Workshop *"Wind Power and Market design"* - University Paris XI

Portfolio analysis and wind power

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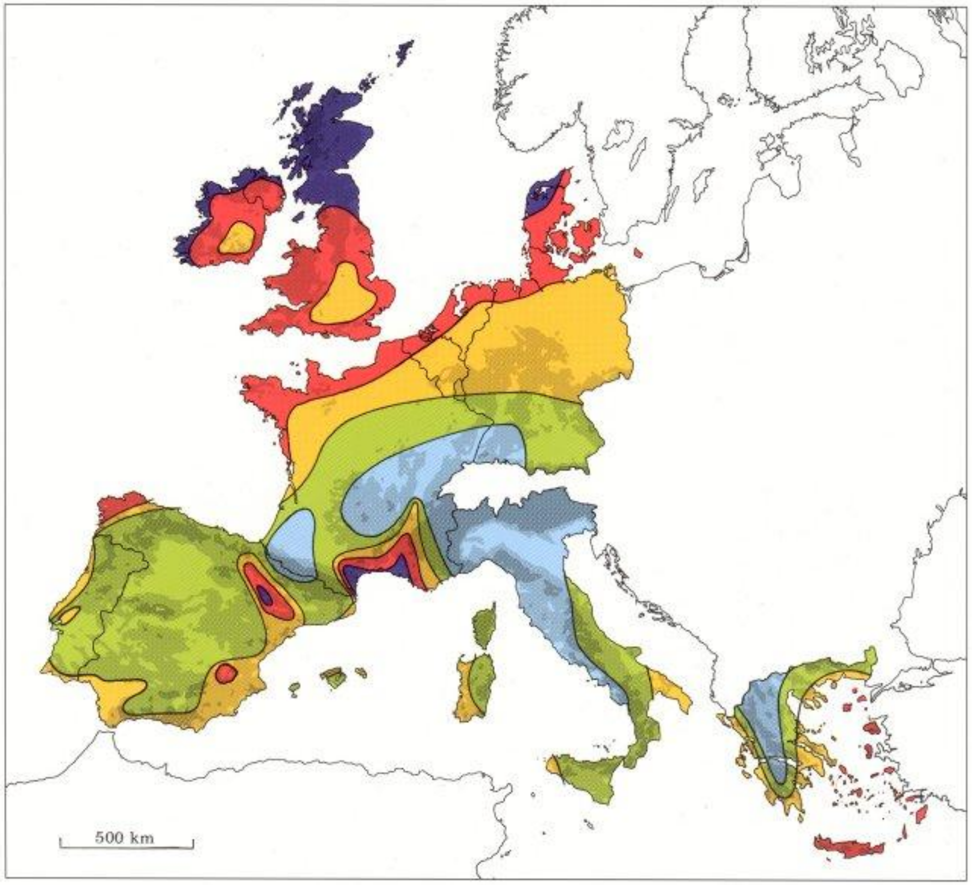
Outline

- **Wind power variability and geographic diversity**
  - Time scale: Hourly variability, seasonality, yearly variability
  - Unit commitment/balancing effects/Capacity credit
- **Applying Mean Variance Portfolio theory to wind power**
  - Physical electricity output vs. financial analysis
  - Social planner (National or EU level) vs. investor project mix
- **Data and preliminary results**
  - Case study for Austria, Germany, Spain and Denmark
- **Next steps…**
  - Taking into account system (transmission constraints) and interactions between load and wind output

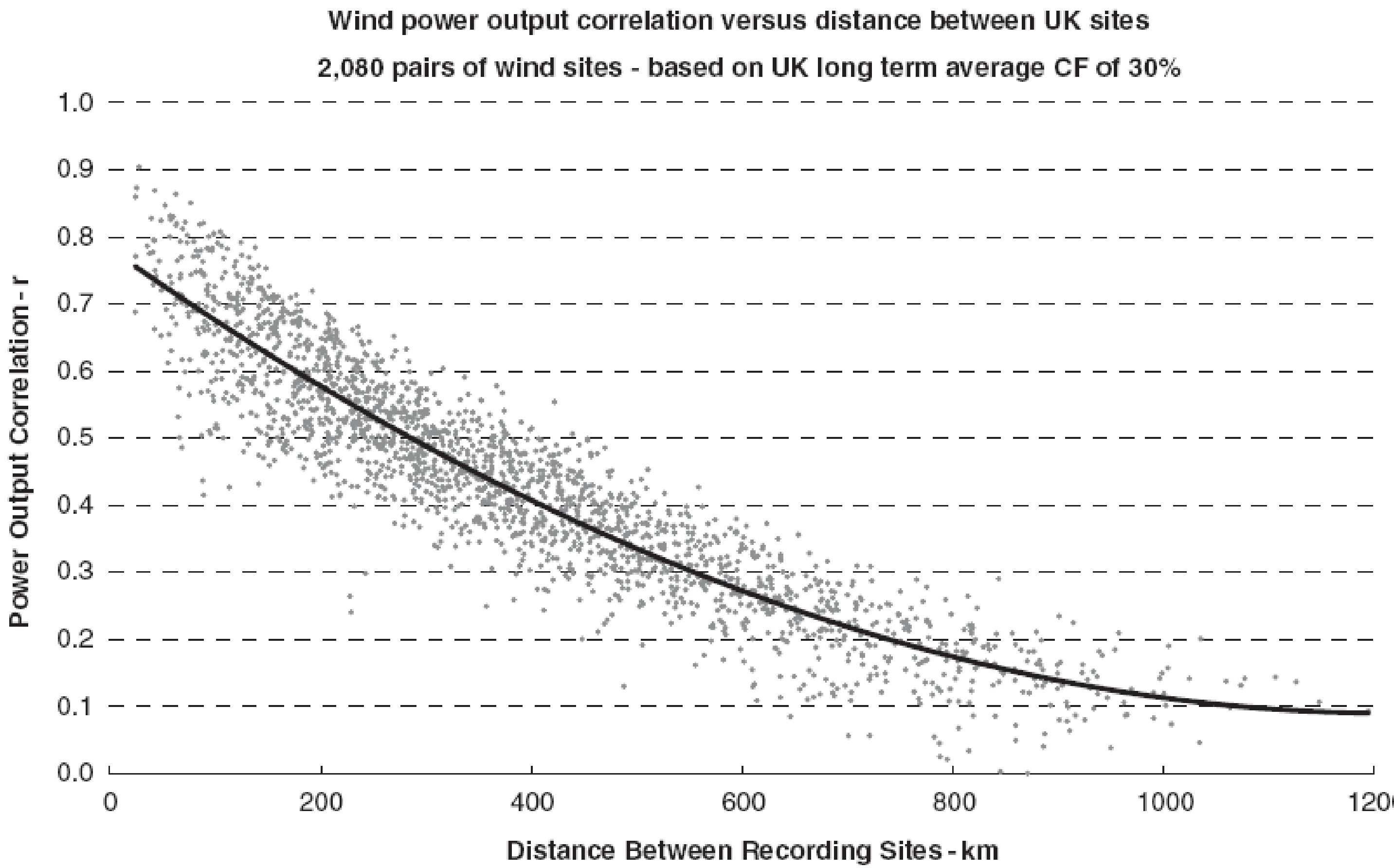
Introduction: EU wind resource and investment planning



Wind resources[1] at 50 metres above ground level for five different topographic conditions										
	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

- National focus on sites with best wind resource
- As penetration increases, investment planning needs to take into account:
  - wind variability and interaction with other technologies (Neuhoff et al., 2008)
  - Integration into power network
  - Transmission constraints, particularly at EU level
  - **Correlation between sites to diversify risk => portfolio approach**

Wind power output correlation decreases with distance between sites



Source: G. Sinden (2007)

UK wind turbine output correlation decreases by about 0.1 every 100/200 km.

Portfolio analysis of wind power development

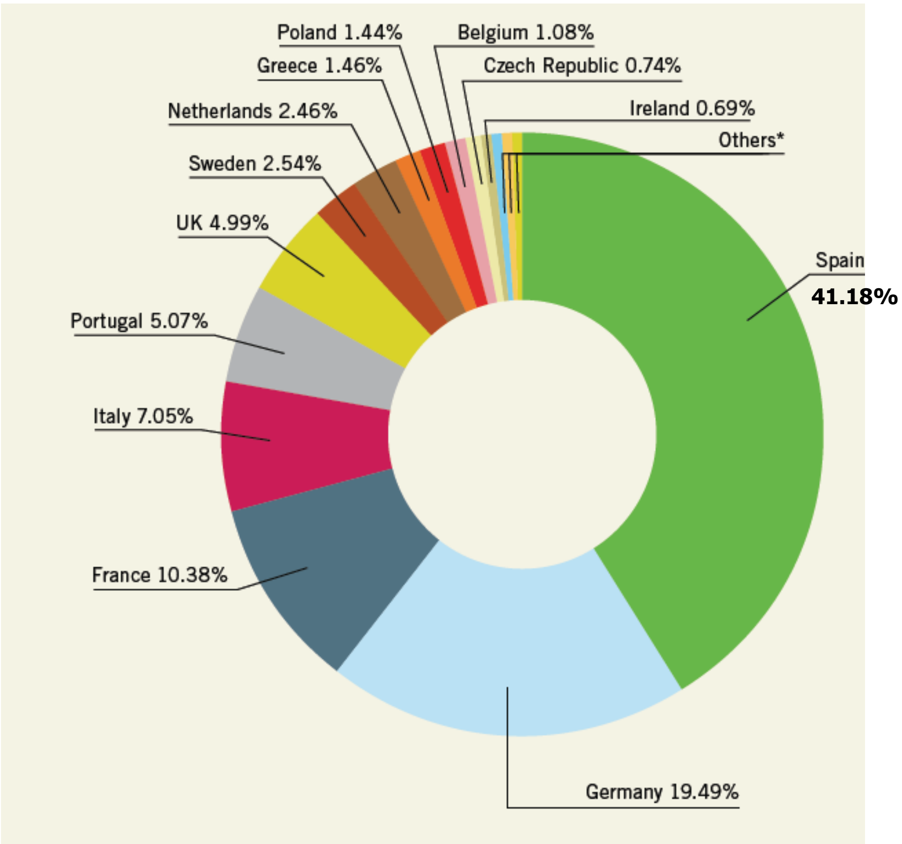
- **Wind power variability and geographic diversity**
  - Diversify ***physical output risk***
  - Diversify ***financial risk exposure*** more complex: related to local market (balancing mechanism) and regulatory (support scheme: feed in tariff or certificates) factors.

  => Focus on physical output risk

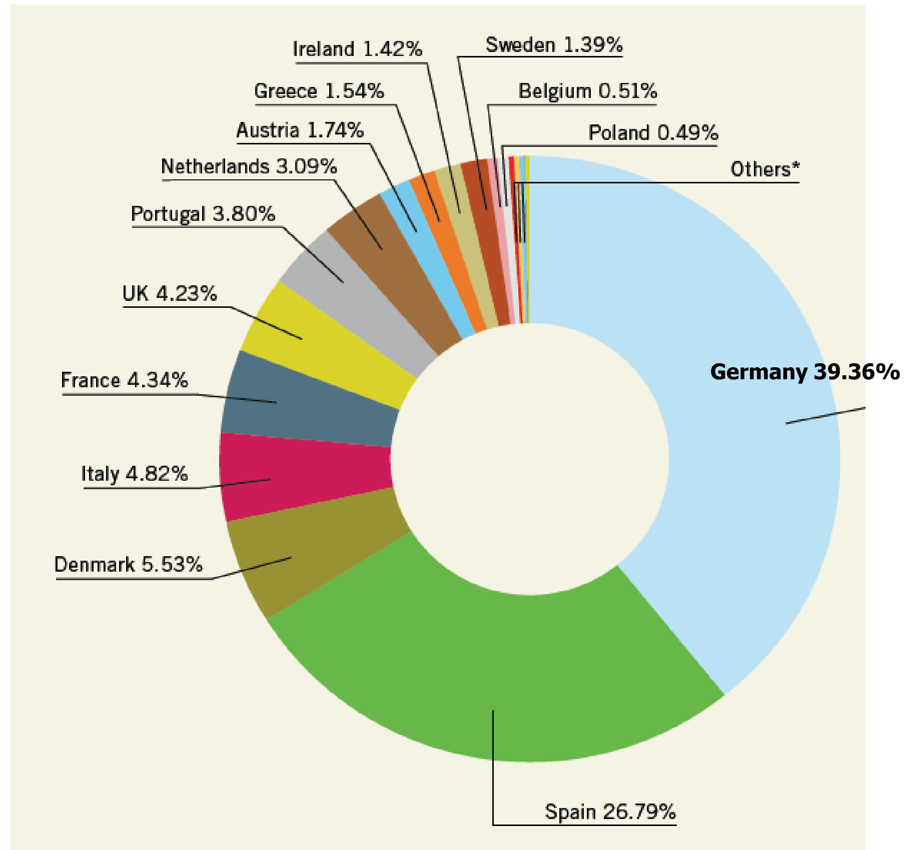
- **Geographic dispersion at which level**? Portfolio approach can help to reduce variability and risk:
  - At the **project** level, within a company's assets portfolio
  - At the **country** level, within a national network system
  - At the **EU** level, countries have particular wind patterns

Wind capacity additions in the EU

2007 new installed capacity, EU27



EU27 Cumulative installed capacity, end 2007



Source: EWEA (2008)

- **Static** perspective: what are the optimal country portfolios?
- **Dynamic** perspective: Are there appropriate incentives for wind power development across the EU countries?

