



Diffusion Models and System Integration: the case of wind energy

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Presented by:

Katherine Dykes

PhD Candidate, MIT Engineering Systems Division

Modeling Development Support from:

Dr. Jeroen Struben

Asst. Prof. of Strategy, Desautels School of Management, McGill University





Diffusion Models and System Integration: Outline

- Motivation and Background
 - History of Wind Energy Technology and Diffusion
 - Recent Growth in Wind Energy Capacity
 - International Policy Landscape for Wind
 - International Reports: Energy Technology Outlooks
- Review of Some Models on Wind and Diffusion
- The Model:
 - Competing Technologies and System Integration Issues
- Summary and Future Work



Brief History of Wind Energy: the Wind Mill

- The First Wind Energy Systems
 - Ancient Civilization in the Near East / Persia
 - Vertical-Axis Wind-Mill: sails connected to a vertical shaft connected to a grinding stone for milling
- Wind in the Middle Ages
 - Post Mill Introduced in Northern Europe
 - Horizontal-Axis Wind-Mill: sails connected to a horizontal shaft on a tower encasing gears and axles for translating horizontal into vertical motion
- Wind in 19th century US
 - Wind-rose horizontal-axis wind mills found throughout rural America



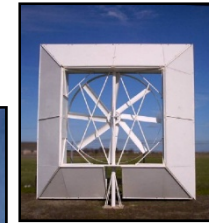
Brief History Continued: First Era Wind Electricity Conversion Systems

- 1888: Charles Brush builds first large-size wind electricity generation turbine (17 m diameter wind rose configuration, 12 kW generator)
- 1890s: US: Lewis Electric Company of New York sells generators to retro-fit onto existing wind mills
- 1890s: Denmark: Poul La Cour builds 20-35 kW machines
- 1920s-1950s: Post WWI, Propeller-type 2 and 3-blade horizontal-axis wind electricity conversion systems (WECS) developed in both the US and Denmark



Brief History of Wind Energy: Second Era of WECS Development

- Design Variety (1970s – 1980s):
 - Emphasis on Experimentation & Variety:
 - Horizontal-Axis
 - 1 to many blades
 - Vertical-Axis
 - Darrieus / Egg-Beater (lift-driven)
 - Savonius (drag-driven)
 - Cross Wind
 - Diffuser / Concentrator
 - Jet-Style Turbine
 - Grid Interconnection established
 - Technology Diffusion US & Europe



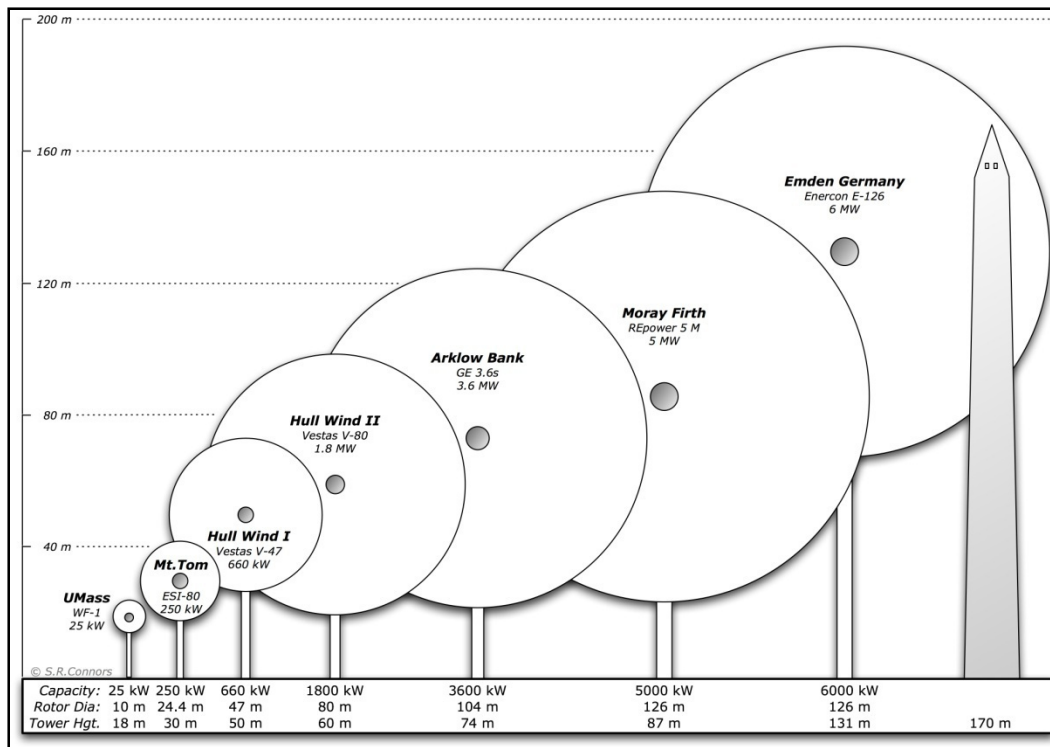
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Brief History of Wind Energy: Third Era of WECS Development & Current Trends

