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
• **Environmental Benefits** - Widely understood–undervalued by regulators	**HIGH**
• **Help Mitigate Market Power** - Help *Unlock* Benefits of Liberalization by Enhancing Competition along Power Network - Requires NO restructuring & incentives	**MOD**
• **Security: *Mitigate/Diversify* Fossil Risk** - *Reduce* overall electricity generating costs - *Minimize* exposure to macroeconomic fossil risk	**LOW**

Most significant aspect of energy security today

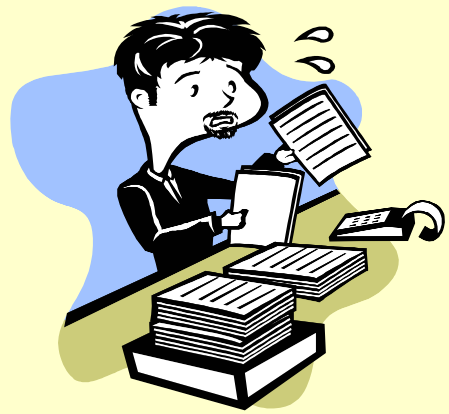
REFLECTING MARKET RISK

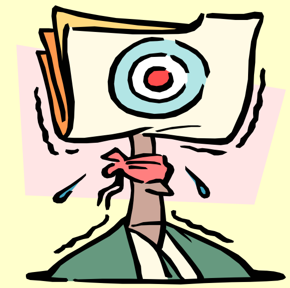
Valuing Energy Technologies Necessarily Involves an Assessment of Financial Risk

Risk Directly Affects KWH Cost Estimates

- Risk affects *value* and economic *expectations*
  - Stock returns mean little without risk
  - Stock X vs. Stock Y

GAS = 3*p*/kWh?





Wind = 5*p*?… 6*p…*?

- Engineering kWh cost estimates use arbitrary discount rates
  - Have no economic interpretation

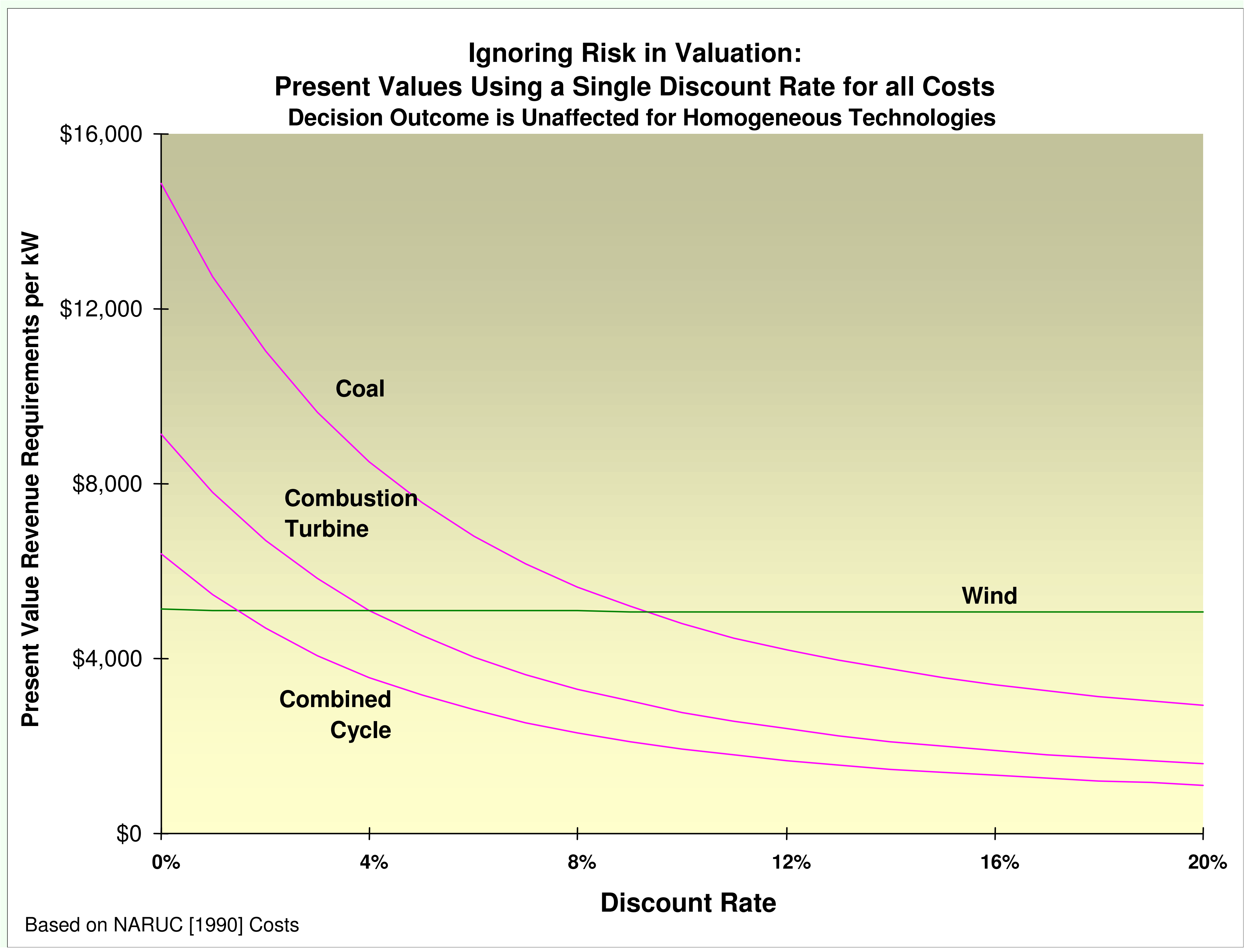
Talking about kWh cost without also talking about risk is like watching a movie……. With the sound turned off!

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 ≈ 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
Present Value Revenue Requirements per kW
$16,000
$12,000
$8,000
$4,000
$0
Coal
Combustion Turbine
Wind
Combined Cycle
0%
4%
8%
12%
16%
20%
Discount Rate
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
Present Value @ 5% Discount	$1,154	$927

But US-Treasury is Worth More!

Ignoring Risk-Differentials: Sensitivity Analysis Makes it Worse

Sensitivity Analysis for Bond Investments With a Single Arbitrary Discount

	Junk Bond		Government Bond	
	Tenet Hlth Care 7-3/8% due 2013		US Treasury 3-7/8% due 2013	
Sensitivity Range	1.0	0.9	1.0	0.9
	Yearly Proceeds		Yearly Proceeds	
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
Net Present Value @5% Discount	**$146**	**$77**	**($69)**	**($136)**
Percent Change	**0%**	**-47.3%**	**0%**	**-96.7%**

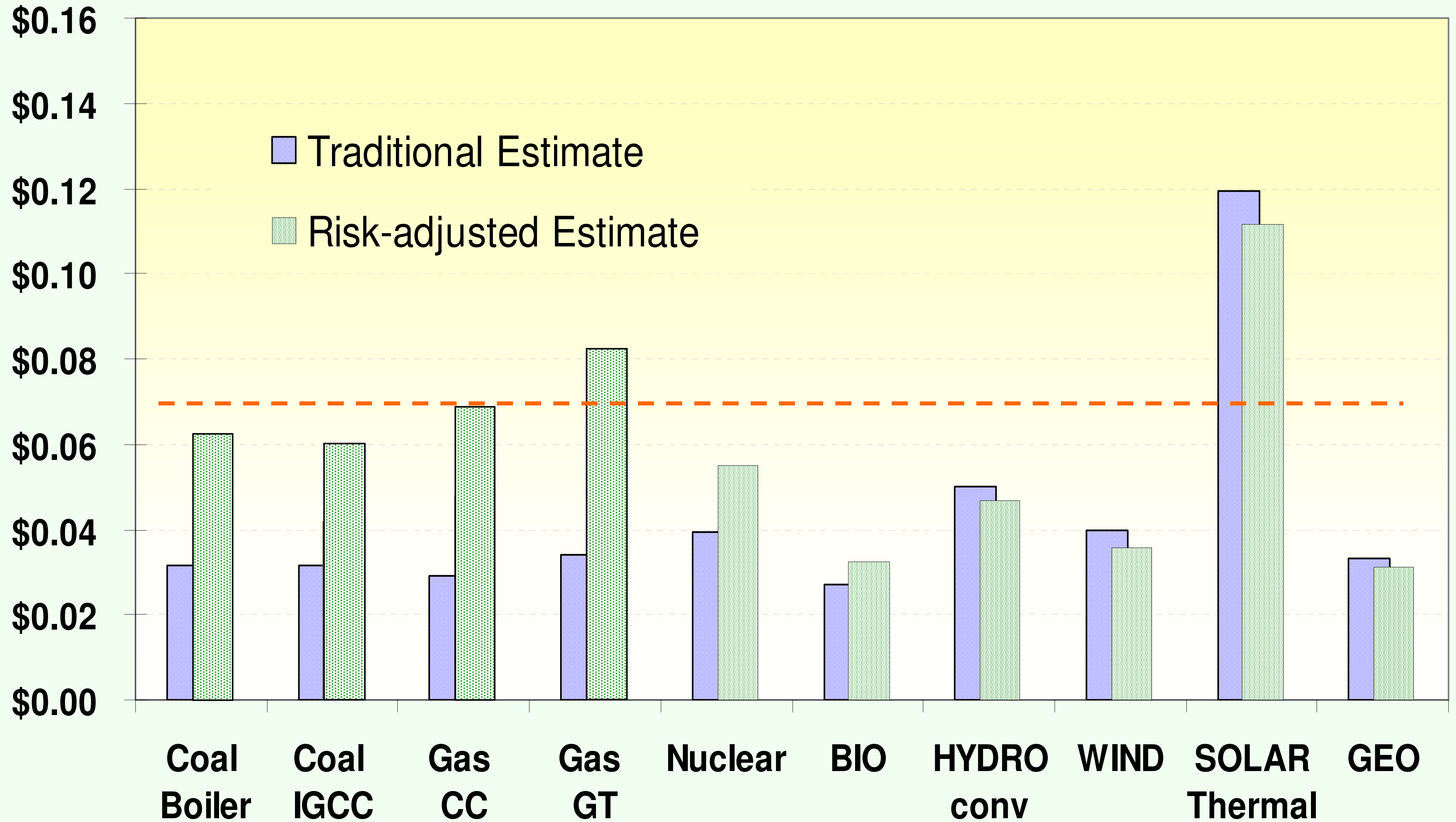
How Standard Procedures Value Fixed & Variable Gas Prices

YEAR	Projected Annual Gas Outlays (Millions TND): Projected Spot-Price Outlays	Projected Annual Gas Outlays (Millions TND): 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

