w w w . g r n N R G . c o m

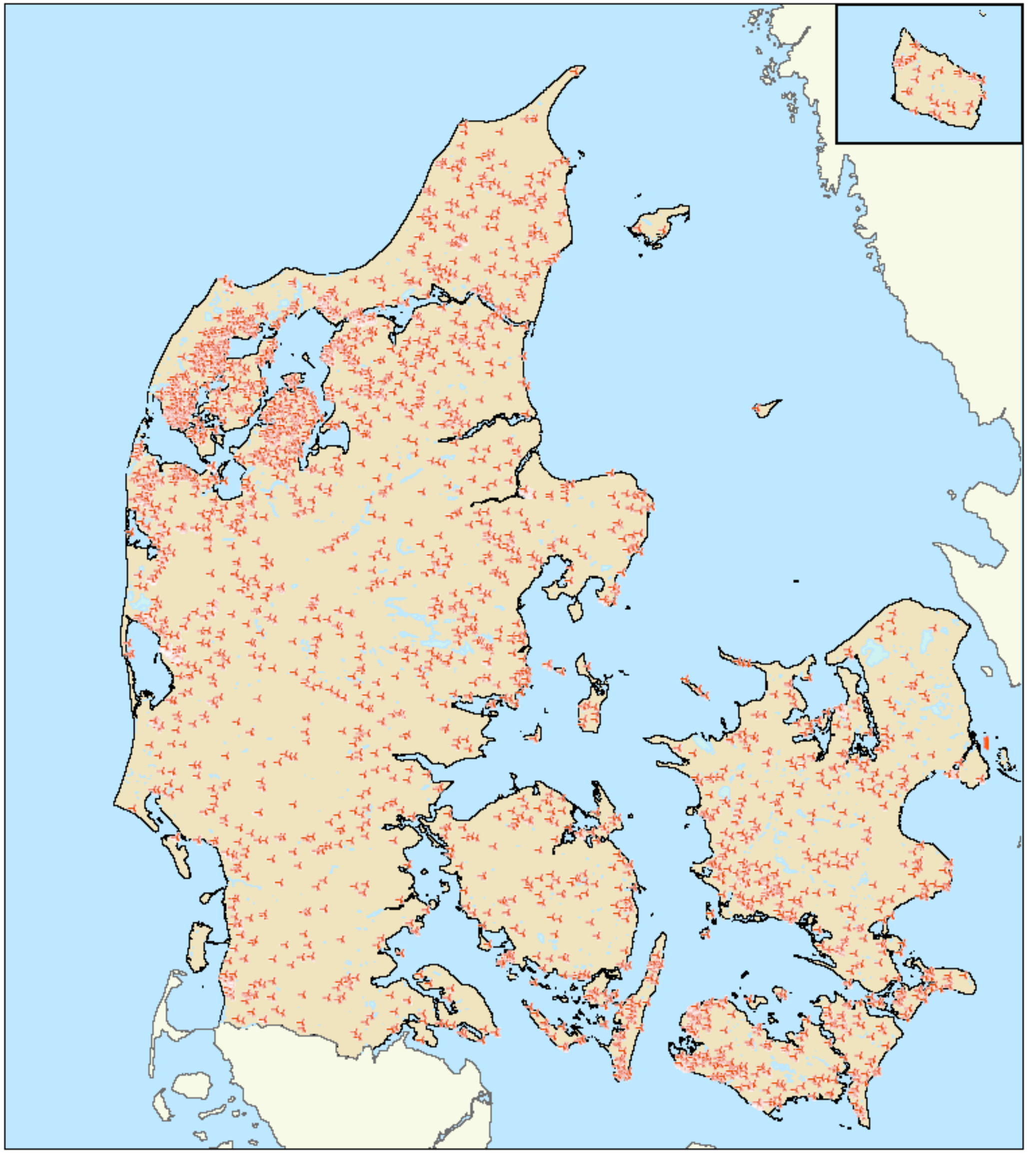
Wind and Hydro – Can We Do A Better Job Modeling These?