Portfolio analysis of wind power development (2)

- **Diversification over which time scale?**
  - Hourly variability, seasonality, yearly variability
  - Unit commitment/balancing effects/Capacity credit
  - Support schemes introduce an additional dimension (Feed in tariffs vs. green certificates, etc.)

- **Type of analysis is key to define time scale:**
  1. **Investment planning from a "social" perspective:** Optimal portfolios based on hourly consideration on national level have lower risk for unit commitment/balancing or capacity credit.

  ⇒ detailed modeling of transmission capacity, market integration – balancing and day ahead, etc.

  2. **Investment projects from an investor perspective:** construct portfolios that minimize quantity risk / maximize return.

  ⇒ Yearly analysis for long term contracts; monthly analysis for medium term contracts and hourly analysis for Day ahead/balancing trade.

Quantifying the optimal degree of diversity

- The extent to which diversity is to be pursued depends on the balance between the ***extra costs*** and the degree of ***risk reduction*** achieved.

- Various methods have been developed to quantify and optimise the diversity of a portfolio of assets:

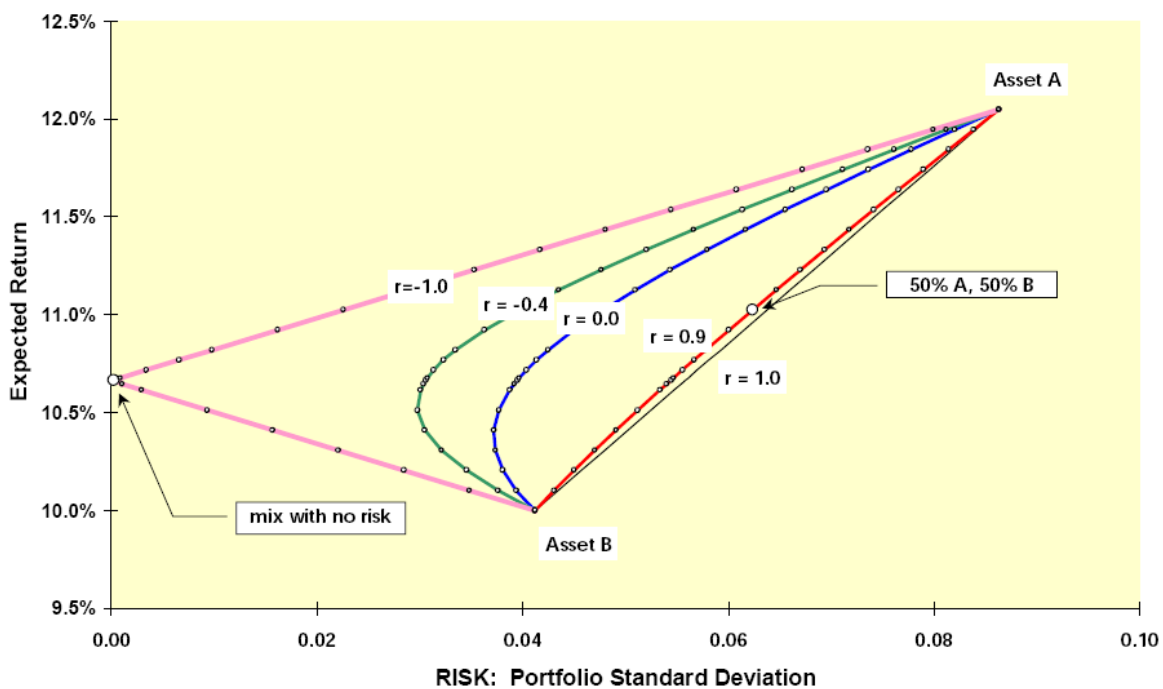
  - **Value at Risk**
    - The Value at Risk (VAR) calculates the maximum loss expected (or worst case scenario) on an investment, over a given time period and given a specified degree of confidence.

  - **Markowitz Mean Variance Portfolio theory**
    - The Mean-variance portfolio theory (MVP) defines efficient portfolios as the ones which have the smallest attainable portfolio risk for a given level of expected return (or the largest expected return for a given level of risk).

The portfolio effect –
The case of a two-asset portfolio

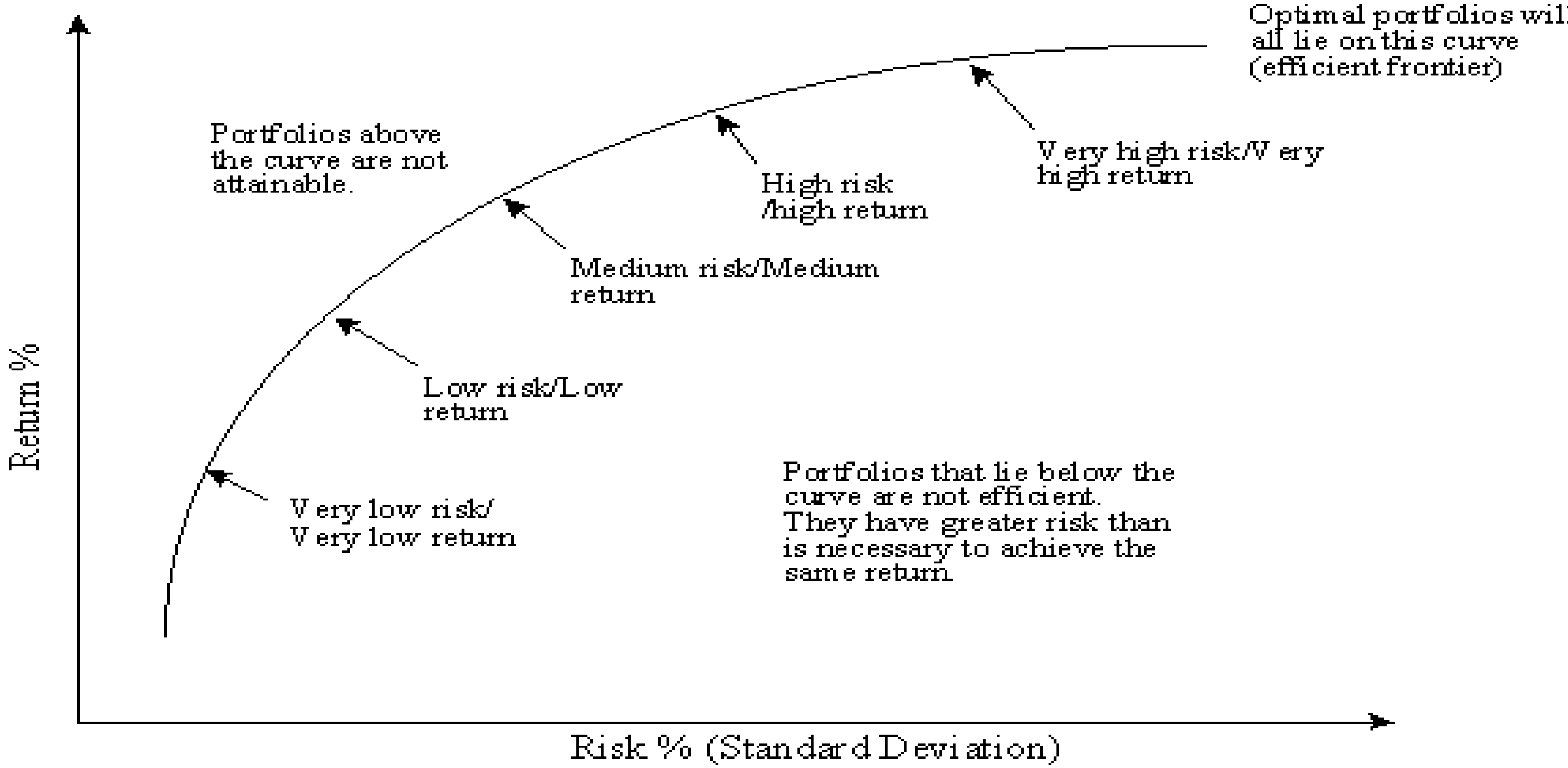
- For two assets (X1, X2) with respective returns (r1, r2) and standard deviation (σ_1, σ_2):
  - Portfolio return: $E(r_p) = X_1 \bullet E(r_1) + X_2 \bullet E(r_2)$
  - Portfolio variance: $\sigma_p = \sqrt{X_1^2 \sigma_1^2 + X_2^2 \sigma_2^2 + 2 X_1 X_2 \rho_{12} \sigma_1 \sigma_2}$
- Efficiency frontier:

Risk and Return for Two-Asset Portfolio
Given Different Correlation Coefficients (r)



Some amount of diversification occurs whenever the returns of two (or more) securities are less than perfectly correlated (i.e. $\rho < 1.0$)

Portfolio theory efficient frontier



- The efficient frontier for a portfolio of two risky assets.
- MVP theory does not prescribe a single optimal portfolio combination, but a **range of efficient choices**.
- Investors will choose a risk-return combination based on their **own preferences and risk aversion**.

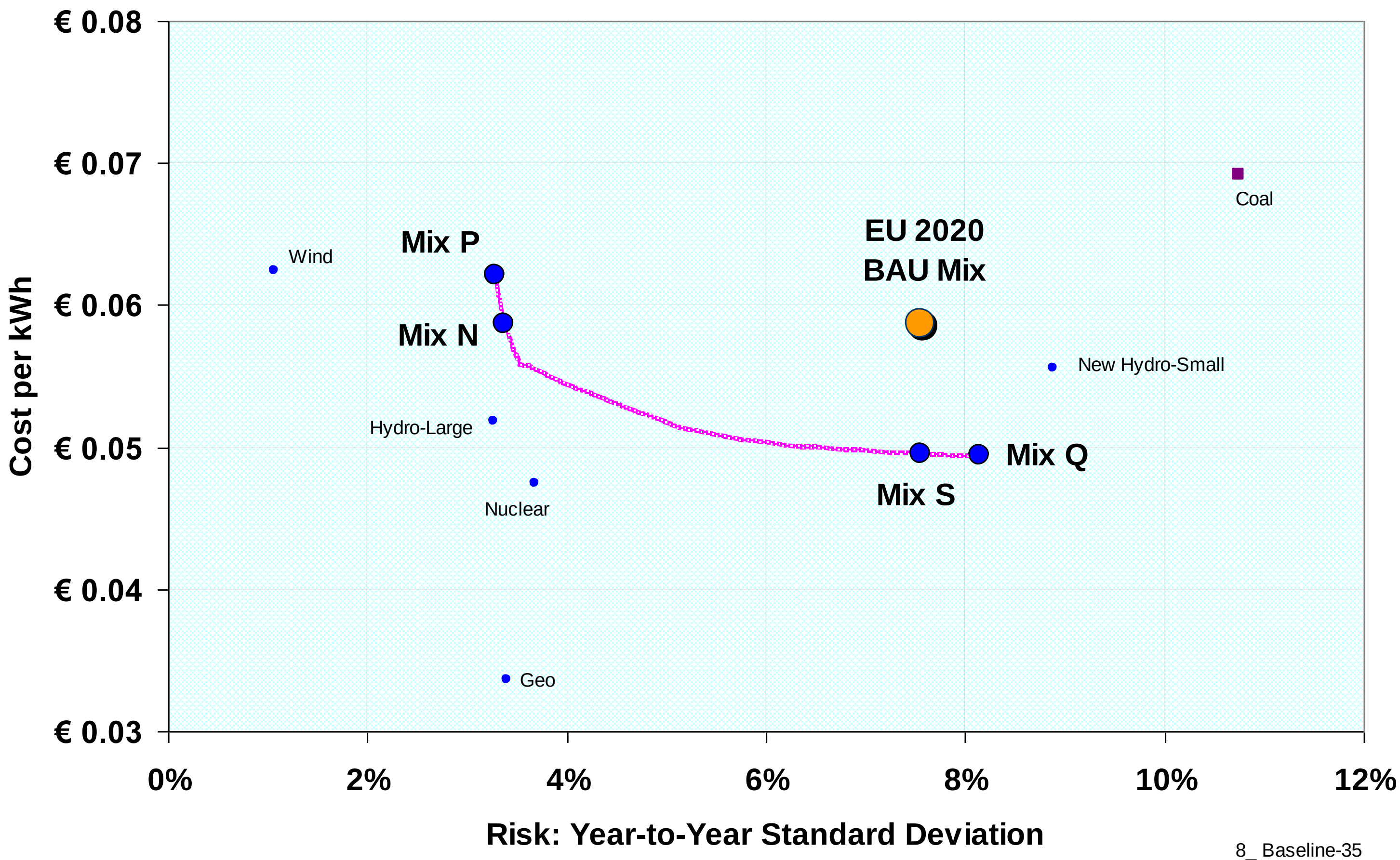
Literature review - Wind power and Portfolio Analysis