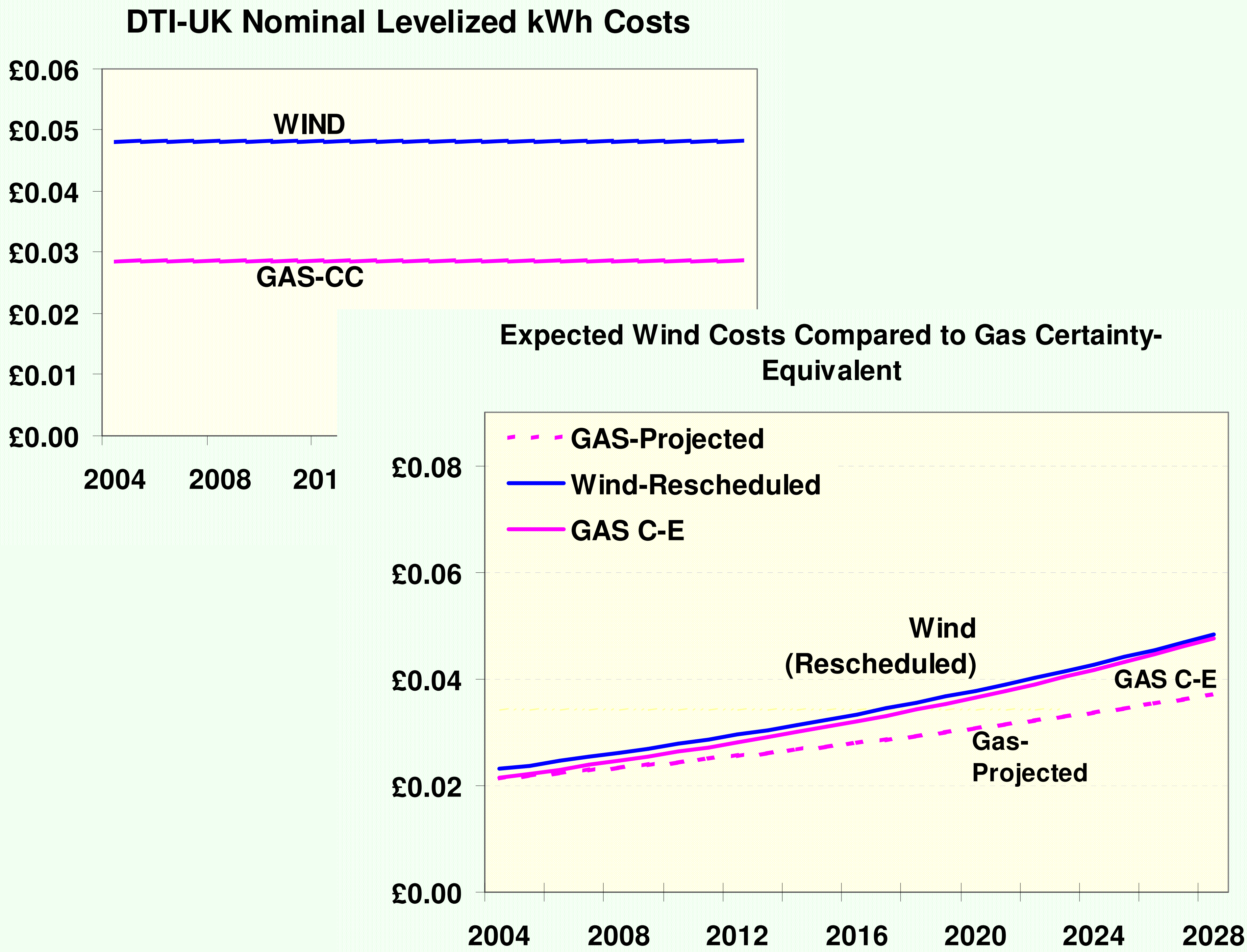
WACC-Based:	*7.0%* TND 19,461	*7.0%* TND 23,354
Market-Based:	*0.50%* TND 30,941	*4.0%* TND 28,698

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



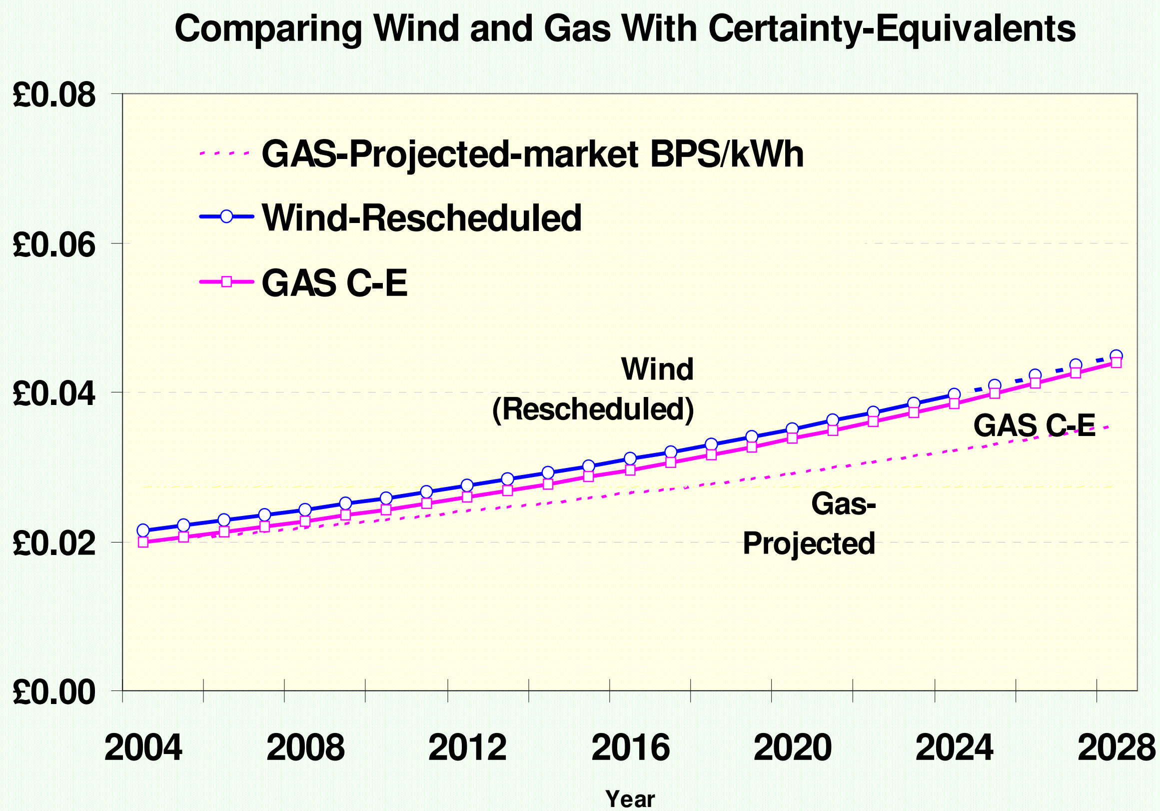
What is *Levelized Cost* anyhow? What does it measure?

- **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
£0.06
£0.05
£0.04
£0.03
£0.02
£0.01
£0.00
2004
2008
201
WIND
GAS-CC
Expected Wind Costs Compared to Gas Certainty-Equivalent
GAS-Projected
Wind-Rescheduled
GAS C-E
£0.08
£0.06
£0.04
£0.02
£0.00
2004
2008
2012
2016
2020
2024
2028
Wind (Rescheduled)
GAS C-E
Gas-Projected

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:*

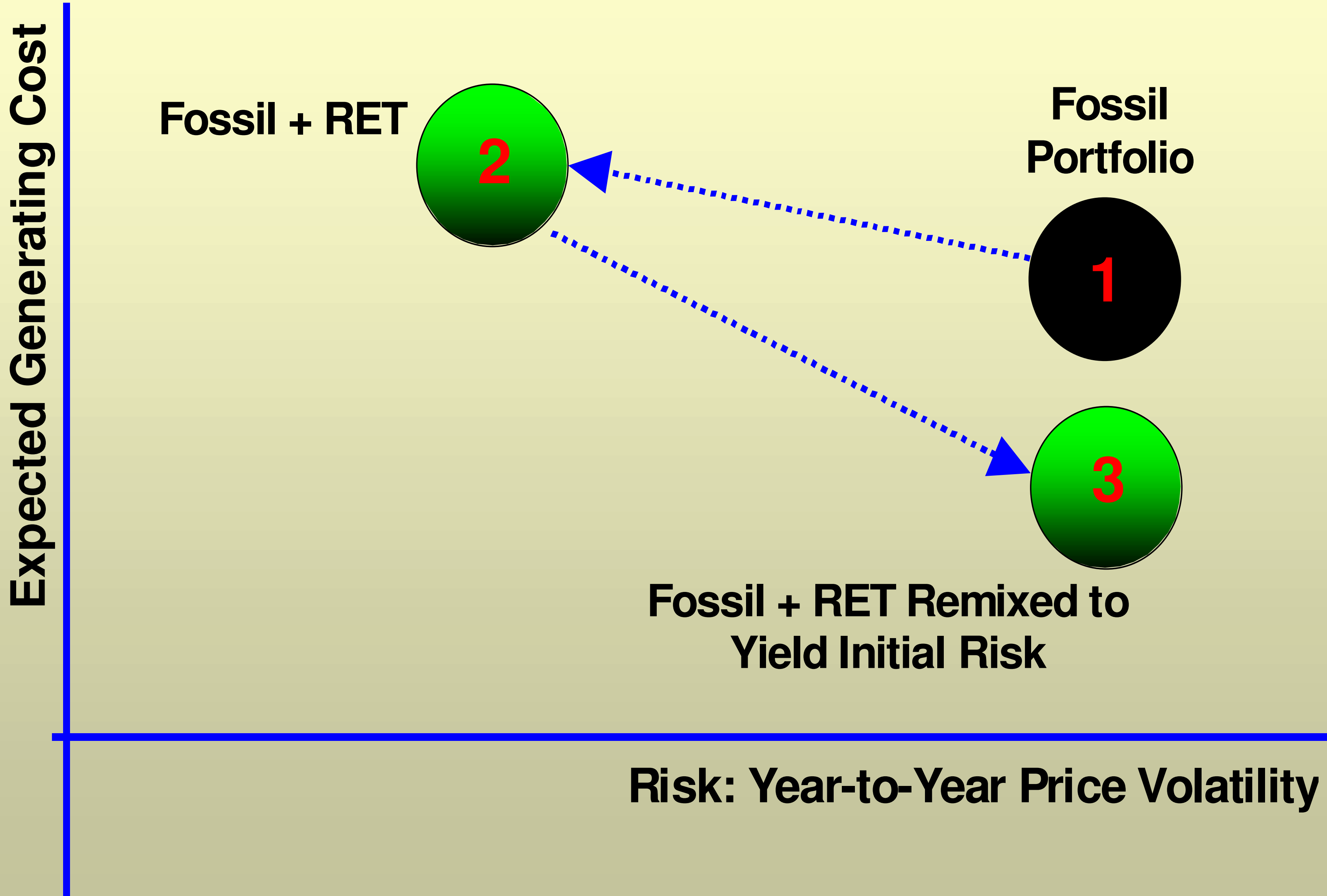
Adding Fixed-Cost Wind, Solar, etc. Generating Mix *Reduces* Overall Generating Cost at any Level of Risk...... Even if *stand-alone* costs are *higher*

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 = <u>3%</u>
- 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

