Grid Integration of Renewables:

Technical issues and impacts on market design

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University College Dublin

Energy Finance/INERC

University Duirburg-Essen October 8th 2010

“Electricity has a value at every instant

in time and at every point in the system”

Schweppe, F. C., et al., *Spot Pricing of Electricity,* Kluwer Academic Publishers, 1988.

Electricity Research Centre (ERC)

ERC Industry Members and Board

Other stakeholders on the ERC board:

seai

ESRI

Department of Communications
Energy & Natural Resources

Electricity Research Centre (ERC)

ERC currently consists of four research strands

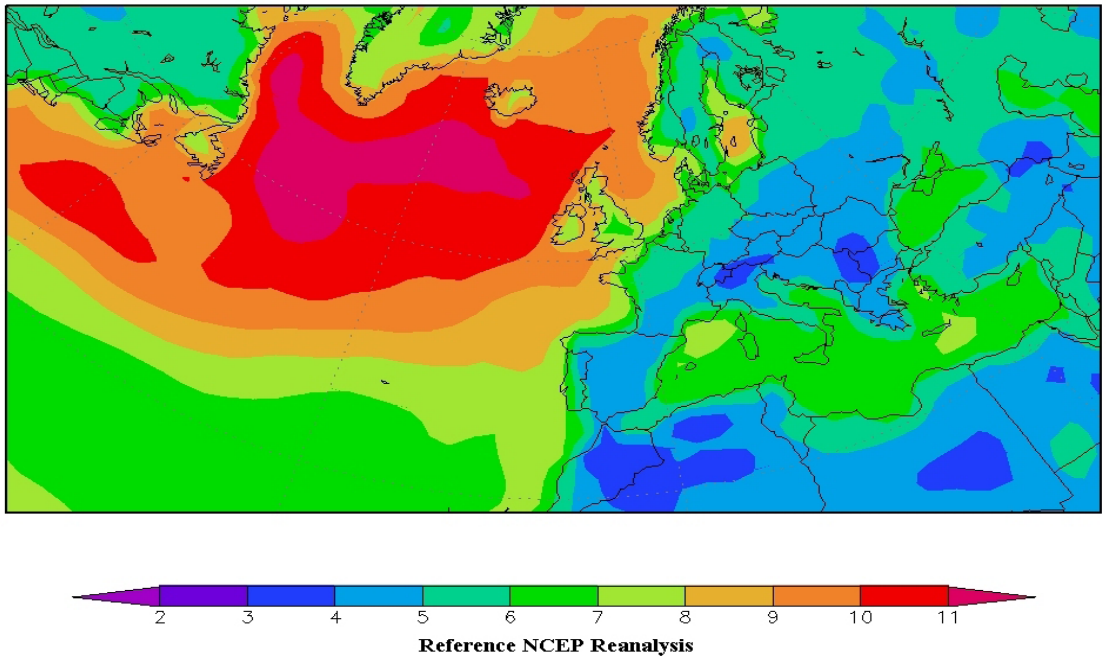
- Operations
- Networks
- Economics
- Systems

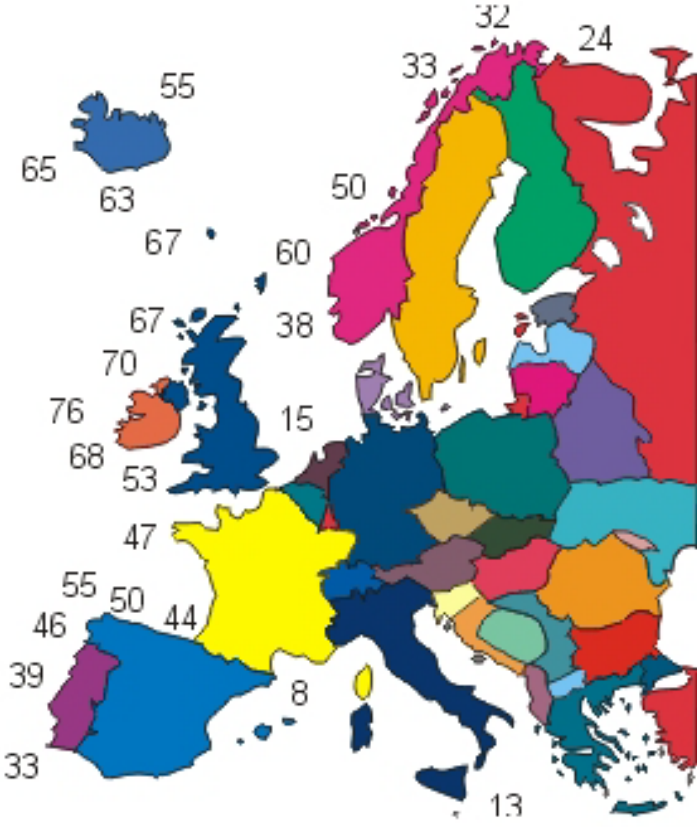
Prof Mark O'Malley, director
Established in 2001
Research group of 33 in 2010

http://erc.ucd.ie

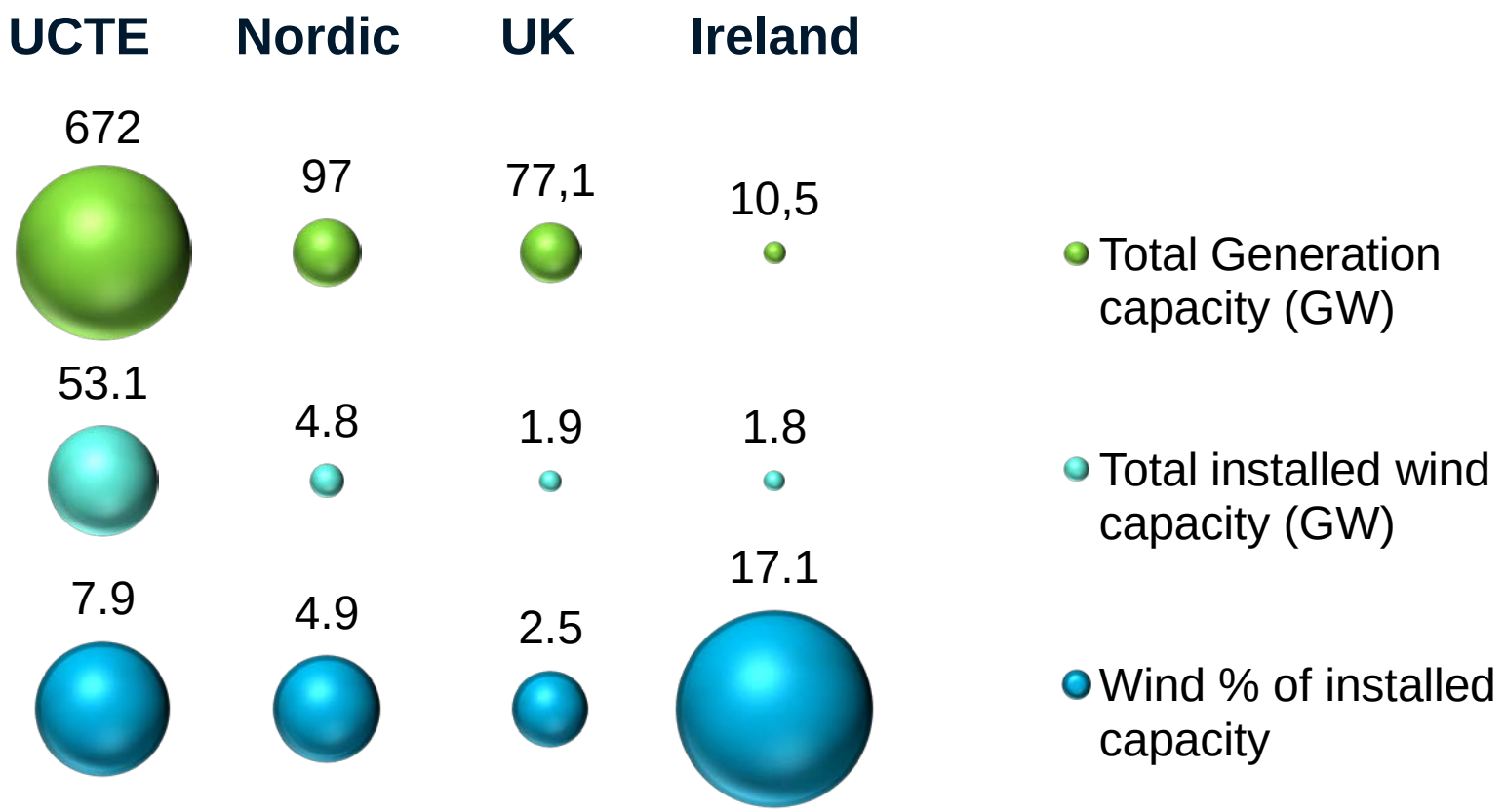
Ireland has a unique renewable resource & technical environment

Ireland: Resource





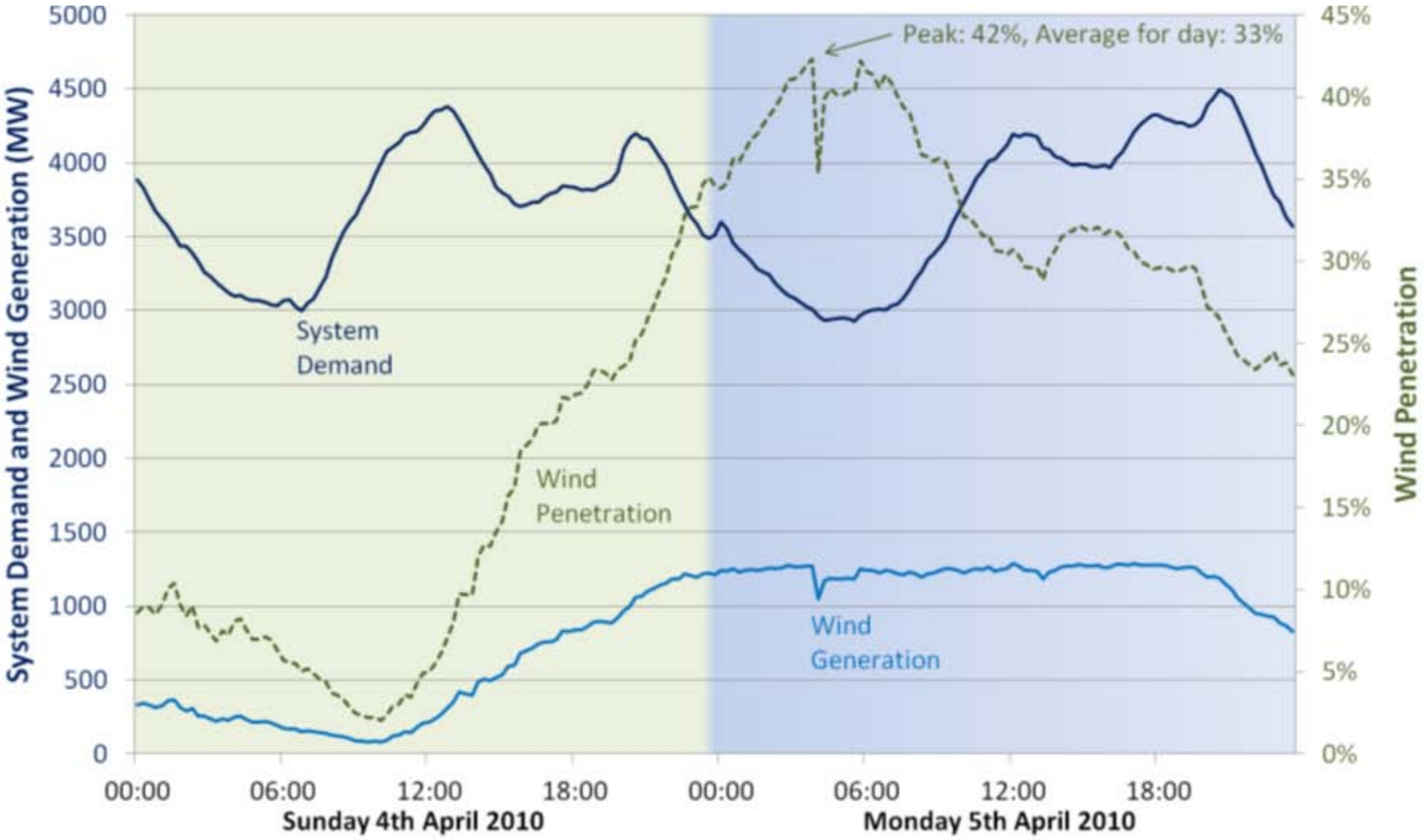
Ireland: Very High Wind Penetration



Figures for end 2008

Source: Global wind energy outlook 2008, EirGrid, UK National Grid, NORDEL, Eurelectric

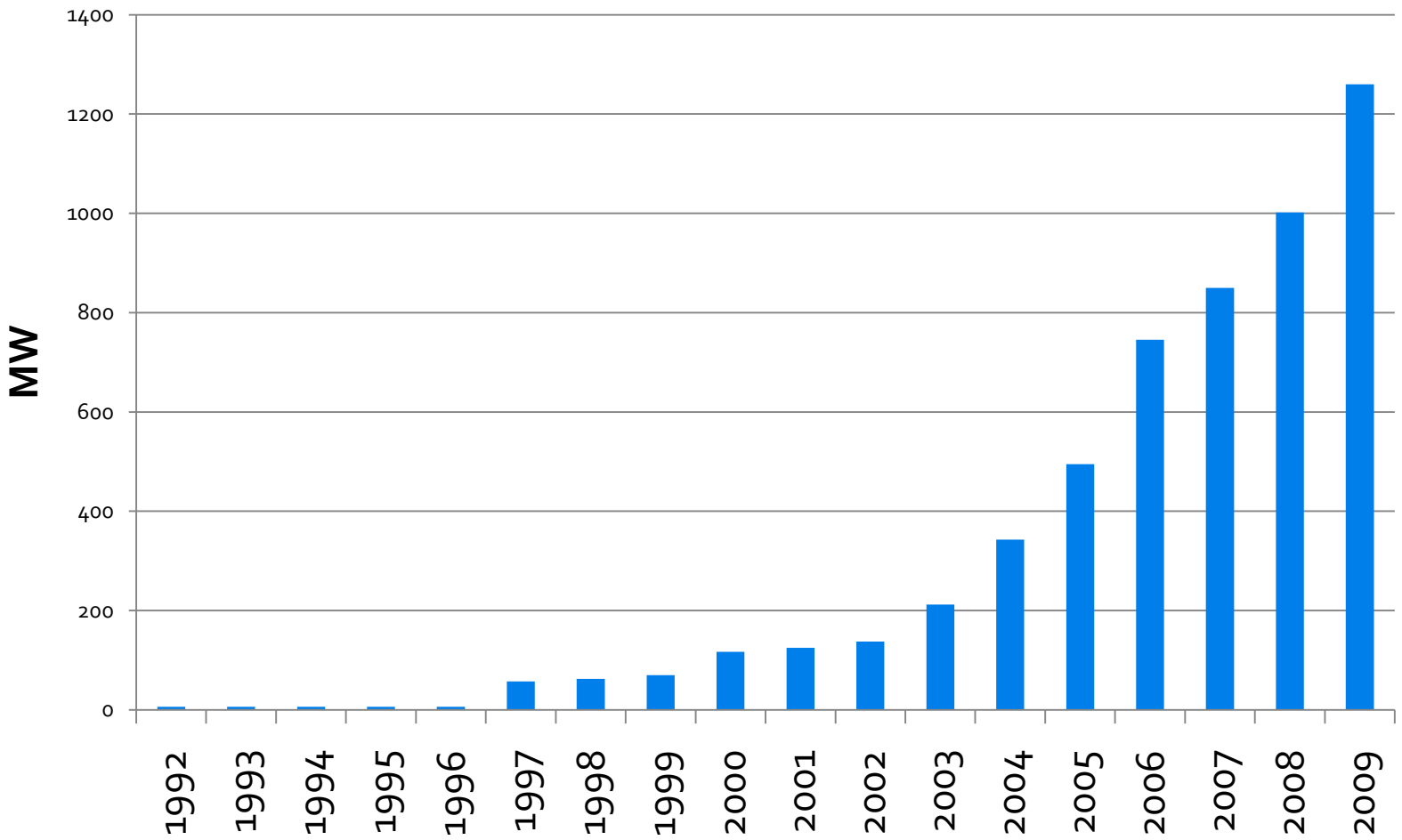
Wind in Ireland, April 2010



~1 .2 GW wind power change in 18 hours
(2 % to 42 % penetration)

