UMassAmherst

Portfolio Modeling for Siting Offshore Wind Farms

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University of Massachusetts, Amherst
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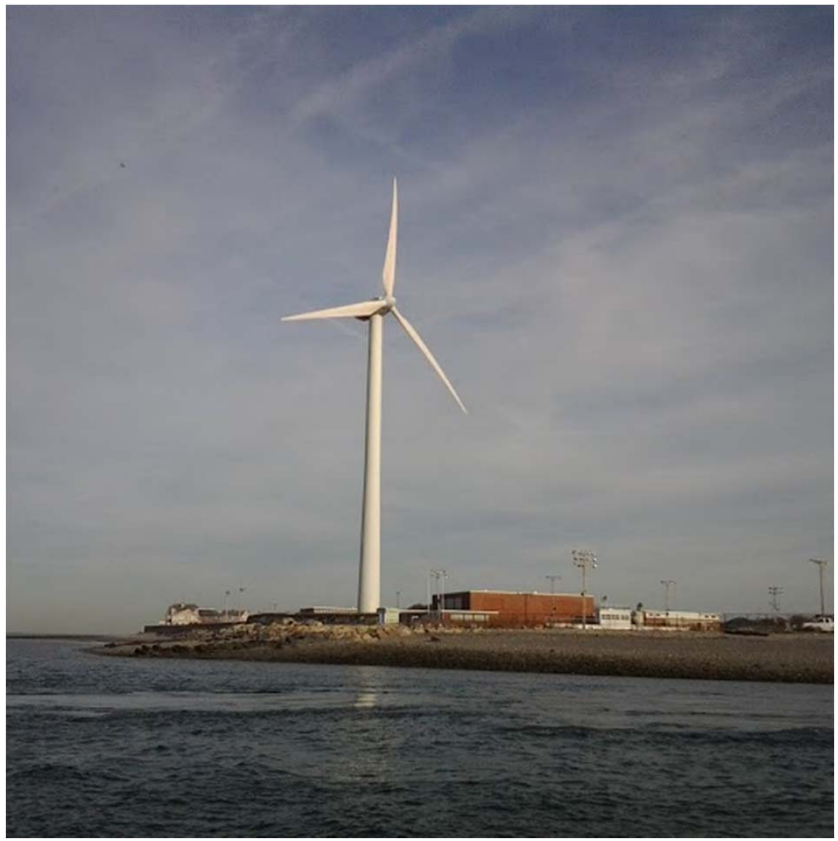
Siting Offshore Wind Energy

- Multicriteria Optimization Problem
  - Values
  - Tradeoffs
  - Outcomes



Part 1

Economics:
Maximizing Profit

Modeling Wind Farm Interactions - Economics

$$U_d = U_0 e^{ad}$$

Barthelmie et. al. 2010; Barthelmie and Jensen 2010; Henderson et. al. 2010; Johnson et. al. 2009; Jensen 1983; Katic et. al . 1987; Nygaard 2014; Phillips et. al. 2010; Schlez and Neubert 2009; Smith et. al . 2011.

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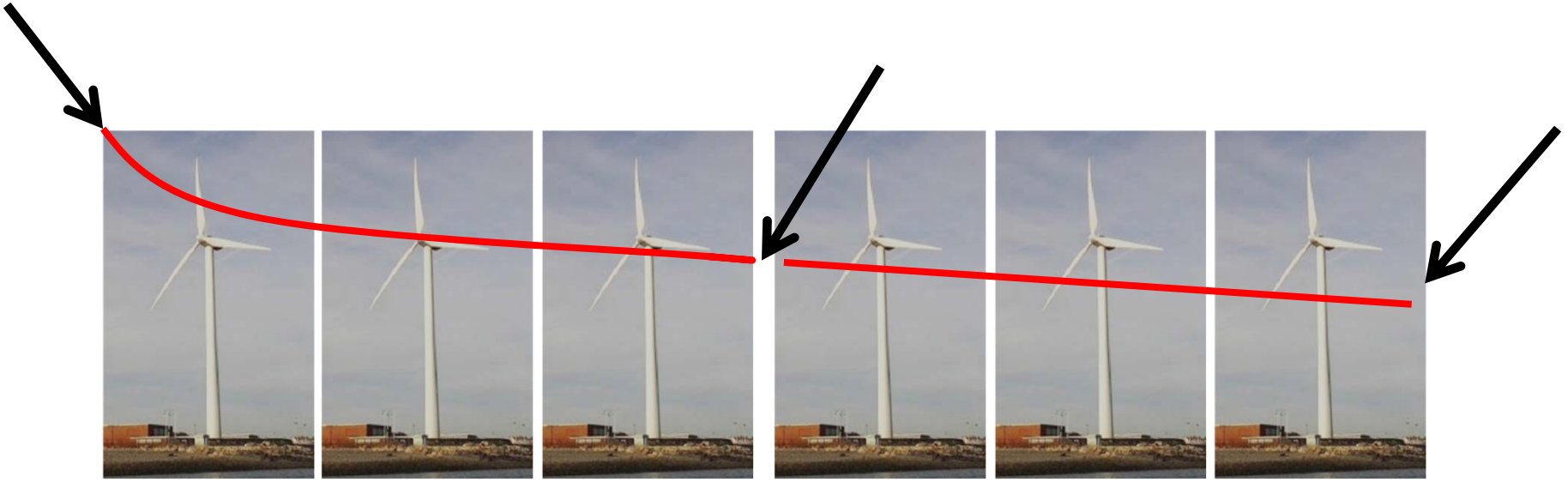

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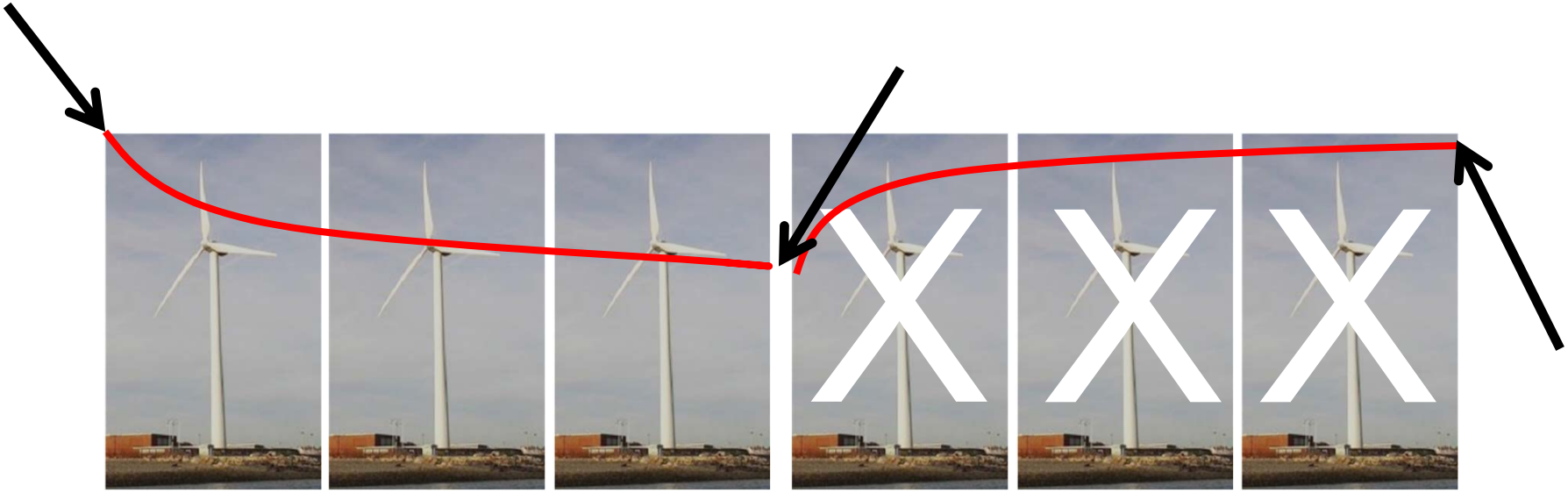