- **Portfolio analysis that consider the effect of wind power in a conventional electricity generation portfolio (gas, coal, nuclear, etc.)**
  - DeLaquil P. et al. (2005), McLoughlin and Bazilian (2006), Kienzle et al (2007), Awerbuch and Berger (2003), Twomey (2005), etc…

- **Geographical or spatial effects of wind power**
  - Correlation analysis: Sinden (2007), Hirst (2002), Giebel (2000), etc.
  - Porfolio analysis:
    - Drake and Hubacek (2007)
    - Kyle Datta E. and Hansen L. (2005)
    - Hansen L. (2005)

- **Other effects (e.g. power network, demand)**
  - Drake and Hubacek (2007) take into account transmission losses.
  - Sinden (2007) takes into account the correlation between wind power and demand

Optimisation of EU power generation mix – Awerbuch and Yang (2005)



2020 EU Baseline Portfolio Optimization (CO2=E35/tonne) – Source: Awerbuch and Ynag (2005)

2020 EU Baseline Portfolio Optimization indicates that renewables can reduce risk and cost

Applying portfolio theory to geographical dispersion

- **The key point: wind speed correlations between different wind farms**
  - Focus can be on ***physical output risk; or***
  - on ***investment project financial risk exposure***

- **Holding period return defined as in finance:**
  - Physical output: (Pt – Pt-1)/Pt
  - Financial return: project NPV, or variation of cash flows/generation cost

- **Constructing the efficiency frontier:**
  - Data on average wind power generation, standard deviations and correlation coefficients
  - Optimization model to compute minimum standard deviation (portfolio risk) that exists for any given rate of average power generation (portfolio return) that is input into the model

The database

- **Type of data:**
  - Real production data (Hirst 2002)
  - Simulated data from wind speed data (Hansen 2005, Kyle Datta and Hansen 2005, Drake and Hubacek 2007, Sinden 2007)

- **Data resolution:**
  - Hourly (Drake and Hubacek (2007) and Sinden (2007))

  ⇒ How many years are necessary to have reliable data?

  ⇒ How does « geographical aggregation » of data impact results?

  ⇒ Which data resolution/filtering for what type of analysis?

- **Our database: aggregated hourly wind production data:**
  - Spain (from 2002 to 2007)
  - Germany by TSO zone (from 2006 to 2008)
  - Austria (from 2006 to 2007)
  - Denmark by zone (from 2000 to 2008)

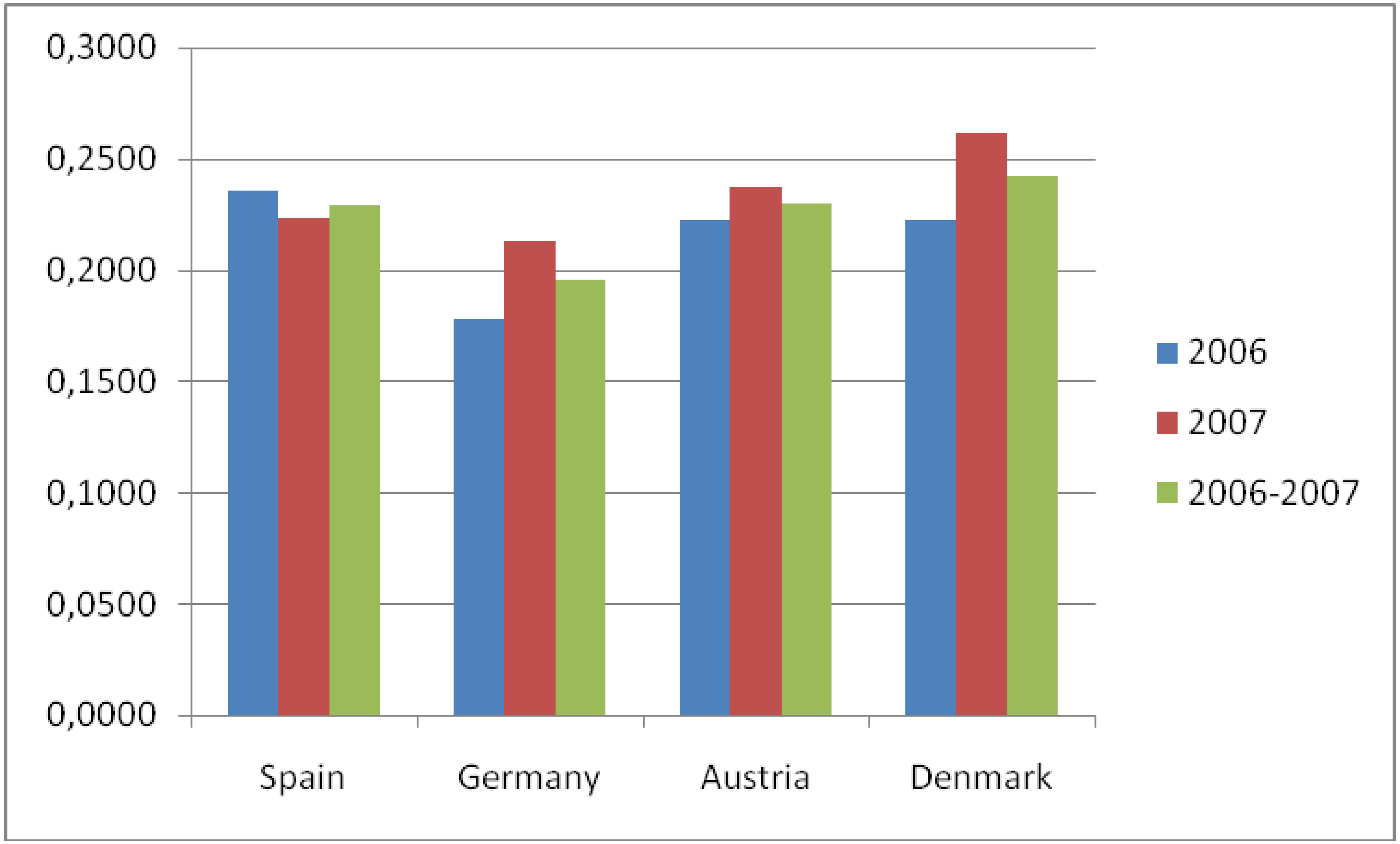
- **We are waiting for:**
  - French production data (from 2006 to 2007)
  - Wind speed data for several European Countries

Preliminary results

- Results based on hourly wind production data (2006 –2007) for Spain, Germany, Austria, and Denmark

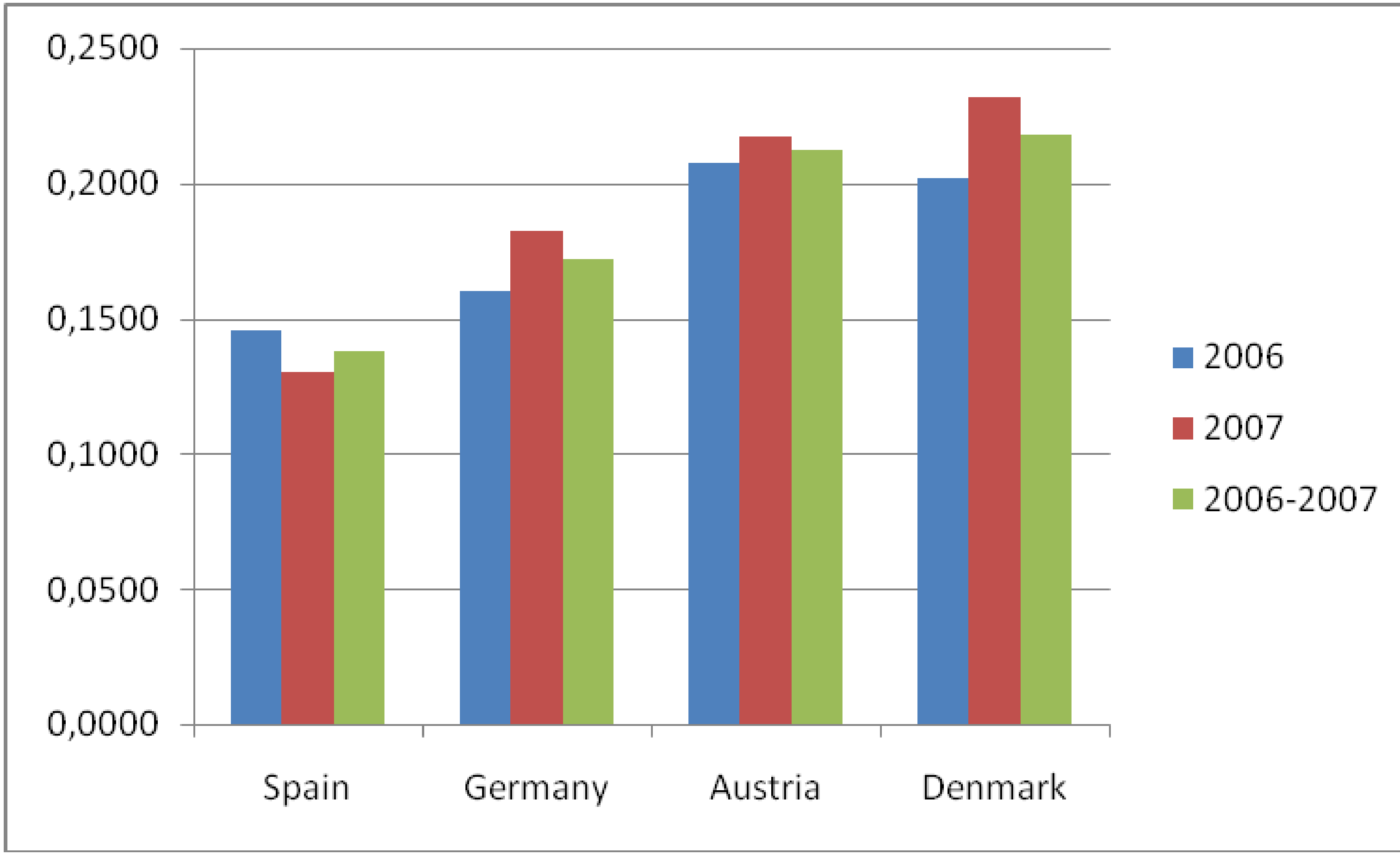
- Outputs:
  - Wind Capacity Factor variability (Sinden 2007)
  - Interaction of wind production and demand (Sinden 2007)
  - **Portfolio Analysis**
    - Wind output
      - Hourly analysis
      - Monthly analysis
    - Wind output and demand