- Highly Standardized Technical System:
 - 3-blade Upwind Horizontal-Axis with some variation in design of a planetary gearbox and induction generator drivetrain on a monopole tower
- Progressive Increase in Size from 1970s to Today

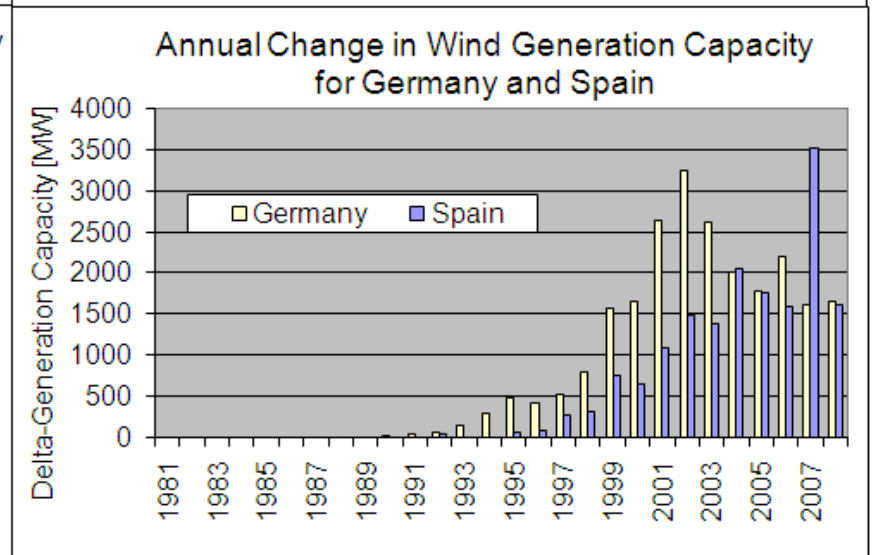
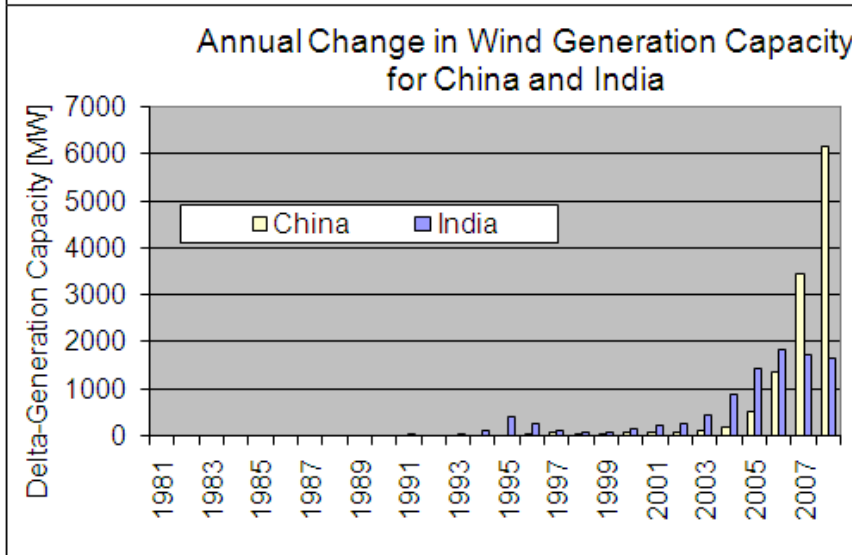