All island data from EirGrid & SONI

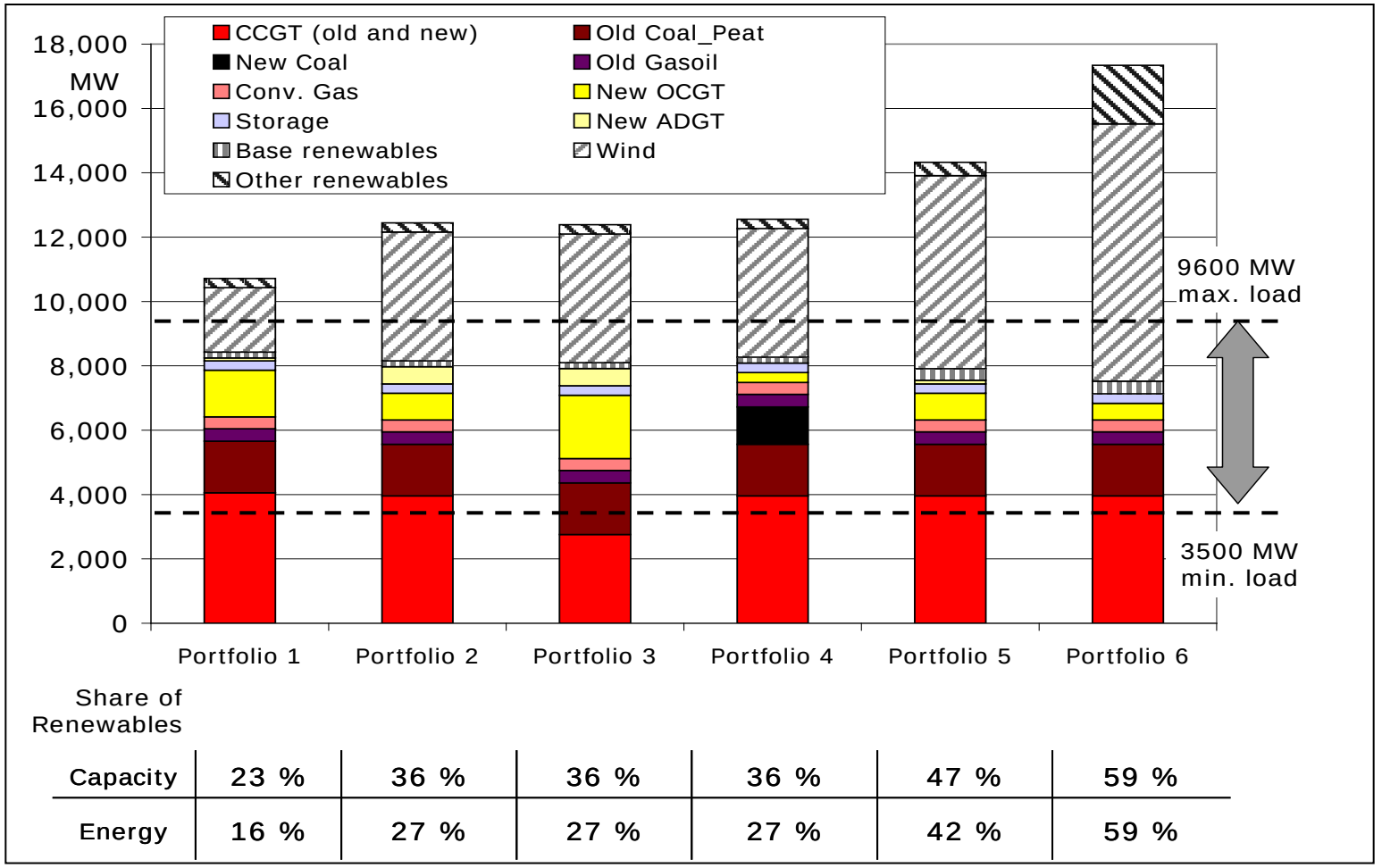
Wind Installed in Republic of Ireland



Source: EirGrid

All Island Grid Study (AIGS)