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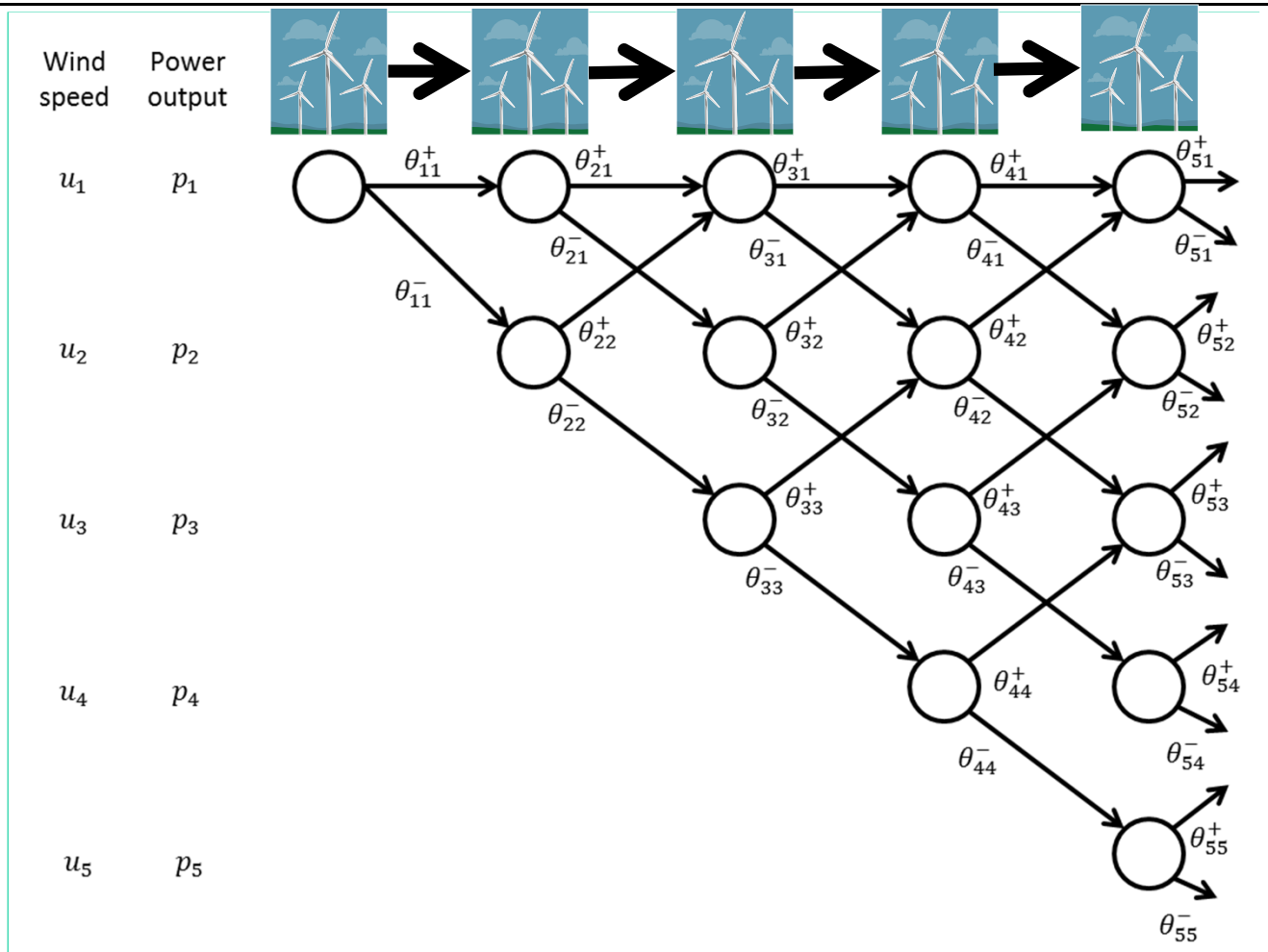
Network Model



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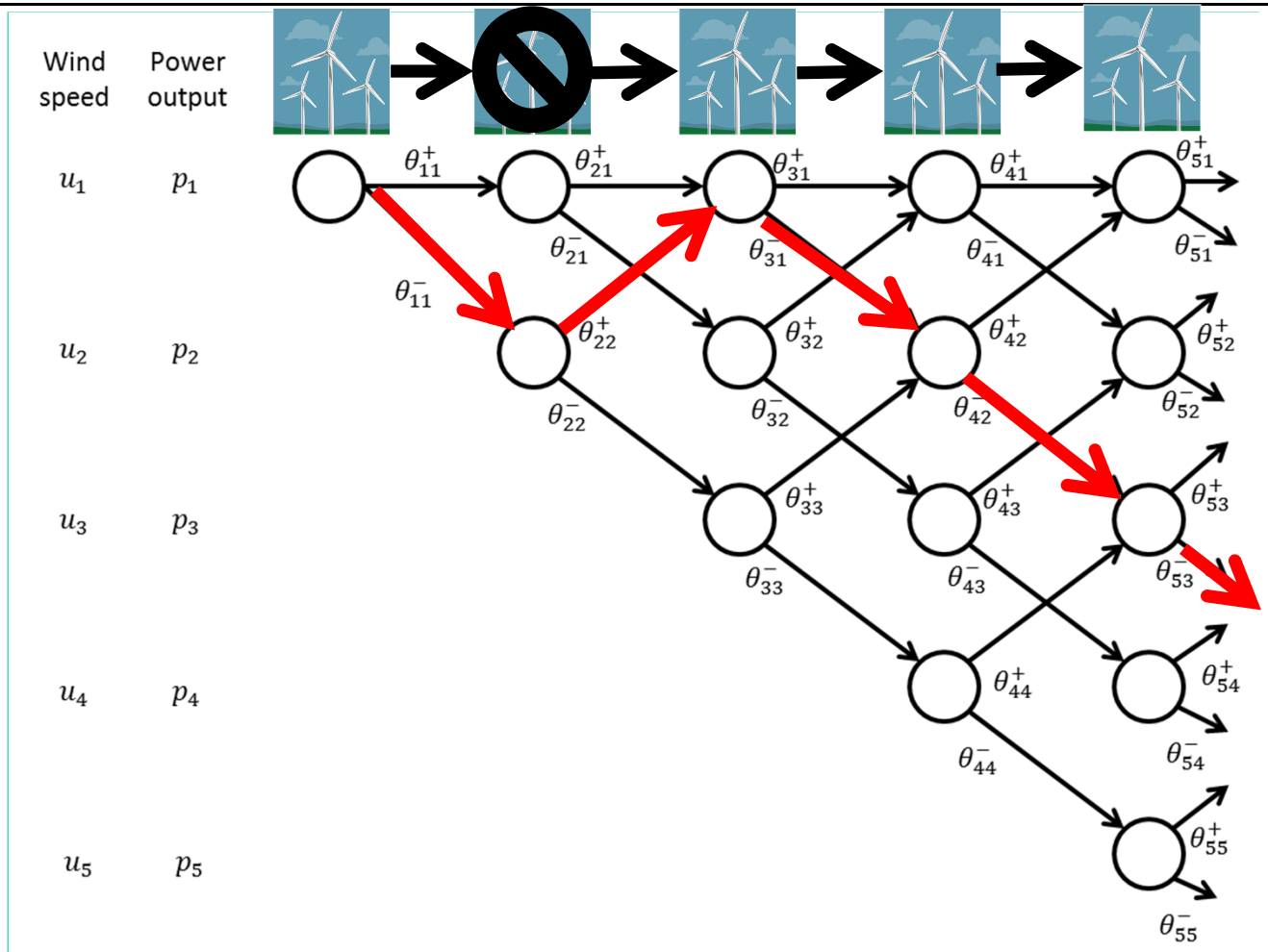


Network Model

- Objective function

$$\max_{Z}\left(R\bar{P}(Z)h\nu - \sum_{(x,y)\in G} C_{x,y}z_{x,y}\right)$$

- Average power value

$$\bar{P}(Z) = \sum_{\omega\in\Omega^{\rightarrow}} f(\omega)\sum_{y=1}^{\bar{y}} P_y^{\rightarrow}\left(\omega, z_{:,y}\right) + \sum_{\omega\in\Omega^{\leftarrow}} f(\omega)\sum_{y=1}^{\bar{y}} P_y^{\leftarrow}\left(\omega, z_{:,y}\right) + \sum_{\omega\in\Omega^{\uparrow}} f(\omega)\sum_{x=1}^{\bar{x}} P_x^{\uparrow}\left(\omega, z_{x,:}\right) + \sum_{\omega\in\Omega^{\downarrow}} f(\omega)\sum_{x=1}^{\bar{x}} P_x^{\downarrow}\left(\omega, z_{x,:}\right)$$

- Network constraints

$$z_{j,y} = \sum_{i=1}^{j} \theta_{ji}^{-}(\omega, y)\,, \forall j = 1, \dots, \bar{x}$$

$$\theta_{11}^{+}(\omega, y) + \theta_{11}^{-}(\omega, y) = 1$$

$$\theta_{11}^{+}(\omega, y) = \theta_{21}^{+}(\omega, y) + \theta_{21}^{-}(\omega, y)$$