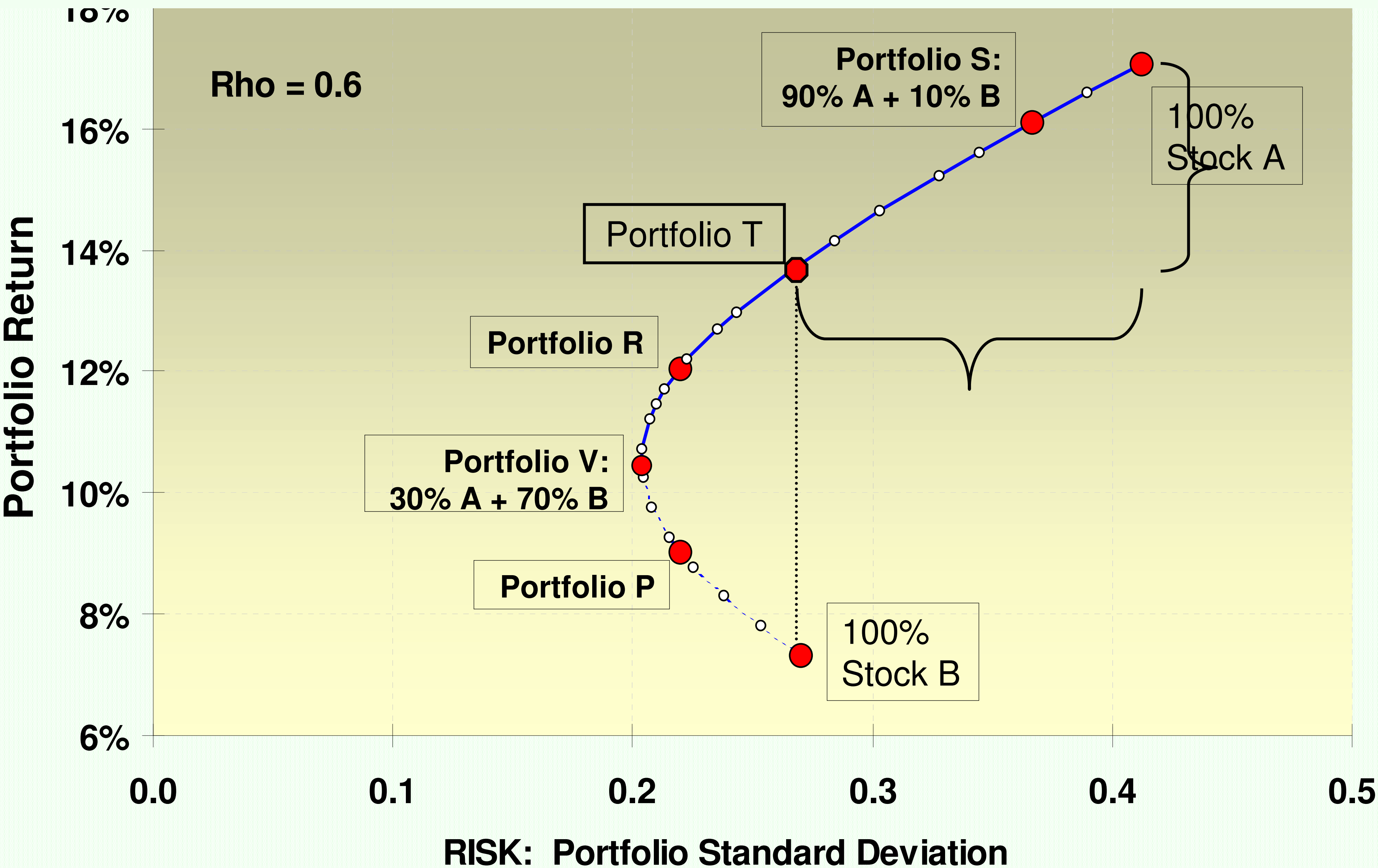


Portfolio Diversity and Security: RETs Provide Important but Poorly Recognized Energy Security Benefits

- **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**

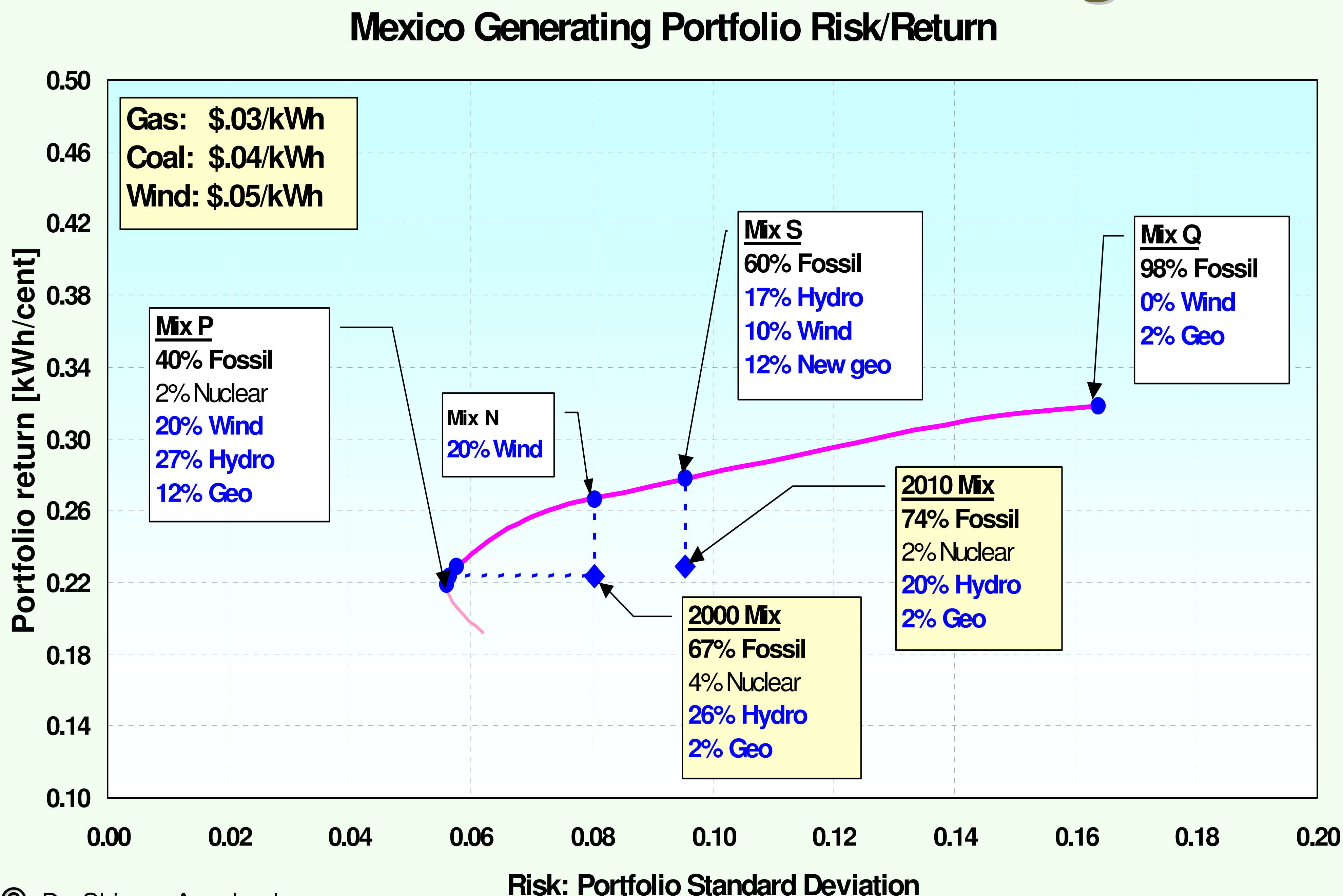
Energy security is reduced when nations hold inefficient portfolios that are needlessly exposed to fossil risk

Risk and Return for A Portfolio of Risky Assets



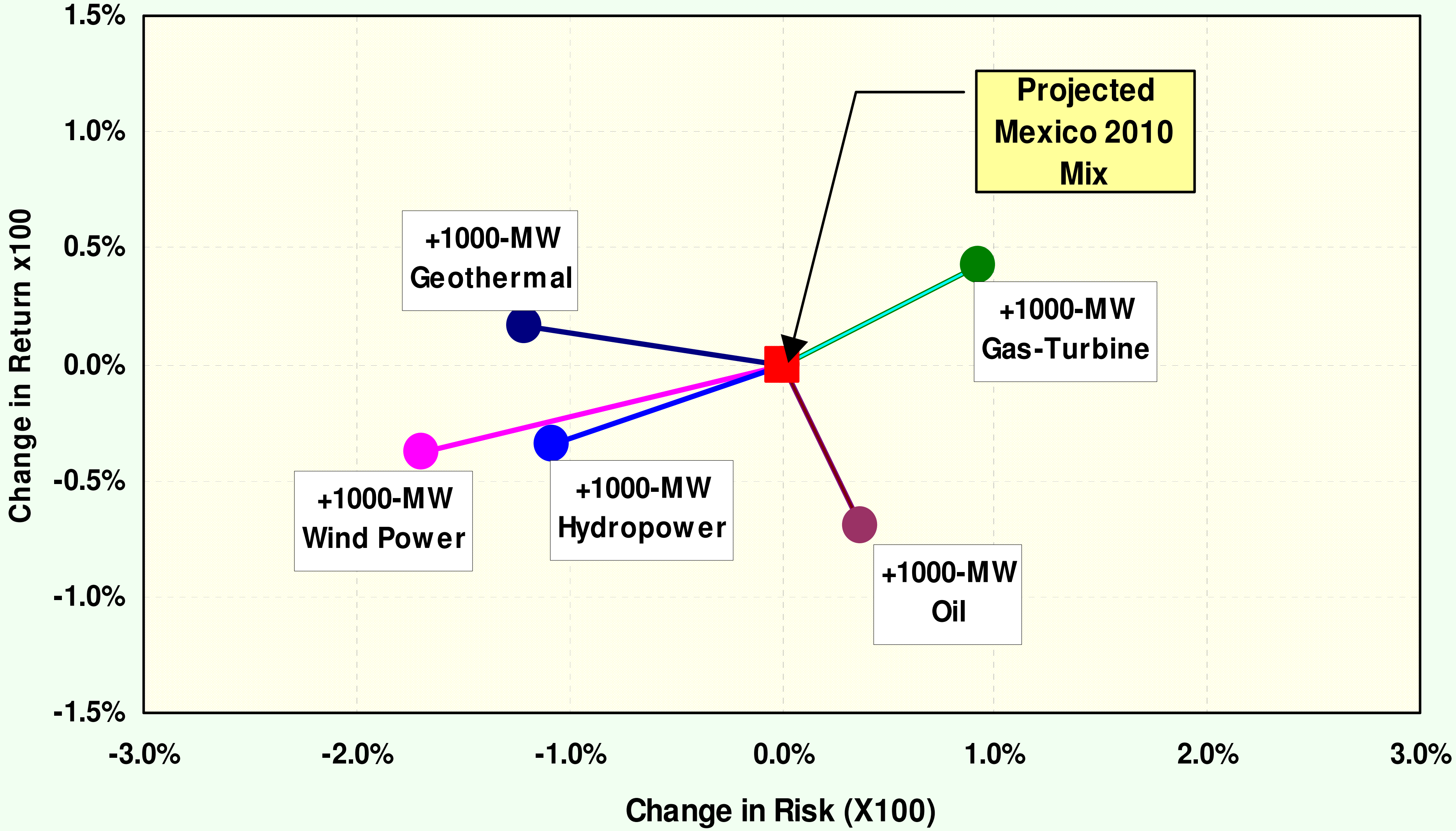
S. Awerbuch, "Getting It Right: The Real Cost Impacts of a Renewables Portfolio Standard," PUF, 2-15-2000.