SSG-WI Economic Valuation of Transmission Additions
Modeling Issues
Sept 15, 2004

Jayson Antonoff – grnNRG Consulting
jaysonA@grnNRG.com

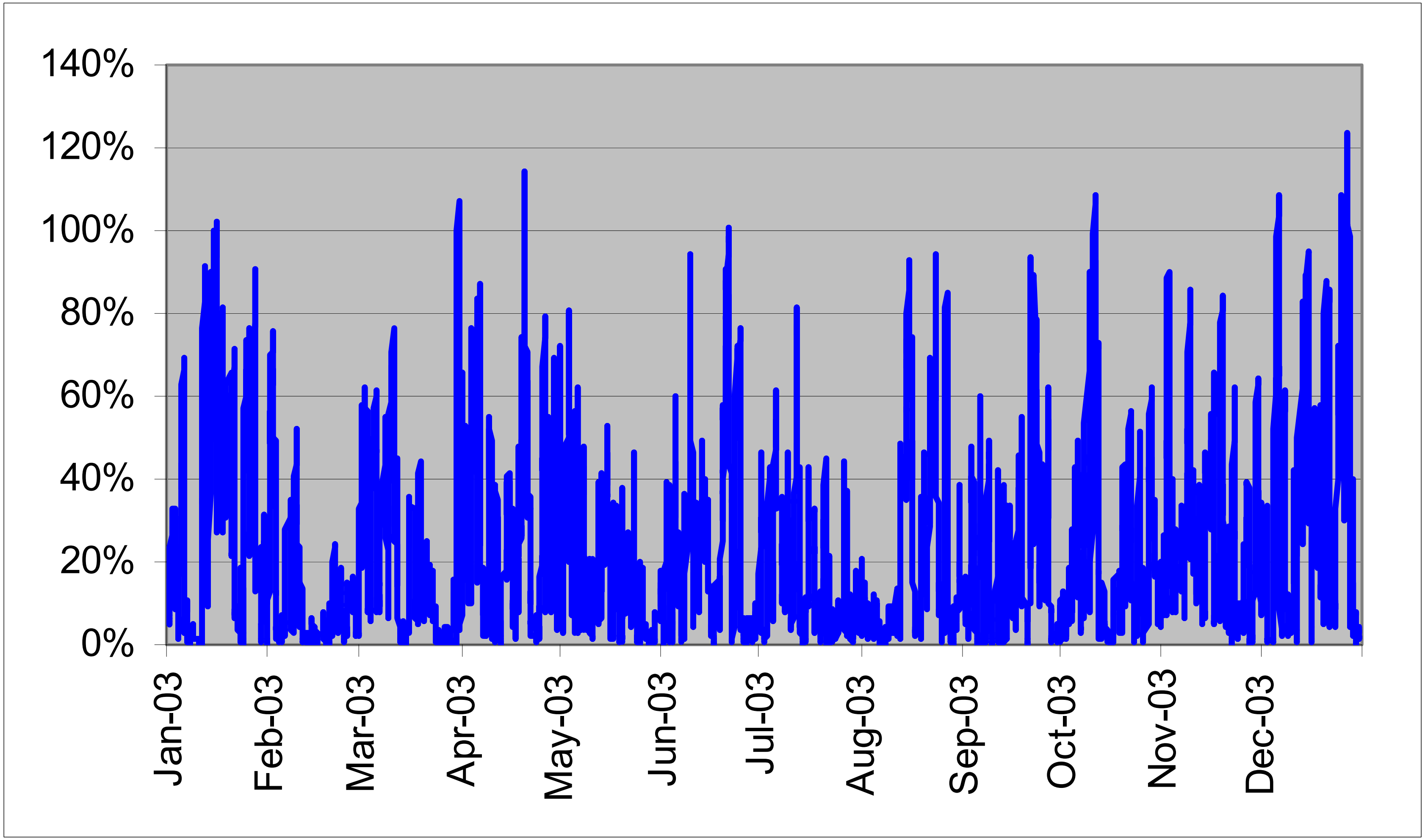
grnNRG Consulting Inc.

Wind in Western Denmark (2003)



- Total installed wind capacity = 2,400 MW
- Annual wind production = 4,363 GWh
- Annual energy consumption = 20,648 GWh

Wind Penetration Level
(Western Denmark)