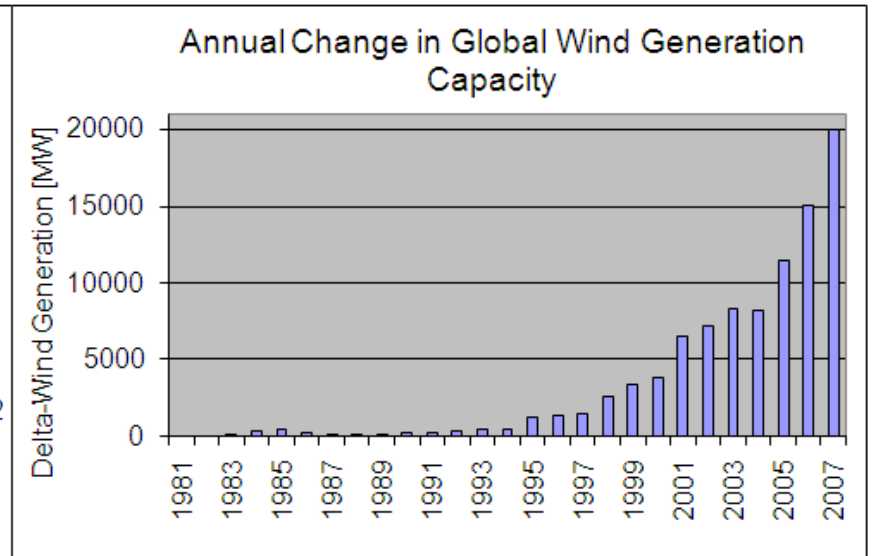
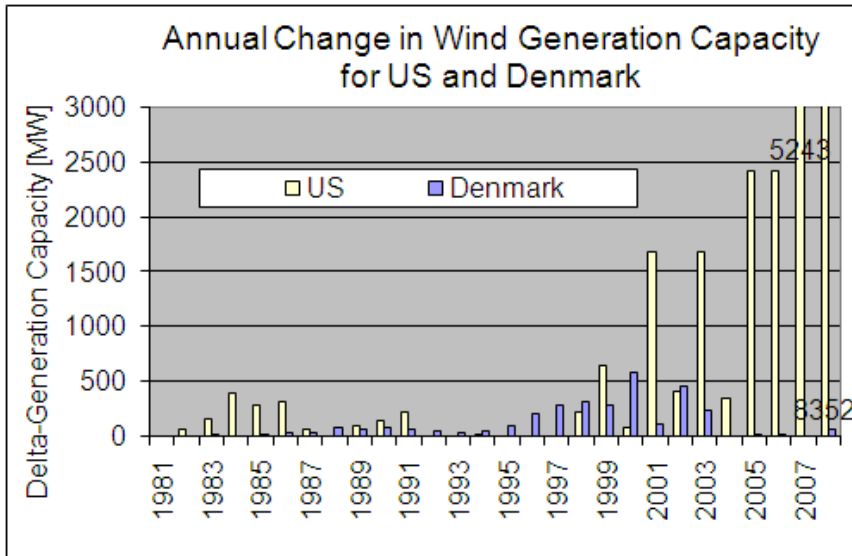


Graphic courtesy of
Steve Connors, MITEI





Brief History of Wind Energy: Growth in installed Capacity



Data source: "Eco-Economy Indicators," Earth Policy Institute, through 2007: http://www.earth-policy.org/Indicators/Wind/2008_data.htm