AIGS: Portfolios

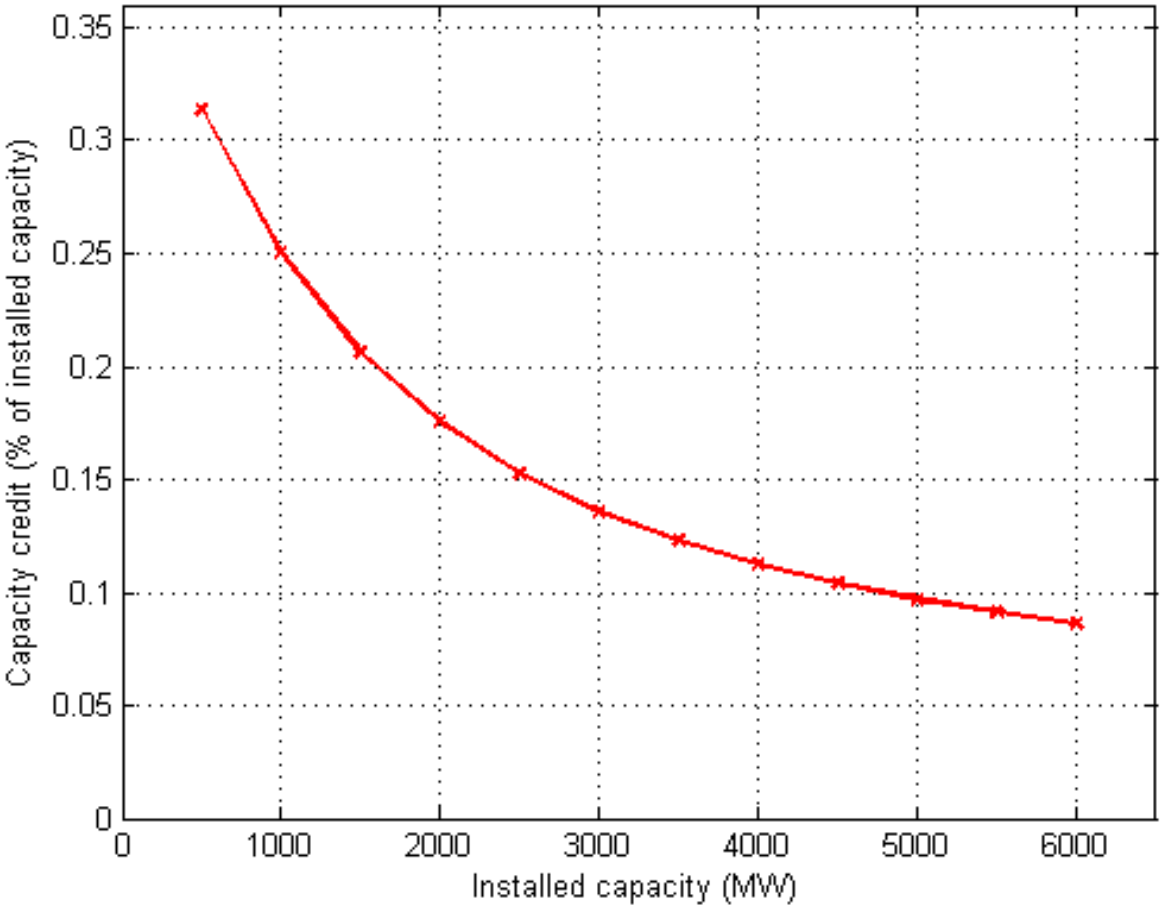


Share of Renewables

Capacity	23 %	36 %	36 %	36 %	47 %	59 %
Energy	16 %	27 %	27 %	27 %	42 %	59 %

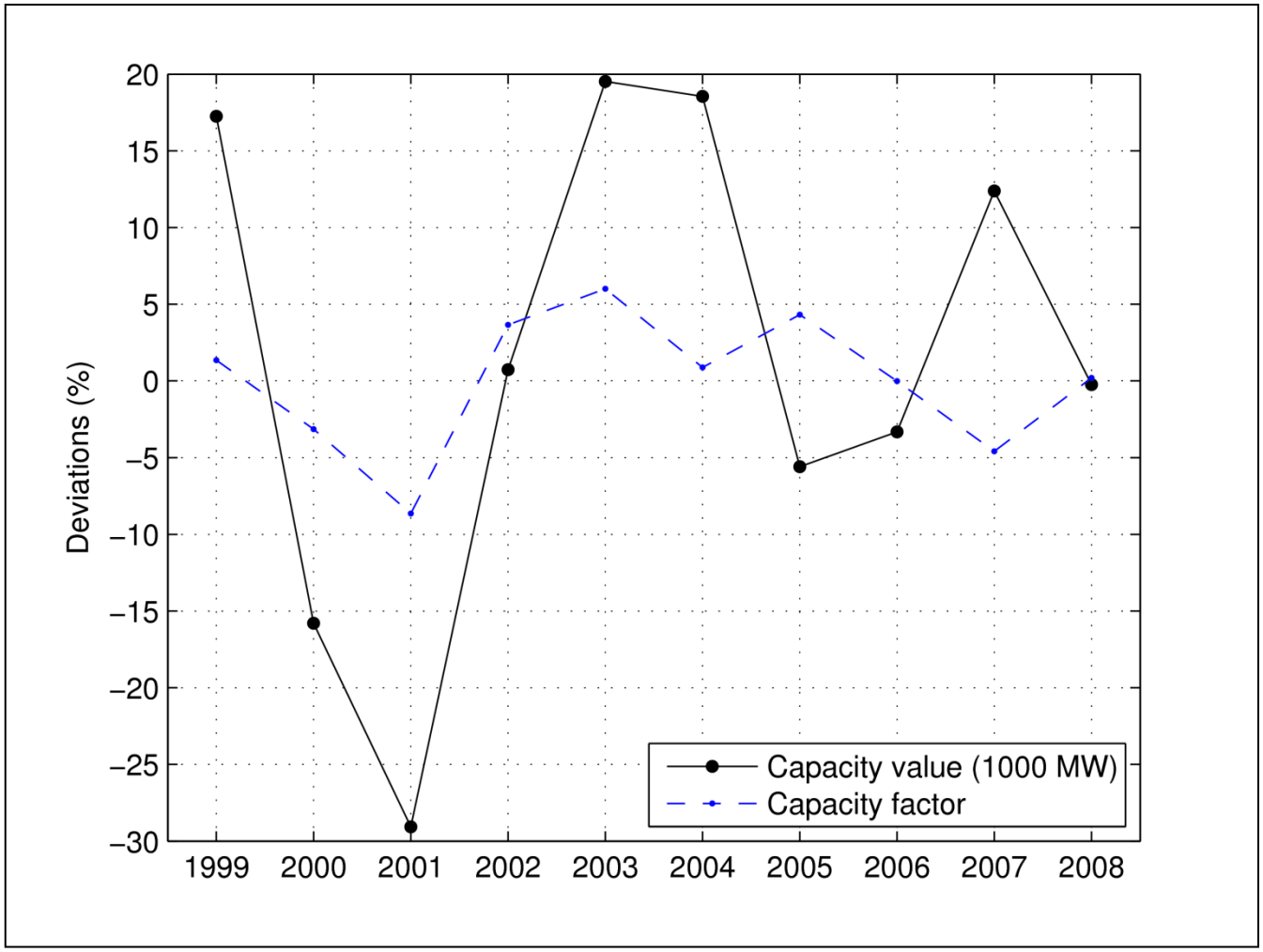
Capacity Credit

Capacity credit declines with more wind



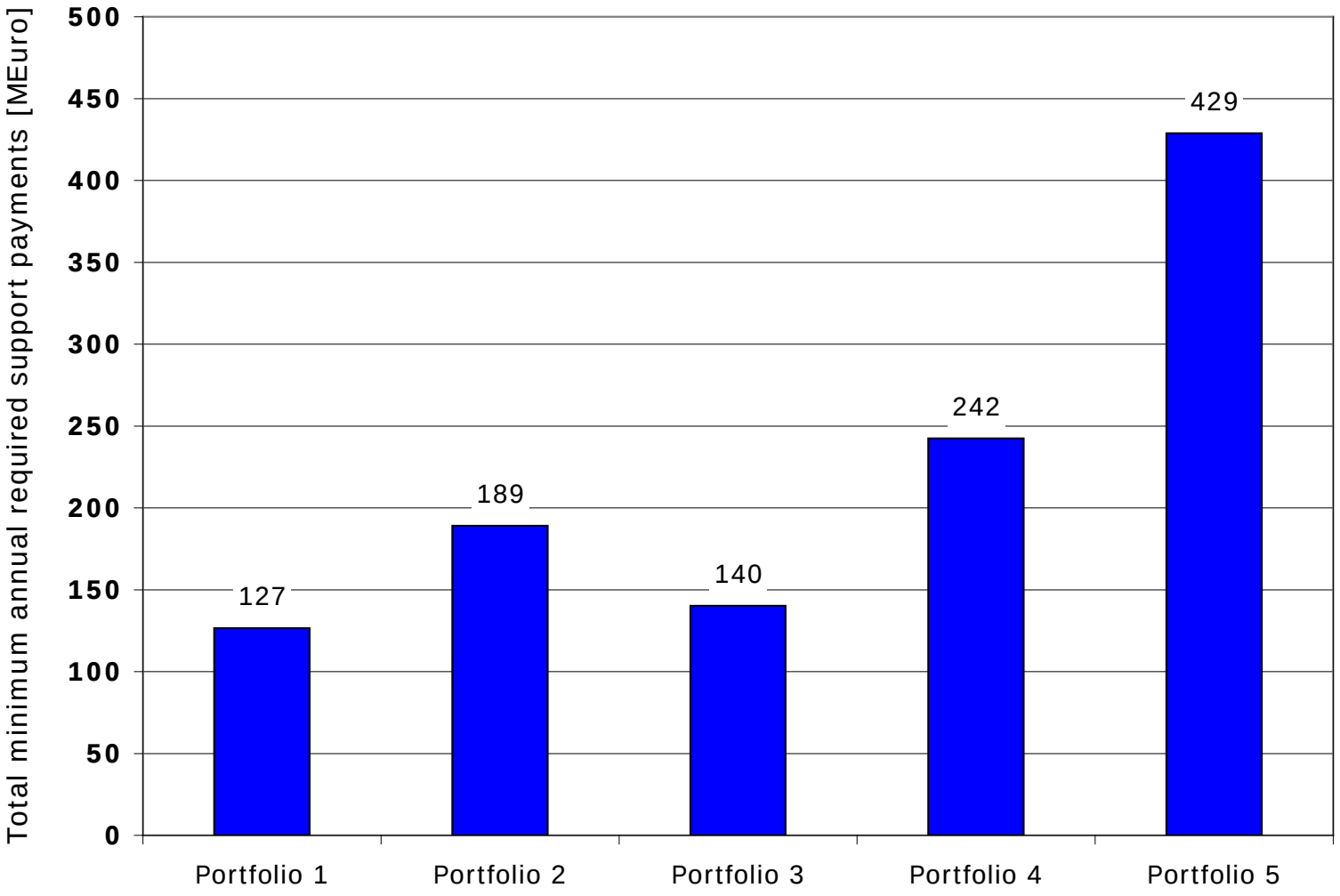
Keane, A., Milligan, M., D'Annuzio, C., Dent, C., Dragoon, K., Hasche, B., Holttinen, Samaan, N., Soder, L. and O'Malley, M.J., "Capacity Credit of Wind Power, *IEEE Trans. Power Syst.,* in press, 2010.

Yearly variations

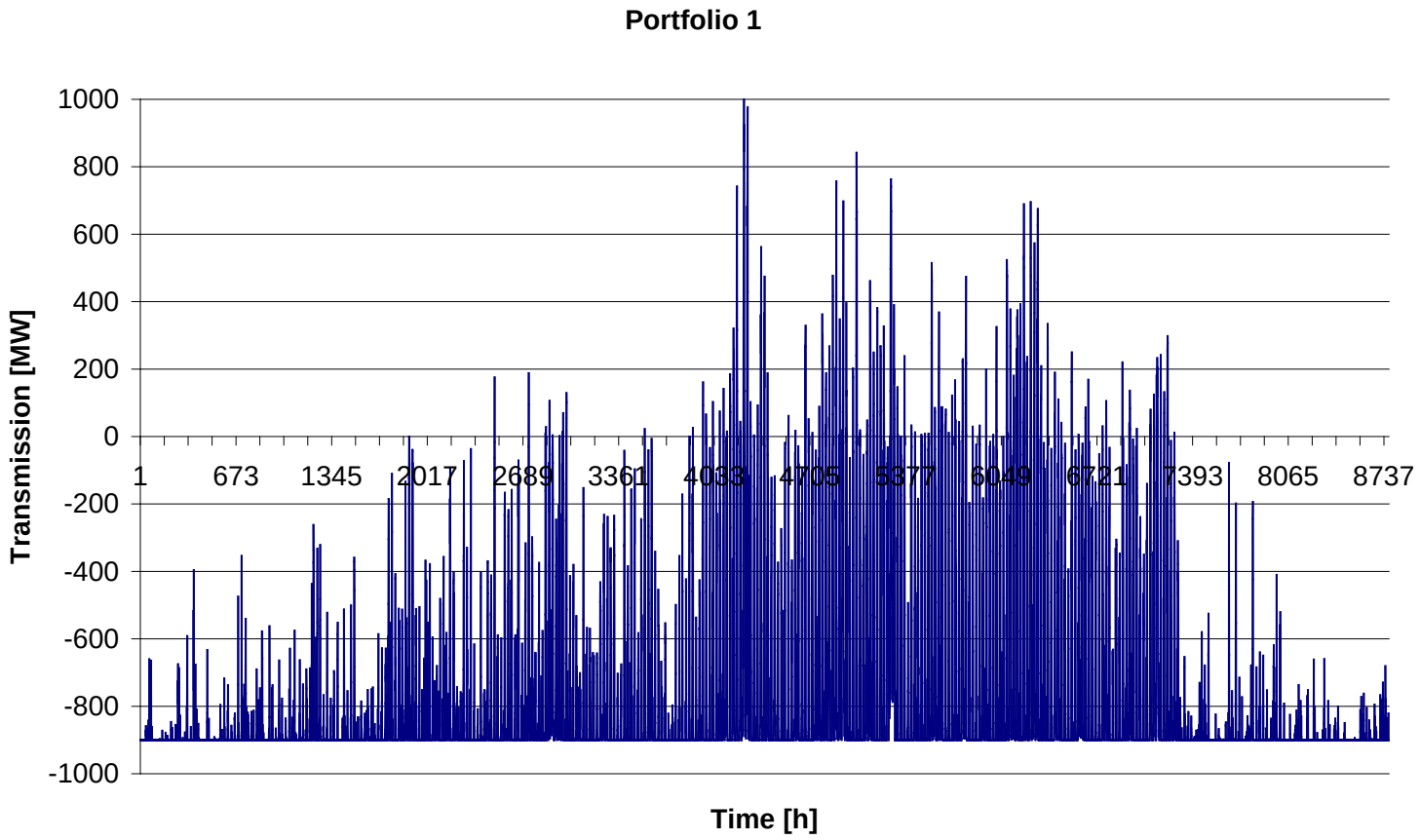


Hasche, B., Keane, A. and O'Malley, M.J. "Capacity credit of wind power: calculation and data requirements", *IEEE Trans. Power Syst.,* in press, 2010.

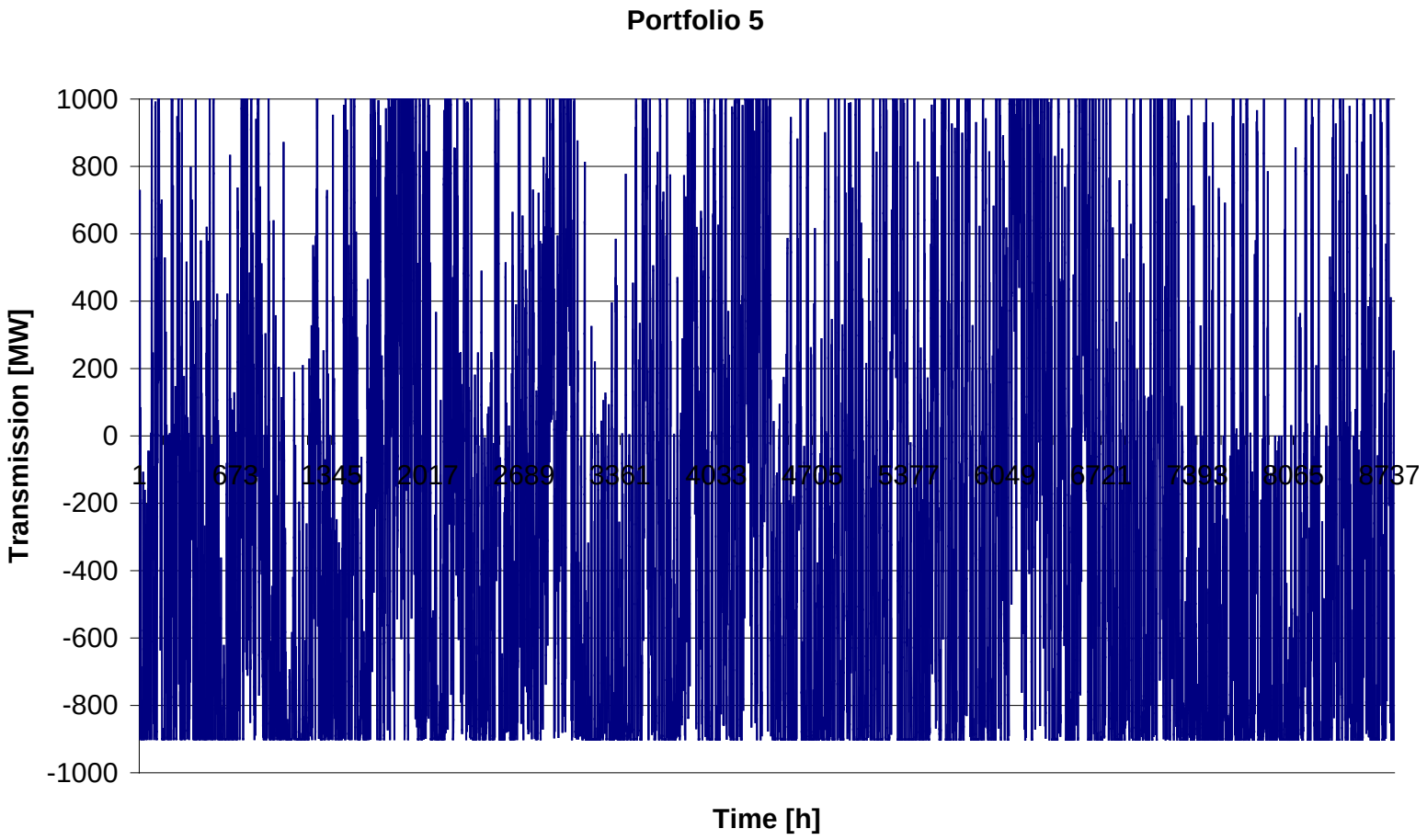
AIGS: Minimum support for renewables



AIGS: Import/export GB (portfolio 1)

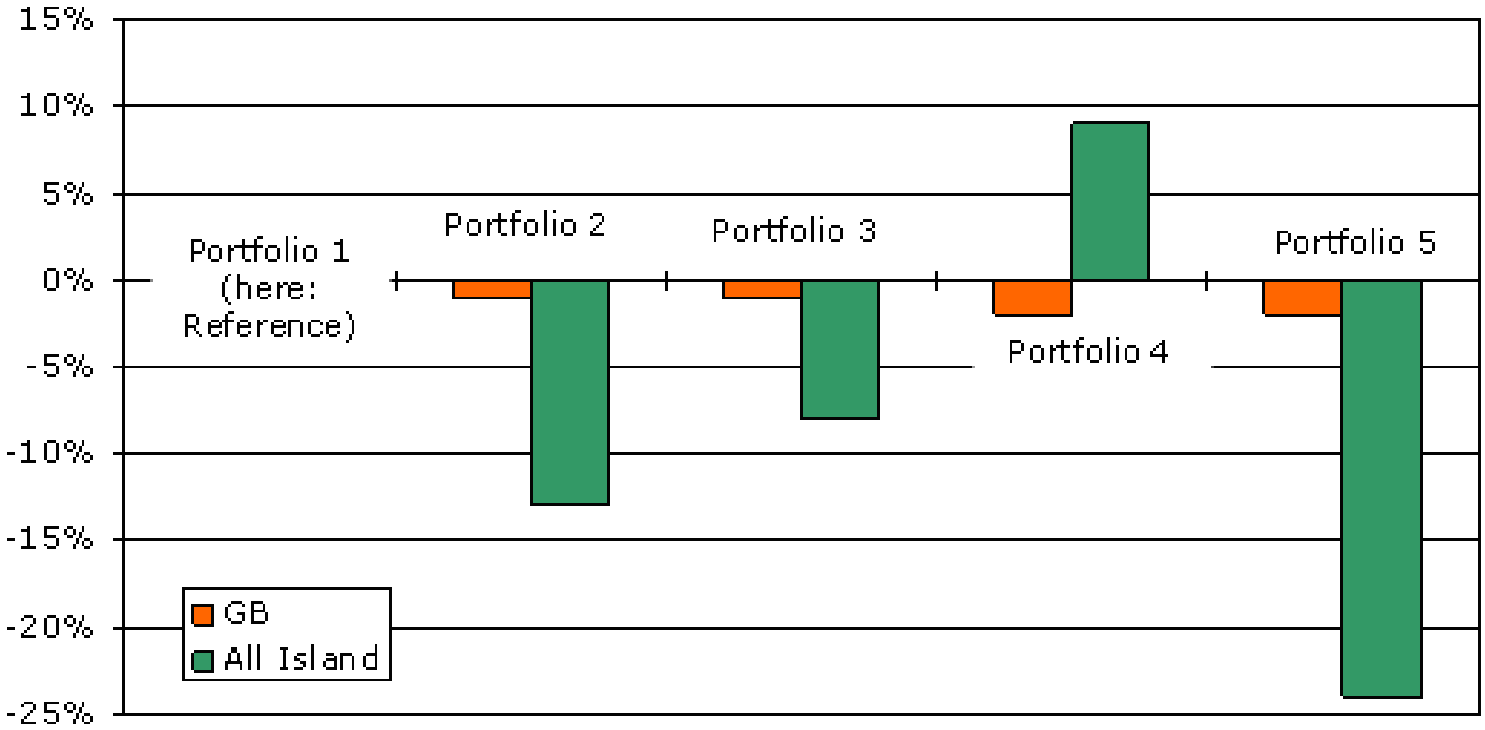


AIGS: Import/export GB (portfolio 5)



Denny, E., Tuohy, A., Meibom, P., Keane, A., Flynn, D. Mullane, A. and O'Malley, M.J., "The Impact of Interconnection on Electricity Systems with Large Penetrations of Wind Generation", *Energy Policy*, in press, 2010.