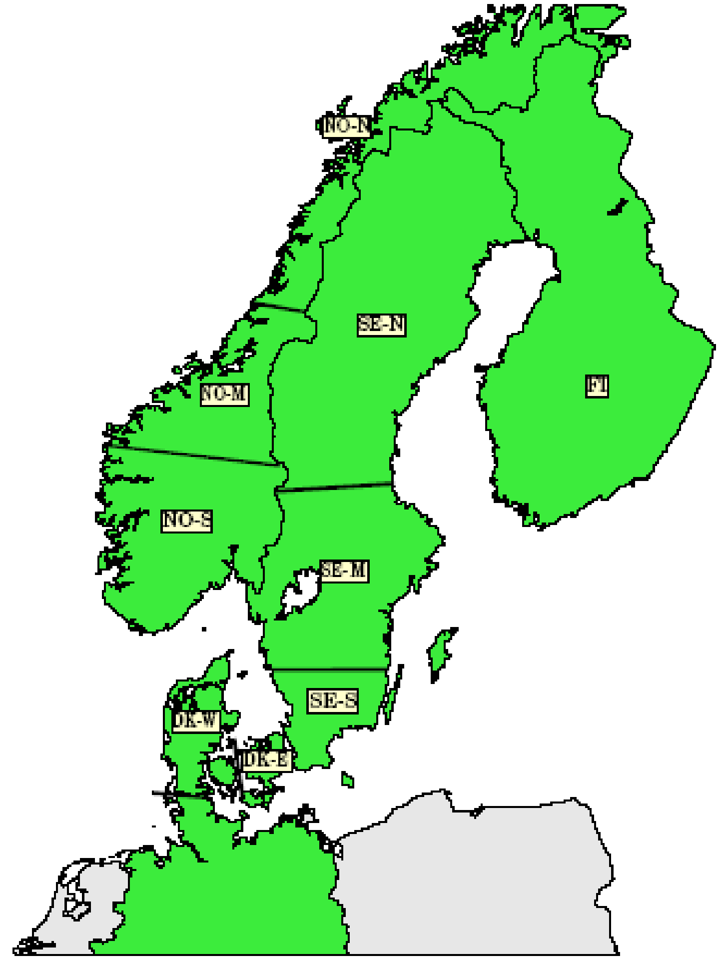


- Wind produced more than 90% of load for 85 hours per year
- Wind provided 21.1% of annual energy needs

grnNRG Consulting Inc.

Scandinavian Energy Systems

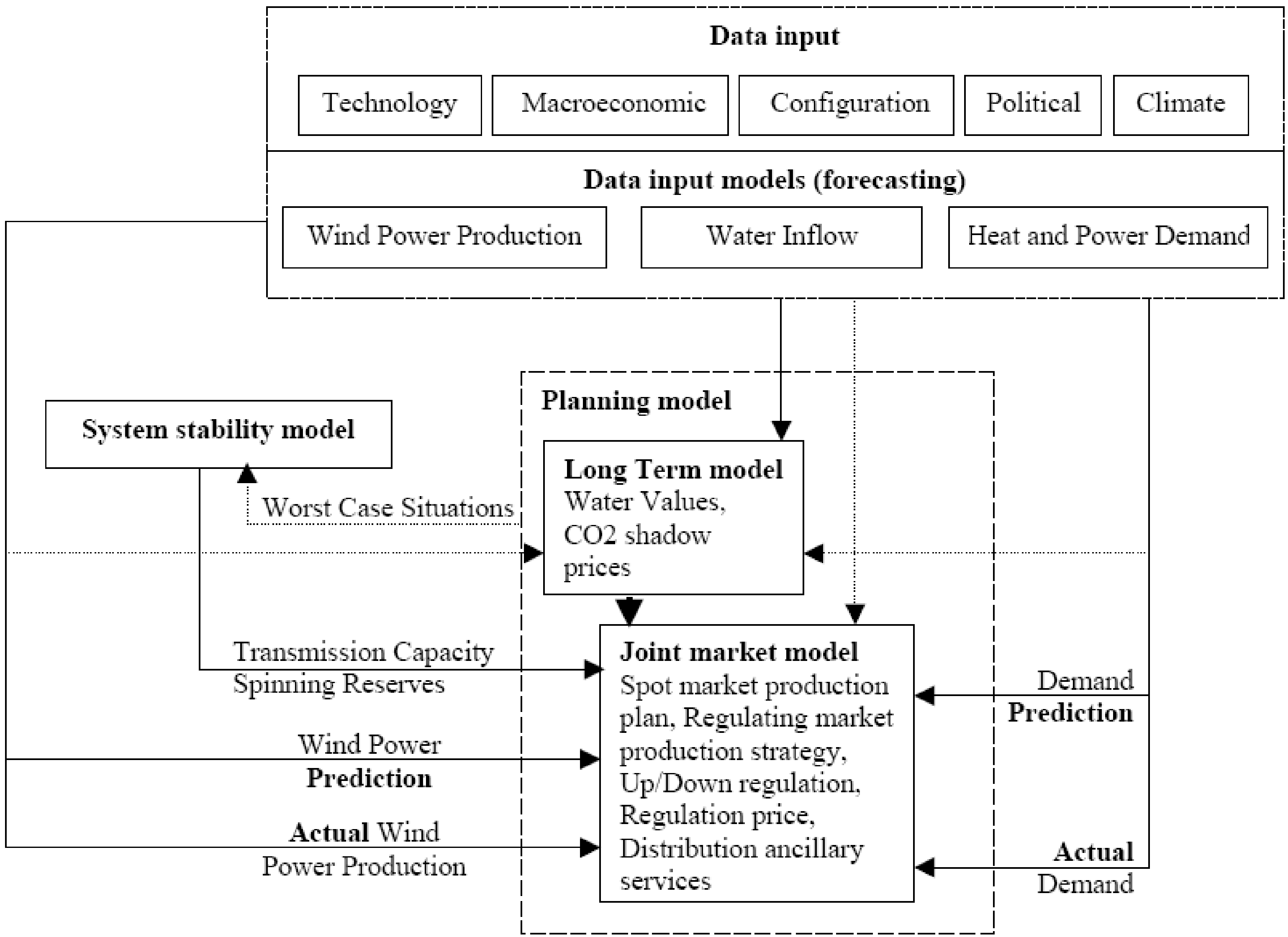
- Trading is in NordPool - a fully functional electricity market, with active day ahead and hour ahead markets.
- Sweden/Norway - highly hydro dependent
- Northern Germany - thermal based generation
- Denmark is in the middle, with lots of energy being wheeled north and south.