Brief History of Wind Energy: Policy Promotion Incentives

Denmark Policy Initiatives	US Policy Initiatives
1977 Investment subsidy in Renewable Energy	1978 PURPA enacted and Energy Tax Act establish investment tax credits of 10%
1979 Investment subsidy in Renewable Energy is tied to standard (removed 1989 after being phased out)	1983 ISO4 established to encourage utilities to sign IPP contracts (suspended April 1985)
1981 establishment of test station and market subsidy	1980 Crude Oil Windfall Profits Act bumps federal investment credit to 15% (along with 10% federal investment tax credit)
1984 – 1 st 100 MW agreement	1985 California state tax credit on capital investment of 25% (expired end of 1986)
1990 – 2 nd 100 MW agreement	1992 Federal Production Tax Credit (through June 1999, extended in 2001, 2003, 2005 - 2008)
1989 Investment subsidy removed after gradual reduction	Germany Policy Incentives
1991 Export Guarantee for with strict standards created (worth 750 Million Danish Kroener)	1989 Germany begins program with 100 MW (feed-in tariff)
1993 Feed-in Tariff Established	1991 Subsidies are continued, 1000 MW planned in each state

References:

van Est, Rinie. Winds of Change. International Books, Utrecht: 1999.

Gipe, Paul. Wind Energy Comes of Age. John Wiley & Sons, Inc., USA: 1995.

Wind Energy Production Tax Credit (PTC), AWEA, 2008: http://www.awea.org/pubs/factsheets/PTC_Fact_Sheet.pdf





International Reports on Energy

- Reports on Energy Outlook:
 - IEA 2008 World Energy Outlook
 - EIA 2008 Energy Outlook
 - McKinsey 2009 Pathways to a Low-Carbon Economy
 - MIT CEEPR 2007 Assessment of US Cap and Trade Proposals
- Reports on Wind Energy Potential:
 - GWEC 2005 Wind Force 12
 - DOE 2008 20% Wind Energy by 2030

Reports on Capacity for the Future of Wind Development			
Report	Year	US	World
IEA	2030		9%
EIA	2030	8%	
McKinsey	2030		14%
CEEPR	2030	negligible	
DOE	2030	20%	
GWEC	2020	6%	12%

Notes: McKinsey 14% is from the more optimistic scenario, EIA report has 15% 2030 electricity net-generation coming from all renewables



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Review of Some Models of Wind and Diffusion

- Various System Dynamics Models on General Processes of Innovation Diffusion (i.e. Milling, Maier, Lyneis)
- Various System Dynamics Models on the Electricity Sector (i.e. Ford, Vogstad, Pruyt)
- Few System Dynamics Models focused on Wind Energy
 - Ozdemier & Oner 2002: Assessment of potential for renewable capacity growth in Turkey under different policy scenarios
 - Pruyt 2004: Recreates the GWEC World Force 12 spreadsheet model in system dynamics modeling environment and enhances model through addition of feedbacks and additional variables
 - Dyner 2006: Assessment of potential for wind capacity growth in Colombia under different policy scenarios



Review of Some Models on Wind and Diffusion

- Pruyt 2004:
 - Starts with the basic Wind Force 12 GWEC model for 12% of world energy from wind by 2020
 - Growth rate in wind capacity an exogenous variable
 - Relaxes some of the more inappropriate assumptions of the GWEC model:
 - Eliminate sudden changes in technology performance, allow for retirement of old technology, and improve treatment of learning processes
 - Develop feedbacks between cumulative capacity, siting, costs, learning effects / experience, profits, new capacity, and new capacity availability
- Dyner 2006:
 - Uses a more traditional basis for diffusion models (Rogers 1995; Geroski 2000)
 - Adds influence of different exogenous policy mechanisms
 - Some attempt at estimating R&D spending influence on costs