Intern-annual variability
Average capacity factor



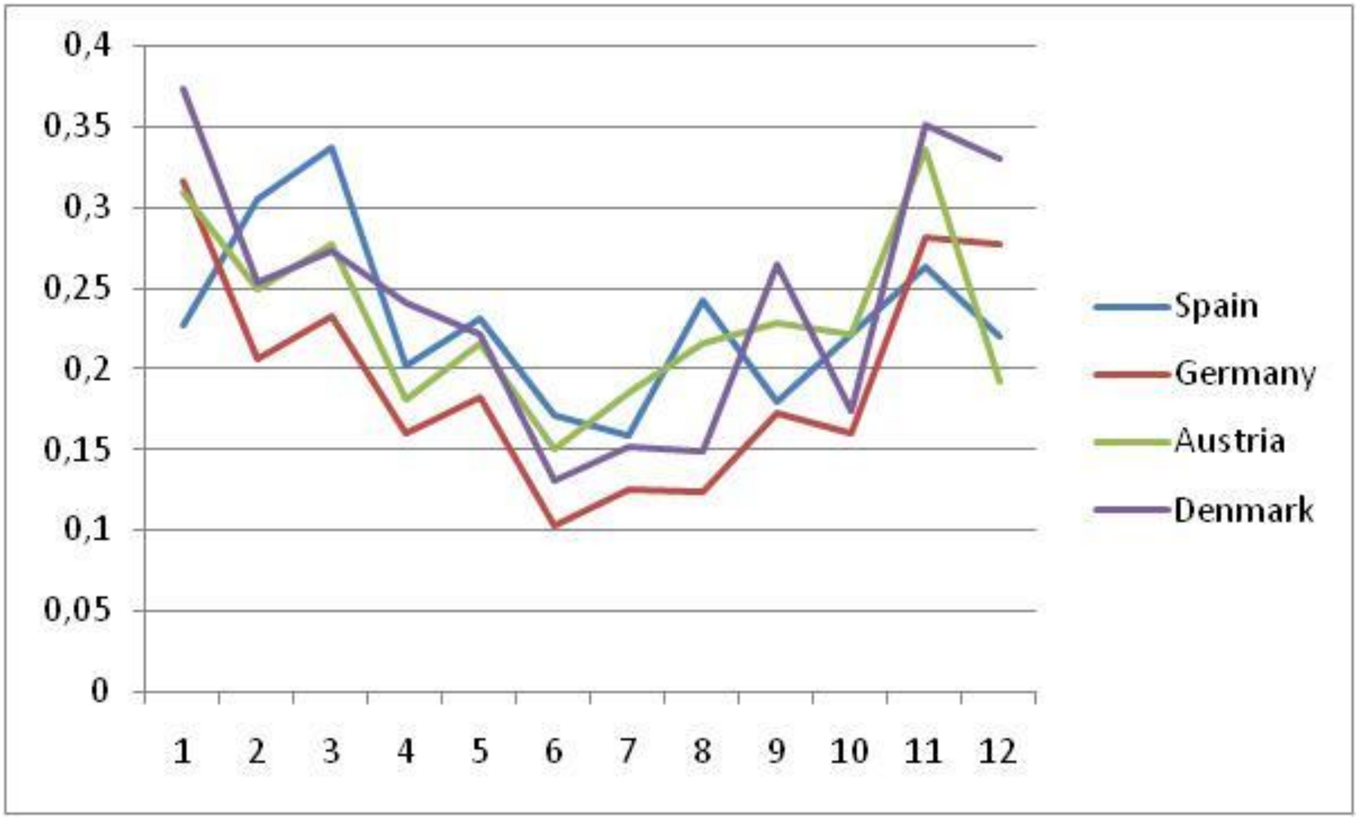
- Capacity factors computed dividing hourly wind power production by installed capacity
- Assumption that installed capacity changes linearly during the year

Intern-annual variability
Standard deviation of capacity factor



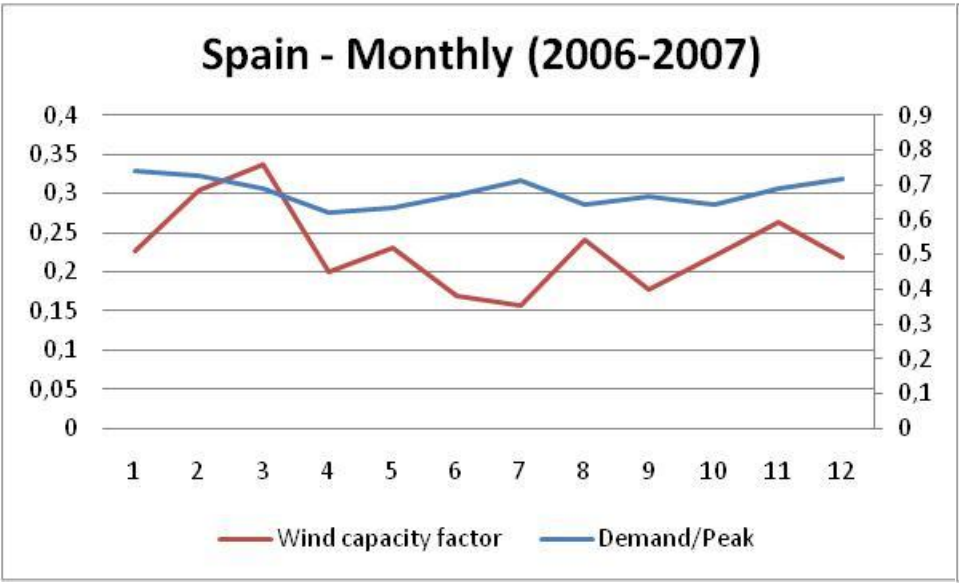
- Hourly standard deviation varies significantly year to year…
- Smaller countries have less dispersed wind farms => higher standard deviation

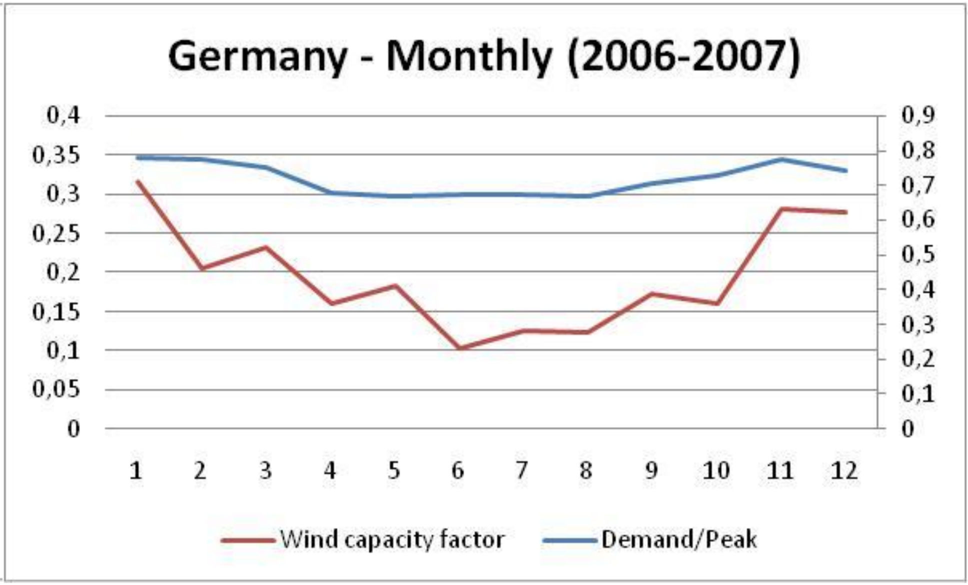
Monthly Wind Power Variability (Monthly Capacity factors)

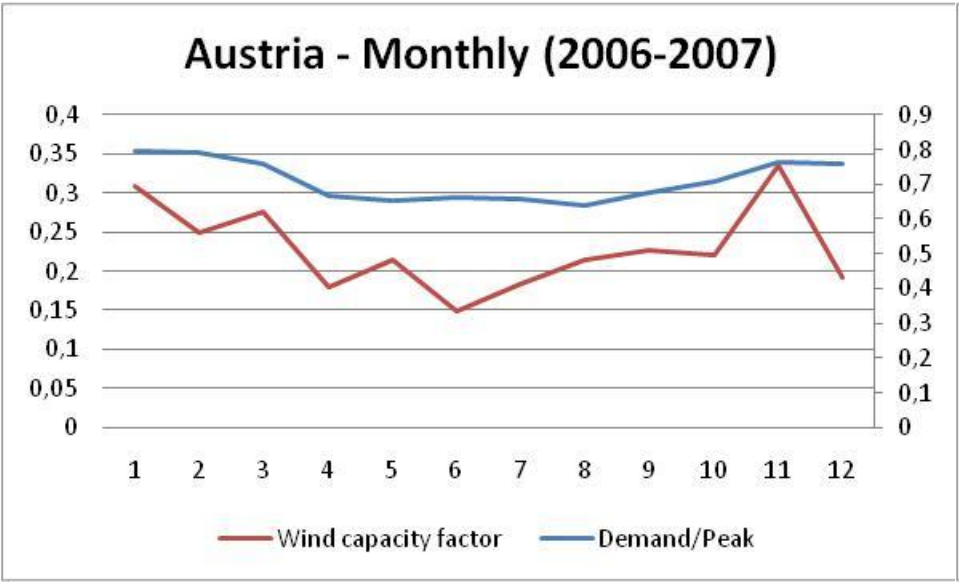


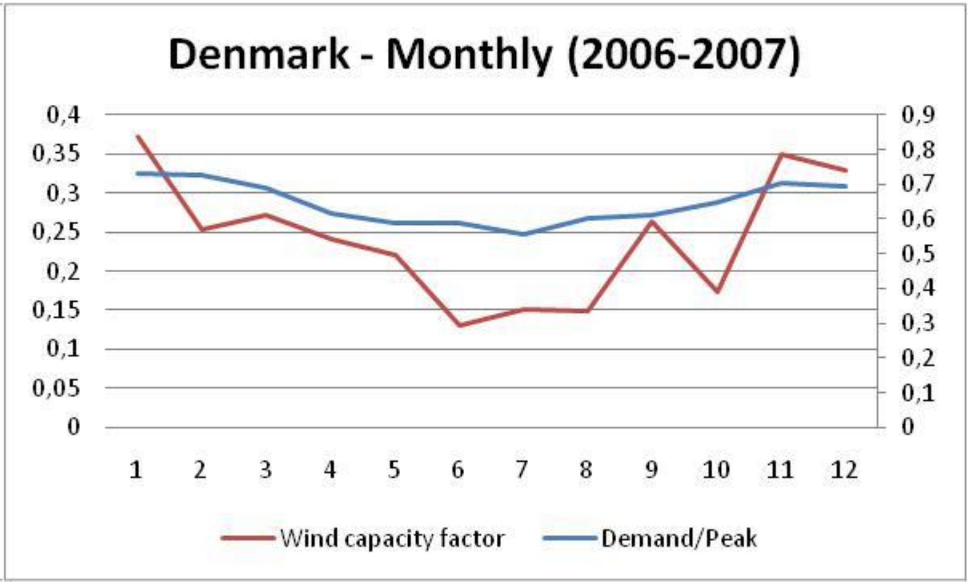
- Patterns significantly different across countries
- Spain has much less seasonal variability