Wind/RE Lowers Mexico Generating Cost

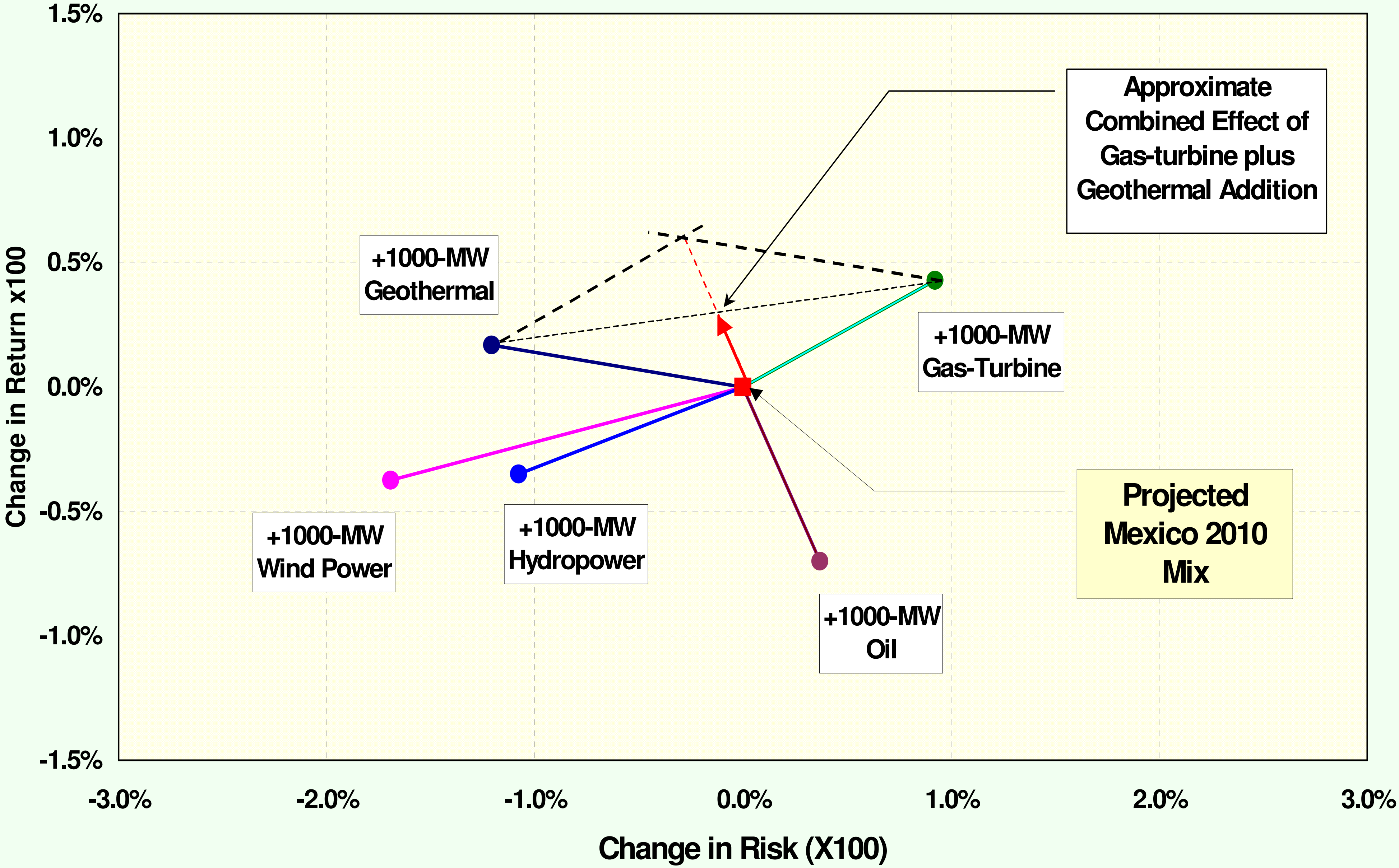


One-Step Analysis for Planners

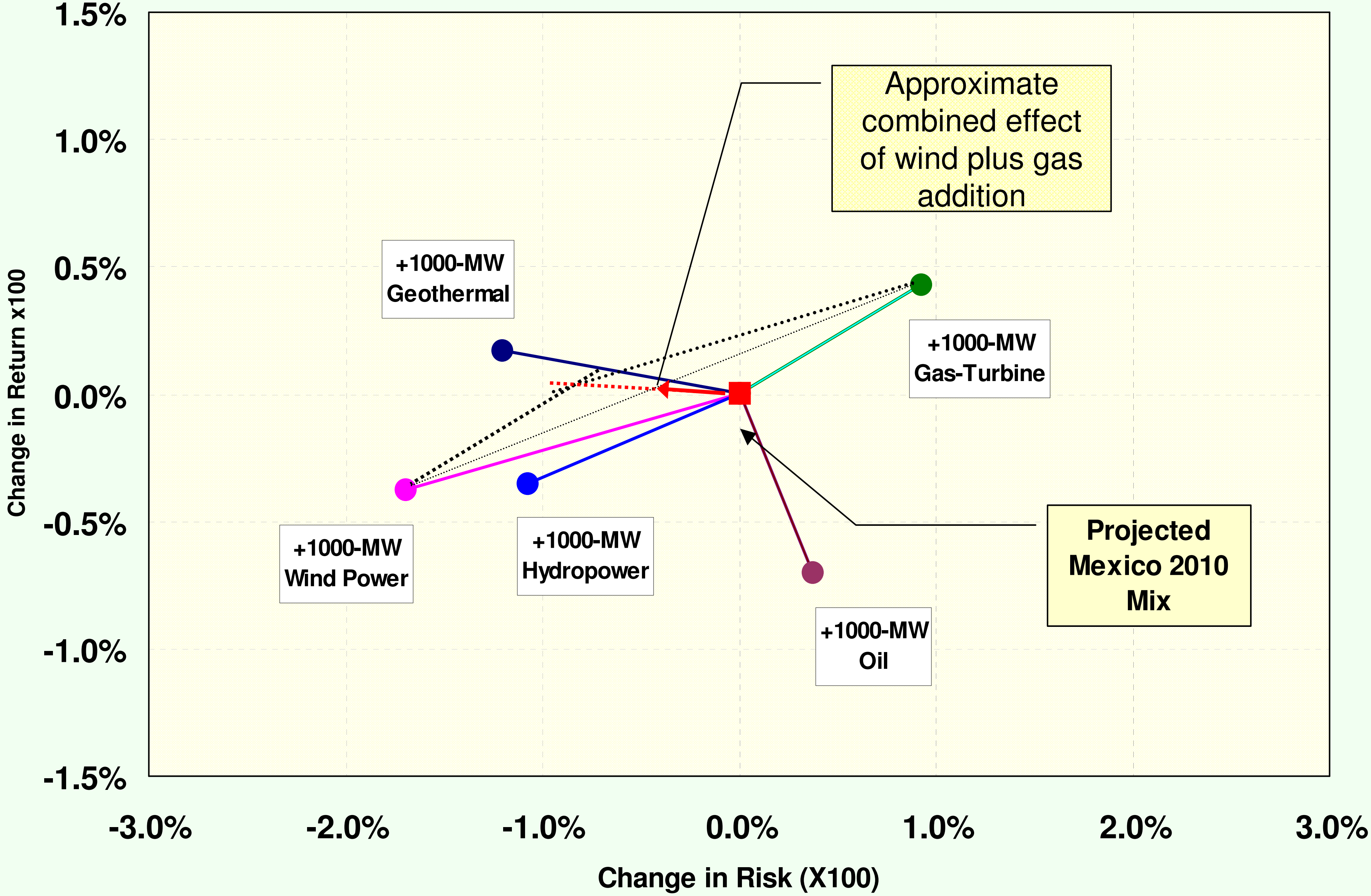
Mexico: Risk-Return Sensitivity of Projected Mexico 2010 Mix to 1000-MW Additions of Various Technologies



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:**

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

  - σ_1, σ_2 = Std. Dev. of annual costs of technologies *1* and *2*
  - ρ_{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

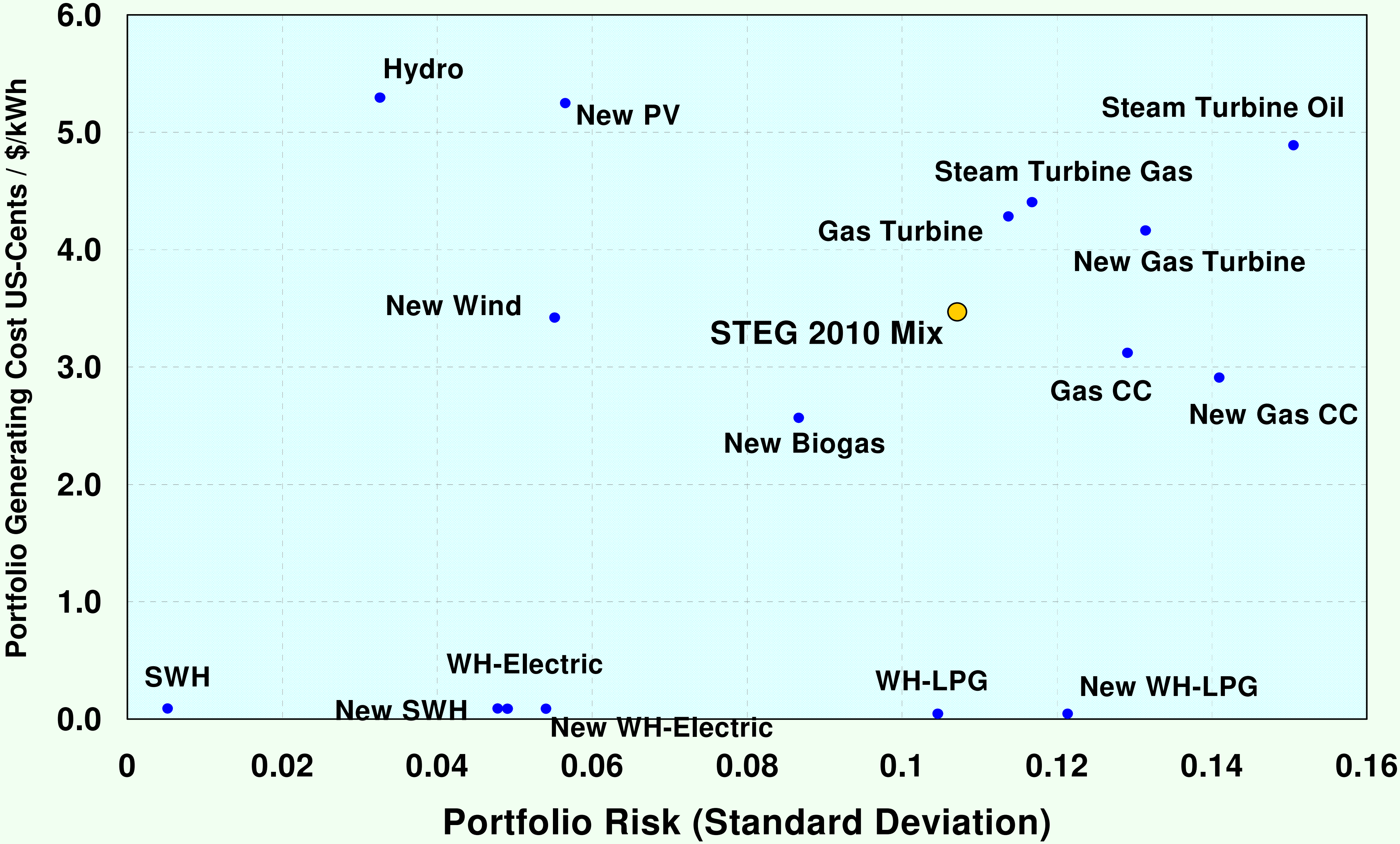
Tunisia 2010 Technology Performance Data