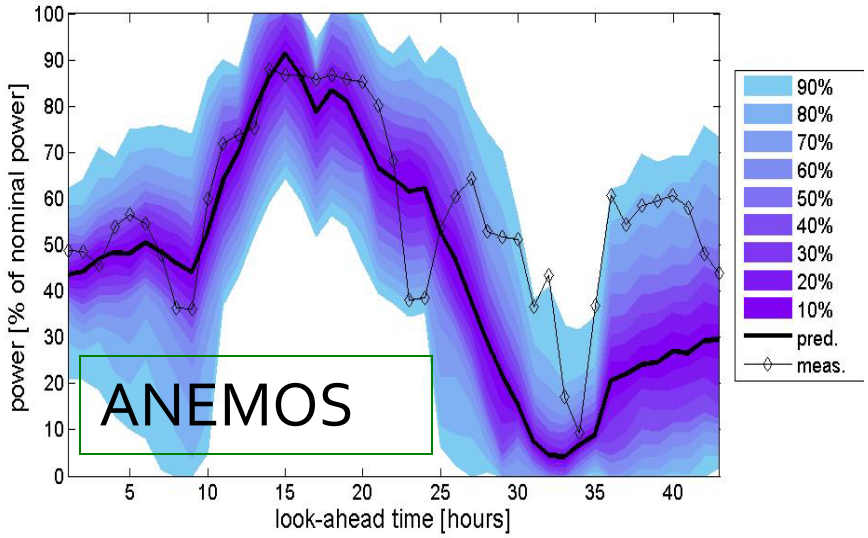
AIGS: Relative CO_2 Emissions Impact

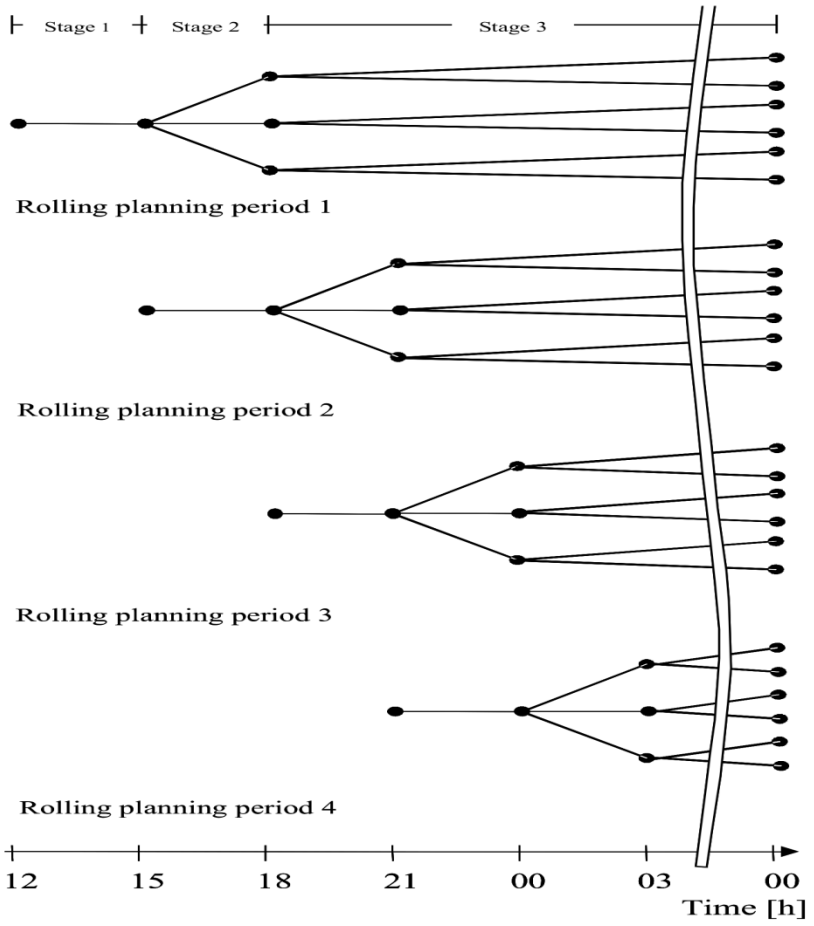


Risø DTU

AIGS: Stochastic Unit Commitment

Wilmar: Stochastic Unit Commitment

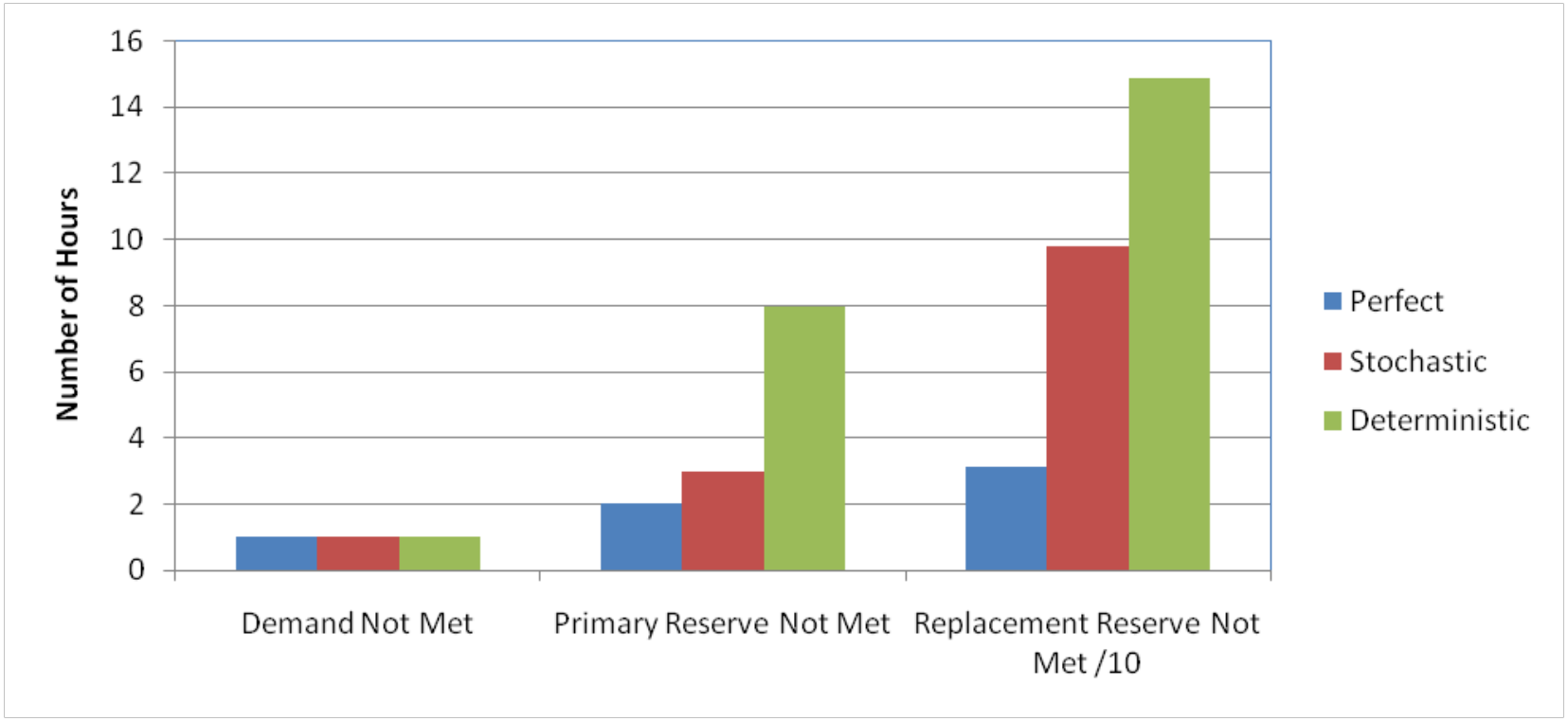




Meibom, P., Barth, R., Hasche, B., Brand, H., Weber, C. and O´Malley, M.J., "Stochastic optimisation model to study the operational impacts of high wind penetrations in Ireland", *IEEE Trans. Power Systems,* in press, 2010.

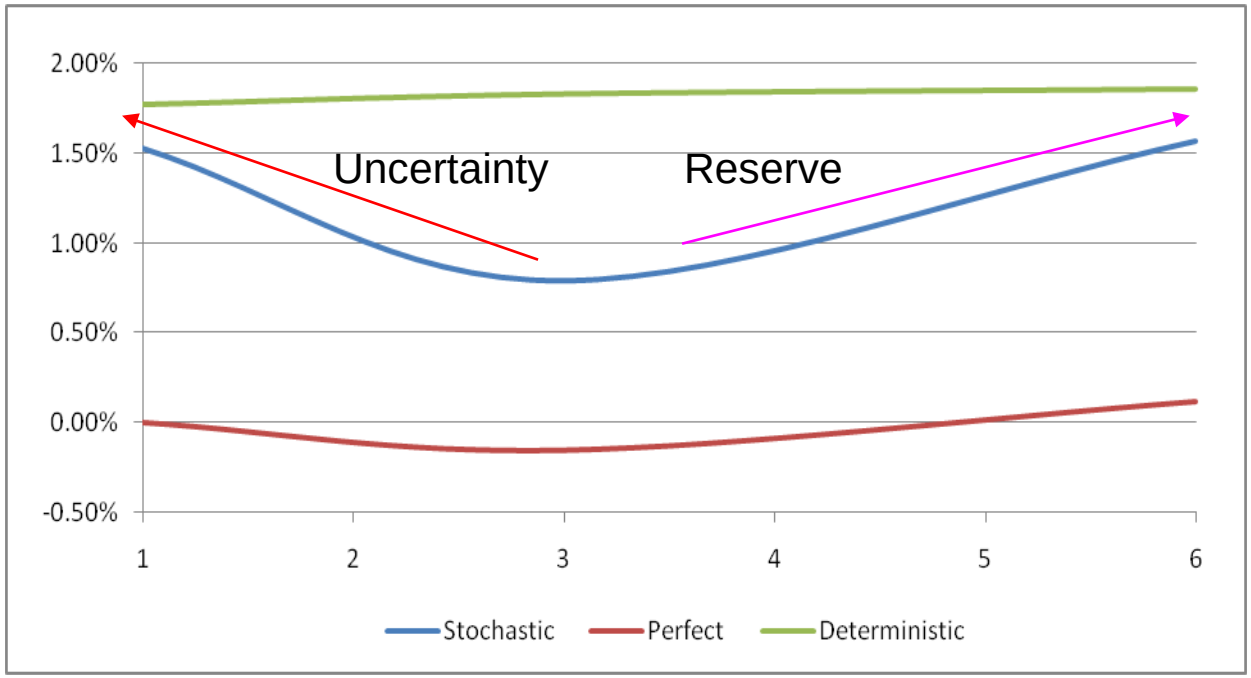
Performance of Schedules

- Not ‘reliability’, but indicates performance
- One hour frequency of commitment



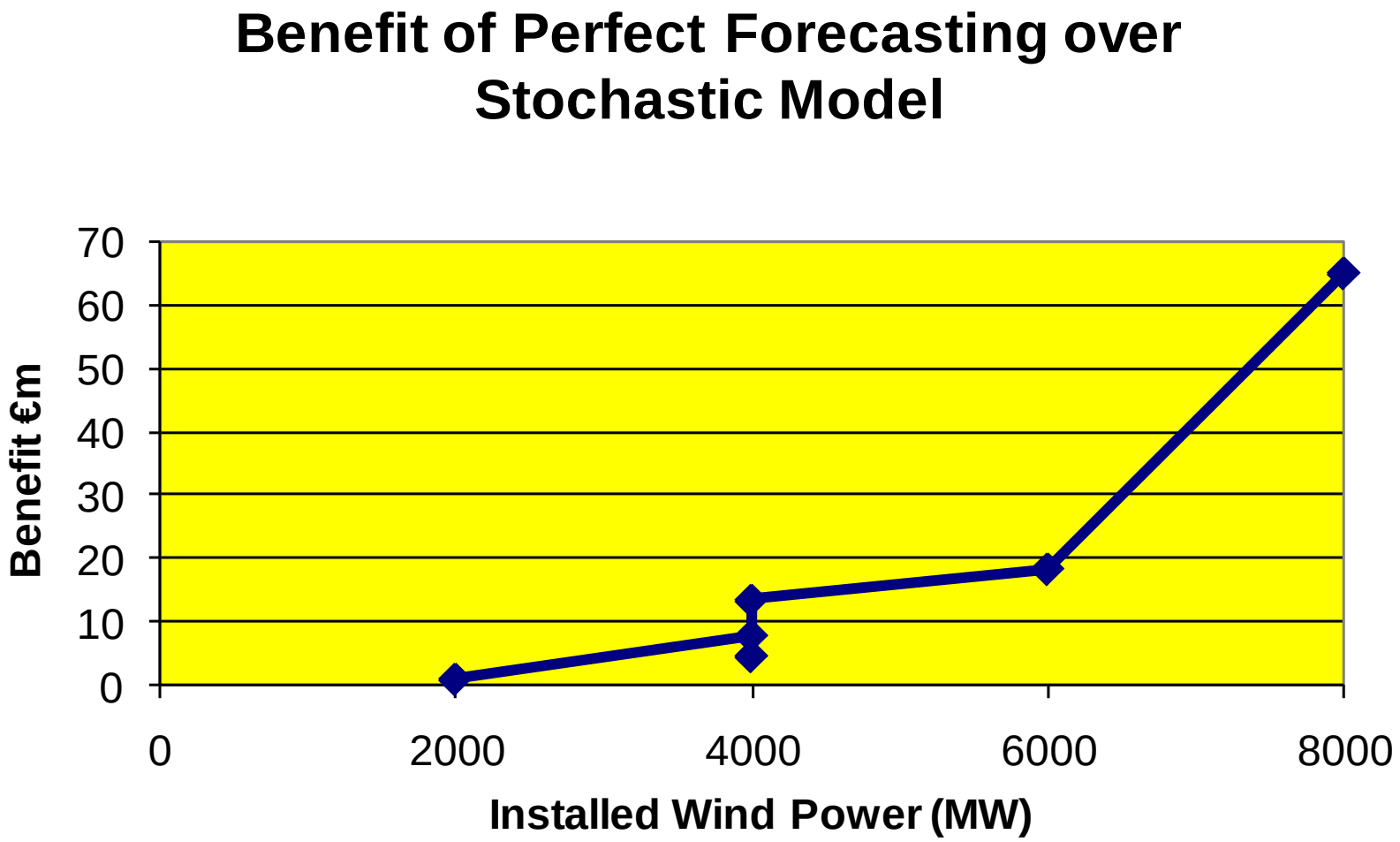
System Costs - Effect of Rolling UC

- Counter intuitive – would expect it to be less expensive as rolling happens more often – due to assumption of perfect forecasting