Wind Power and demand Monthly comparison

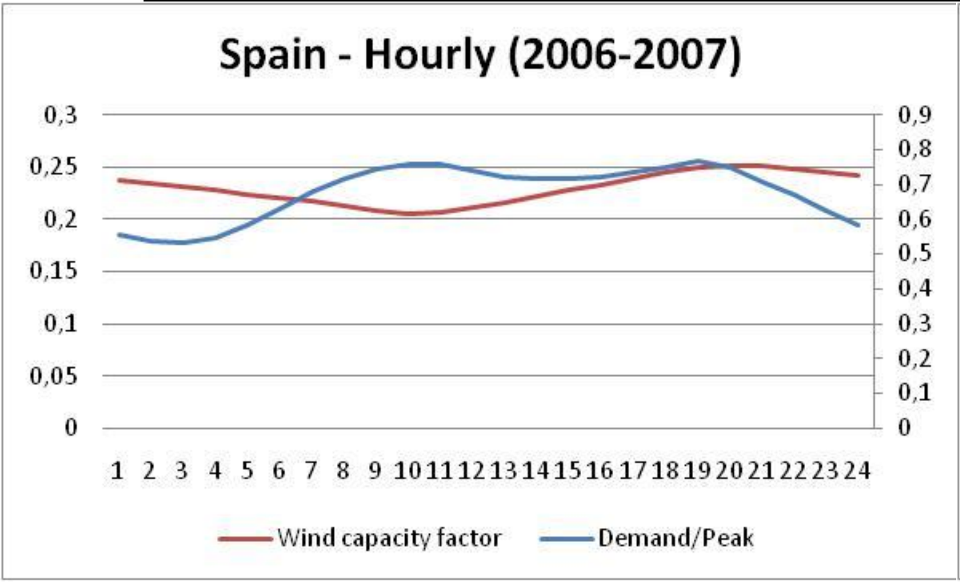


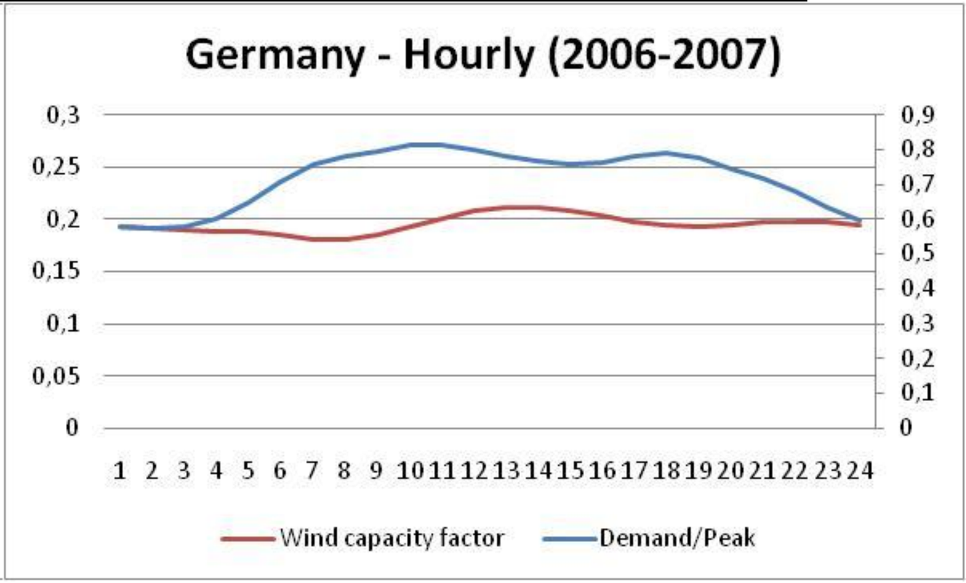


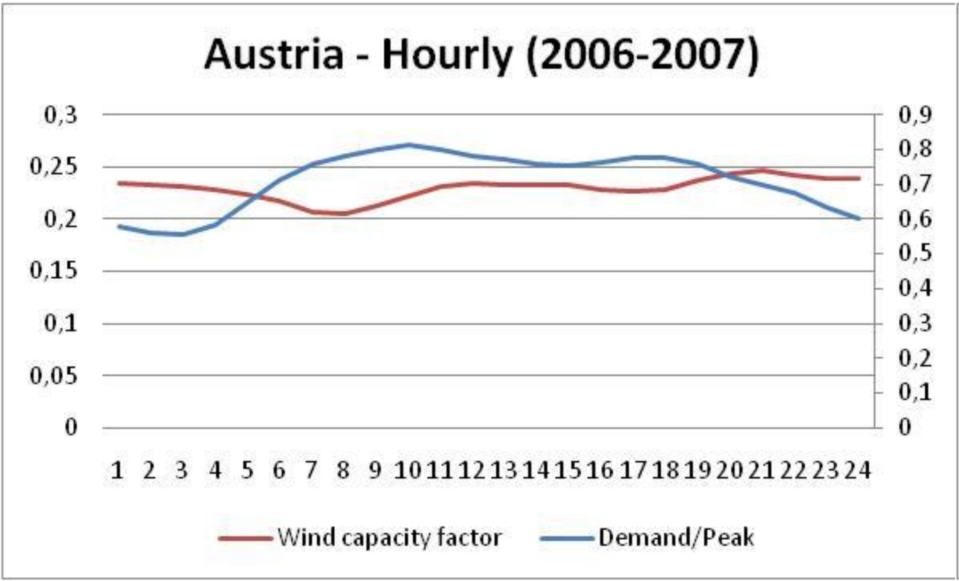


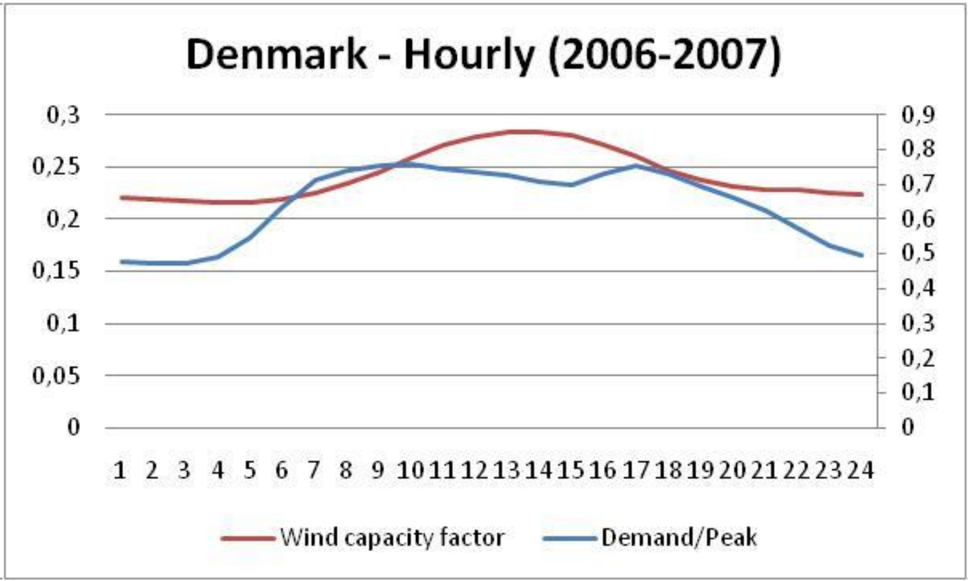


Wind Power and demand
Hourly comparison









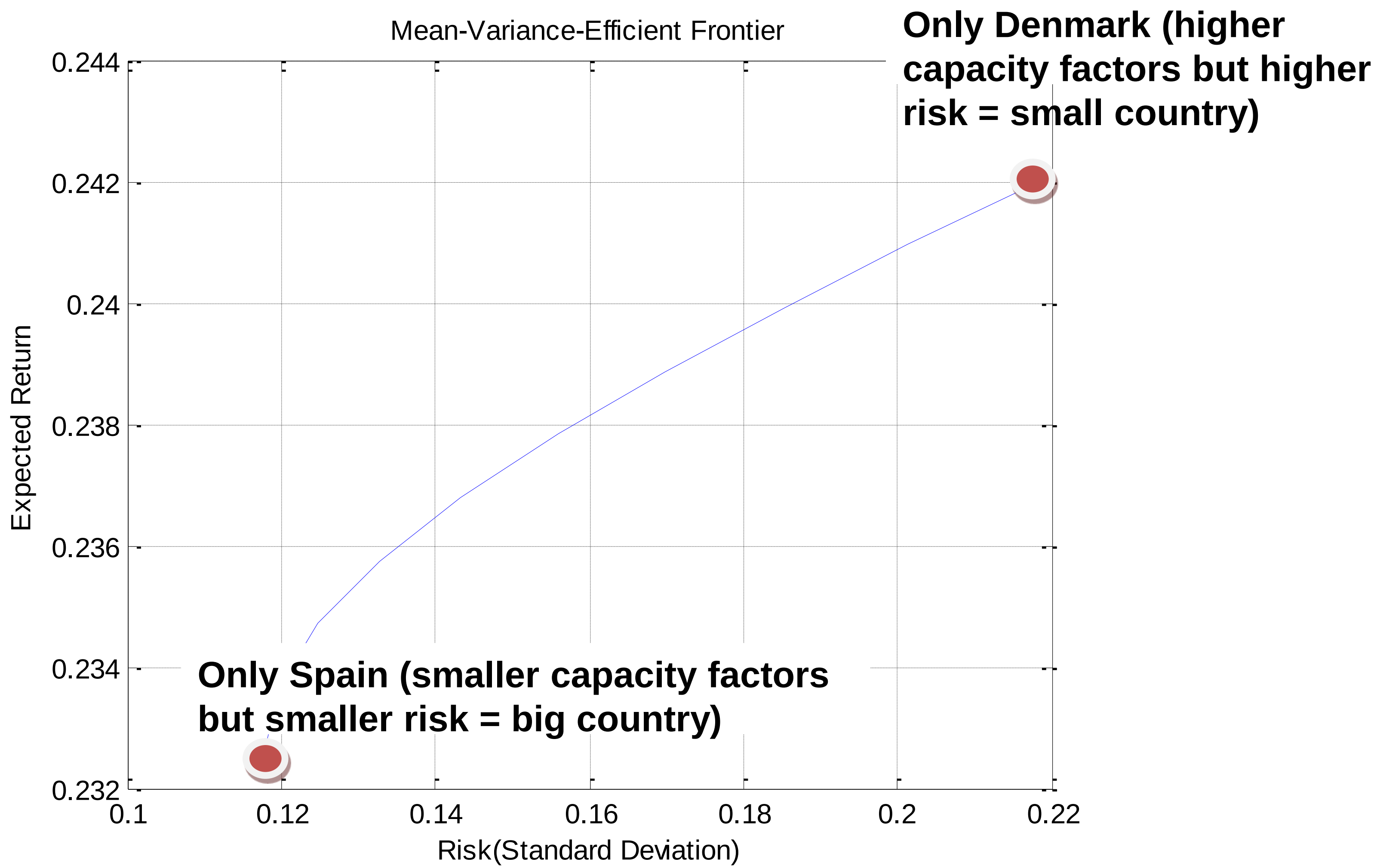
Portfolio analysis (à la Hansen 2005) Wind power only (Hourly analysis)

Correlations analysis

Correlation				
	Spain	Germany	Austria	Denmark
Spain	**1,0000000**	**0,0970128**	**0,1516223**	**0,0235352**
Germany		**1,0000000**	**0,2473075**	**0,7092889**
Austria			**1,0000000**	**0,1045161**
Denmark				**1,0000000**

- Social planner optimisation, assuming:
  - only four countries
  - no physical constraints (integrated markets)
  - no limit in wind potential
  - that capacity factors by country are geographically consistent

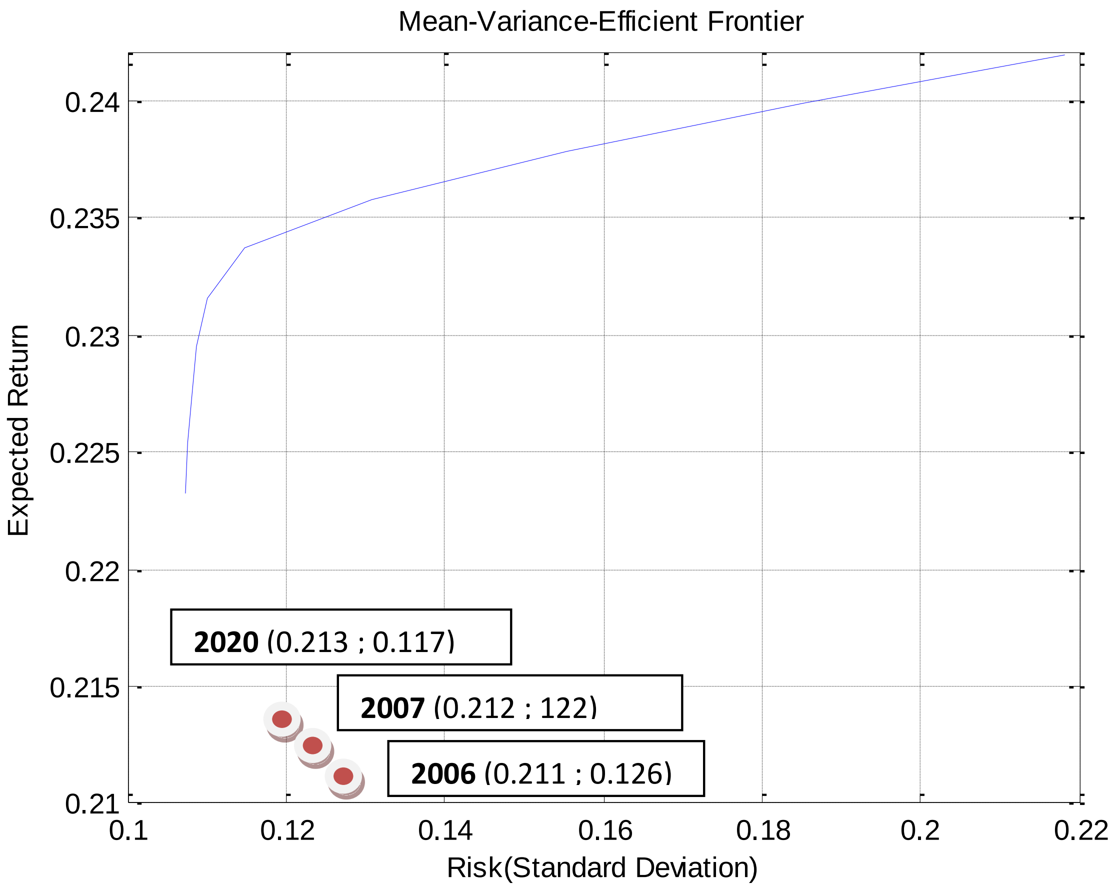
Optimal wind portfolios for Spain and Denmark (weakest correlation = 0.0235) – Only Wind Power