Technology	Cost (US-Cents/kWh) Initial Outlay	Fuel	Fix OM	Var OM	Capacity (MW)	Energy (GWH)
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 Technlogy 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	0.7	0.2262
Oil	0.5745	1	0	0.8	0.3	0.2676
Renewable	0	0	1	0	0	0
LPG	0.46	0.8	0	1	0.24	0.24084
Electricity	0.7	0.3	0	0.24	1	0.07

Assumed Correlations:

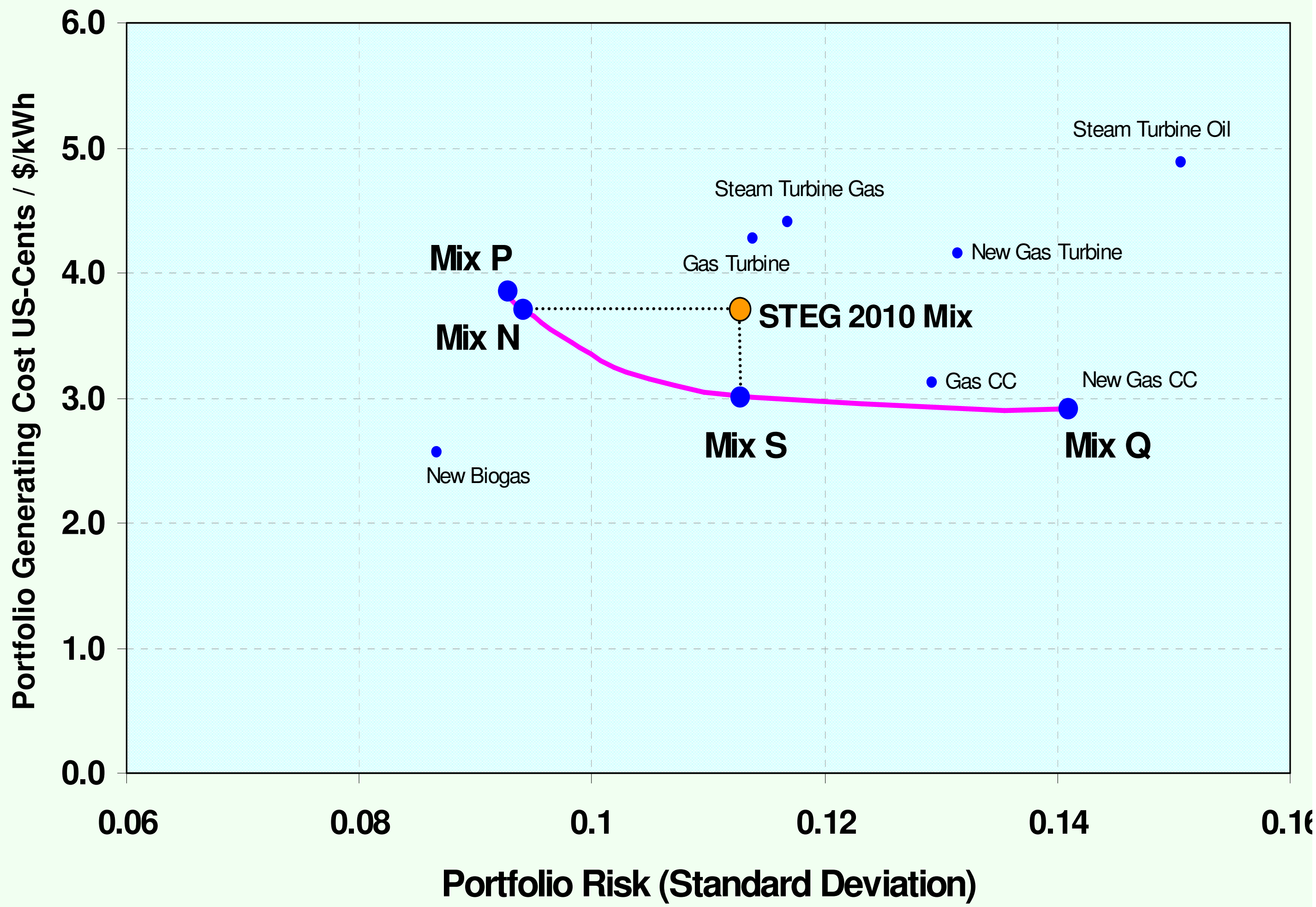
LPG-Oil = 0.8
Electric-Gas = 0.7

Non-Fuel Correlation Factors

		Technology A		
	Cost Stream	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

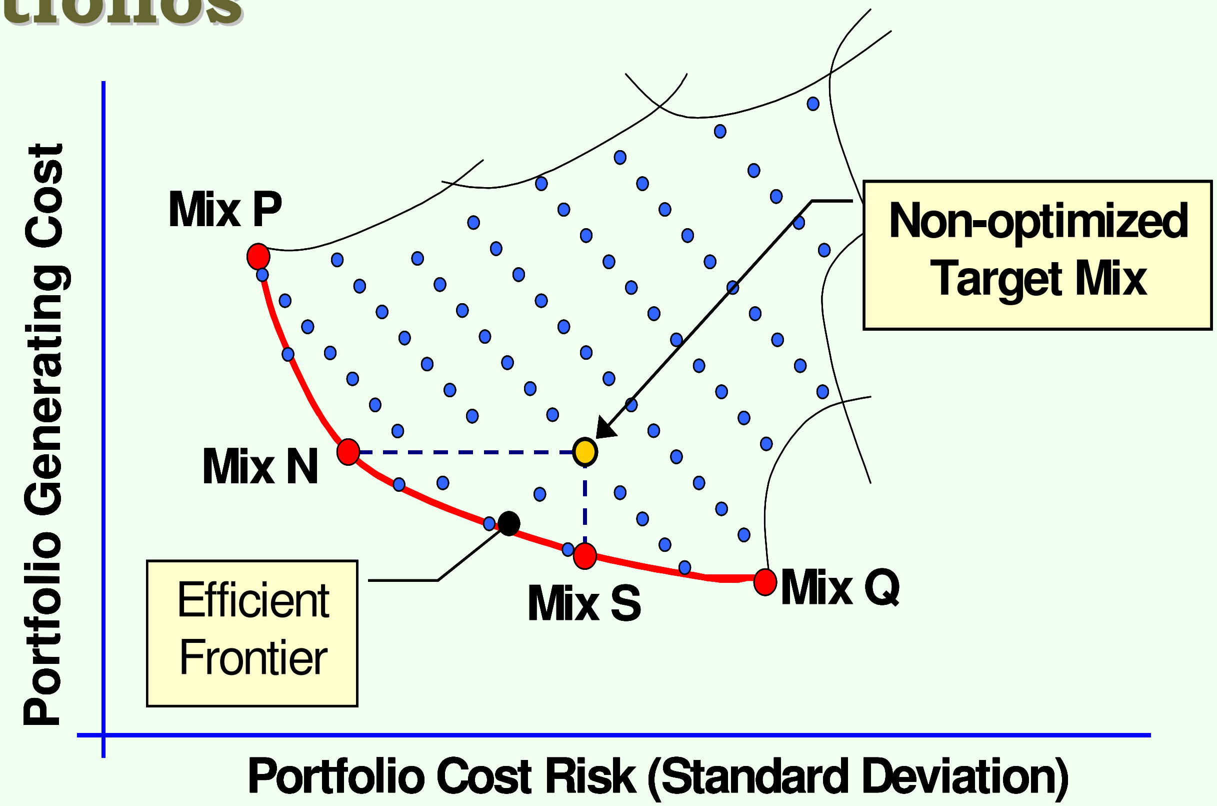
- Charts Show Generating Portfolio Cost and Risk
- *Efficient Frontier* shows all optimal mixes
- Along the EF, cost reductions attained only at higher risk
- Infinite solutions exist
- We locate the following *typical* mixes:



  - *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

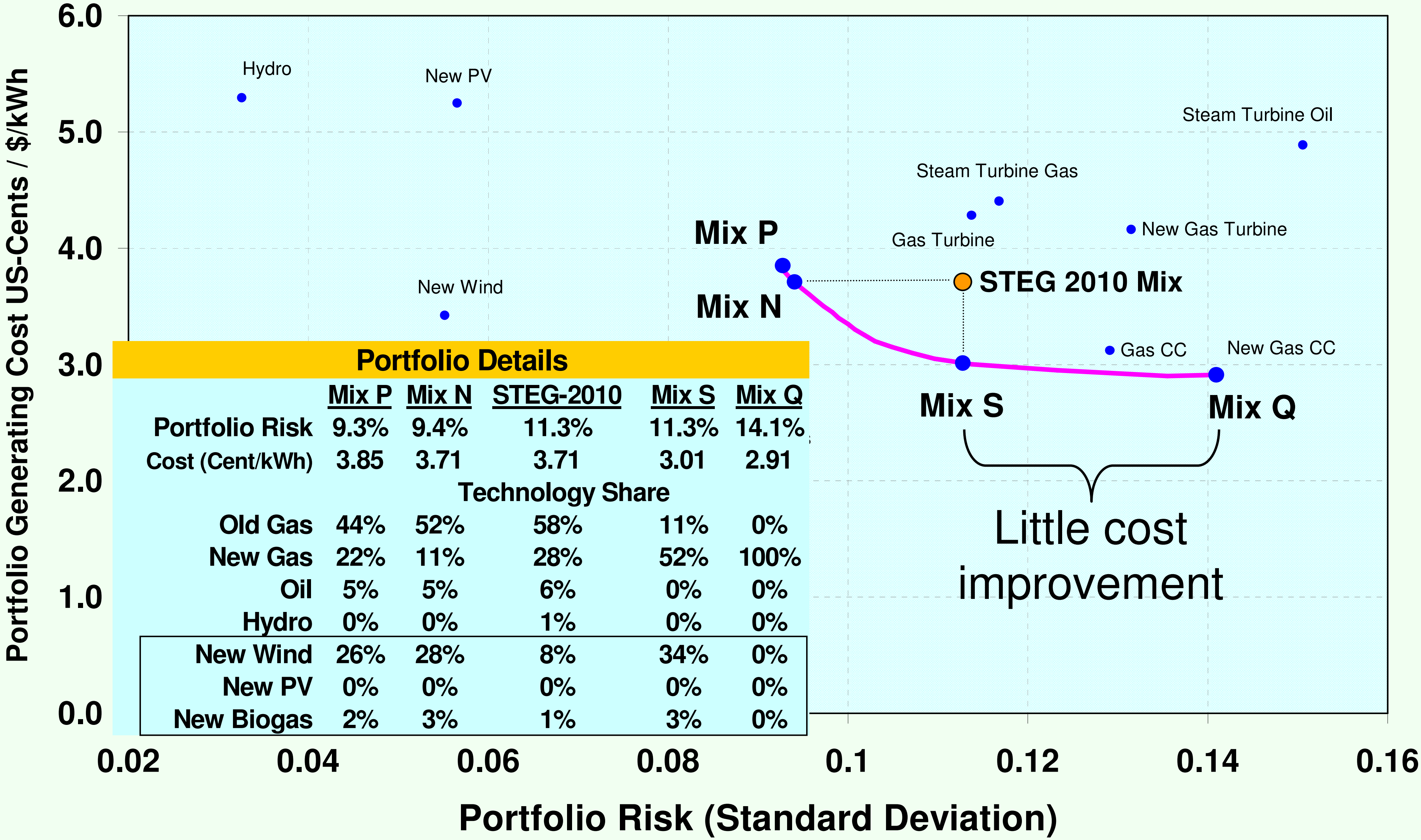
Feasible Region and Efficient Frontier For Multi-Asset Portfolios

- 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 -



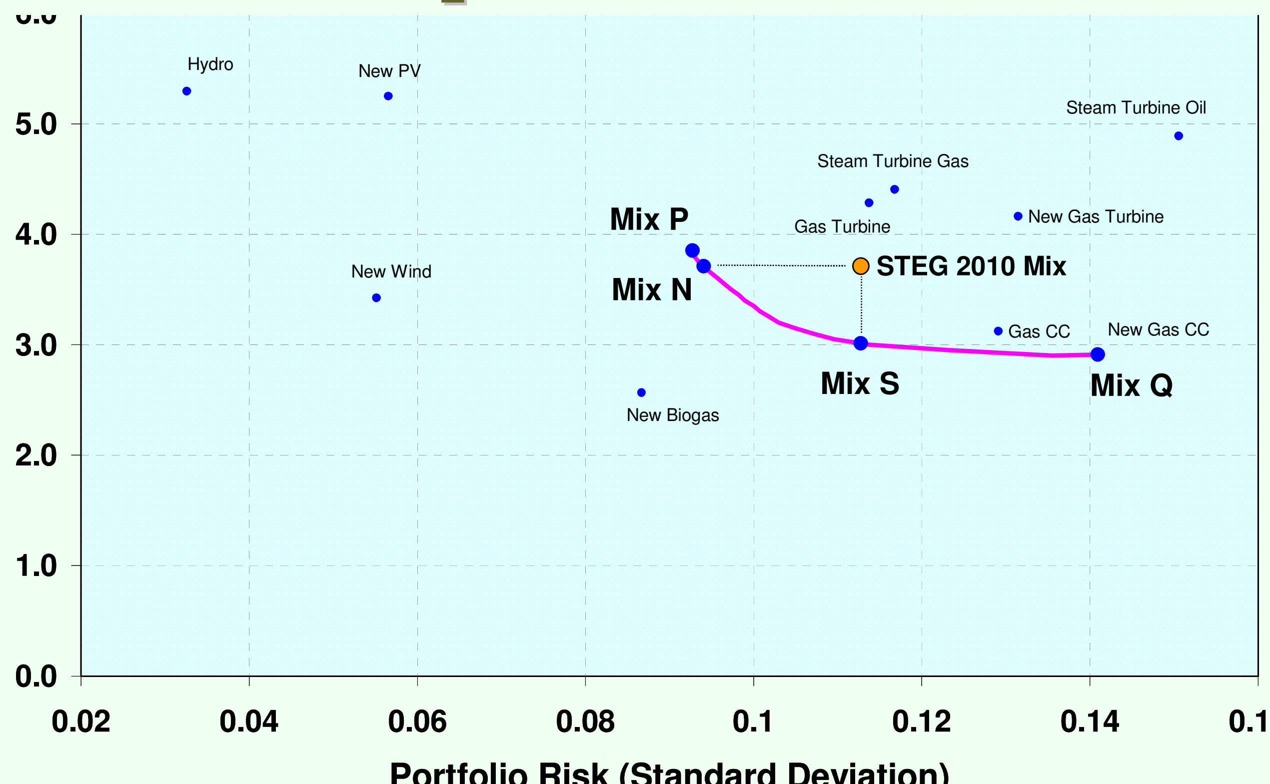
Portfolio Details

	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%

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

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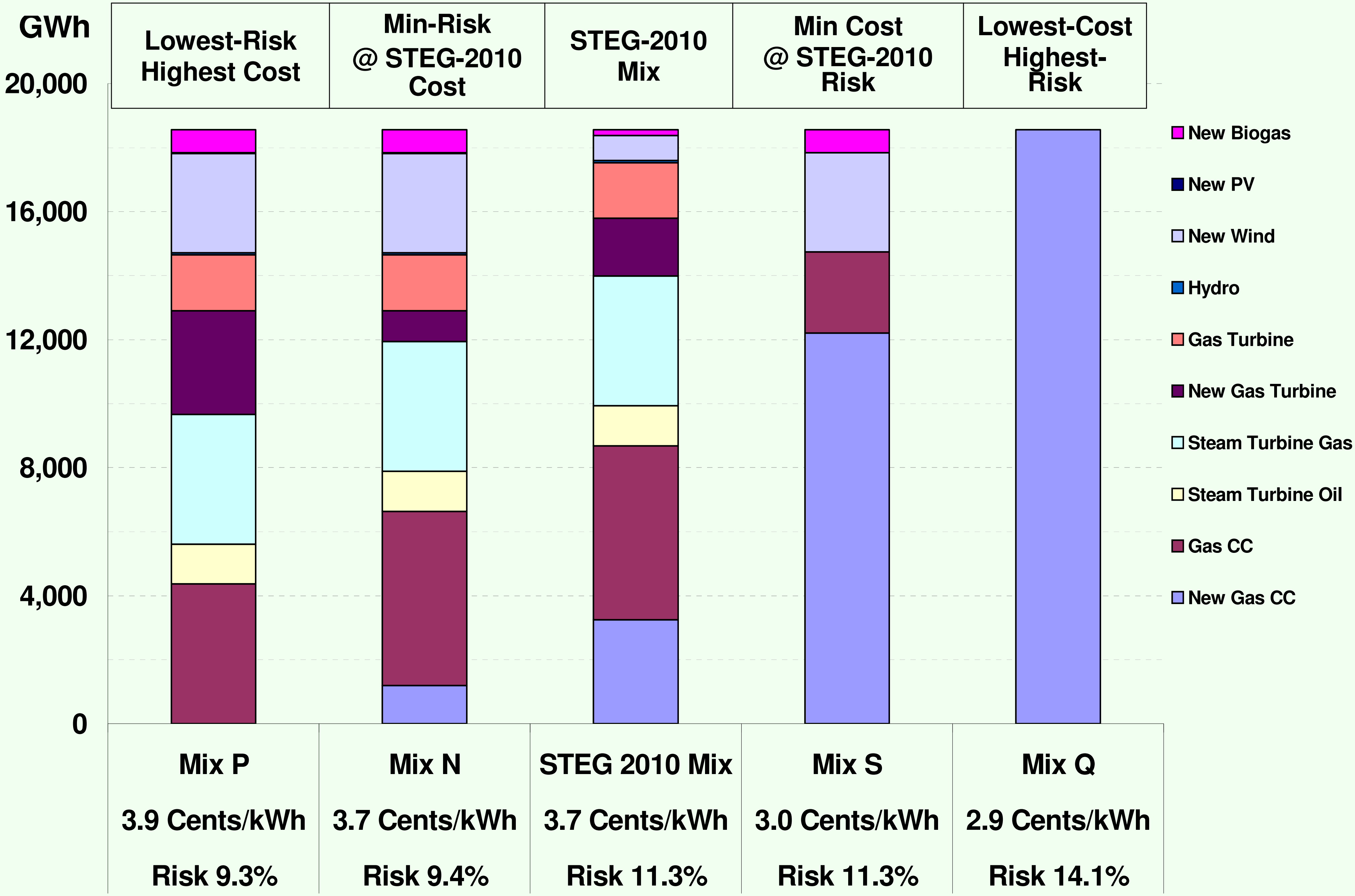
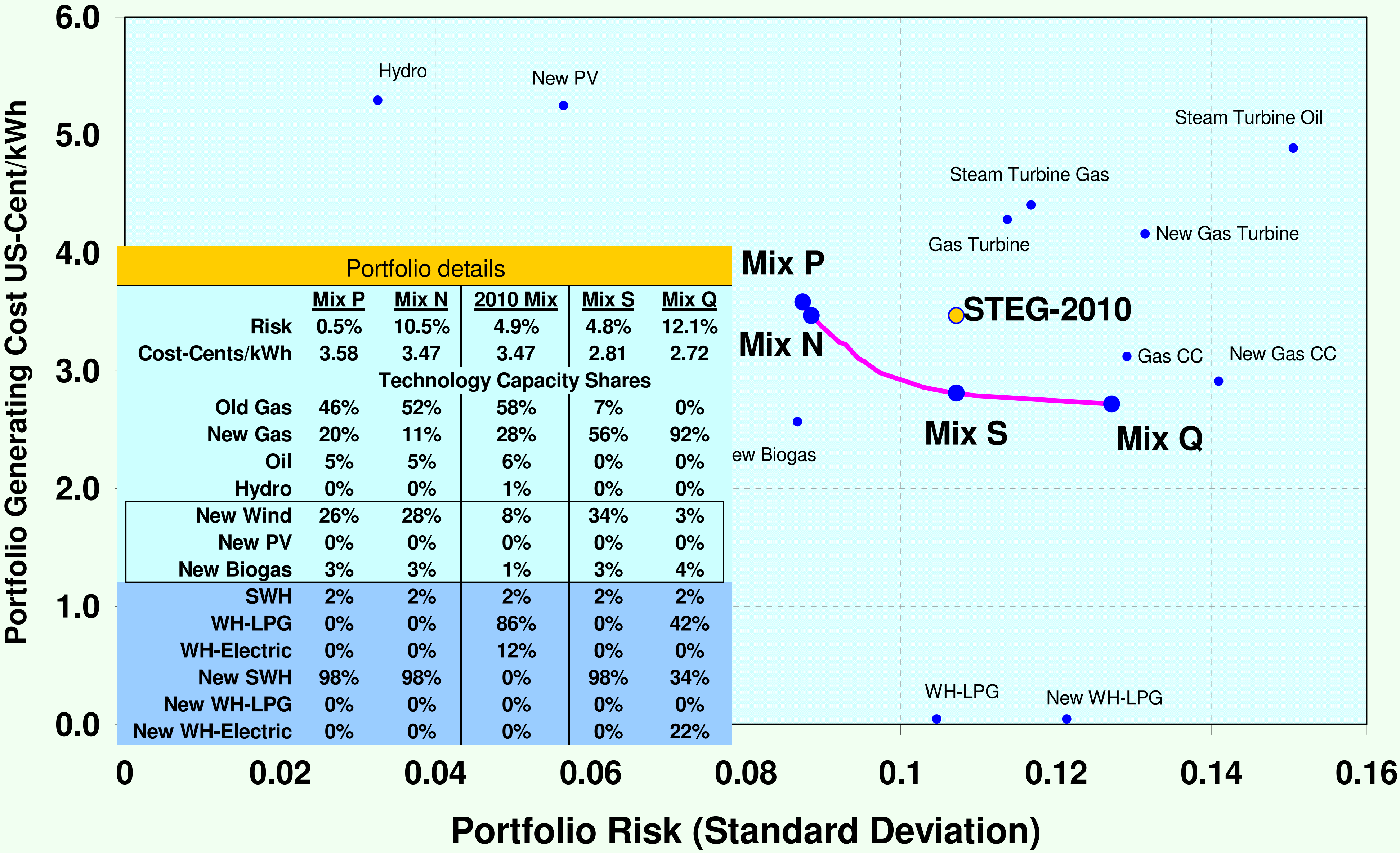
Oil	5%	5%	6%	0%	0%
Hydro	0%	0%	1%	0%	0%
New Wind	26%	28%	8%	34%	0%
New PV	0%	0%	0%	0%	0%
New Biogas	2%	3%	1%	3%	0%