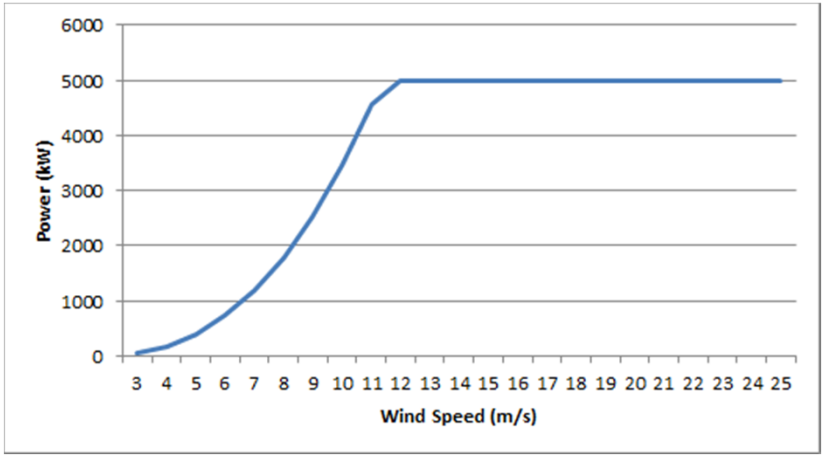
$$\theta_{j-1,1}^{+}(\omega, y) + \theta_{j-1,2}^{+}(\omega, y) = \theta_{j,1}^{+}(\omega, y) + \theta_{j,1}^{-}(\omega, y)\ \forall j = 3, \dots, \bar{x}$$

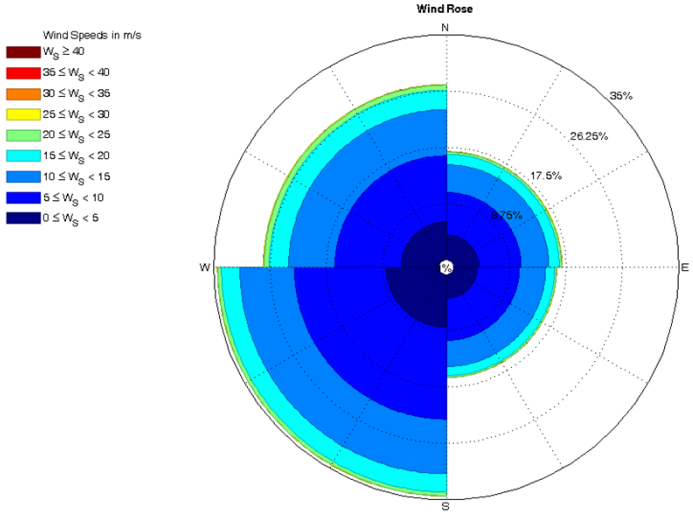
$$\theta_{j-1,i+1}^{+}(\omega, y) + \theta_{j-1,i-1}^{-}(\omega, y) = \theta_{j,1}^{+}(\omega, y) + \theta_{j,1}^{-}(\omega, y)\ \forall j = 4, \dots, \bar{x}, i = 2, \dots, j-2$$

$$\theta_{j-1,j-1}^{-}(\omega, y) = \theta_{j,j}^{+}(\omega, y) + \theta_{j,j}^{-}(\omega, y)\ \forall j = 2, \dots, \bar{x}$$

$$\theta_{j-1,j-2}^{-}(\omega, y) = \theta_{j,j-1}^{+}(\omega, y) + \theta_{j,j-1}^{-}(\omega, y)\ \forall j = 3, \dots, \bar{x}$$

Application





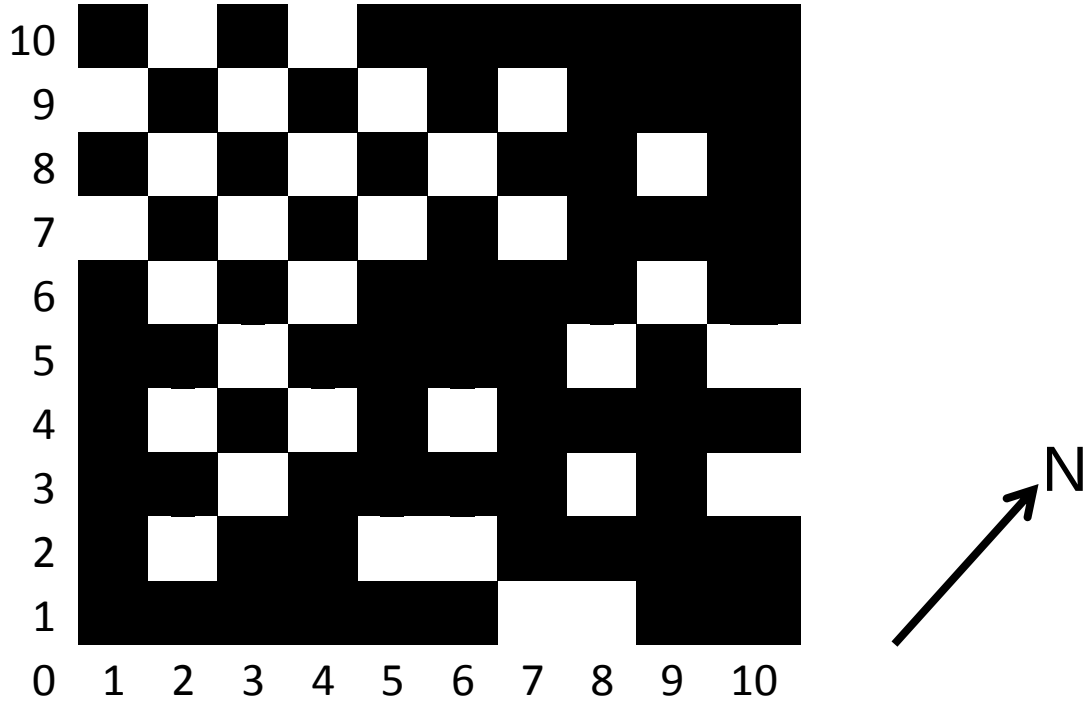
Jonkman,2009; NOAA National Data Buoy Center (NDBC)

Top Left: NREL 5MW power curve
Bottom Left: Wind rose for the Gulf of Maine with four wind direction bins.
Table 1: Joint and marginal probabilities for three divisions of wind speed and four of wind direction. Expected wind speed of the bins is {3.76, 8.80, 15.72} m/s.

	Low U<6	Mid 6≤U<12	High U≥12	Total
SE	0.0659	0.0750	0.0290	0.1699
SW	0.1098	0.1858	0.0702	0.3658
NW	0.0749	0.1147	0.1008	0.2904
NE	0.0556	0.0754	0.0430	0.1740
Total	0.3061	0.4509	0.2430	1

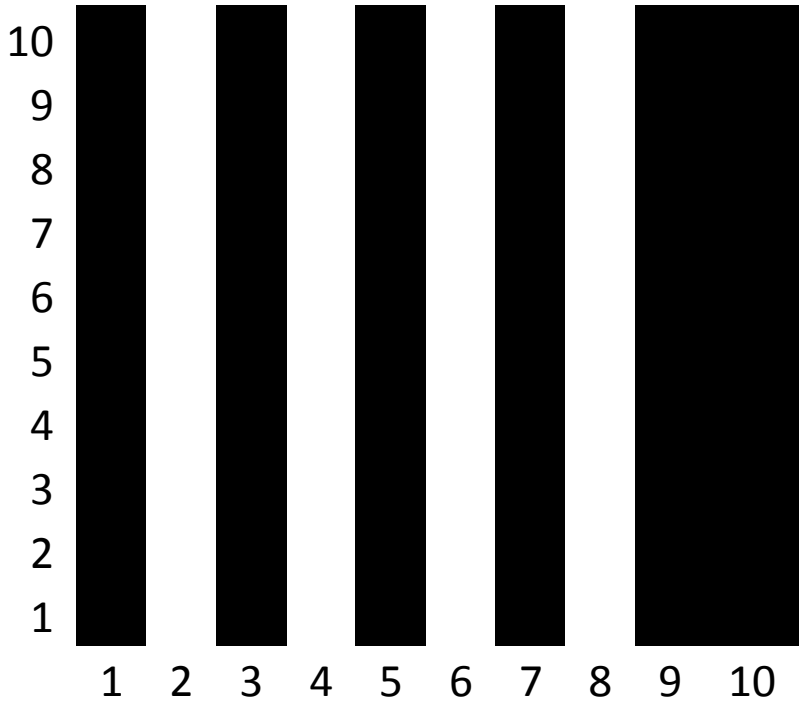
Results

Results using Gulf of Maine distribution
with three wind speeds and four directions.
Black indicates a wind farm.