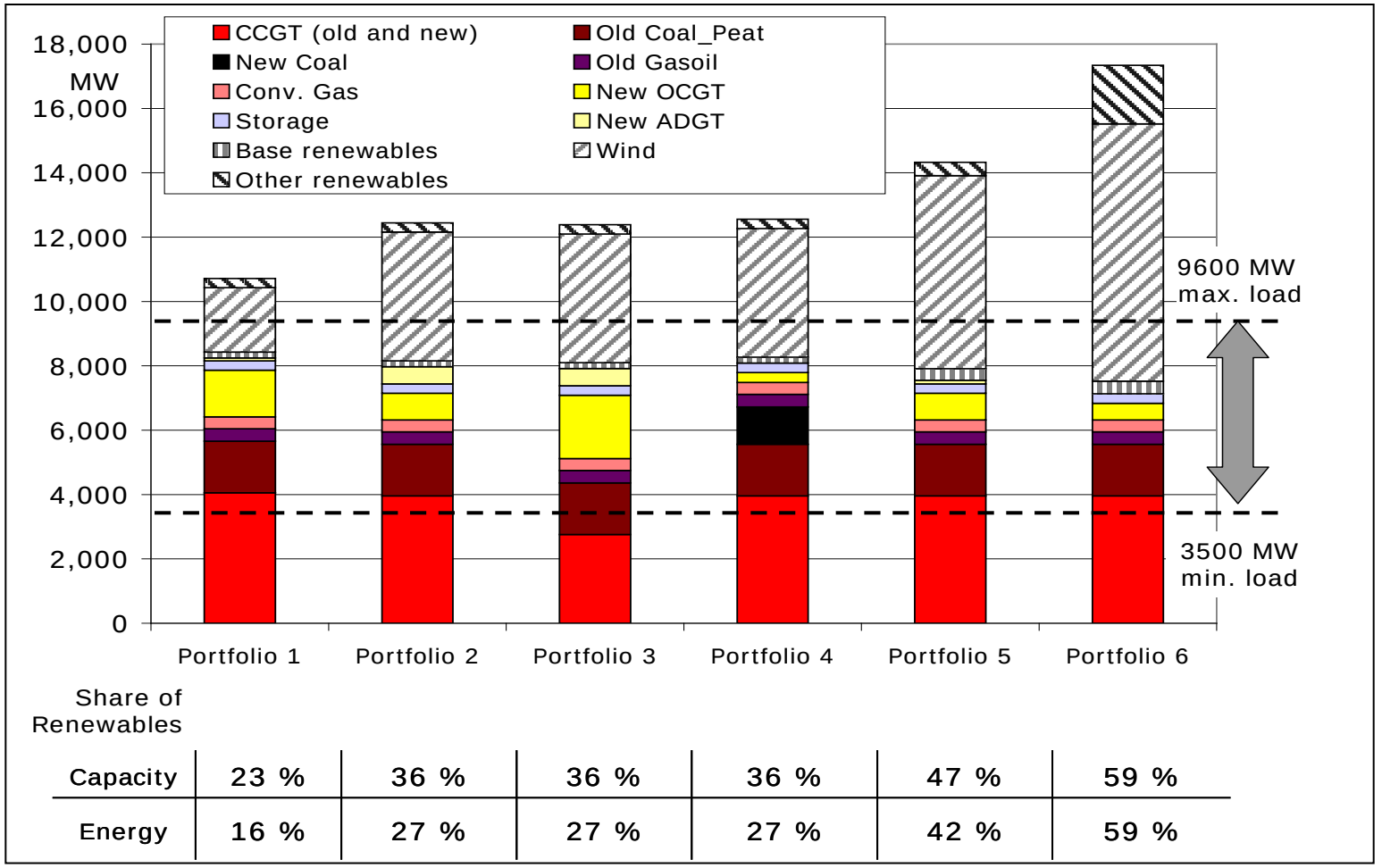


Tuohy, A., Meibom, P., Denny, E., & O'Malley, M., "Unit commitment for Systems with Significant Installed Wind Penetration", *IEEE Transactions on Power Systems* , Vol, 24, pp. 592 – 601, 2009.

AIGS: Benefits of Improved Forecasting



AIGS: Portfolios



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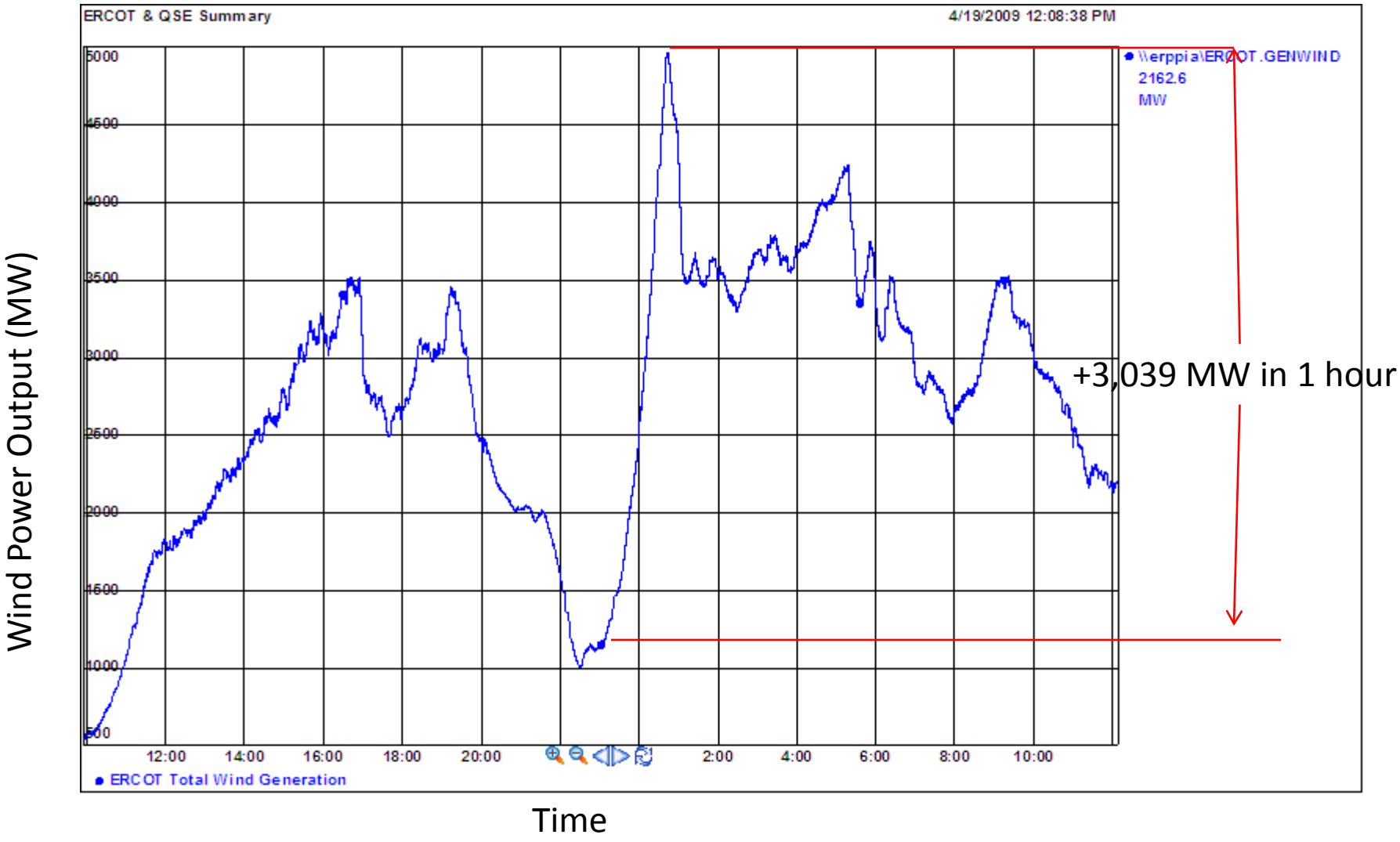
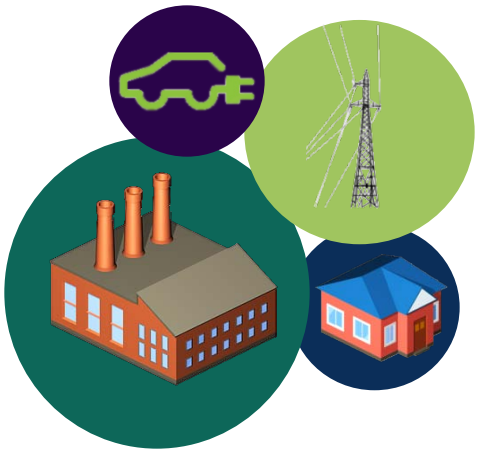
Flexibility

ERCOT Today

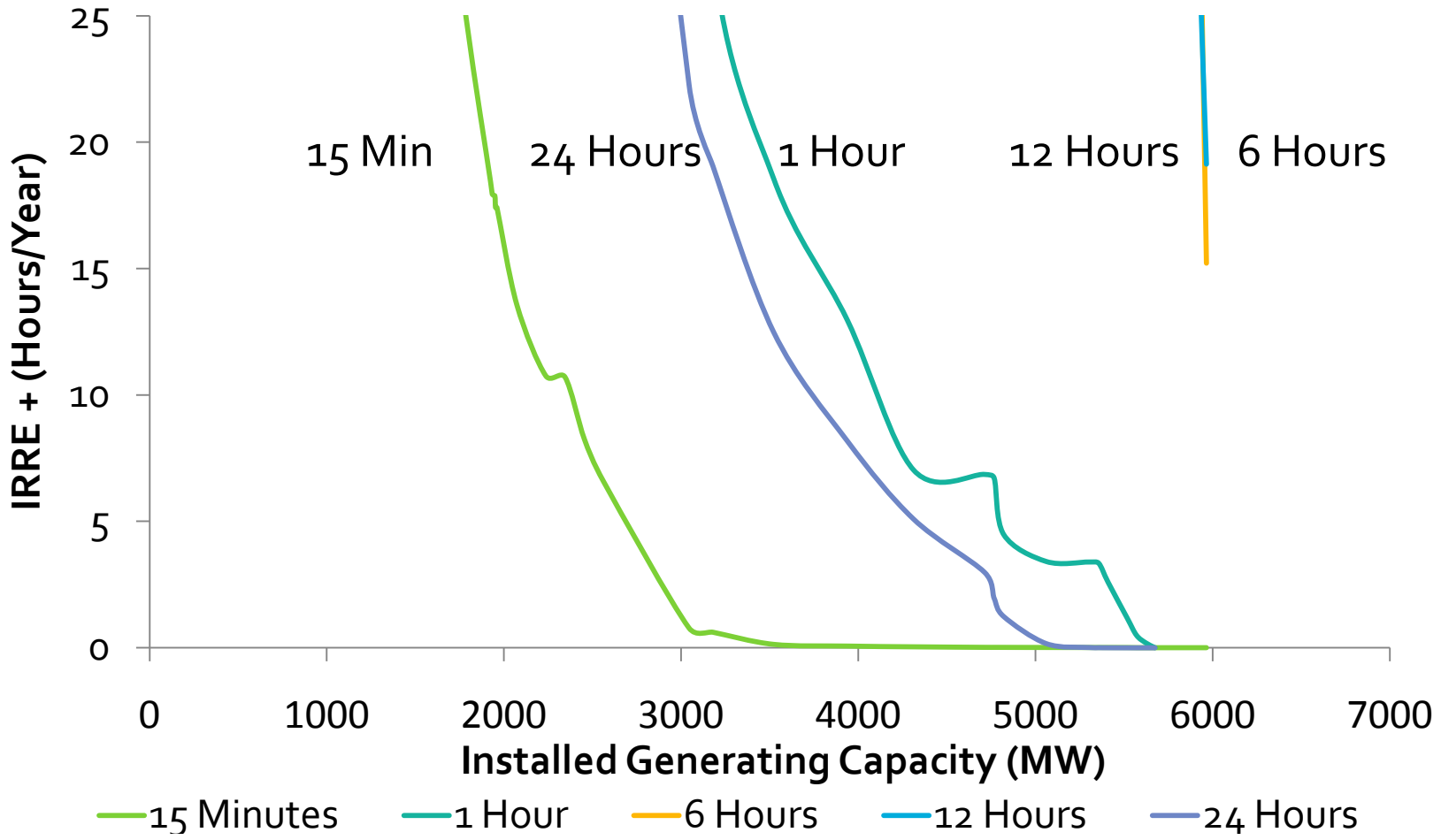

ERCOT & QSE Summary
4/19/2009 12:08:38 PM
\\erppia\ERCOT.GENWIND
2162.6
MW
+3,039 MW in 1 hour
Wind Power Output (MW)
Time
ERCOT Total Wind Generation

Flexibility Paradigm

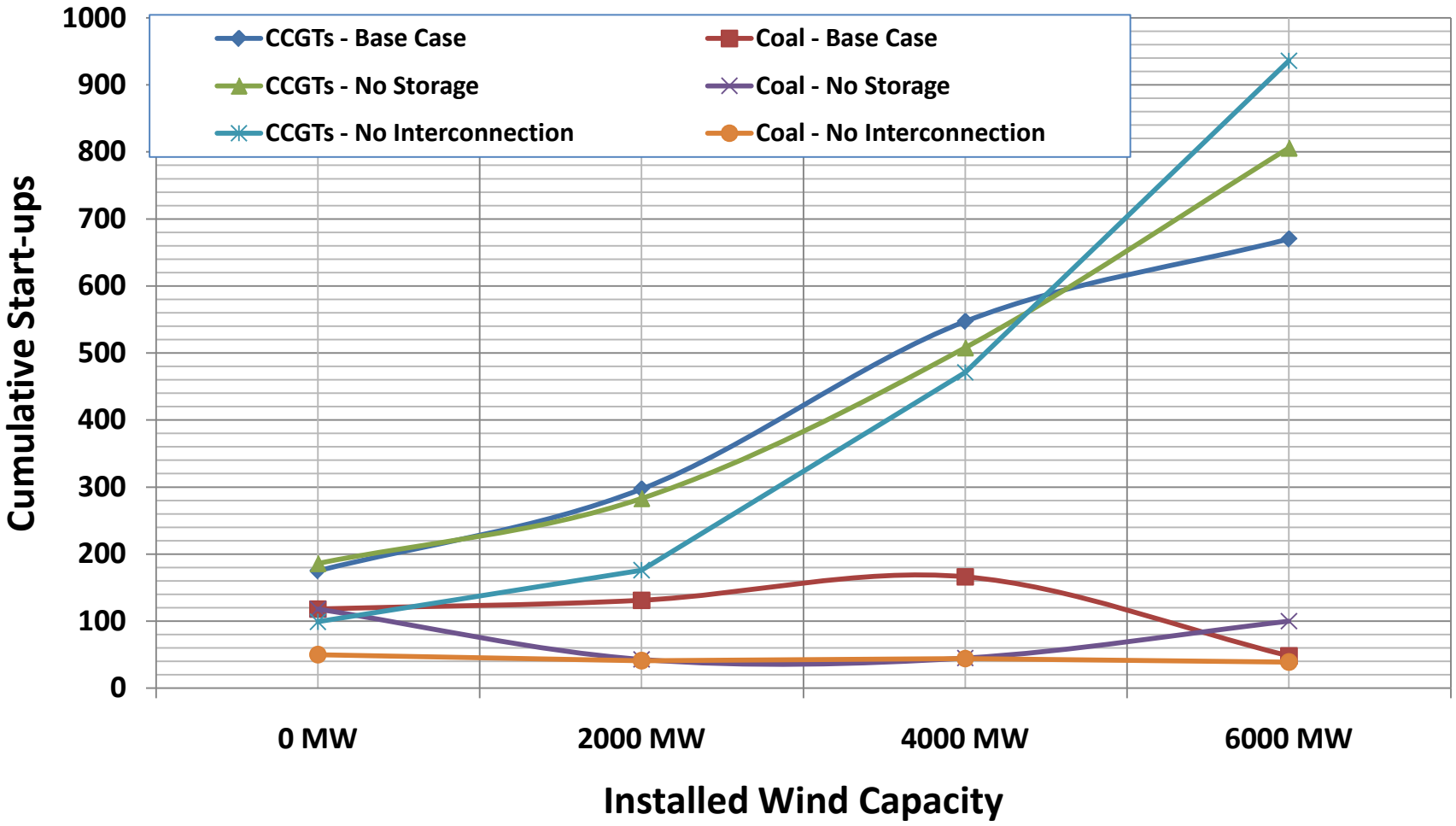
	Sources	Match Makers	Sinks	
Physical	•DSM •Electricity Storage •VG •Interconnection •Conventional Generation	•Transmission Networks •Fuel Storage	•Load •Solar •Wind etc..	Planning
Institutional	•Forecasting •Market Resolution •Gate Closure •Balancing Area Size •Grid Codes •Unit Commitment			Operations
Economic	•Ancillary Services Markets •Cycling Costs			Markets



Flexibility metric (can we measure it ?)