Optimal portfolios for Spain-Germany-Austria-Denmark

Mean	Risk	Weight Spain	Weight Germany	Weight Austria	Weight Denmark
0,2233	0,107	53,99%	20,99%	14,87%	10,15%
0,2254	0,108	54,79%	16,11%	15,64%	13,46%
0,2274	0,108	55,58%	11,22%	16,42%	16,78%
0,2295	0,109	56,37%	6,34%	17,20%	20,09%
0,2316	0,11	57,16%	1,46%	17,98%	23,41%
0,2337	0,115	49,46%	0,00%	14,84%	35,71%
0,2358	0,131	38,14%	0,00%	10,04%	51,82%
0,2378	0,156	26,83%	0,00%	5,24%	67,94%
0,2399	0,185	15,51%	0,00%	0,44%	84,05%
0,242	0,218	0,00%	0,00%	0,00%	100,00%

Efficient frontier for wind portfolios in Spain-Germany-Austria-Denmark



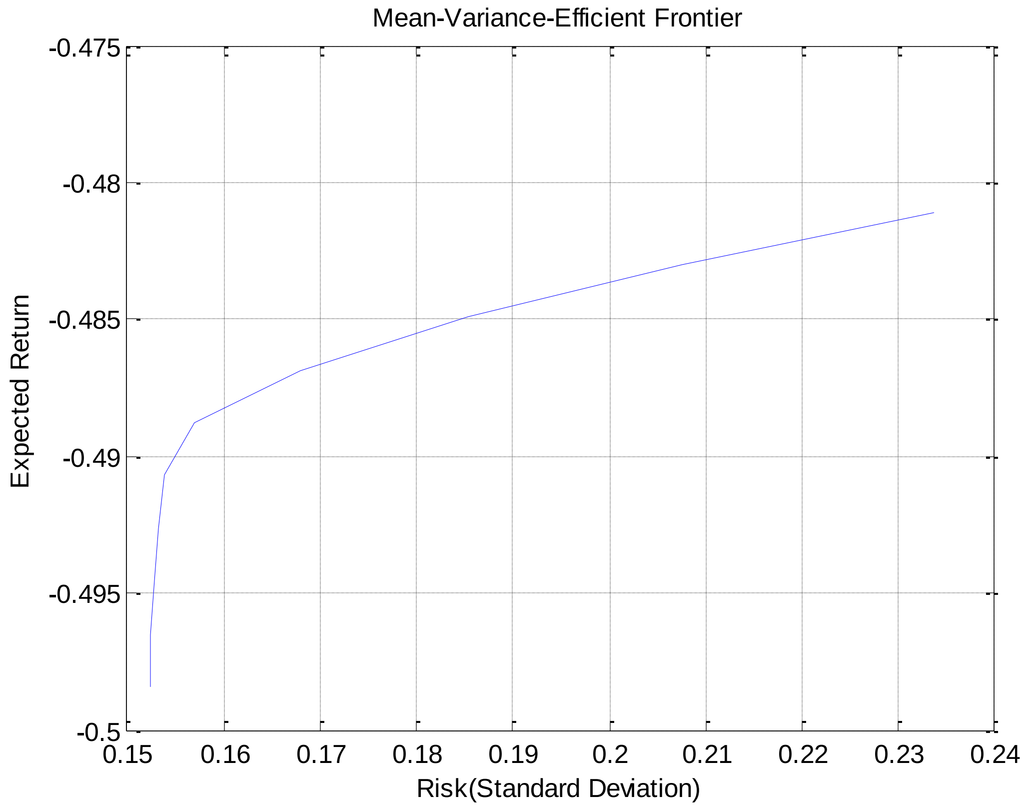
- Current portfolio is far from efficient frontier
- Things will improve in the future as weight of Germany decreases

Wind Power and demand "Net demand" variability

- **Correlations between**
  - Demands
  - Wind power productions
  - Net demands?

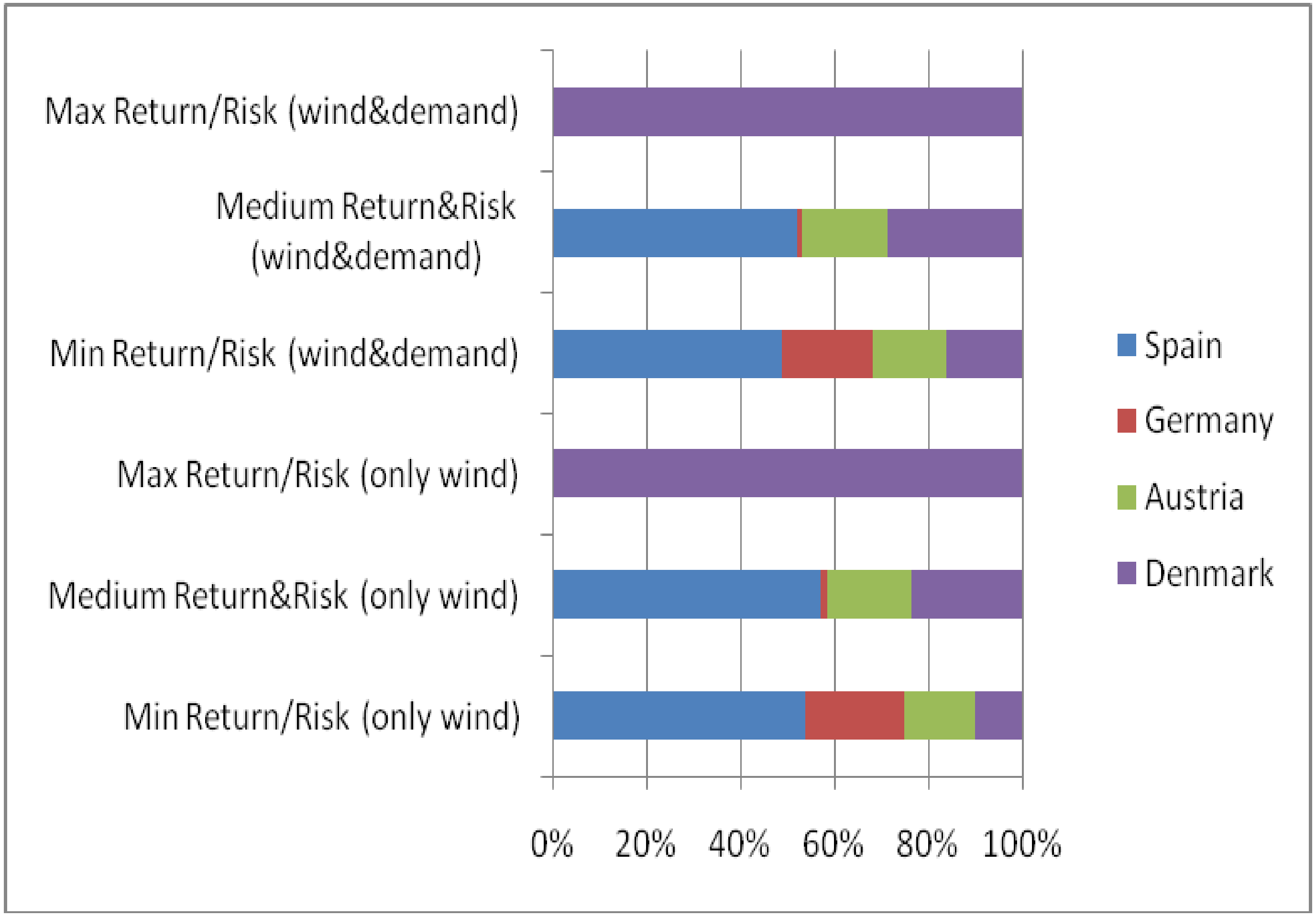
- **Methodology:**
  - To construct data series for hourly wind capacity factor by country "i" (this capacity factor is the production for 1 MW installed in each country assuming that these aggregated capacity factors are representative for the whole country) --> WCFi
  - To construct a data series for hourly total demand factor (this represents hourly demand in terms of global installed capacity or peak load) --> TDF
  - To construct data series for hourly "needed generation capacity" as NCi = WCFi – TDF. Then, computing efficient frontier for NCi and determine "efficient portfolio"

Wind Power and demand « Net demand » variability



- This ”net demand approach” is not so realistic (because we are not considering wind potential, transmission constraints and lack of market integration).
- It could become more interesting if we can include these issues.

Summary of results



- Correlation between each country wind capacity factor and total demand:

Spain	Germany	Austria	Denmark
0,04770768	0,13084032	0,07255191	0,15446145

Conclusions

- **As wind power penetration increases:**
  - Focus shifts from best sites towards optimization of utilities / countries portfolios
  - Correlation between wind sites is key, but also correlation with load and other power production technologies

- **Portfolio theory is a powerful tool to optimize wind portfolios at different geographical levels…**
  - Risk-reward tradeoffs of utilities investments
  - Social planners for deployment support policy

- **…But realistic analysis requires to take into account dispatching and transmission constraints…**

References

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Thank you for your attention!

Comments much welcome!

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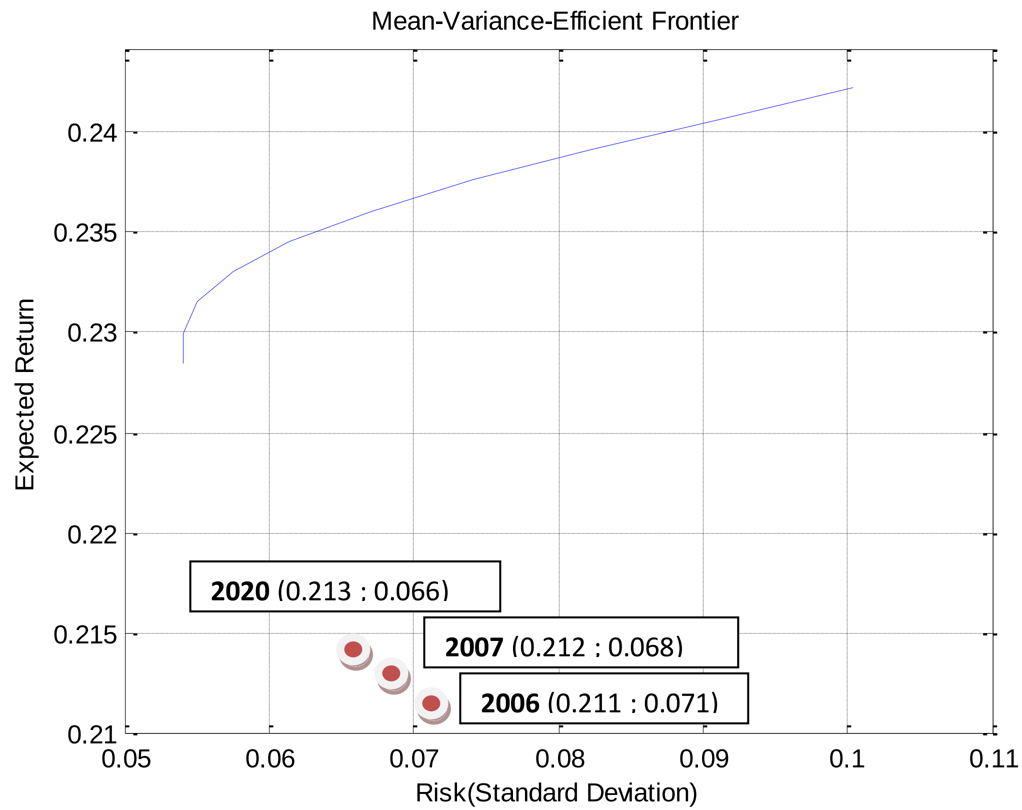
Next steps