WILMAR Wind Power Integration in Liberalised Electricity Markets

- WILMAR – Wind Power Integration in Liberalized Electricity Markets
- Project goal - Calculate the effect that wind has on balancing and regulating needs in a well functioning electricity market.
- Key Issues tackled:
  1. Uncertainty
  2. Modeling of hydro power
  3. Modeling wind power
- A stochastic representation of input variables is inherent within the fundamental decision making engine of WILMAR.

System Architecture



Modeling Hydro Resources

- Hydro output consists of combination of unregulated outflow (run of the river – non-dispatchable), regulated outflow (reservoir controlled - dispatchable), and flood.
- Water values (economic dispatch of stored water) – when should you use water to maximize total benefits? (considers time of year, current and projected prices, current reservoir level and total capacity projected inflow and outflow)

Multi Stage Process

- Long term model calculates energy prices and hydro conditions on a weekly basis. These become inputs into the daily dispatch model.
- Perform stochastic dynamic programming to minimize the total expected costs over one year, for each season, at different levels of hydro production in the season.
- Combine these costs with stochastic hydro inflows and reservoir volumes in a stochastic dynamic program to find the solution that provides the minimum expected costs.

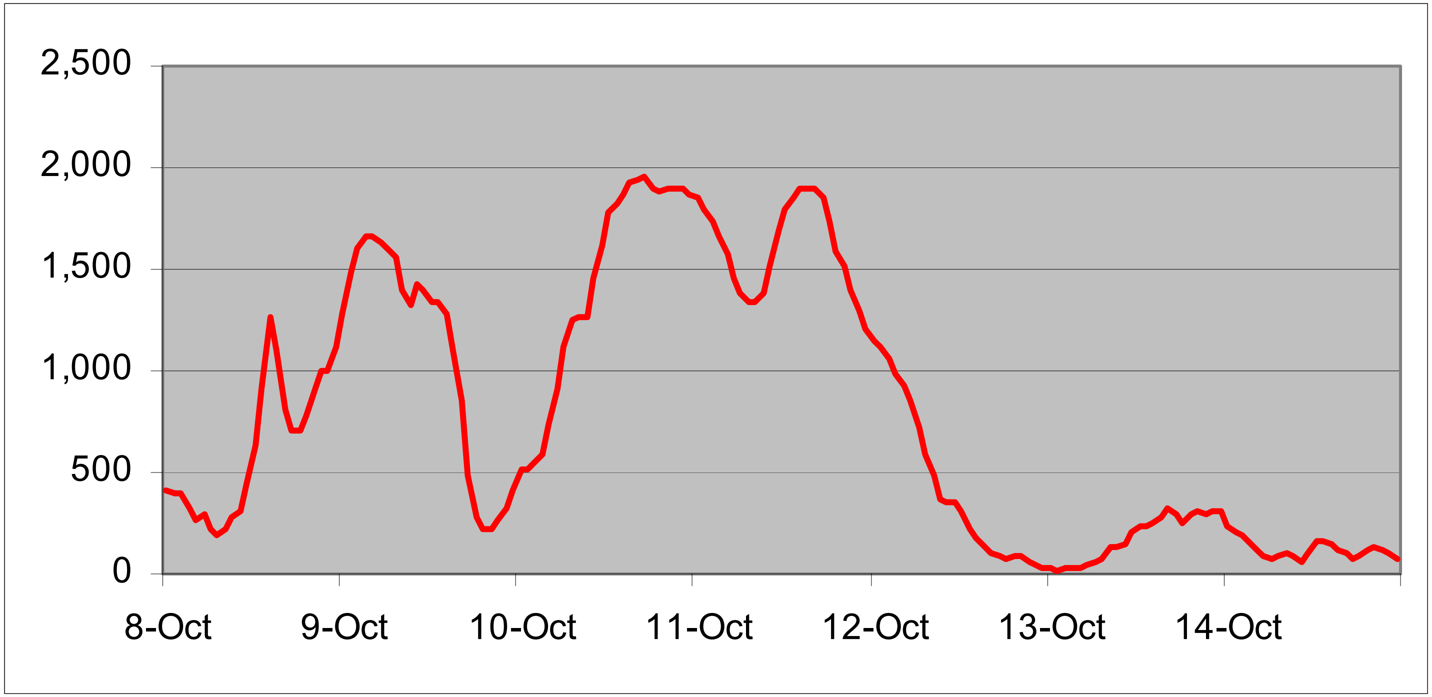
Advantages

- Hydro is modeled as a dispatchable supply source (not reduction of load)
- Calculates the optimal hydro production level corresponding to each season and reservoir level for each region.

w w w . g r n N R G . c o m

Modeling Wind

- Wind was modeled stochastically because it is a rapidly changing variable that influences outcomes.



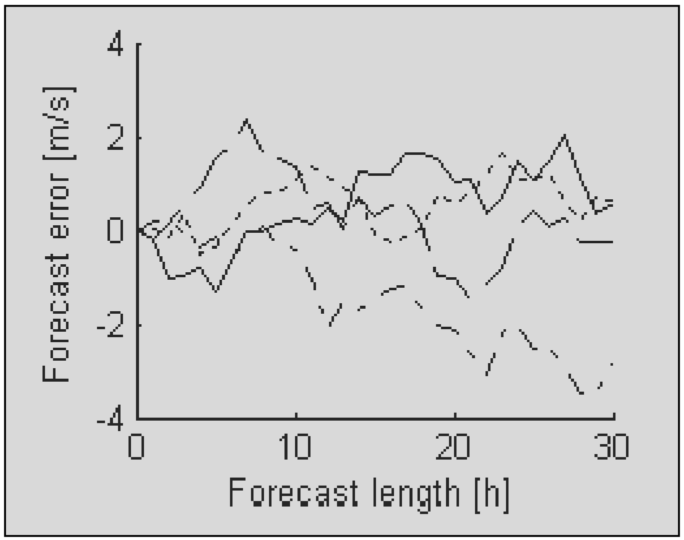
grnNRG Consulting Inc.

Wind Power Projections

- Based on actual power production time series for 2000 to 2002 – concept of capacity factor is included implicitly.
- Wind power forecasting algorithm is used to determine probability distribution of wind output for the following hour.
- Future wind output IS predictable within a given confidence range – this can be used to quantify decision making.