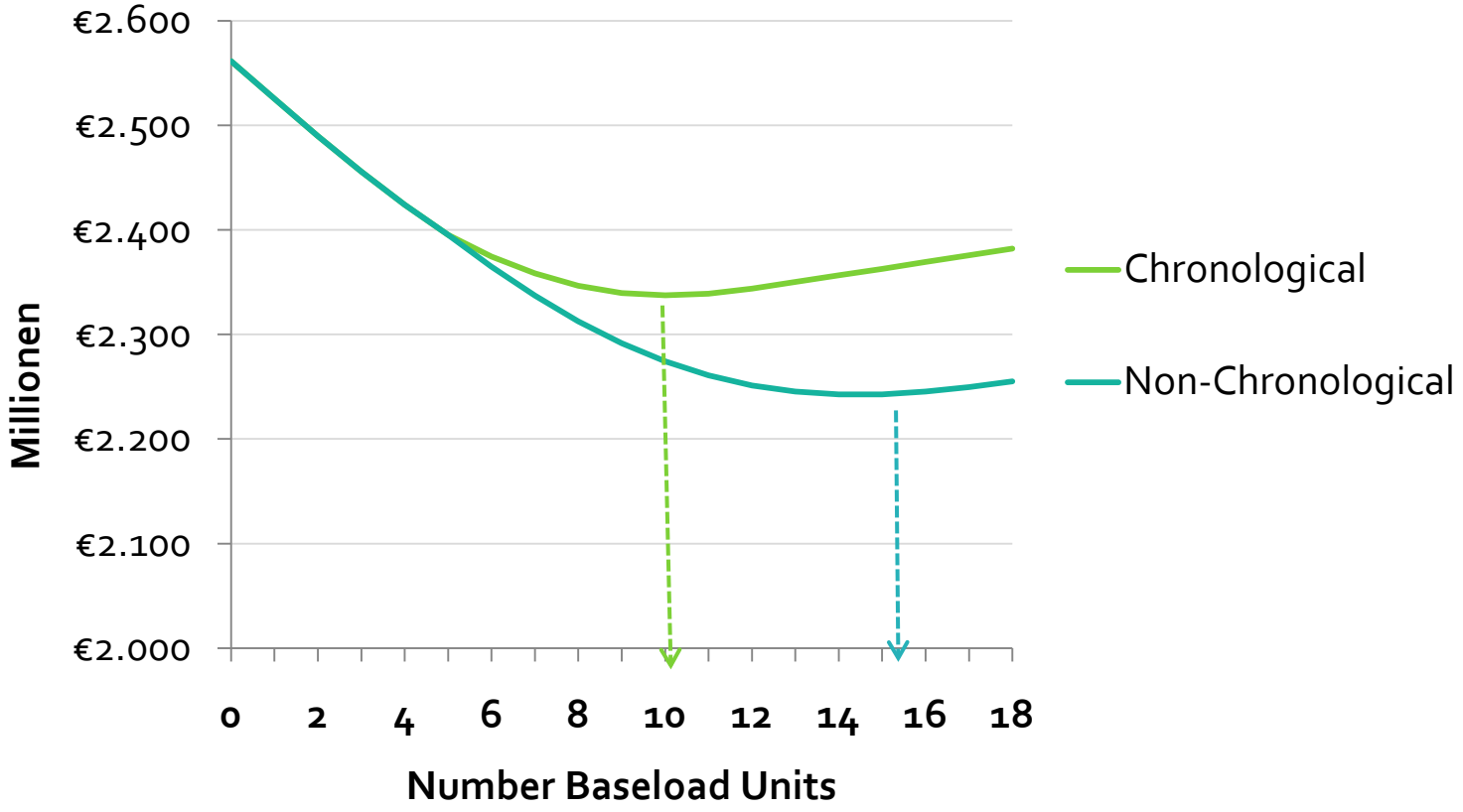


Impact of Wind on Base-load Start-ups



Troy, N., Denny, E. and O'Malley, M.J. "Base load cycling on a system with significant wind penetration", *IEEE Trans. Power Syst.*, Vol. 25, pp. 1088 - 1097, 2010.

Portfolio optimisation (under uncertainty)

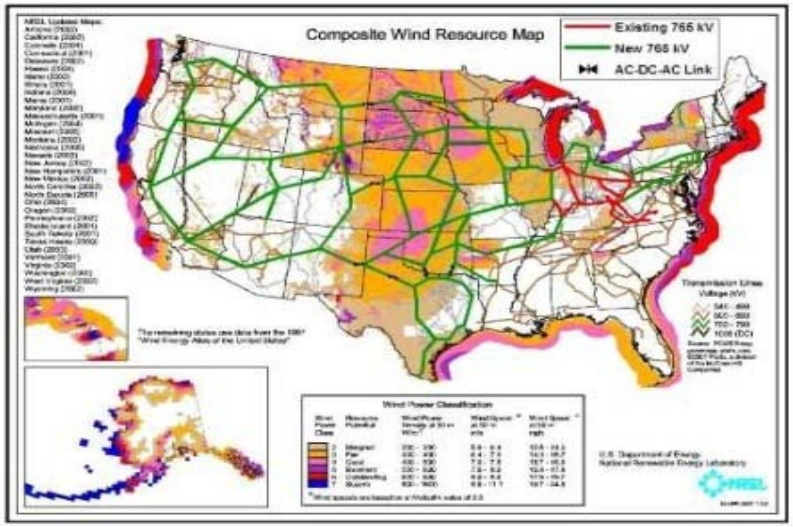


Doherty, R., Outhred, H. and O'Malley, M.J., "Establishing the role that wind generation may have in future generation portfolios", *IEEE Transactions on Power Systems*, Vol. 21, pp. 1415 – 1422, 2006.

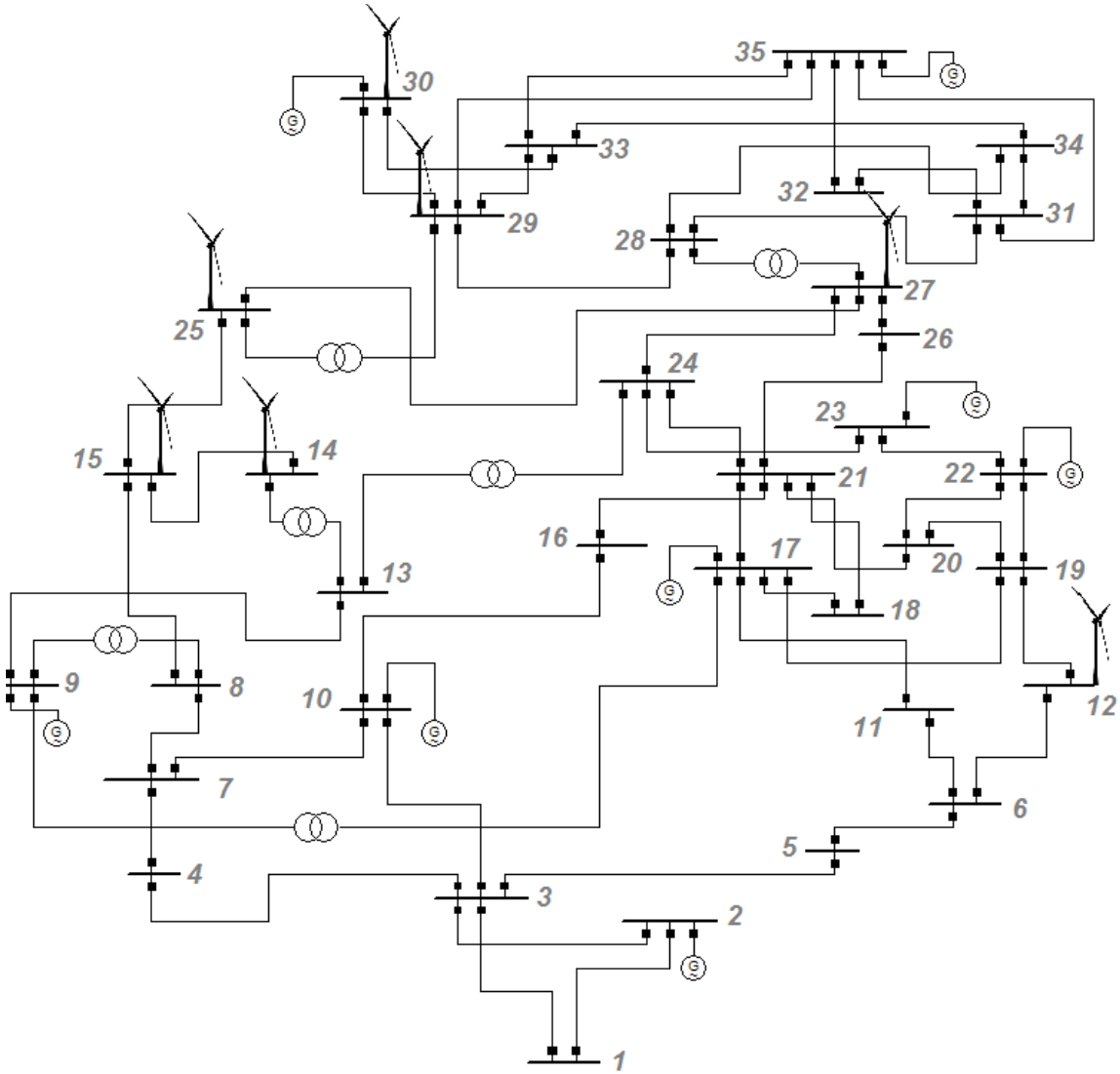
Shortt, A. and M. O'Malley, "Impact of Variable Generation in Generation Resource Planning Models", *IEEE PES General Meeting*, Minneapolis, USA, July 2010.

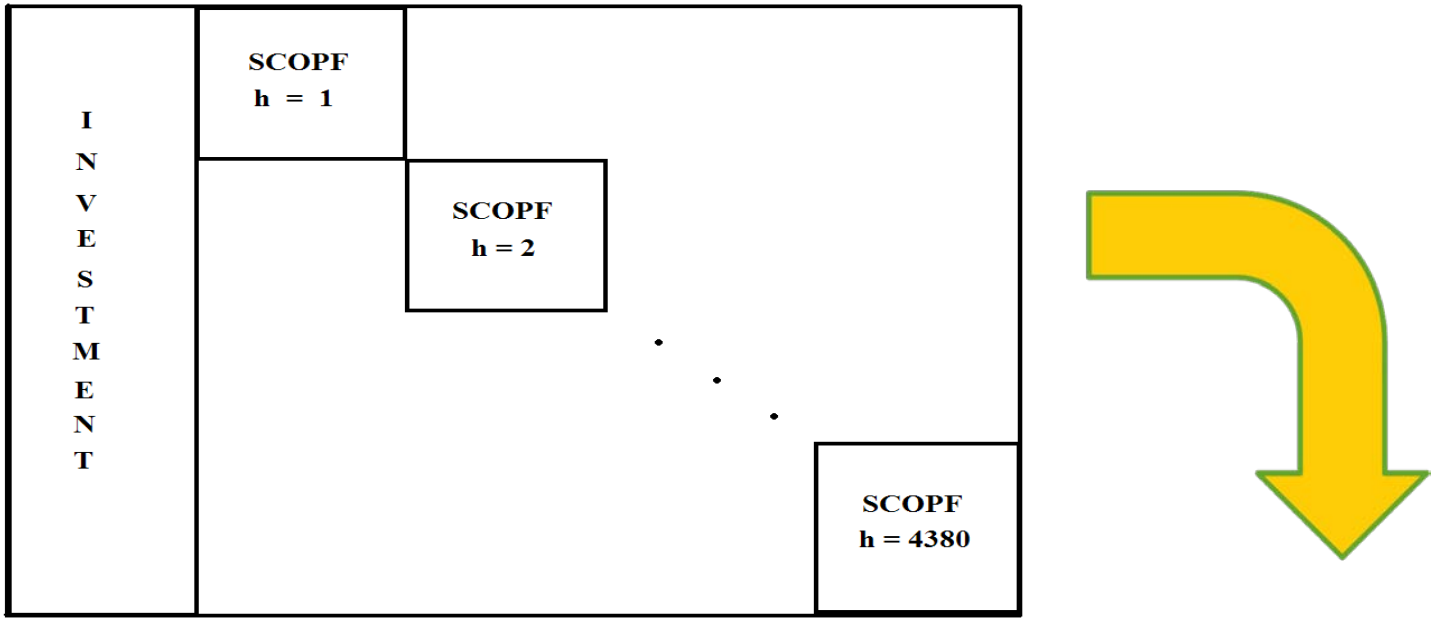
Transmission: Ultimate form of flexibility