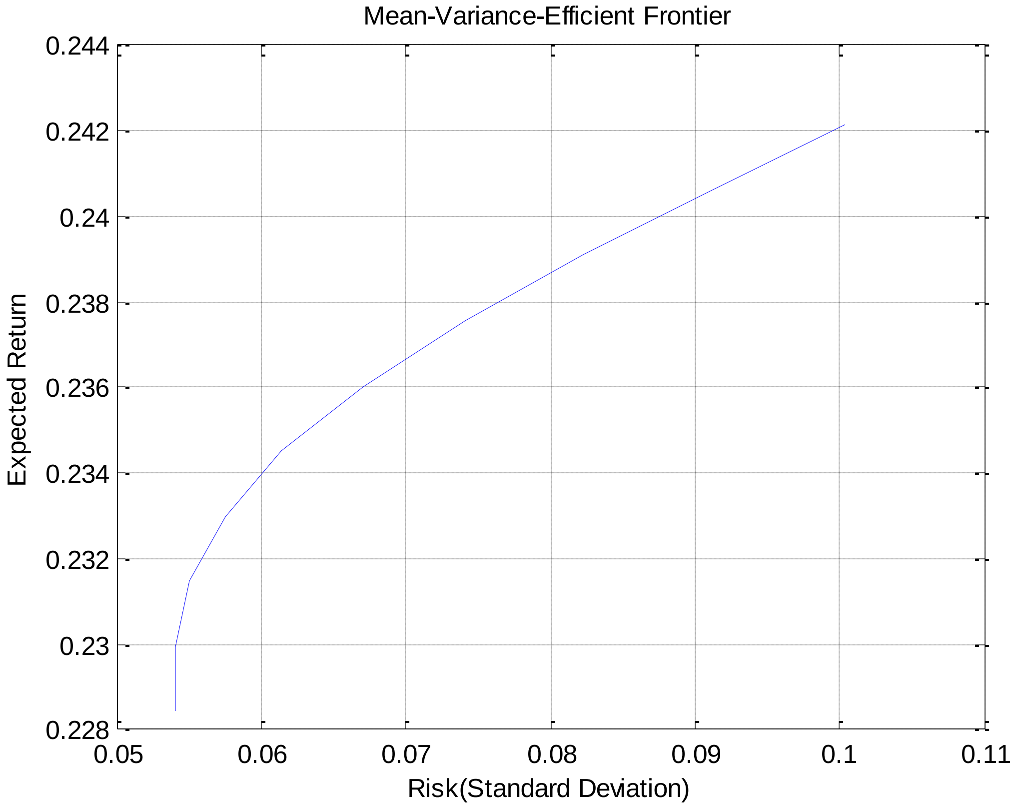
- Data
  - Type of data (we will have more real wind power generation)
  - Scaling data?
  - What to do with data for different years ?
    - Construct probability distribution and simulate wind power generation?
  - Is it possible to combine different type of data (actual generation and simulated generation with wind speed)?
    - Under which assumptions
  - Costs & support scheme Data → $ porfolio analysis
- Computations to do
  - Scenarios

With average monthly data – wind only



- Same mean but different variance changes optimal portfolios
- More comment?

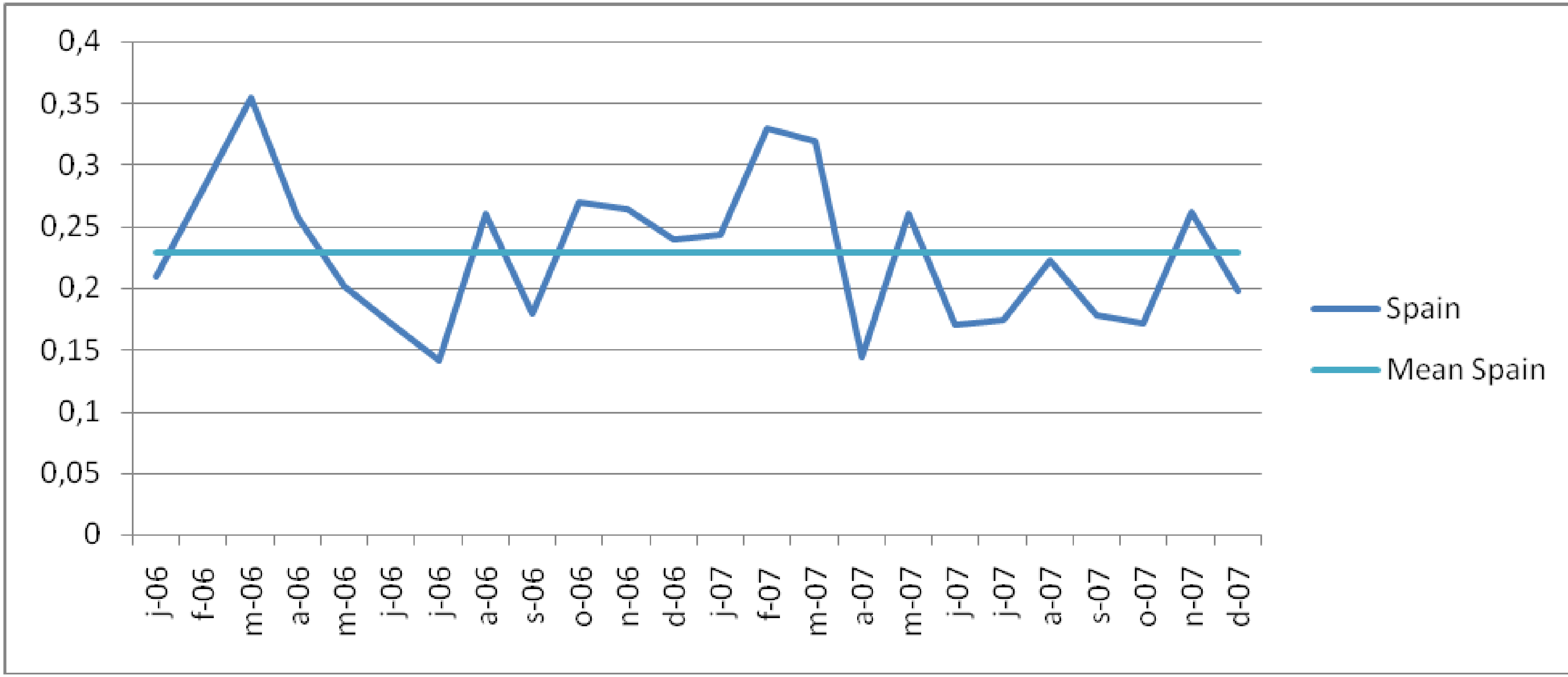
With average monthly data – wind only



- Same mean but different variance changes optimal portfolios
- More comment?

Mean	Risk	Weight Spain	Weight Germany	Weight Austria	Weight Denmark
0,2284	0,054	63,34%	2,96%	33,00%	0,71%
0,23	0,054	63,82%	0,00%	31,44%	4,75%
0,2315	0,055	65,53%	0,00%	17,62%	16,85%
0,233	0,057	67,24%	0,00%	3,80%	28,96%
0,2345	0,061	59,13%	0,00%	0,00%	40,87%
0,236	0,067	47,31%	0,00%	0,00%	52,69%
0,2376	0,074	35,48%	0,00%	0,00%	64,52%
0,2391	0,082	23,65%	0,00%	0,00%	76,35%
0,2406	0,091	11,83%	0,00%	0,00%	88,17%
0,2421	0,1	0,00%	0,00%	0,00%	100,00%

Monthly Wind Power Variability (Monthly Capacity factors)



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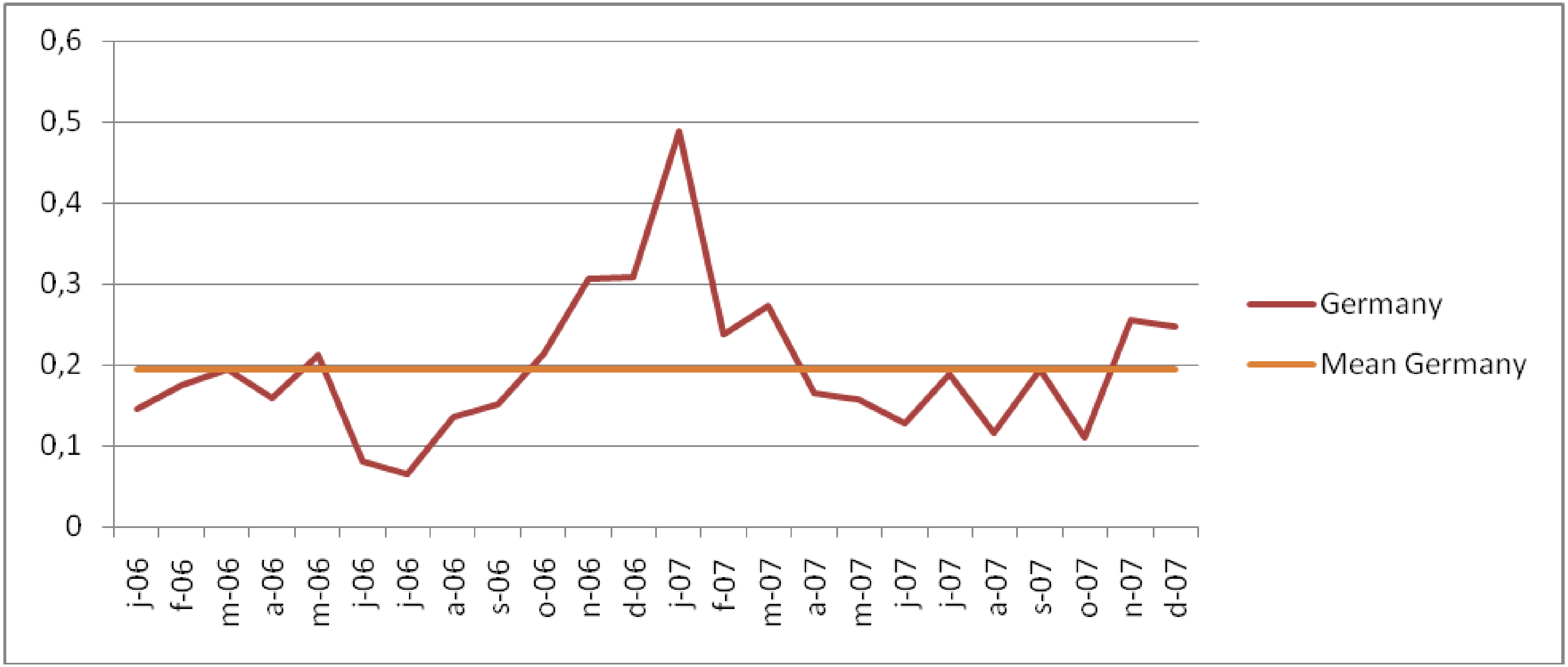

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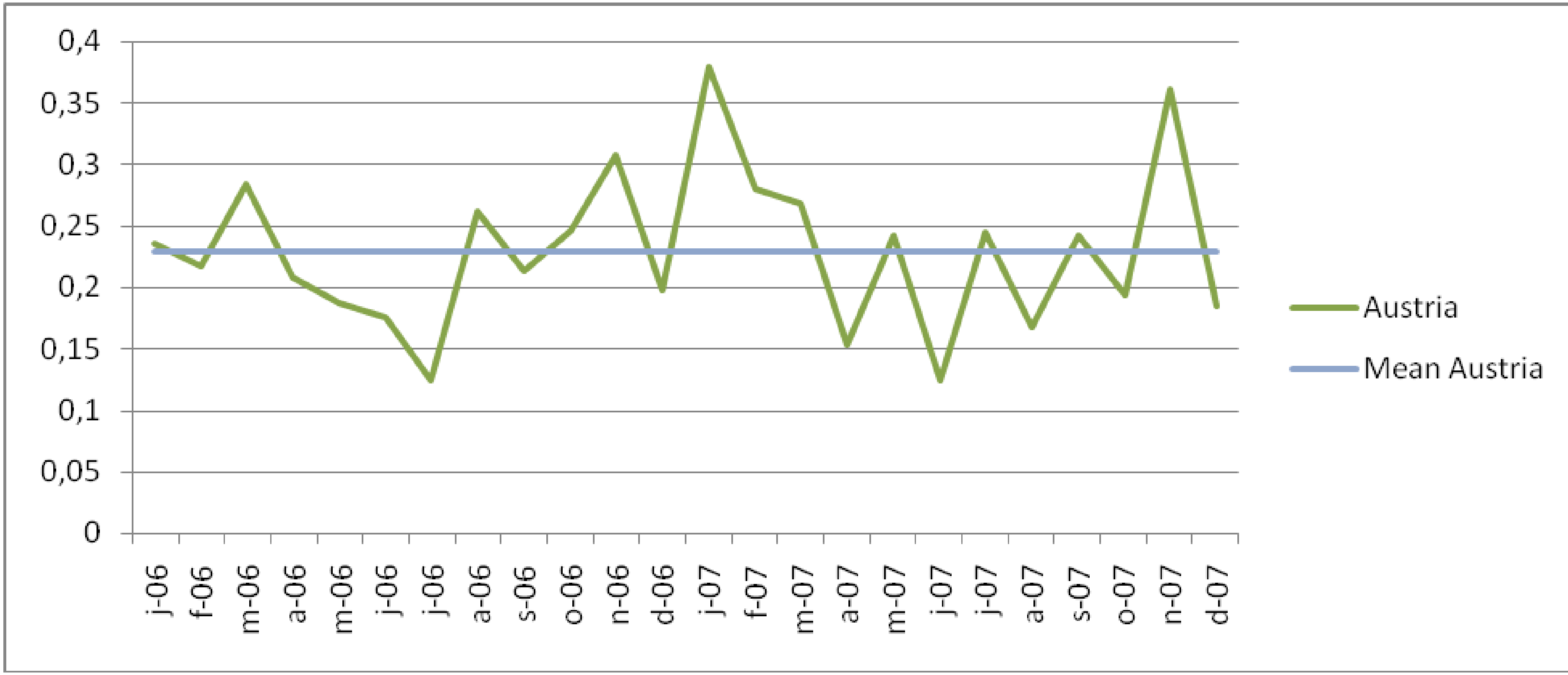