Tunisia (Elec): Typical Mixes and STEG Target Mix



Tunisia: 2010 Portfolio Optimization
- Electricity and Water Heating -

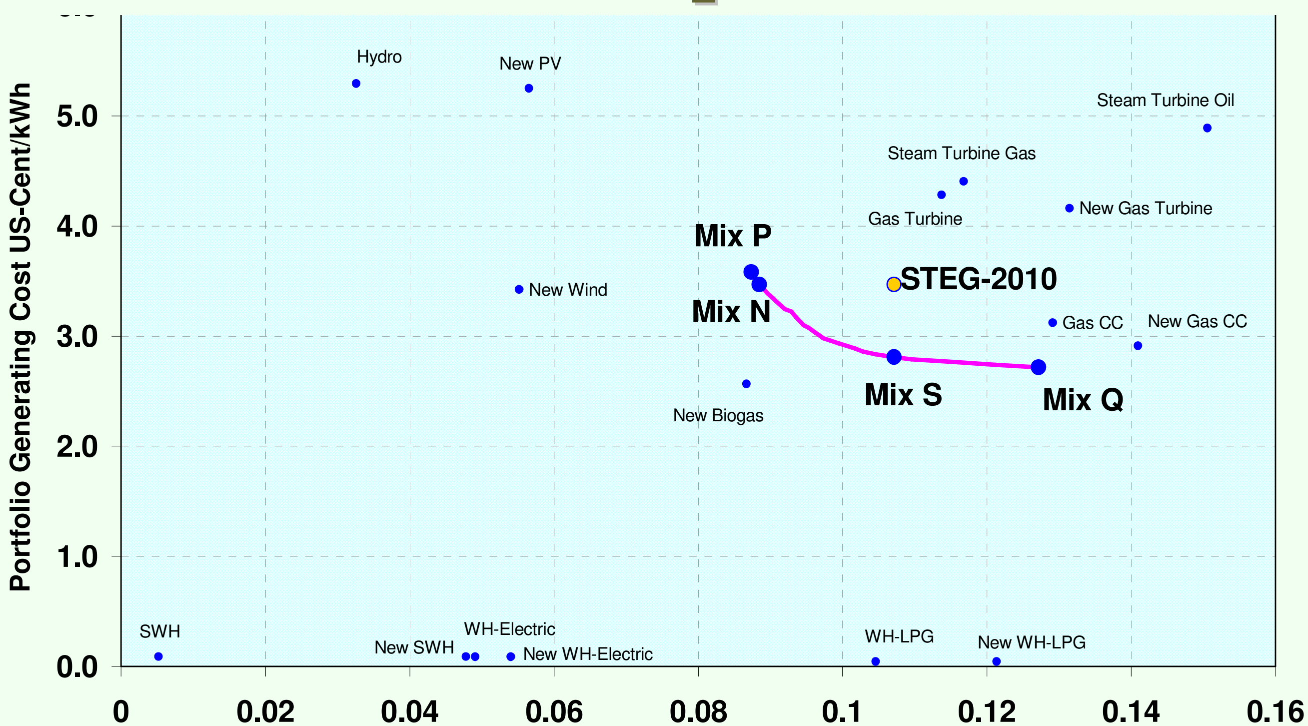


Portfolio details

	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 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**



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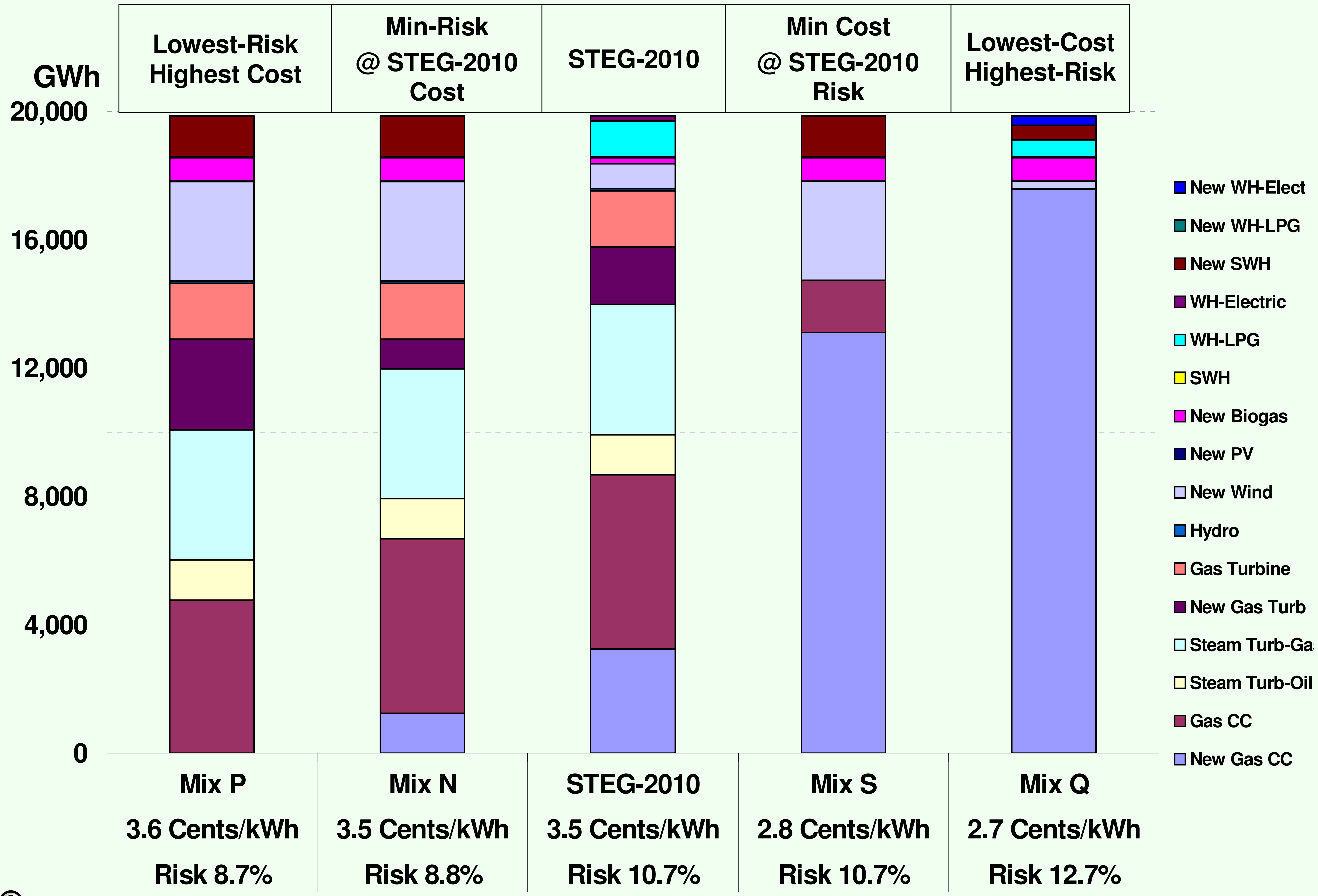
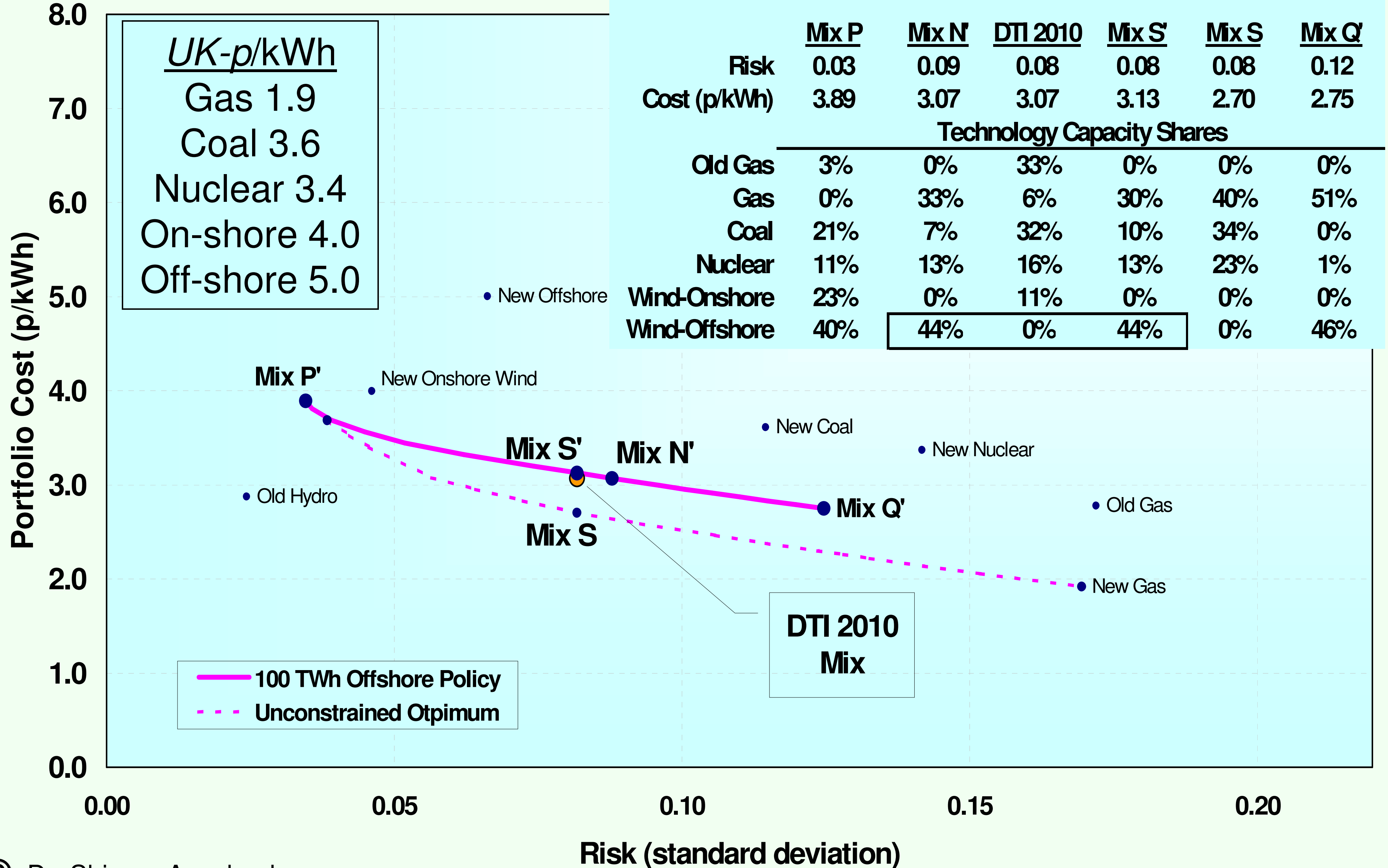
Oil	5%	5%	6%	0%	0%
Hydro	0%	0%	1%	0%	0%
New Wind	26%	28%	8%	34%	3%
New PV	0%	0%	0%	0%	0%
New Biogas	3%	3%	1%	3%	4%
SWH	2%	2%	2%	2%	2%
WH-LPG	0%	0%	86%	0%	42%
WH-Electric	0%	0%	12%	0%	0%
New SWH	98%	98%	0%	98%	34%
New WH-LPG	0%	0%	0%	0%	0%
New WH-Electric	0%	0%	0%	0%	22%

