%	0%
New PV	0%	0%	0%	0%	0%
New Biogas	2%	3%	1%	3%	0%

# Tunisia (Elec): Typical Mixes and STEG Target Mix



# Tunisia: 2010 Portfolio Optimization - Electricity and Water Heating -



# Tunisia 2010 E+WH Portfolio Optimization

## • STEG-2010 mix

- Generating Cost: 3.47 us-¢/kWh
- Wind+Bio+PV: 9%

## • Optimization reveals other alternatives:

### 1. Mix P:

- Cost: 3.58 us-¢/kWh
- Wind+Bio+PV: 29%
- SWH+NewSWH: 100%

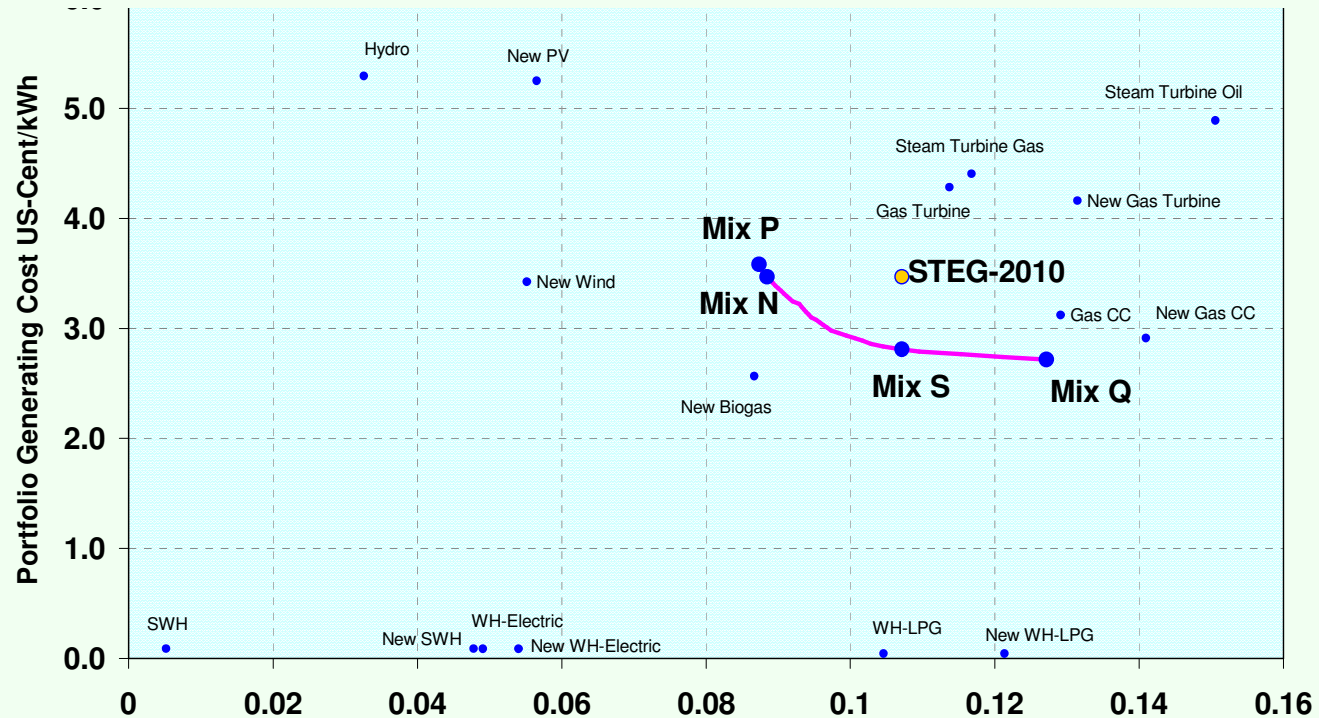
### 2. Mix N:

- Cost: 3.47 us-¢/kWh
- Wind+Bio+PV: 31%
- SWH+New-SWH: 100%

### 3. Mix S:

- Costs: 2.81 ¢/kWh
- Wind+Bio+PV: 37%
- SWH+New-SWH: 100%

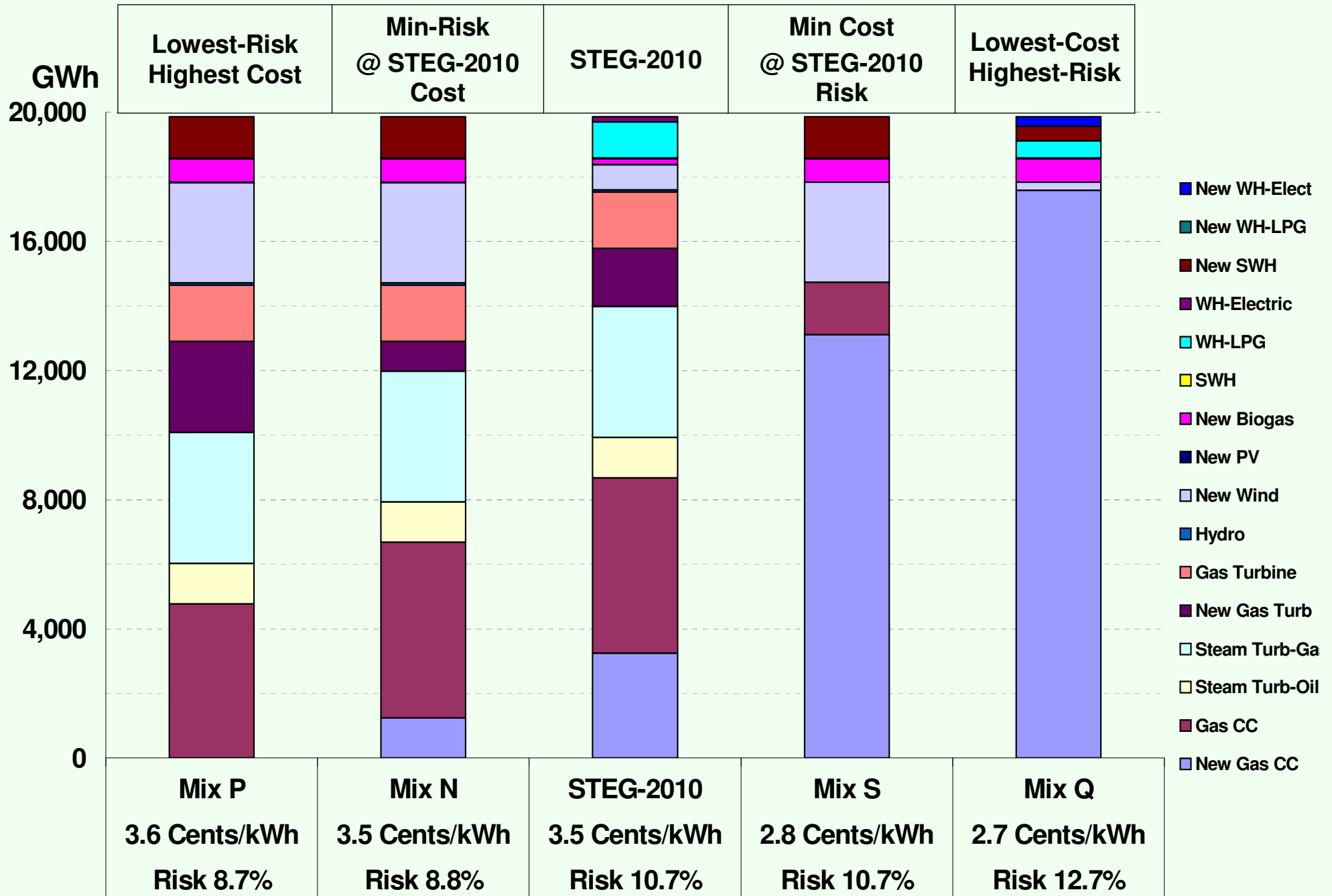
### 4. Infinite other solutions exist



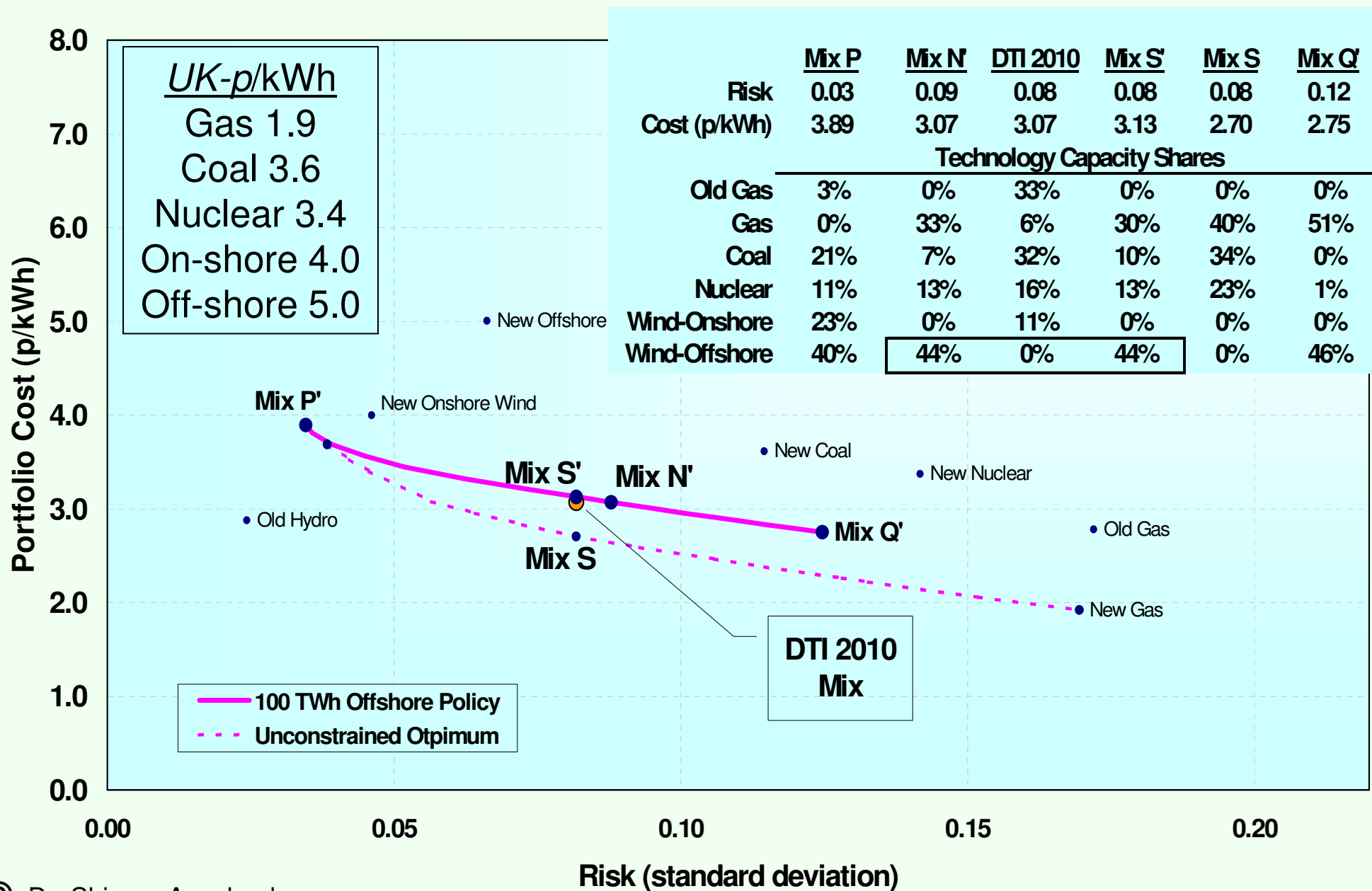
Portfolio details

	Mix P	Mix N	2010 Mix	Mix S	Mix Q
Risk	0.5%	10.5%	4.9%	4.8%	12.1%
Cost-Cents/kWh	3.58	3.47	3.47	2.81	2.72
Technology Capacity Shares					
Old Gas	46%	52%	58%	7%	0%
New Gas	20%	11%	28%	56%	92%
Oil	5%	5%	6%	0%	0%
Hydro	0%	0%	1%	0%	0%
New Wind	26%	28%	8%	34%	3%
New PV	0%	0%	0%	0%	0%
New Biogas	3%	3%	1%	3%	4%
SWH	2%	2%	2%	2%	2%
WH-LPG	0%	0%	86%	0%	42%
WH-Electric	0%	0%	12%	0%	0%
New SWH	98%	98%	0%	98%	34%
New WH-LPG	0%	0%	0%	0%	0%
New WH-Electric	0%	0%	0%	0%	22%