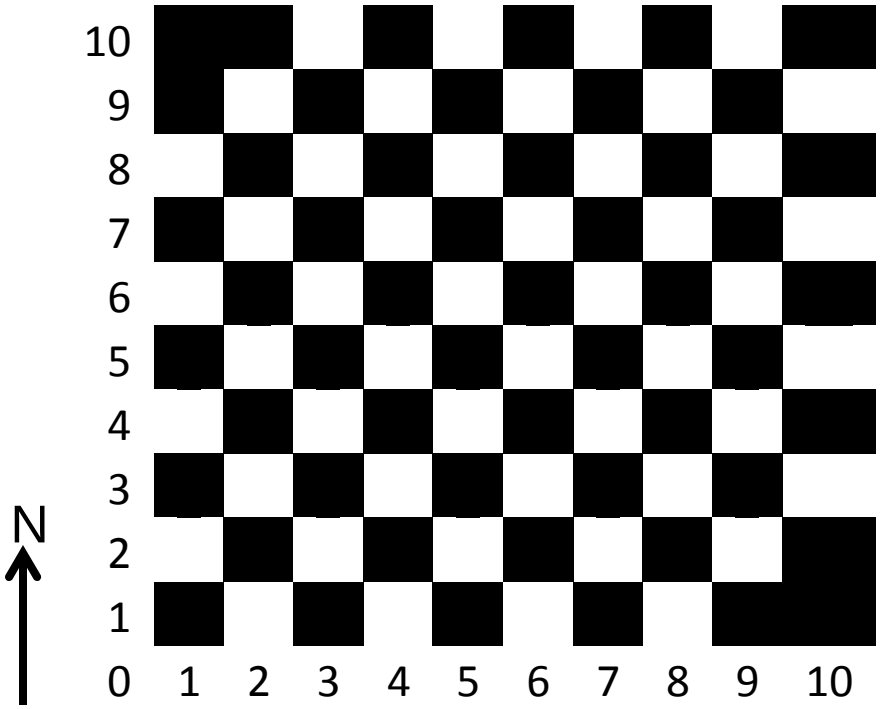


Results

West wind only, 8.8 m/s

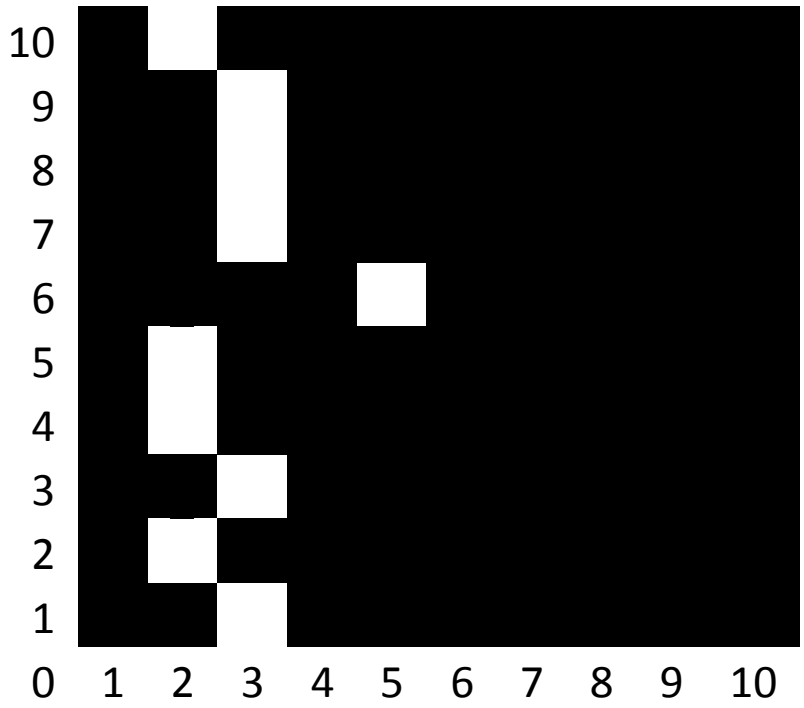


Wind from all four cardinal directions with equal frequency, 8.8 m/s



Results

West wind only, 15.72 m/s



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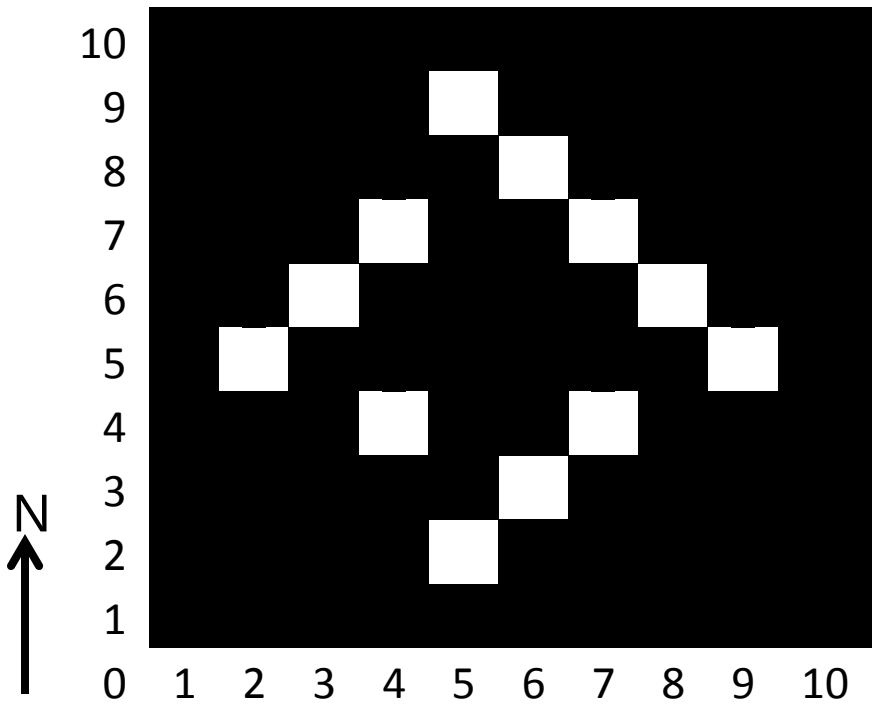