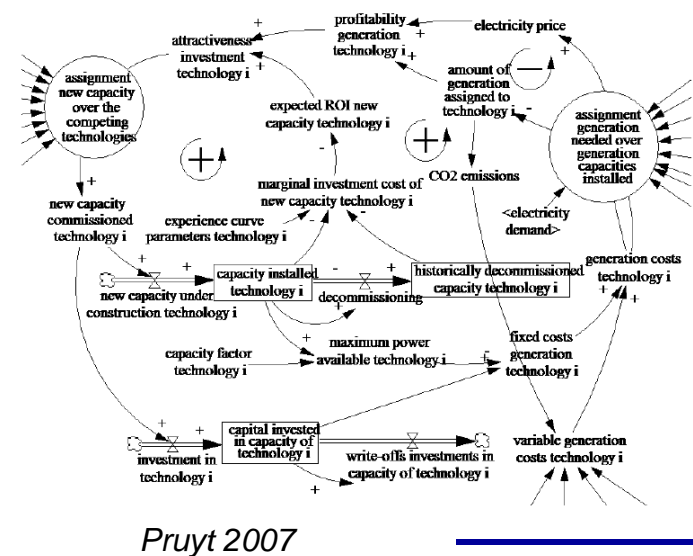
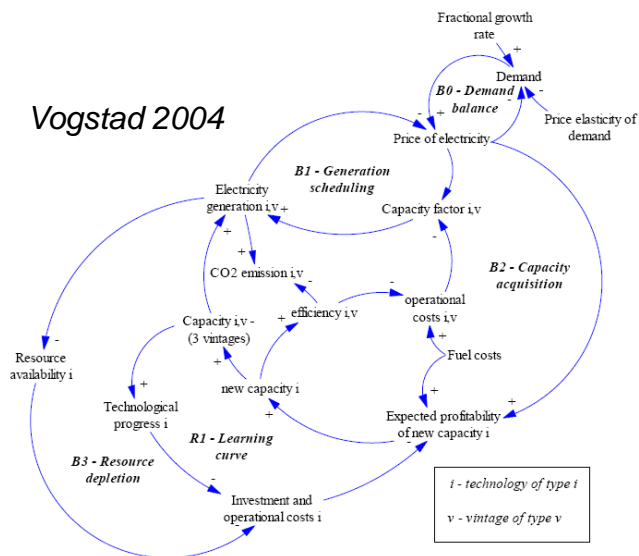
Review of Some Models on Wind and Diffusion

- Suggested Model Improvements:
 - In Pruyt 2004, CO2 prices treated as endogenous, other government policy mechanisms exogenous
 - In both, expected electricity price treated as exogenous
 - Role of competing technologies
 - Role of electricity demand
 - In both, ignores auxiliary (non-economic) sources of uncertainty:
 - Technical system integration issues, for example:
 - Technical limitations of high wind penetration (grid stability)
 - Associated development of complementary technology
 - Availability of transmission
 - Environmental and community issues that may limit siting



Review of Some Models on Wind and Diffusion

- Vogstad 2004:
 - Looks at the issue of competing technologies: feedback loops for generation scheduling, demand balance, learning curves, capacity acquisition and resource depletion
- Pruyt 2007:
 - Looks at the issues of competing technologies: feedback loops for new capacity commissioned, learning curves, electricity price and CO2 emissions



Pruyt 2007





Review of Some Models on Wind and Diffusion

- Residual concerns:
 - In Pruyt 2007, competing technology comparison added at the expense of resolution on wind energy specifics:
 - Endogeneity of capacity factor removed
 - No manufacturing component constraint (new turbine availability)
 - Both still ignore auxiliary (non-economic) sources of uncertainty / restraints:
 - Technical system integration issues, for example:
 - Technical limitations of high wind penetration (grid stability)
 - Associated development of complementary technology
 - Availability of transmission
 - Environmental and community issues that may limit siting
 - Both still treat policy as an exogenous variable



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The Model:

Competing Technologies and System Integration Issues

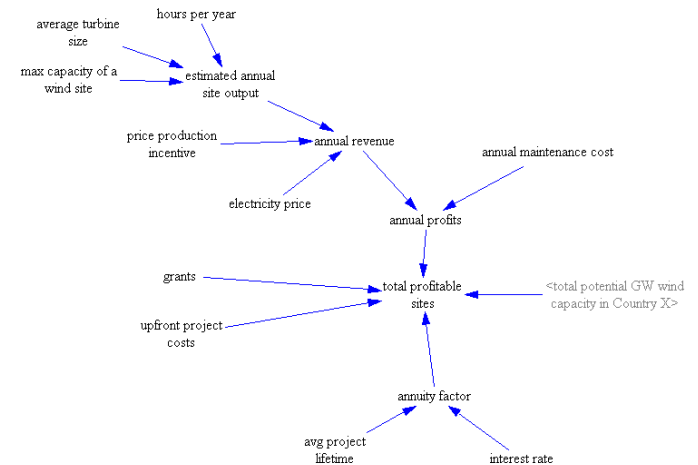
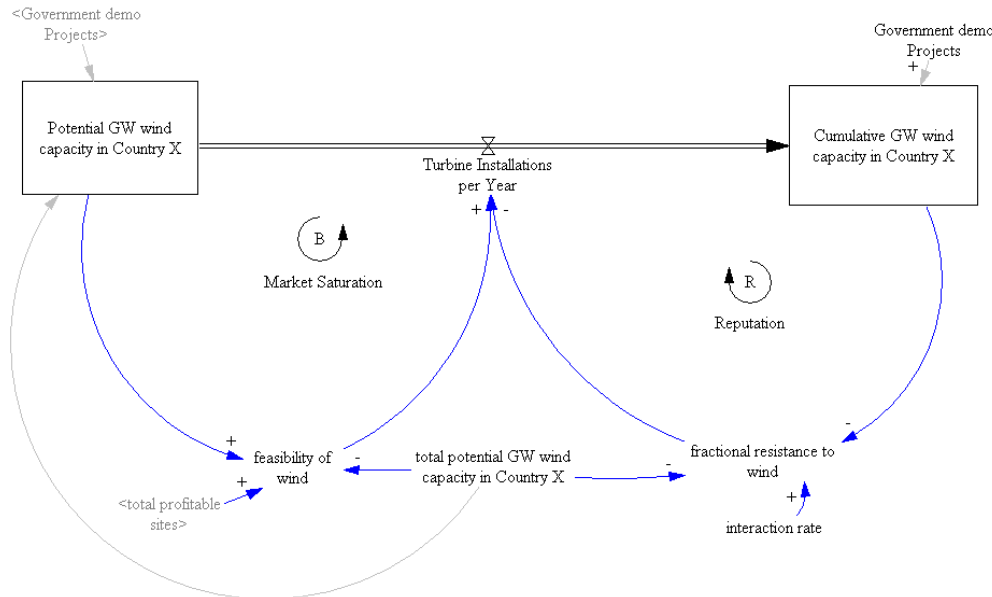
- Focus on diffusion of technology into pre-existing socio-technical systems
 - Examples: wind energy on the grid, alternative propulsion vehicles in transportation, new designs into systems of satellites
 - Limitations due to socio-technical constraints on system; similar to path dependence (Shapiro and Varian 1998), including:
 - economies of scale
 - durable purchases
 - standards for technology
 - manufacturing abilities
 - development of complementary technologies
 - learning curve effects
 - Economies of scale, learning curves, manufacturing abilities, durable purchases partially treated by above models
 - Complementary technology and technical standards potential area for analysis



The Model: Competing Technologies and System Integration Issues

- Basic Model Design:

- Bass diffusion model not realistic, parallels created for
 - primary reinforcing loop (increased familiarity with wind technology)
 - primary balancing loop (depletion of high wind resource sites profitable for development)
- Policy, electricity price, costs and demand initially treated as exogenous





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Summary and Future Work

- Many issues of interest with growth of wind energy capacity in electricity sector
- Various system dynamics models focusing directly or indirectly on wind energy focusing on such issues as:
 - Manufacturing capacity
 - Policy influence on adoption
 - Endogeneity of resource depletion, electricity prices, demand
- Less attention paid to issues of system integration: new technology, old system
- Presented an initial model development focusing on system integration



Summary and Future Work

- Future work will focus on
 - Refinement of system integration aspects of the model
 - Relaxing assumptions concerning inclusion of variables and missing feedback loops present in other models
 - Attempts to calibrate model to actual historical data from the US
 - Relax assumptions concerning exogeneity of policy in this system
 - Development of more general model work on the issues of system integration and diffusion



Wind Energy Technology: Resources

- References:

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- Righter, R. 1995. *Wind Energy in America*
- Sterman, J. 2000. *Business Dynamics*.
- Torrey, V. 1978. *Wind-Catchers*
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- www.windpower.org

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What's With Wind

Thanks!
Q&A