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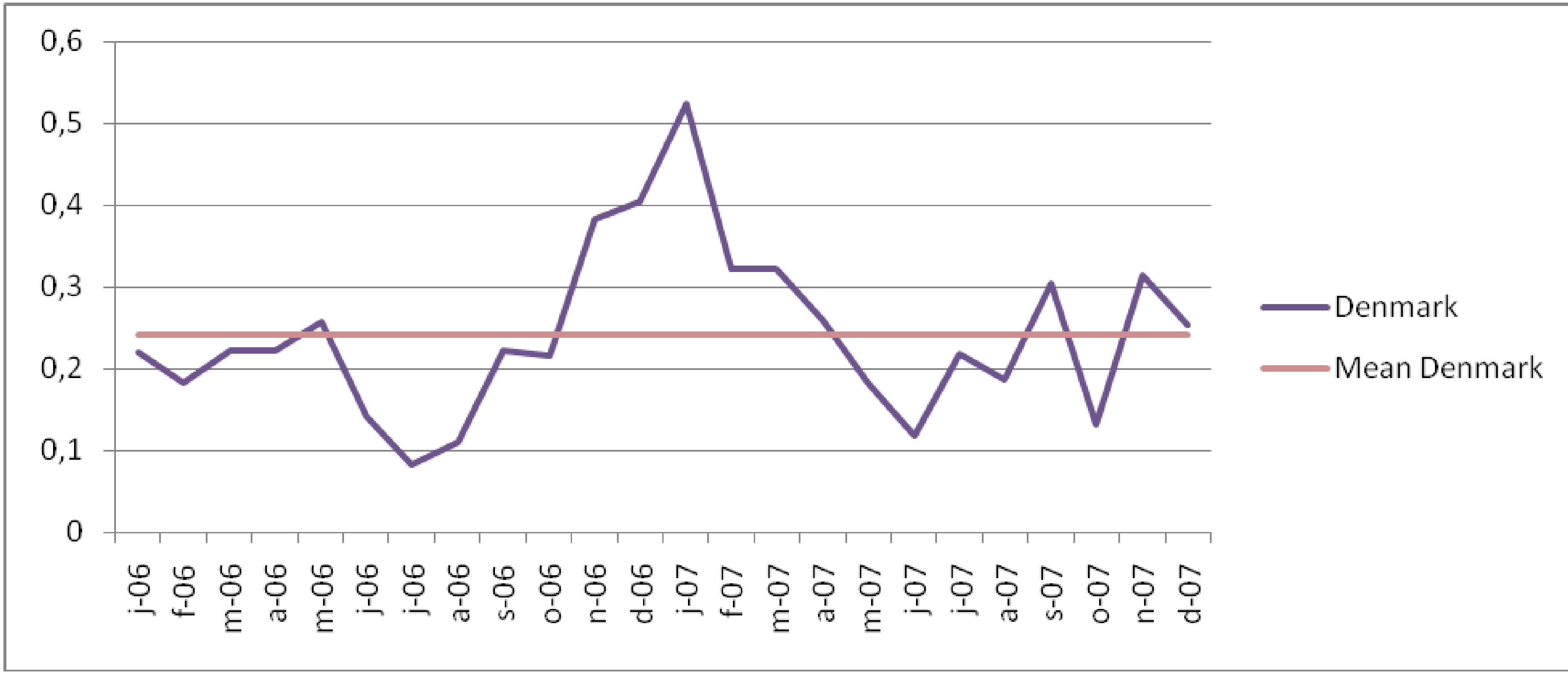

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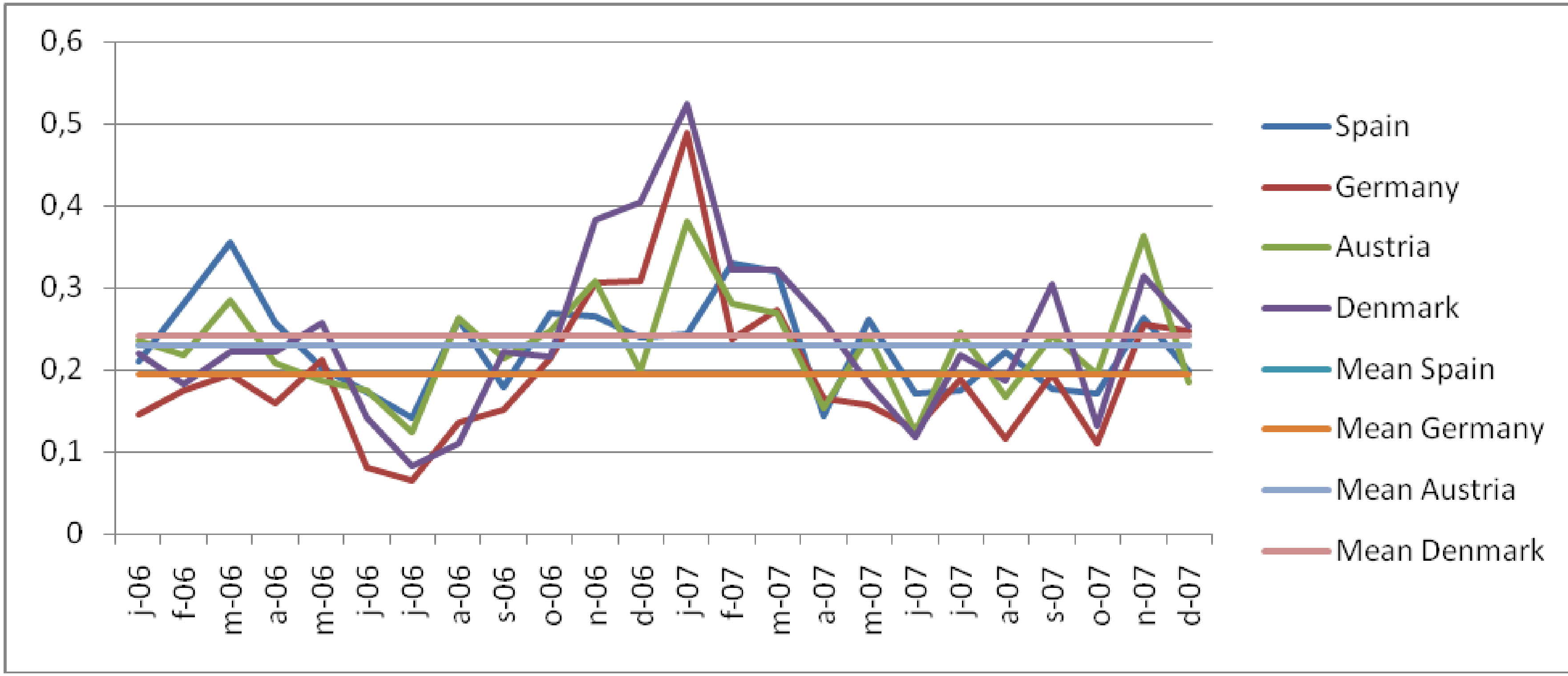
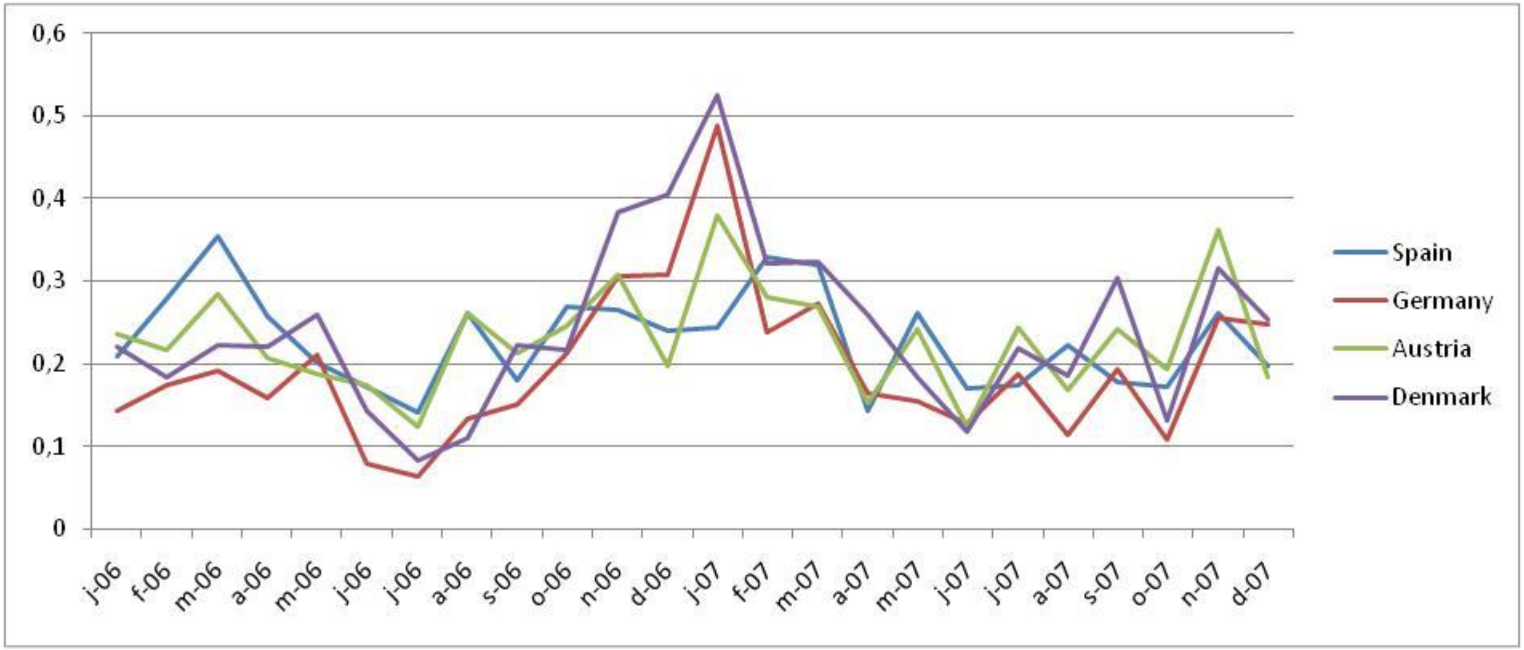


Summary of results

	Spain	Germany	Austria	Denmark
Min Return/Risk (only wind)	53,99%	20,99%	14,87%	10,15%
Medium Return&Risk (only wind)	57,16%	1,46%	17,98%	23,41%
Max Return/Risk (only wind)	0,00%	0,00%	0,00%	100,00%
Min Return/Risk (wind&demand)	49,04%	19,30%	15,43%	16,23%
Medium Return&Risk (wind&demand)	51,97%	1,19%	18,31%	28,52%
Max Return/Risk (wind&demand)	0,00%	0,00%	0,00%	100,00%

- Comment here

Monthly Wind Power Variability (Monthly Capacity factors)



Efficient frontier for wind portfolios in Spain-Germany-Austria-Denmark