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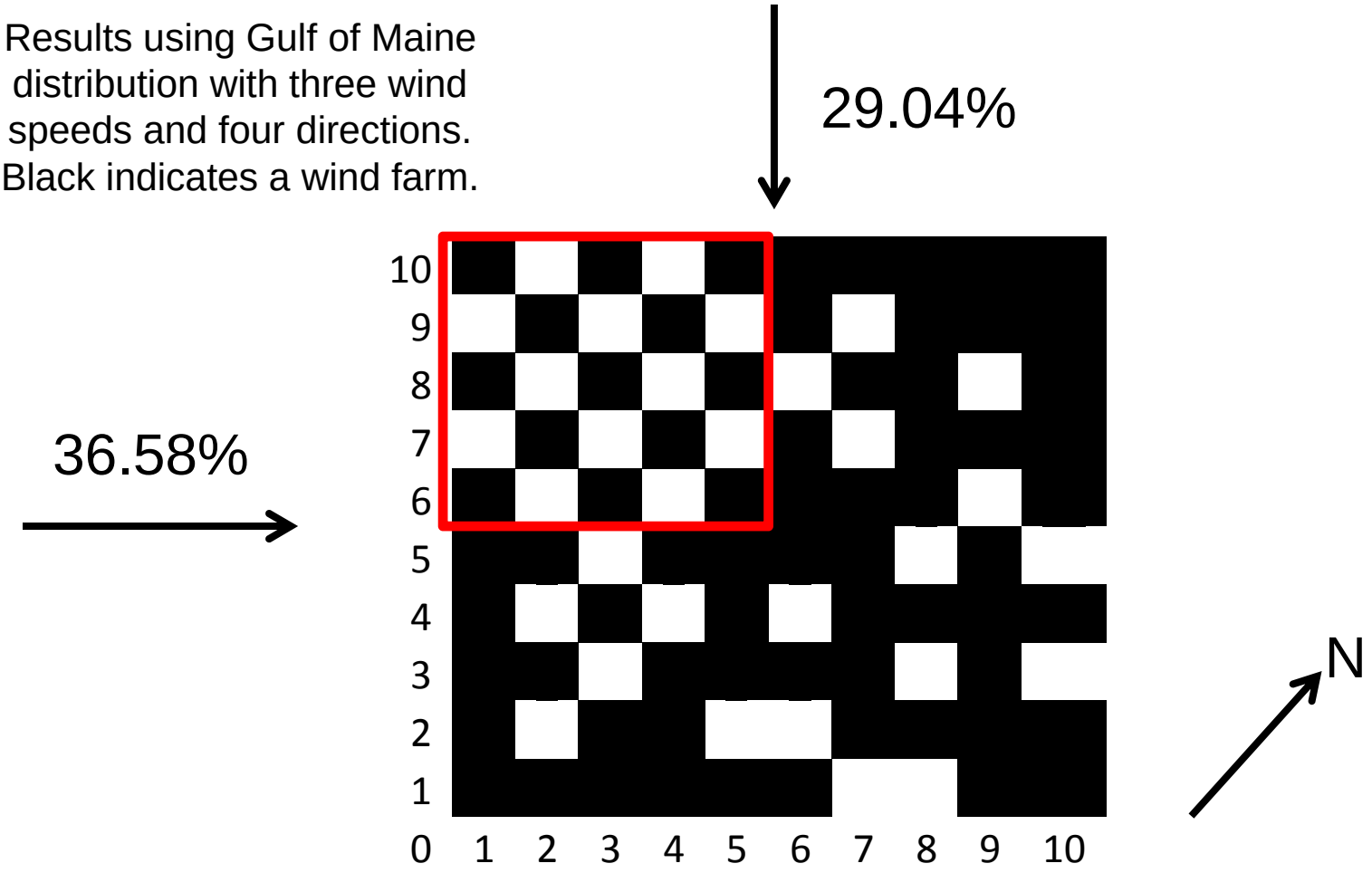
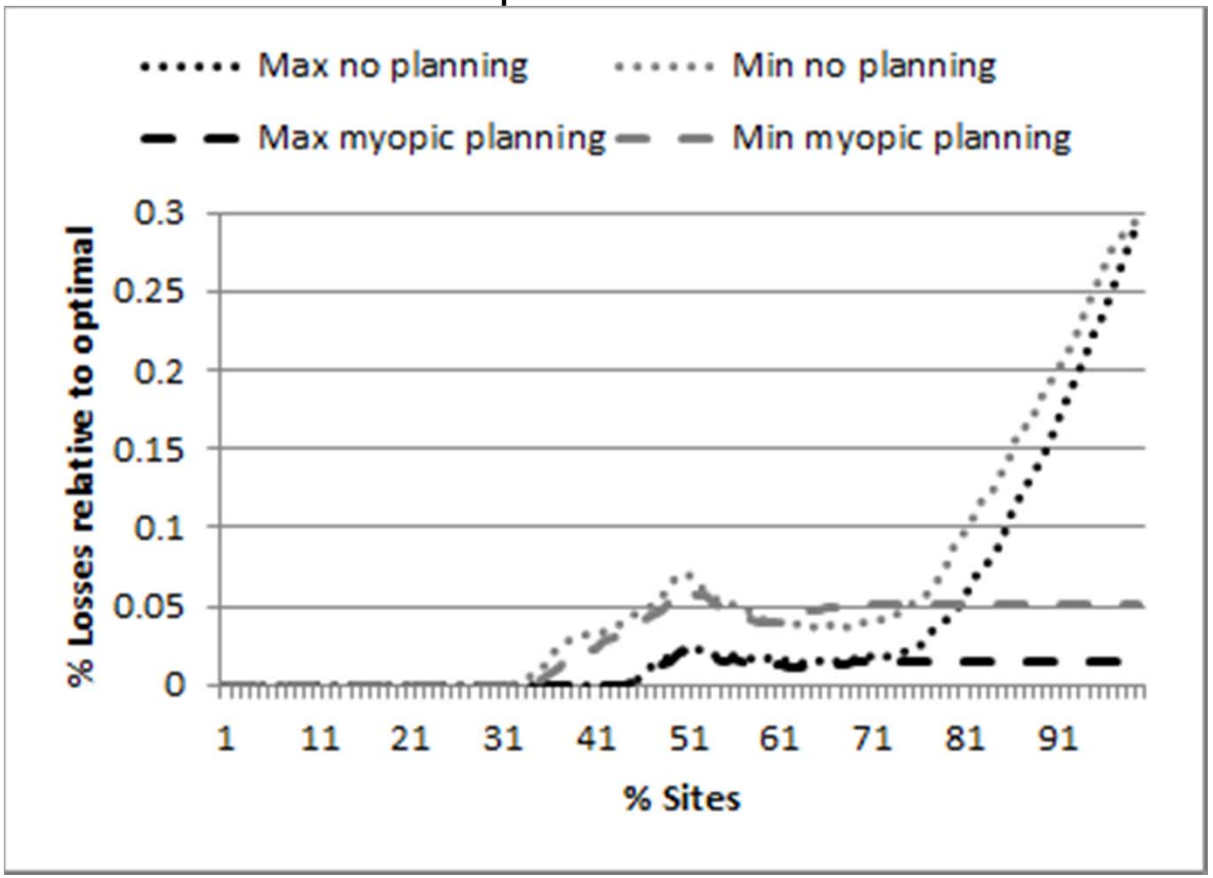


Value of the Portfolio Approach

The no planning model chooses sites for their economic value, the myopic planning model assesses their impact on the total value of all sites.

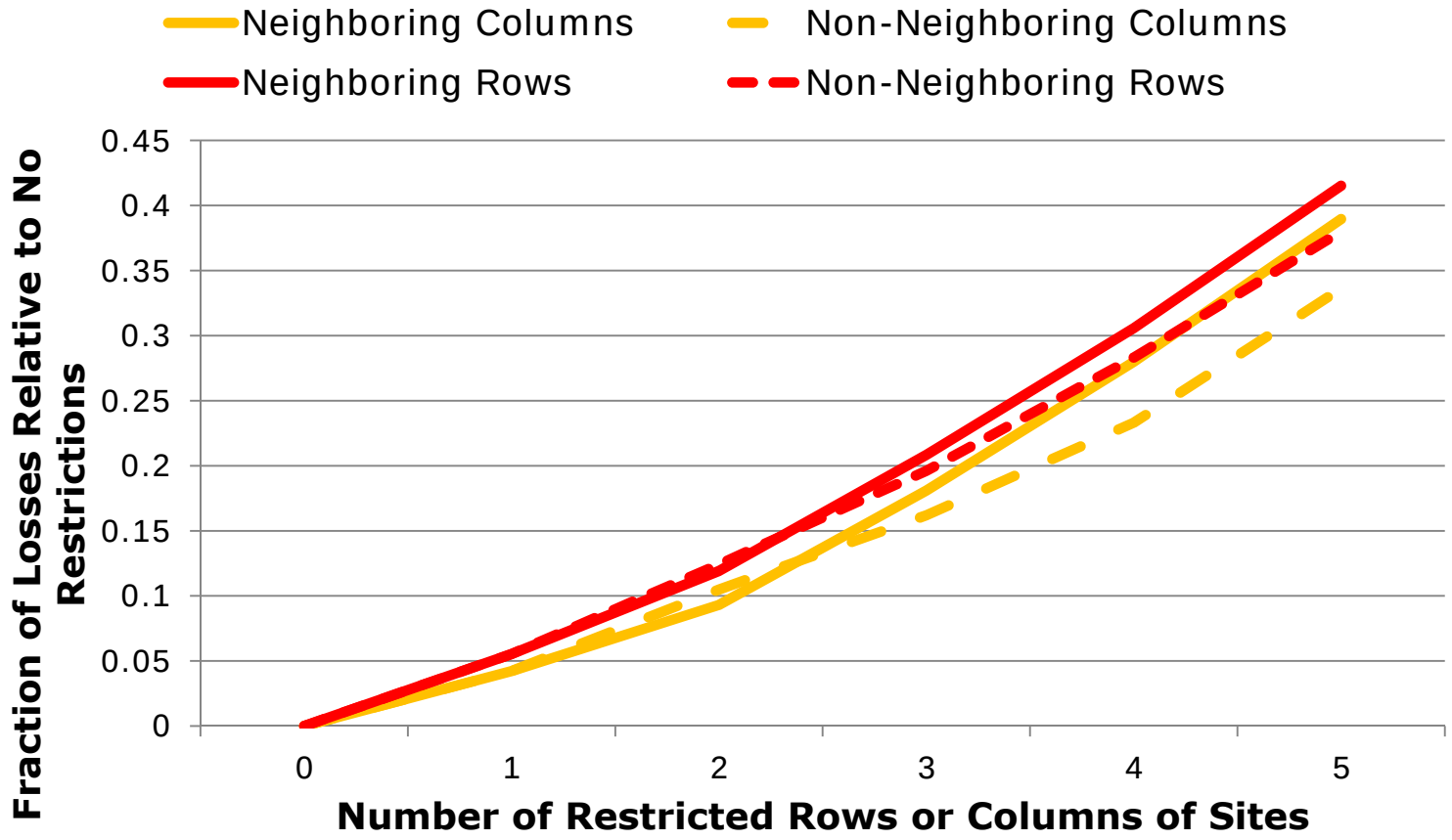


Part 2

Environment:
Ecological Value

Results

Losses in profit from restricting sites. Columns are perpendicular to predominant wind direction, rows are parallel to predominant wind.