Harvesting renewable energy

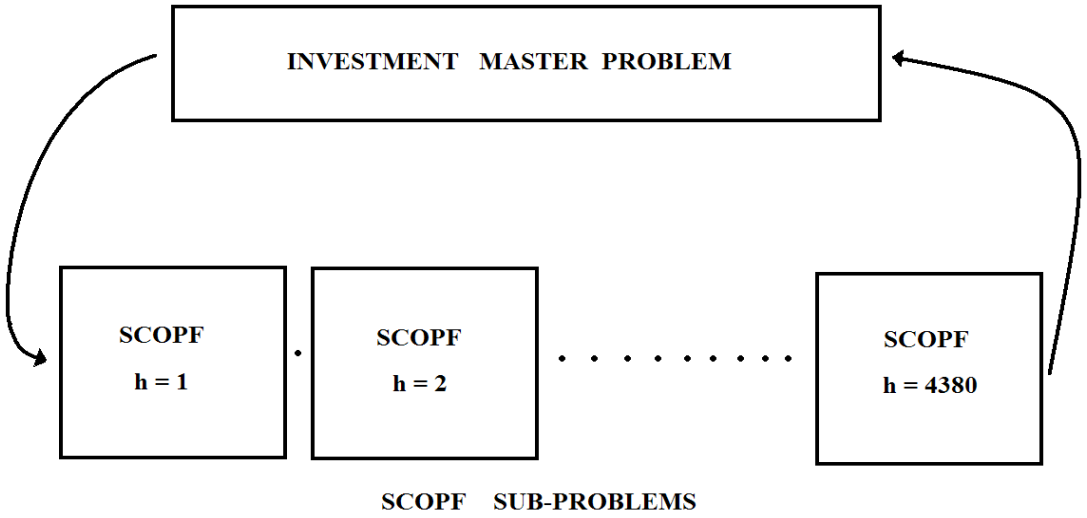


Test Network

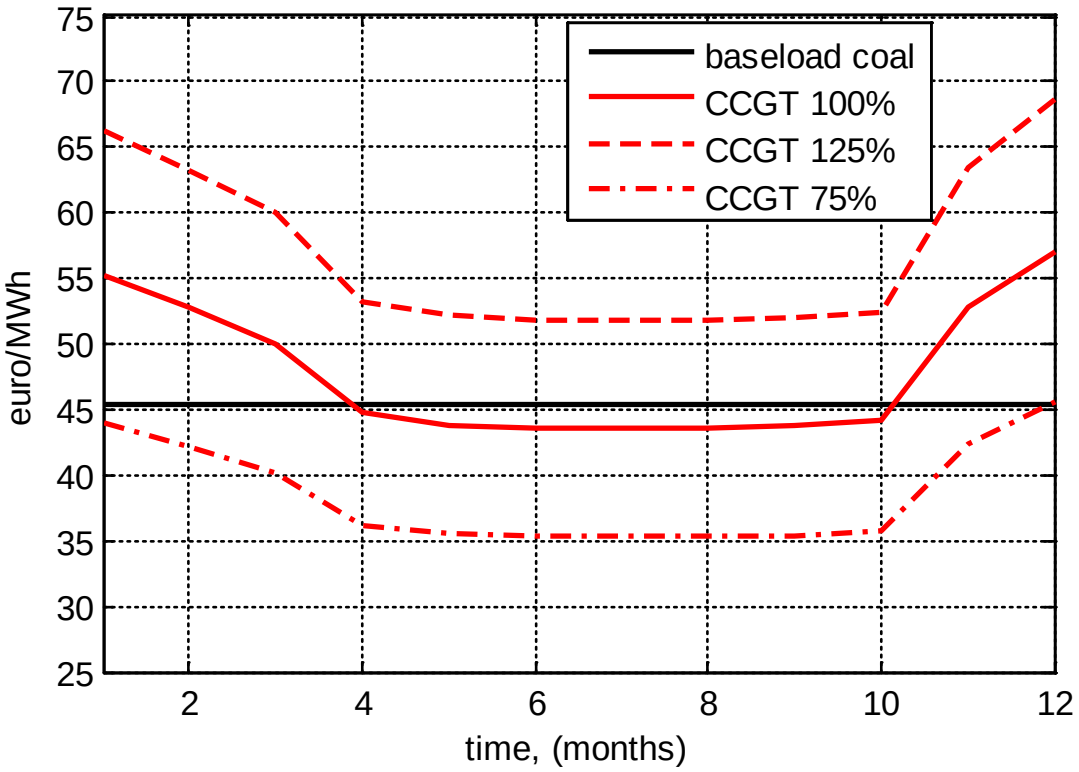




- Decomposition schemes will be necessary for structure exploitation



Merging Operational and Planning Timeframes?



Base-Case Fuel Prices :

Gas – 5.9 (€/GJ)
Coal - 1.75 (€/GJ)
Carbon – 30 (€/ton CO_2)

- Which ‘version’ of the future is most likely..?

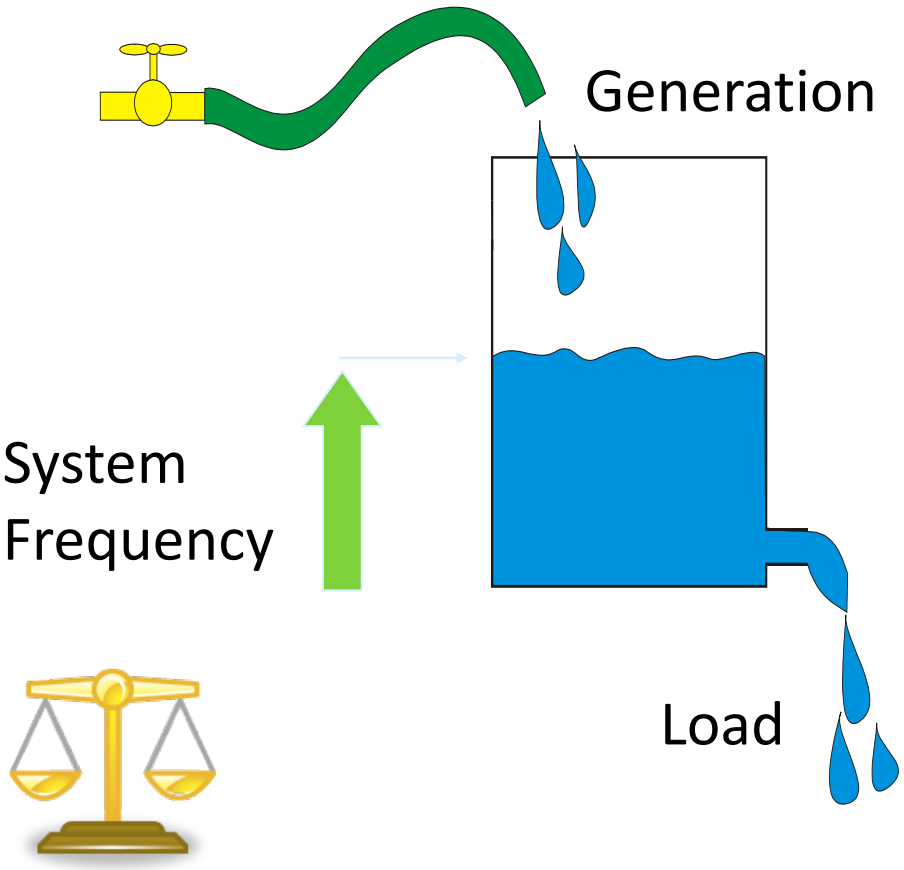
Results – Firm Access

Energy % Penetration	Wind Farm Bus Number						
	12	14	15	25	27	29	30
5	0	0	93.1	0	81.4	0	0
6	0	0	101.3	0	90.2	0	0
7	0	0	88.1	9.5	147.0	0	0
8	33.4	38.9	45.0	35.5	138.9	0	0
9	73.6	51.6	44.6	30.9	128.3	0	0
9.5	68.7	54.6	51.5	40.2	132.7	0	0
10	*infeasible*						

Burke, D. and O'Malley, M.J., "Maximising firm wind power connection to security constrained transmission networks" *IEEE Transactions on Power Systems,* Vol. 25, pp. 749 – 759, 2010.

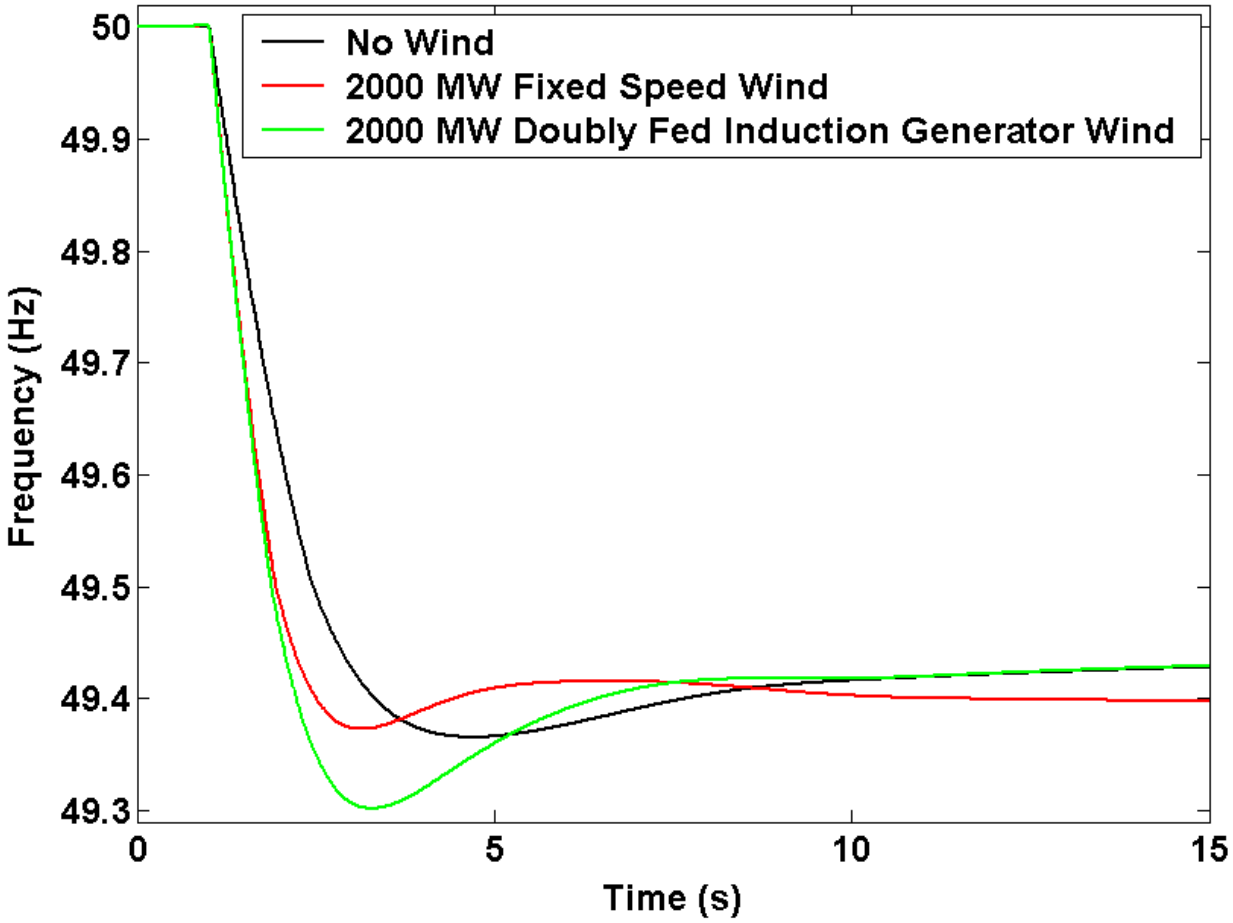
Dynamics: Frequency Stability

System Frequency control



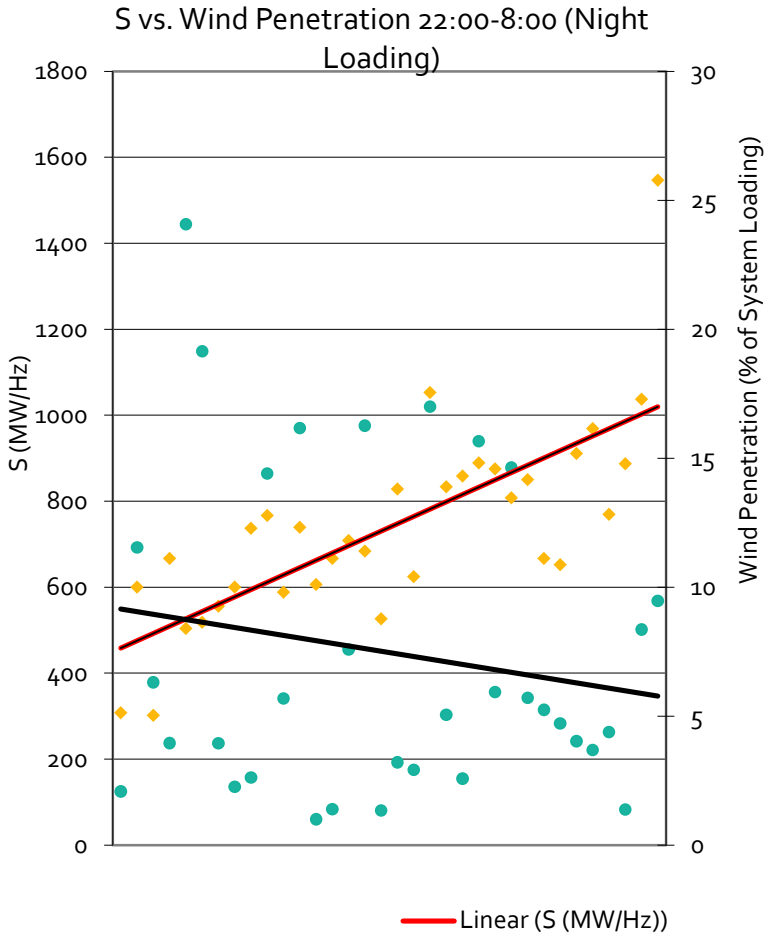
- If generation and load are matched water level (system frequency) will remain constant
- Mismatches will result in a change in water level (system frequency)

Frequency Response



Doherty, R, Mullane, A., Lalor, G., Burke, D., Bryson, A. and O'Malley, M.J. "An Assessment of the Impact of Wind Generation on System Frequency", *IEEE Trans. Power Syst.,* Vol. 25, pp. 452 – 460, 2010.