Tunisia: E+WH - Typical and Target Mixes



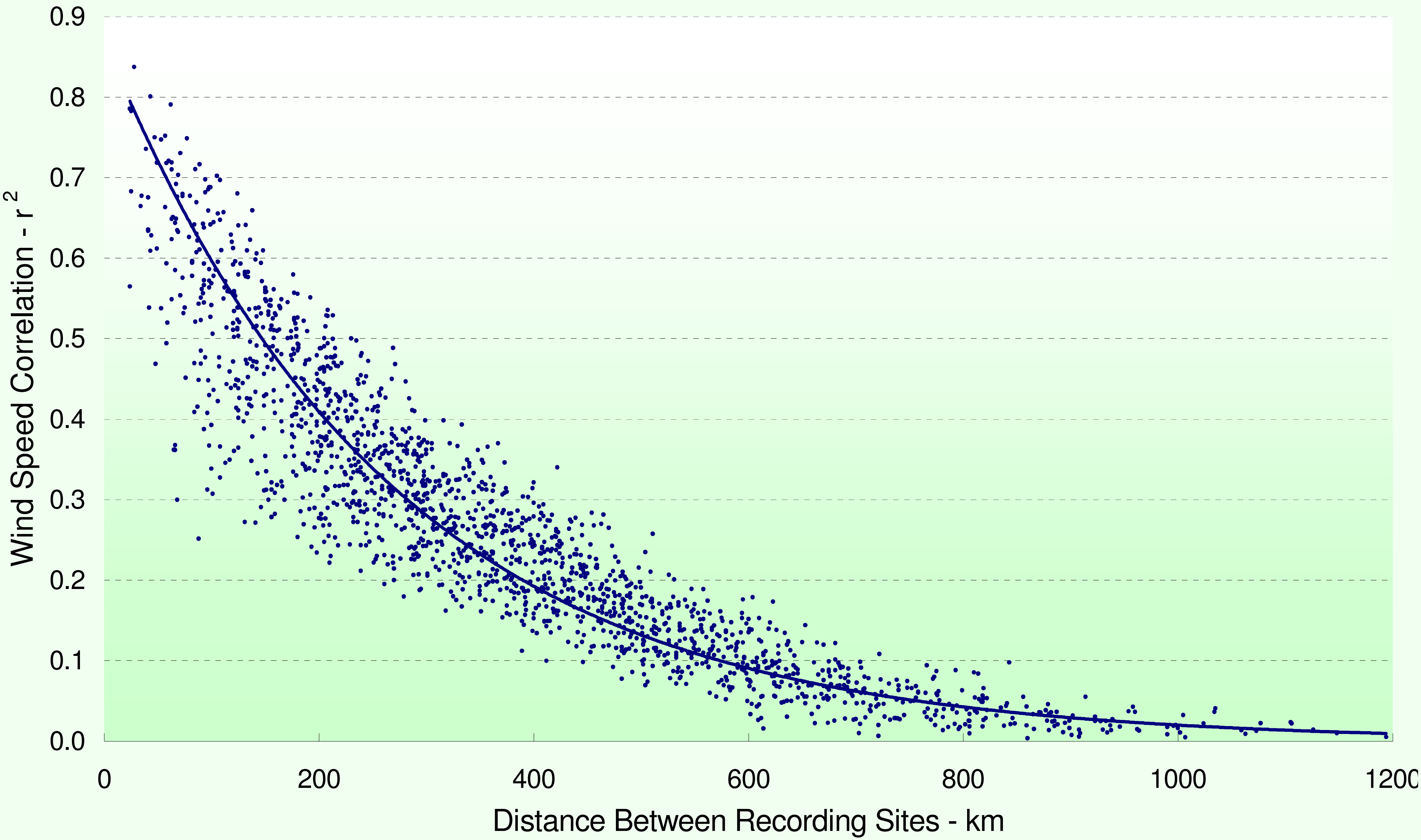
2010 Effect Of UK Accelerated Wind Deployment Policy - Alternate Wind Costs

	Mix P	Mix N'	DTI 2010	Mix S'	Mix S	Mix Q'
Risk	0.03	0.09	0.08	0.08	0.08	0.12
Cost (p/kWh)	3.89	3.07	3.07	3.13	2.70	2.75
Technology Capacity Shares						
Old Gas	3%	0%	33%	0%	0%	0%
Gas	0%	33%	6%	30%	40%	51%
Coal	21%	7%	32%	10%	34%	0%
Nuclear	11%	13%	16%	13%	23%	1%
Wind-Onshore	23%	0%	11%	0%	0%	0%
Wind-Offshore	40%	44%	0%	44%	0%	46%



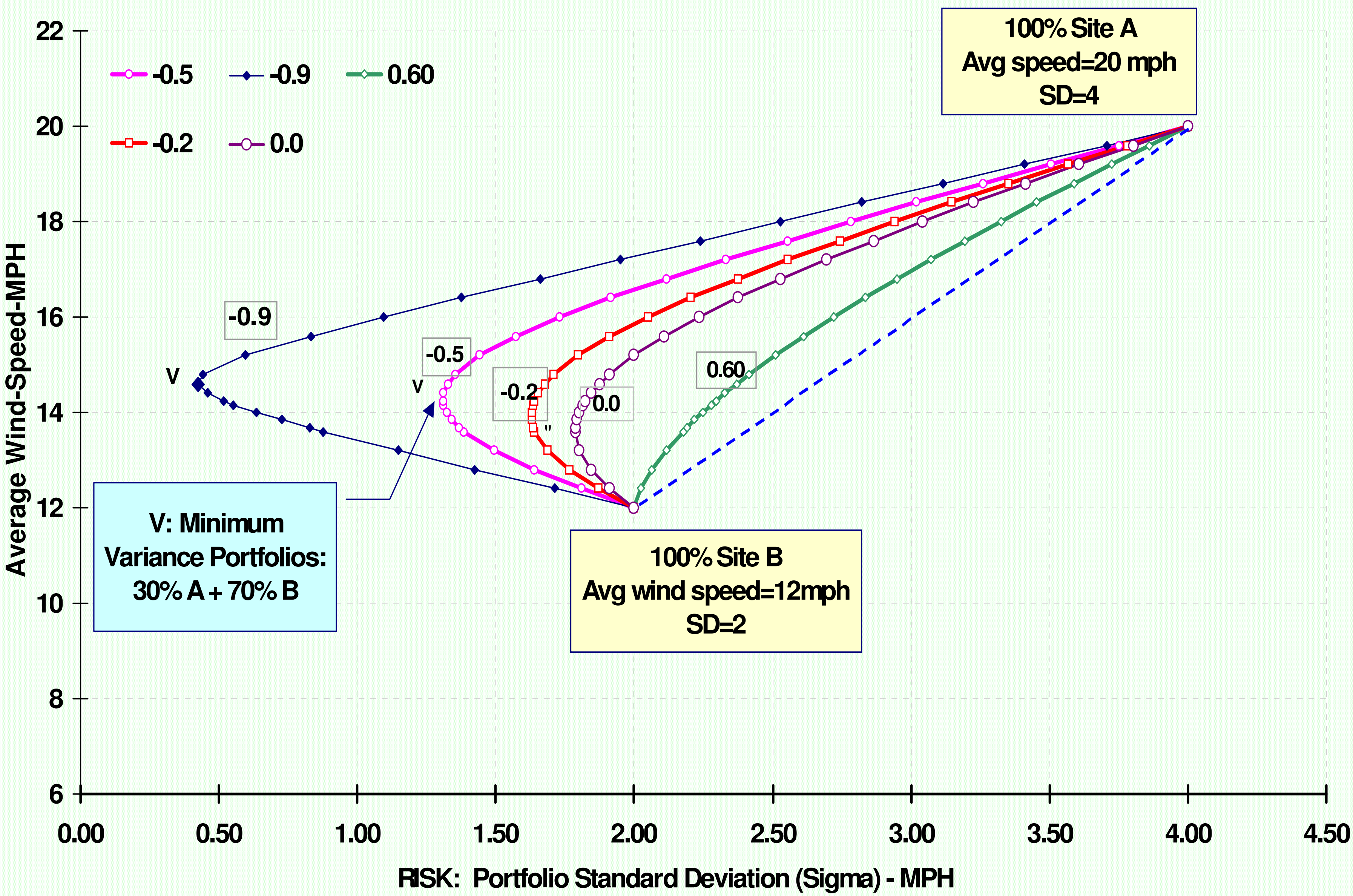
Onshore Wind Speed Correlation by Distance - UK

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




Grazie
Vielen Dank
THANK YOU
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Shimon
Awerbuch
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Díky
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Obrigado!
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Merci
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