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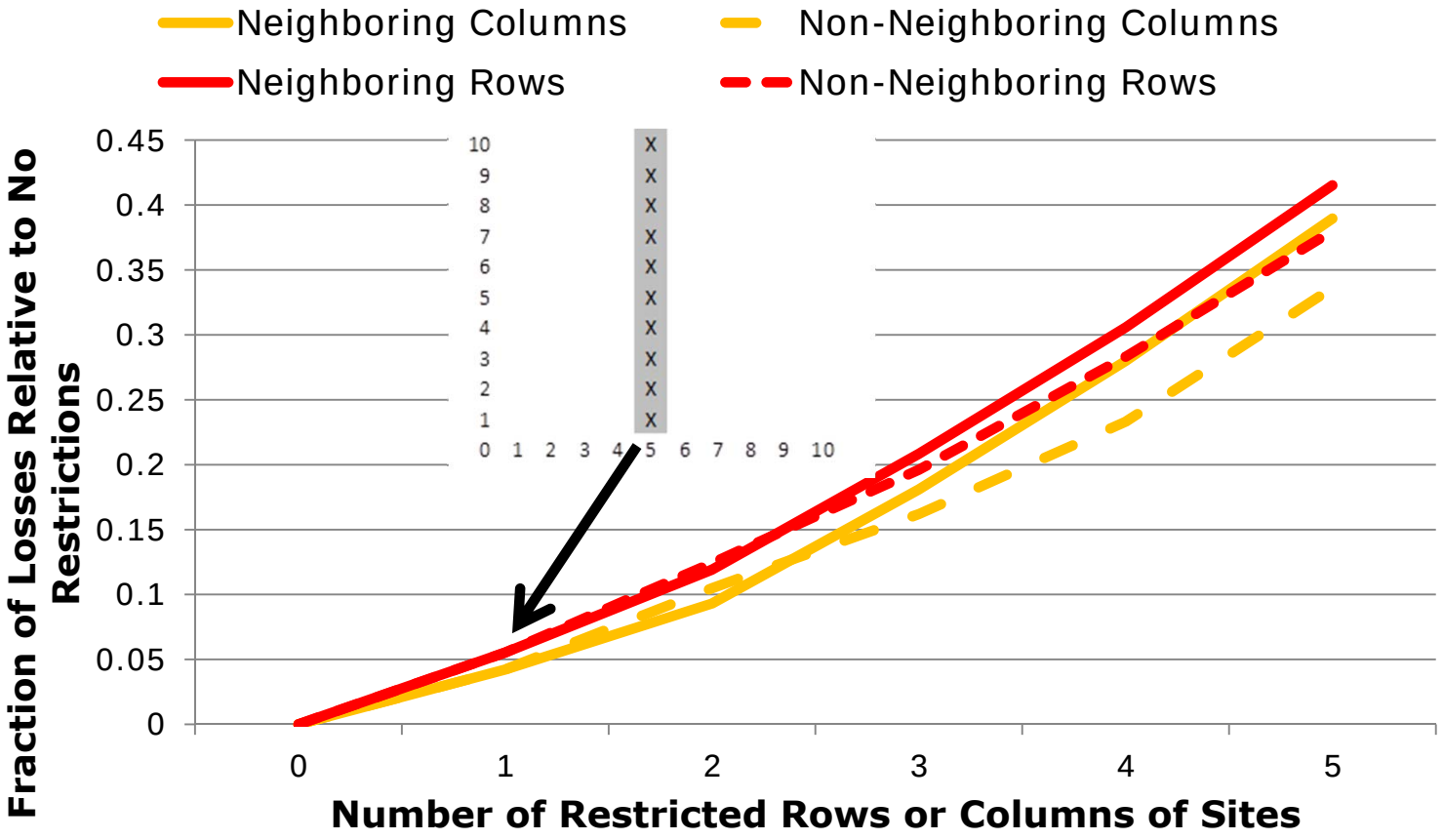

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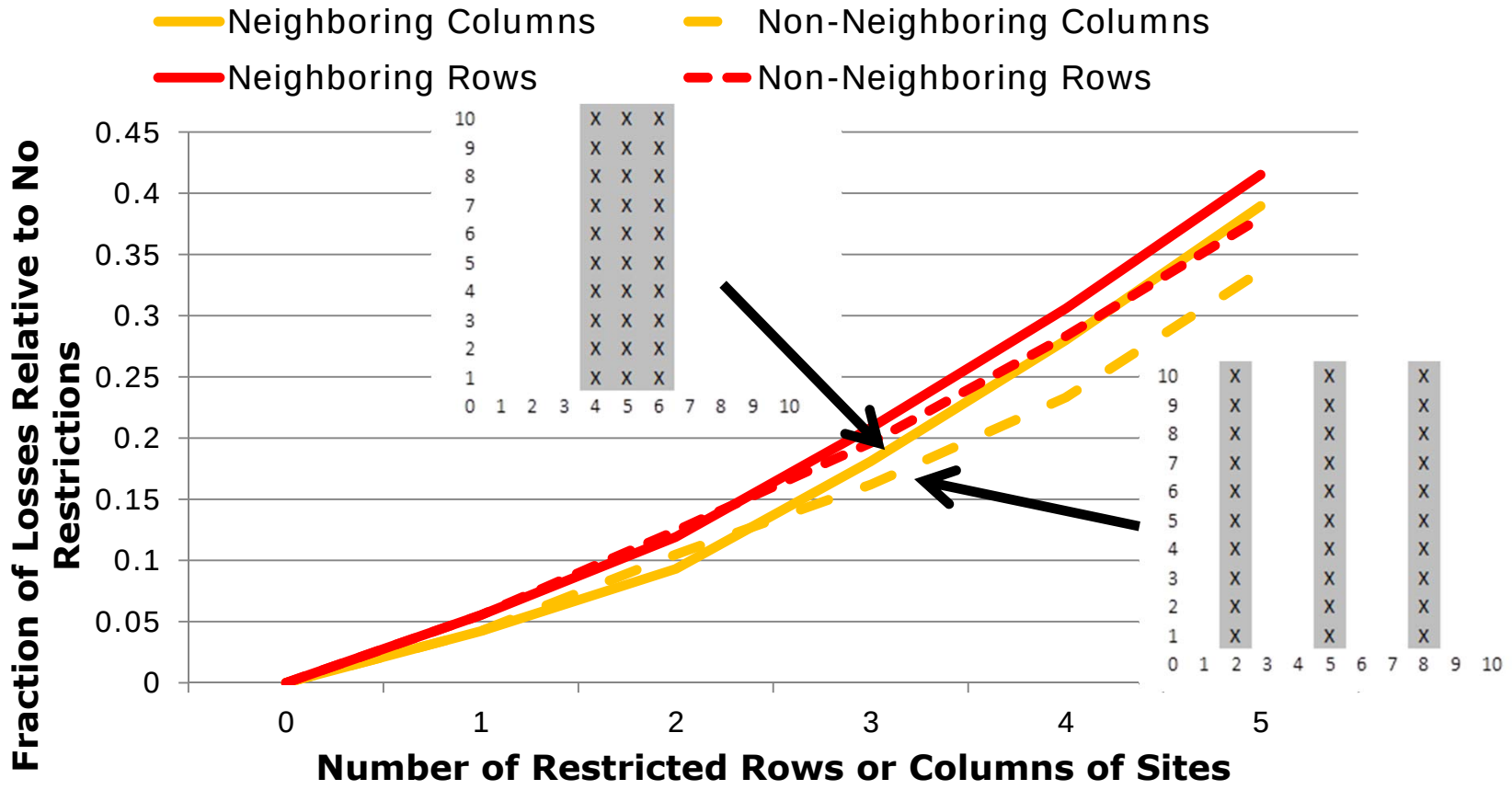