Stochastic Decision Making

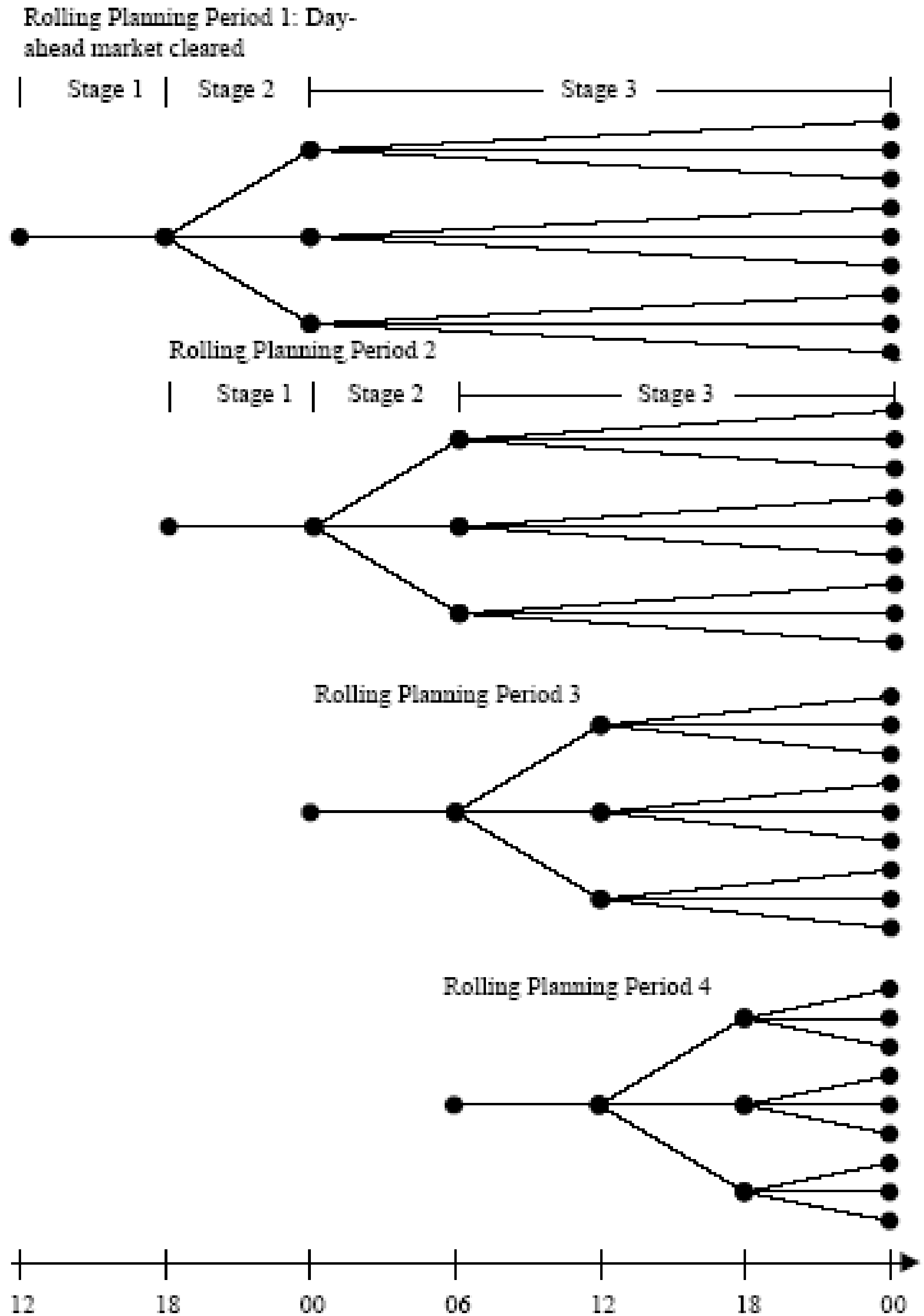
Stochastic decision making looks at the probability set of "all" possible outcomes for an event before determining the optimal solution.



To reduce this to a feasible solution set, possible outcomes for each decision are mathematically reduced to a set of three solutions that best describe the projected probability space.

Balancing and Regulating Markets

- In Nord Pool, bids for the Elspot market must be delivered by noon for the following day's commitment schedule.
- Decision on how much wind power to schedule must be made before we know how much wind will be available – stochastic programming is used to determine likely amount that will be available AND how much of that should be committed to day-ahead market. This decision problem can be formulated mathematically as a multi-stage, stochastic optimization problem.


Rolling Planning Period 1: Day-ahead market cleared
Stage 1
Stage 2
Stage 3
Rolling Planning Period 2
Stage 1
Stage 2
Stage 3
Rolling Planning Period 3
Rolling Planning Period 4
12
18
00
06
12
18
00

Joint Optimization

- The model optimizes the supplies on both the day-ahead market and the intra-day market (joint optimization), taking the stochastic nature of the demand for regulating power on the intra-day market into account.
- The amount of wind power offered at the day-ahead market will not always be the maximal power output available; they may offer less at the day-ahead market due to expected increased revenues from the selling of up-regulation at the intra-day market.

Modeling Recommendations

- Better access to real-world wind production data.
- Better understanding of time variant. characteristics of wind resource – probability distribution mapping.
- Resources and other inputs with high short term variability should be modeled stochastically.
- Treat wind and hydro as dispatchable resources for downward regulation.
- Consider effects of greater geographic aggregation of resources.
- Future – consider financial implications of day ahead and hour ahead trading markets in wind commitment schedules.

Seeking additional partners for further validation of methodology.

Questions?