Historical data Ireland



- Frequency response

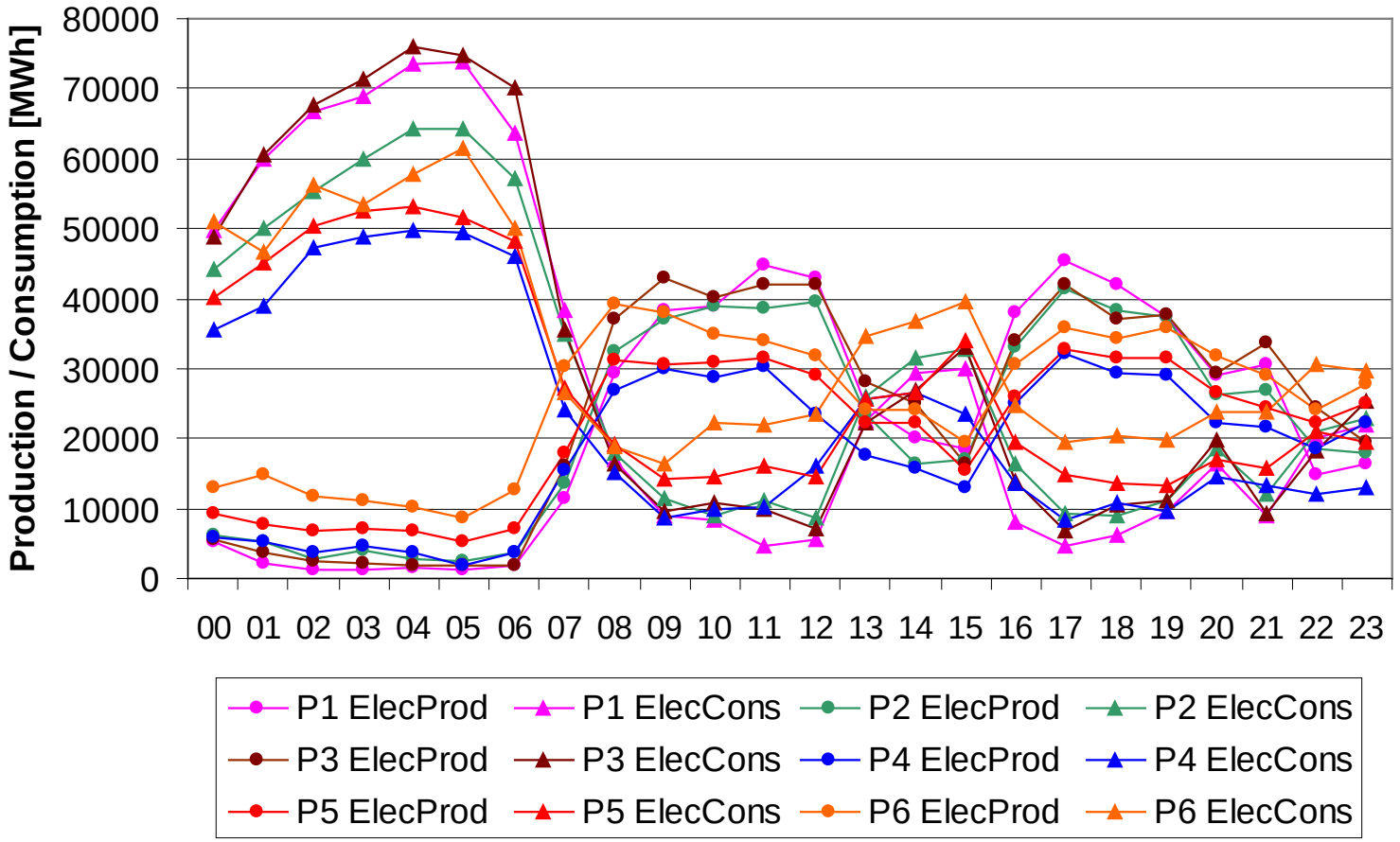
$$S = \left(\frac{MW_{Lost}}{f_{pre\text{-}event} - f_{nadir,post\text{-}event}} \right)$$

  - Wind penetration increases
  - Stiffness decreases
    - Indicates increased vulnerability to a loss of generation event

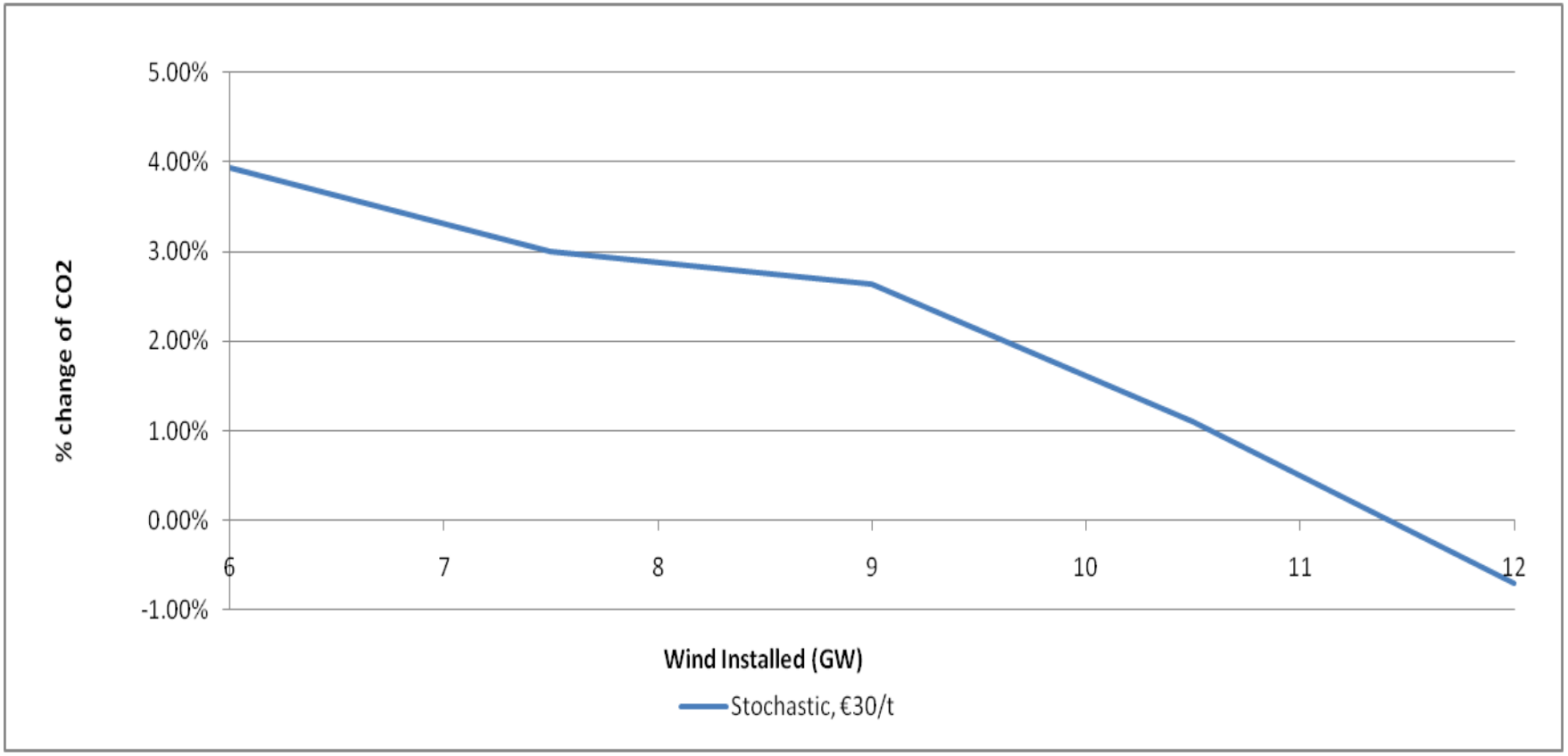
- Should there be a market in frequency response ?

Storage

AIGS: Pump storage utilisation

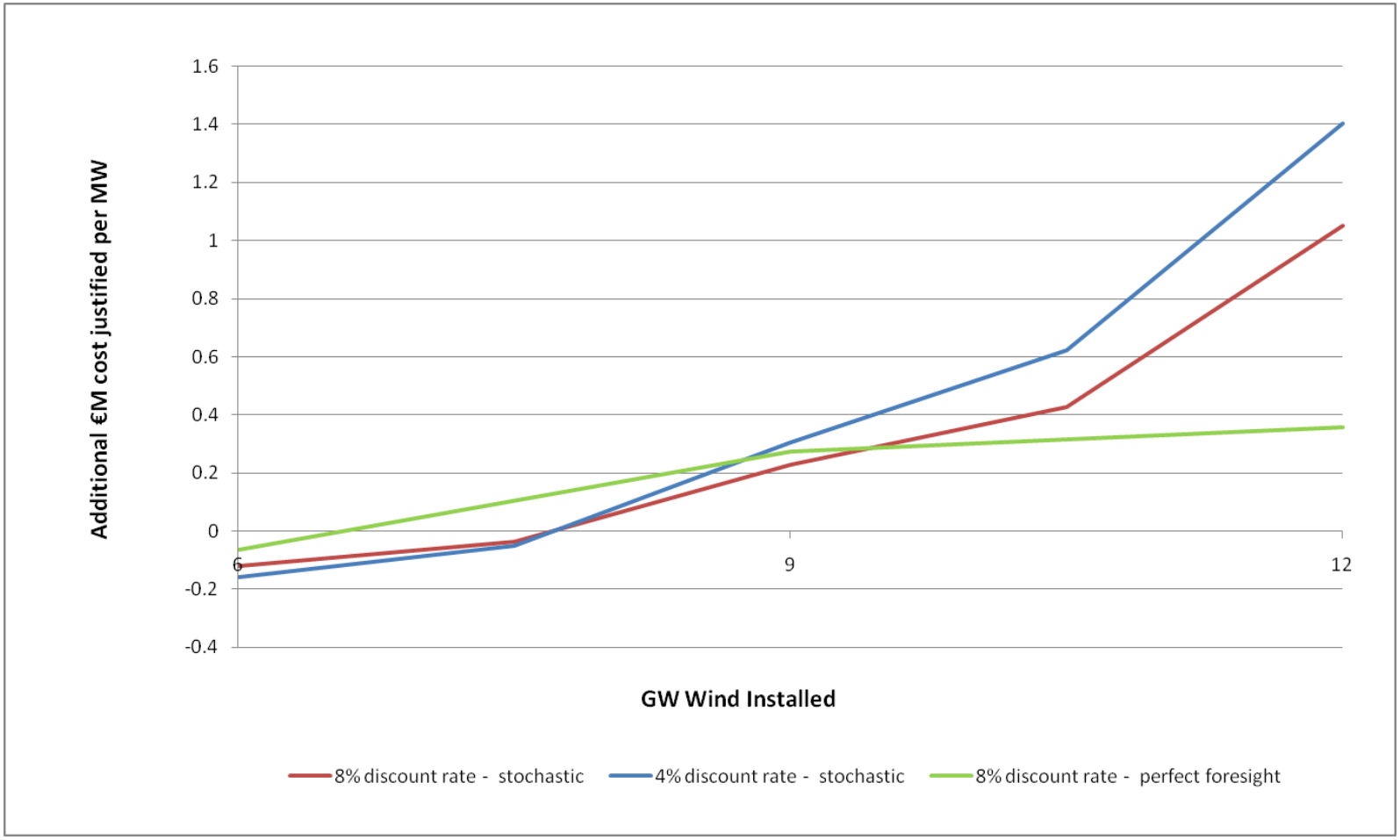


Emissions



Nyamdash, B., Denny, E., and O'Malley, M.J. "The viability of balancing wind power with large scale energy storage", *Energy Policy*, in press, 2010

Additional Capital Expenditure justified



Tuohy, A. And O'Malley, M.J., "Pumped Storage in Systems with Very High Wind Penetration", *Energy Policy*, in review, 2010.

Demand Side Management (DSM)

Teenage girls changed the world

Conclusions

- Nature of the grid is changing
- New markets will evolve
  - Energy: Capacity: Ancillary services (e.g. Inertia, Flexibility)
- Laws of physics dominate – prices are driven by constraints
- Have to develop metrics
- Plenty of stochastic optimisation problems
  - More data is required
- It is a system problem
- Modelling behaviour may become more important

Acknowledgements

- Prof. Dr. Kiesel Rüdiger, University of Duisburg-Essen
- Industry: Bord Gais, Bord Na Mona, Commission for Energy Regulation, Cylon Controls, EirGrid, EPRI, ESB Energy International, ESB Networks, ESB Energy Solutions, Gaelectric, Siemens, SSE Renwables, Viridian
- Funding Agencies: Department of Communications Energy and Natural Resources, Enterprise Ireland, EU, Irish Research Council for Science, Engineering & Technology, Science Foundation Ireland, Sustainable Energy Ireland, Teagasc, IRCHSS, PRTLI
- Current research Team: Dr. Damian Flynn, Dr. Eleanor Denny, Dr. Andrew Keane, Dr. Ciara O'Connor, Dr. Andrej Gubina, Mr. Paul Smith, Mr. Michael Power, Dr. Aidan Tuohy, Mr. Daniel Burke, Mr. Ronan Fitzmaurice, Mr. Batsaikhan Nyamdash, Mr. Eknath Vittal, Mr. Bernhard Hasche, Mr. Daniel Burke, Mr. Peter Richardson, Ms. Niamh Troy, Mr. Aonghus Short, Ms. Sonya Twohig, Ms. Amy O'Mahoney, Ms. Maeve O'Connor, Ms. Paul Cuffe, Mr. Eamonn Lannoye, Mr. Brendan Connolly, Mr. David Kavanagh, Mr. Colm Lowery, Mr. Stefano Verde, Ms. Lisa Ruttledge, Ms. Muireann Lynch, Mr. Eamon Keane, Mr. Erik Ela, Mr. Benish Paily, Mr. Mario Džamarija, Mr. Gaspar Artac, Ms. Rachael O' Hegarty, Ms. Magda Szczepanska
- Graduated PhDs: Dr. Daniel Burke, Dr. Garth Bryans, Dr. Eleanor Denny, Dr. Ronan Doherty, Dr. Meadhbh Flynn, Dr. Andrew Keane, Dr. Gill Lalor, Dr. Jonathan O'Sullivan, Dr. Michael Walsh
- Graduated Masters: Ms. Sonya Twohig, Mr. Jody Dillon, Mr. Shane Rourke, Mr. Paul Sheridan, Mr. Fintan Slye
- Collaborators: Peter Meibom, Brian Parsons, Michael Milligan, Erik Ela, Prof. Janusz Bialek, Dr. Brendan Fox, Prof. John FitzGerald Dr. Chris Dent

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