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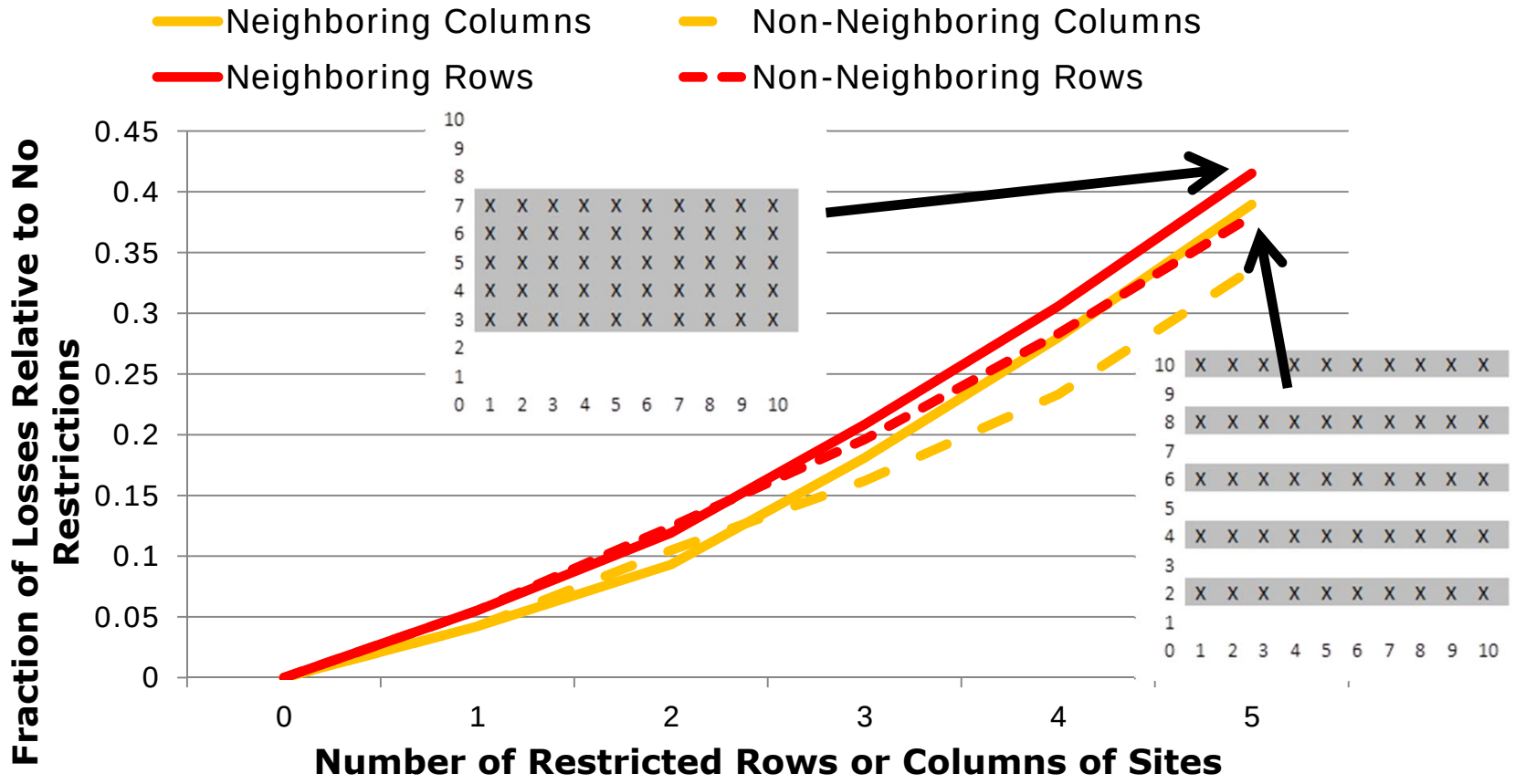
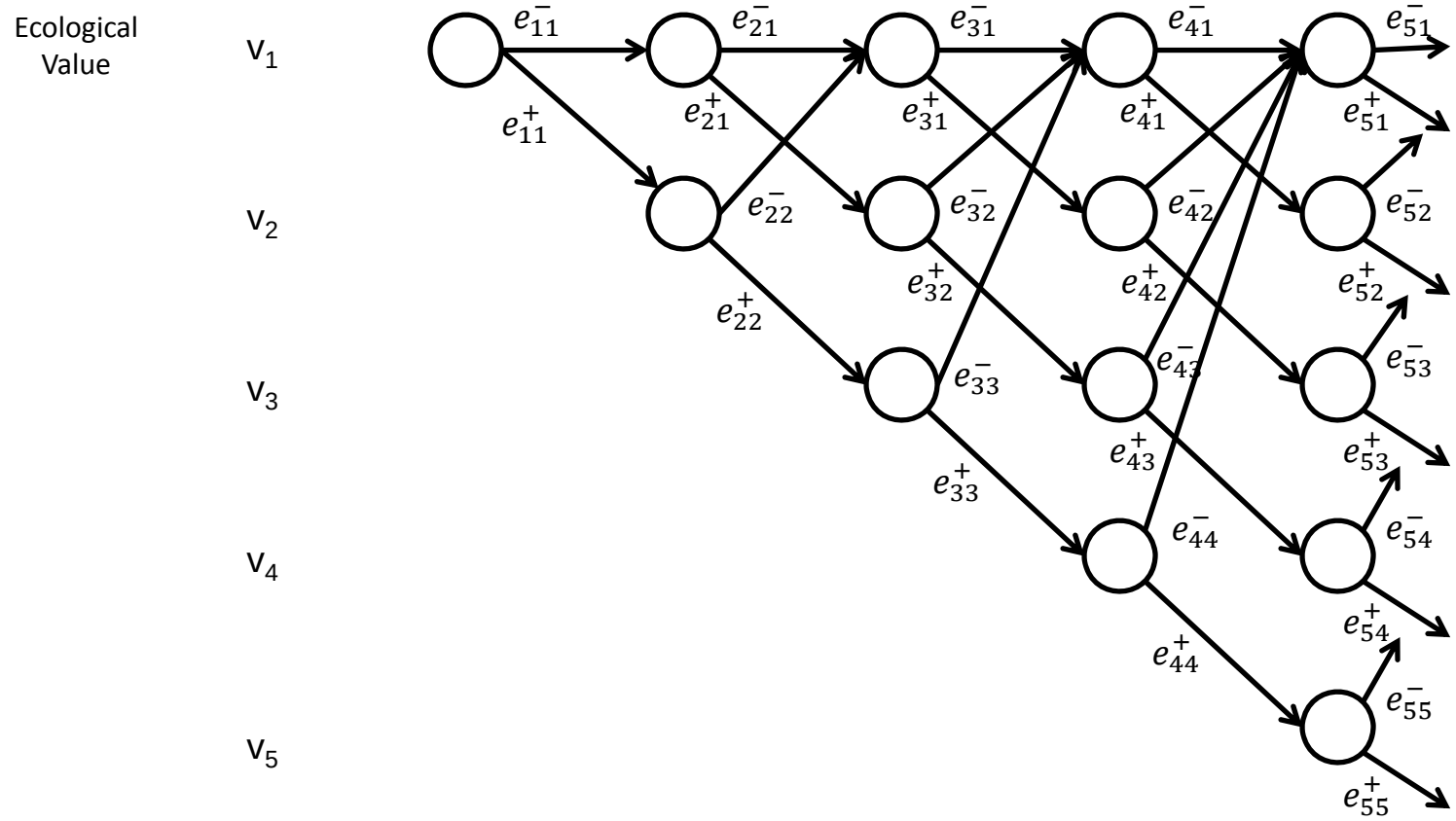