# Tunisia: E+WH - Typical and Target Mixes

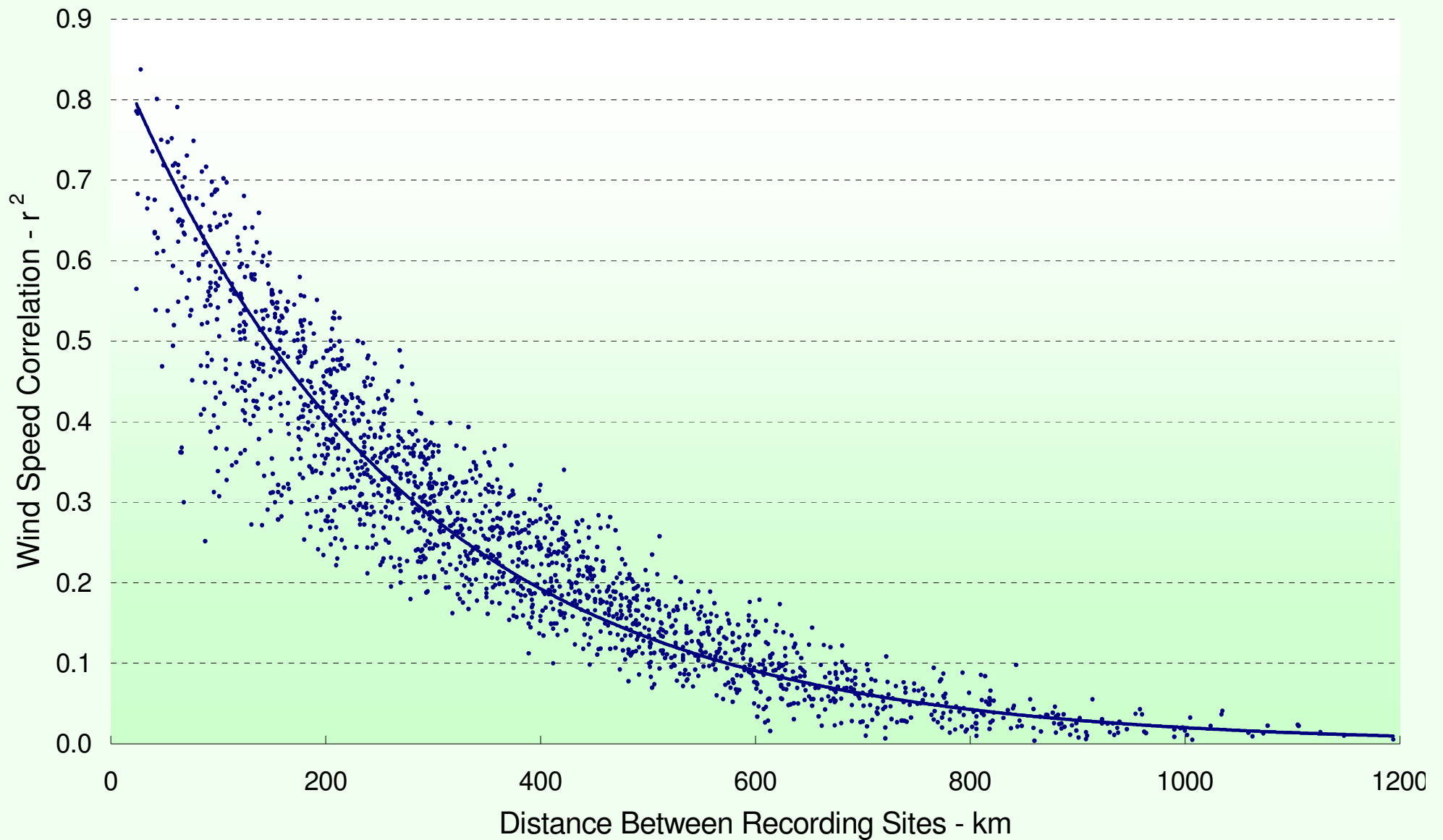


# 2010 Effect Of UK Accelerated Wind Deployment Policy - Alternate Wind Costs



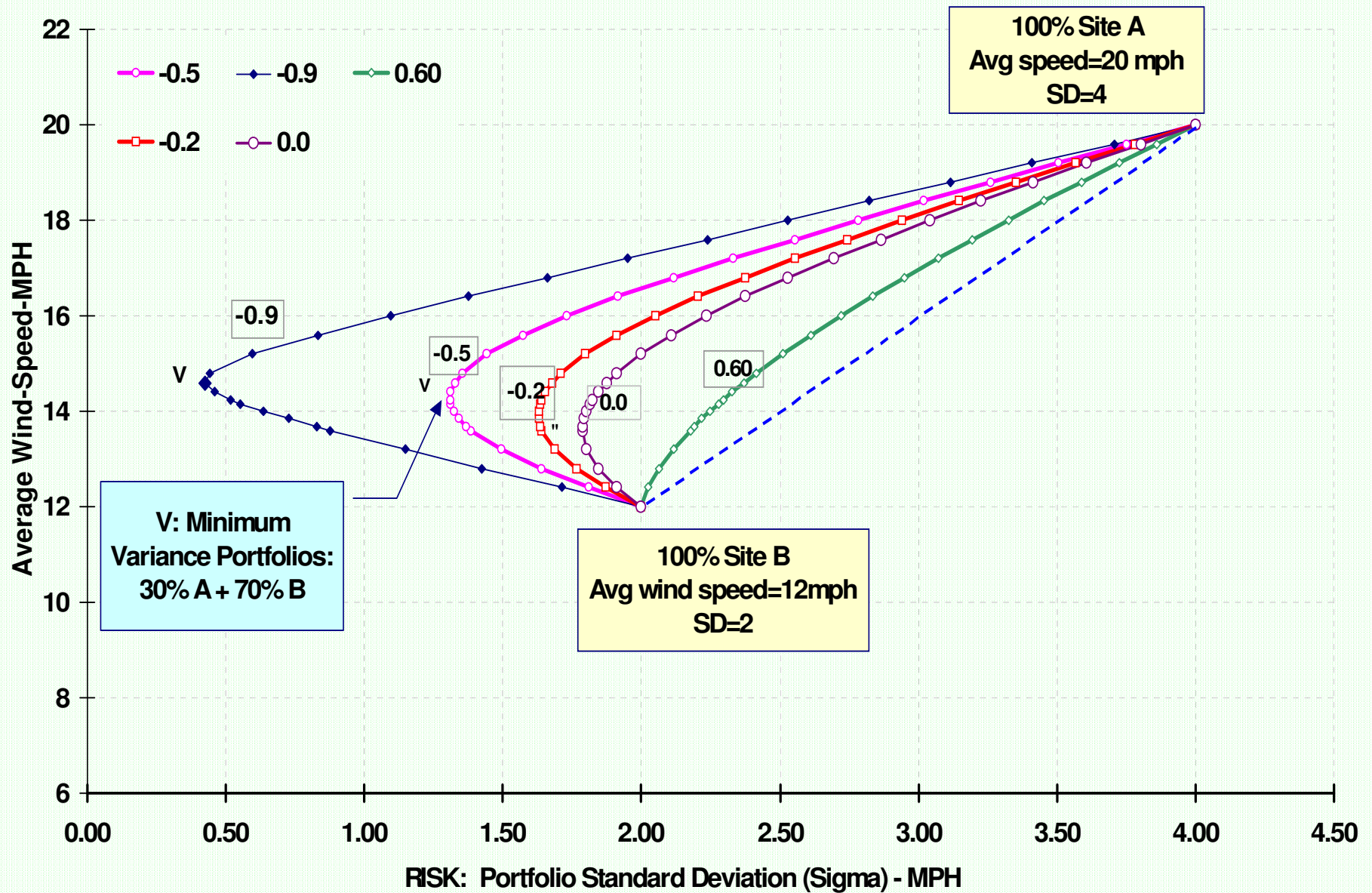
# Onshore Wind Speed Correlation by Distance - UK

1,770 pairs of wind speed recording sites - surface wind speed - typically ~30 years data per pair



Source: M. Grubb, L. Butler, G. Sinden, "Diversity and Security in UK Electricity Generation: The Influence of Low Carbon Objectives," Submitted to Energy Policy

# Expected Variability for Two-Site Wind Portfolio





THANK YOU



Shimon  
Awerbuch