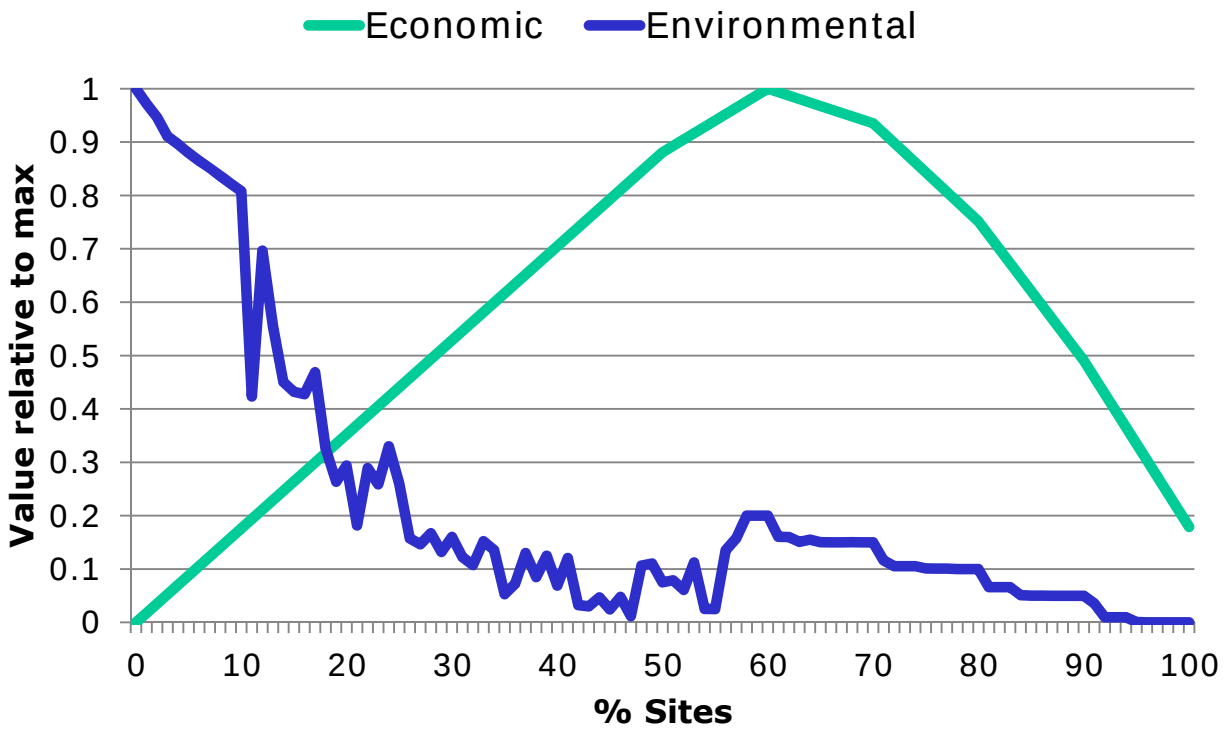
Environmental Value

- Maximize continuous open area



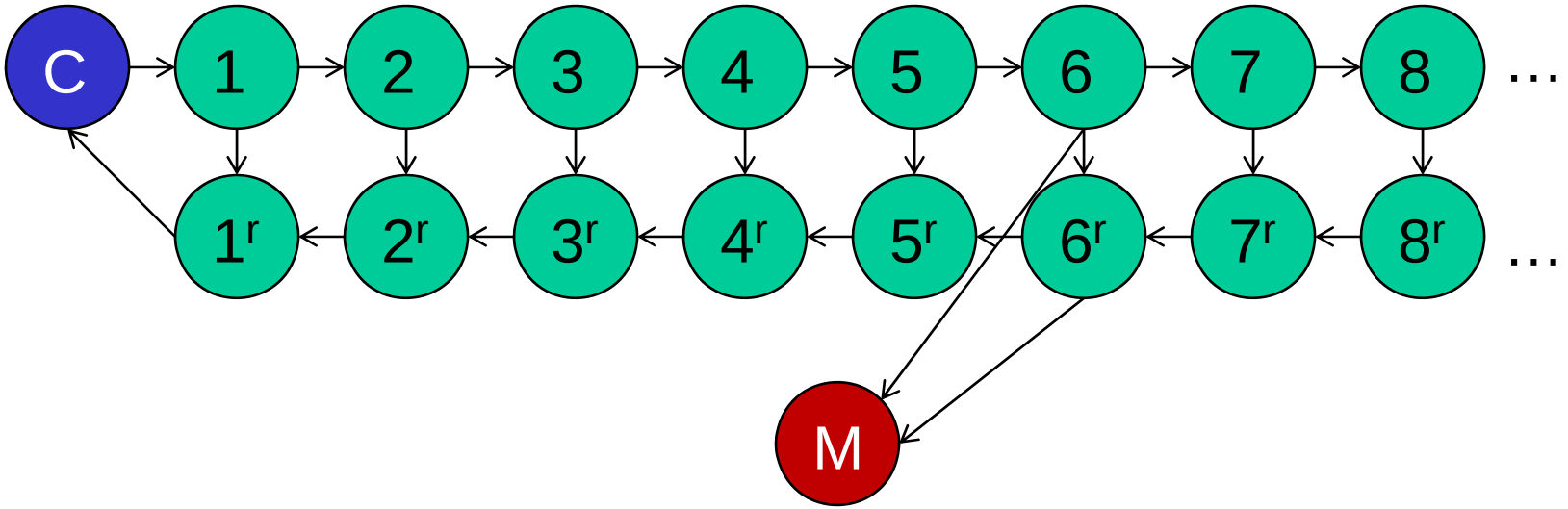
Trade Offs

- Trading off between open space and profit value



Modeling Avian Movement

- Markov model with colony, outgoing, inbound, and mortality states
- Mortality state is connected to location of a wind farm



Part 3

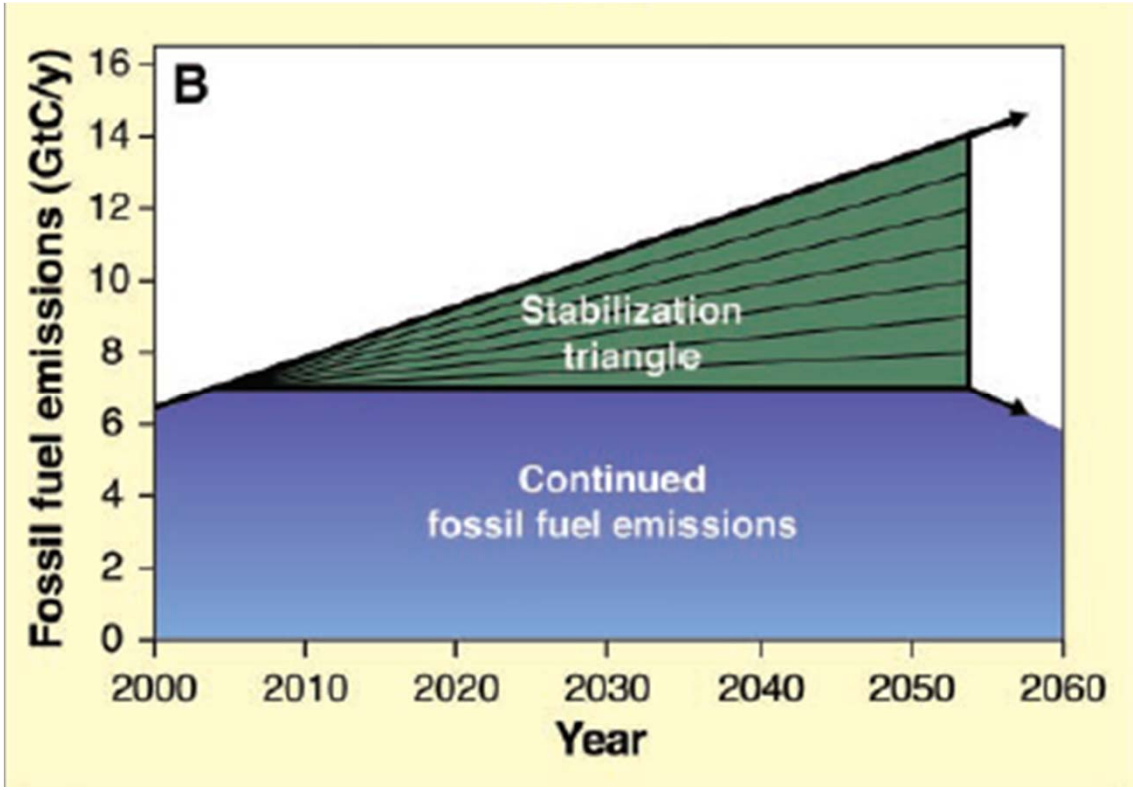
Outcomes

Ranking Economics and Environmental

- If economics > environment
  - Excellent wind resources
  - High electricity prices
  - High demand
- If environment > economics
  - Sensitive habitat
  - Endangered or threatened species
  - High aesthetic value

Outcomes

- Global Change Assessment Model
  - How does wind contribute in different scenarios?



Pacala and Socolow 2004

Acknowledgements

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- Thank you to my collaborators from Aalto University, Juuso Liesiö and Ahti Salo

Thank You!

Questions?