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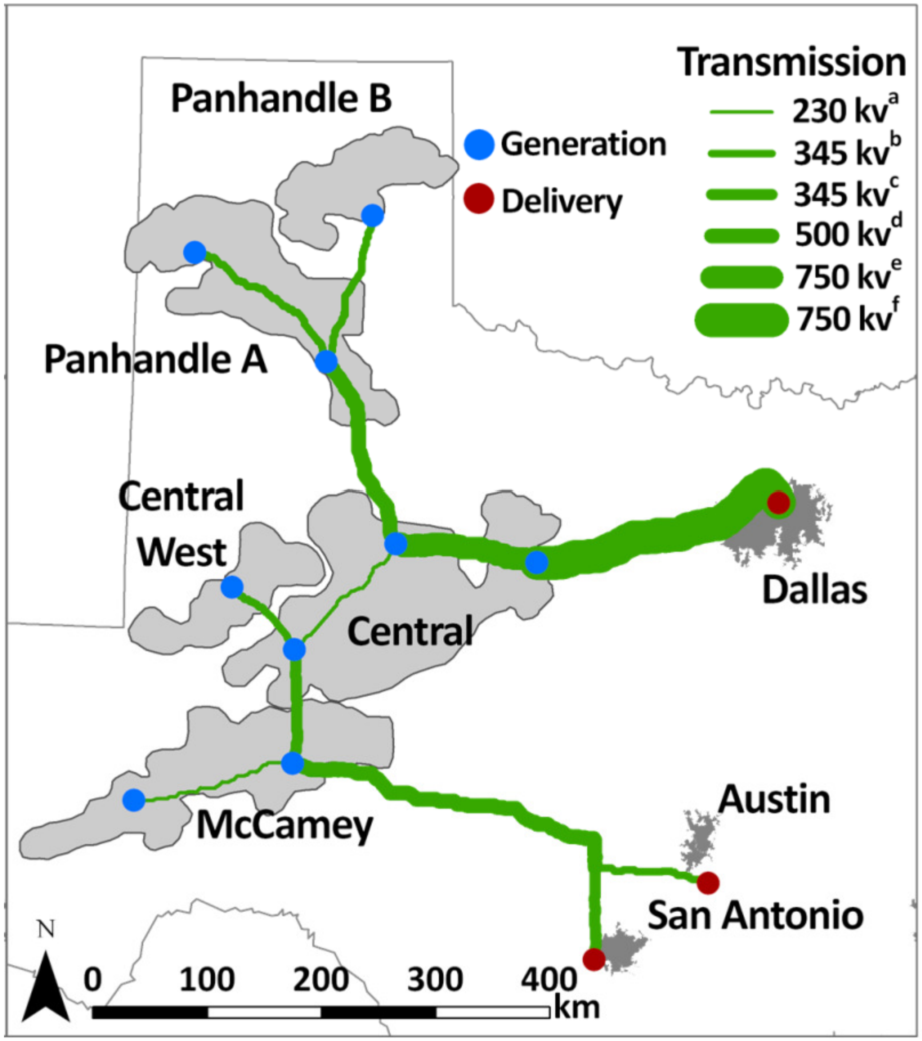
SIMWIND: A Geospatial Infrastructure Model for Optimizing Wind Power Generation and Transmission

Benjamin Phillips
DOE

Richard Middleton
Los Alamos National Laboratory



SimWIND: A Geospatial Infrastructure Model for Optimizing Wind Power Generation and Transmission

Benjamin R. Phillips

SRA International, Inc. /
U.S. Department of Energy

Richard Middleton

Los Alamos National Laboratory,
Earth and Environmental Sciences

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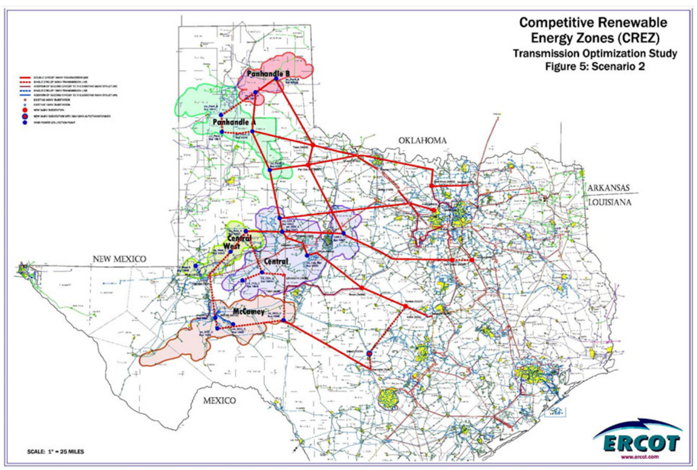
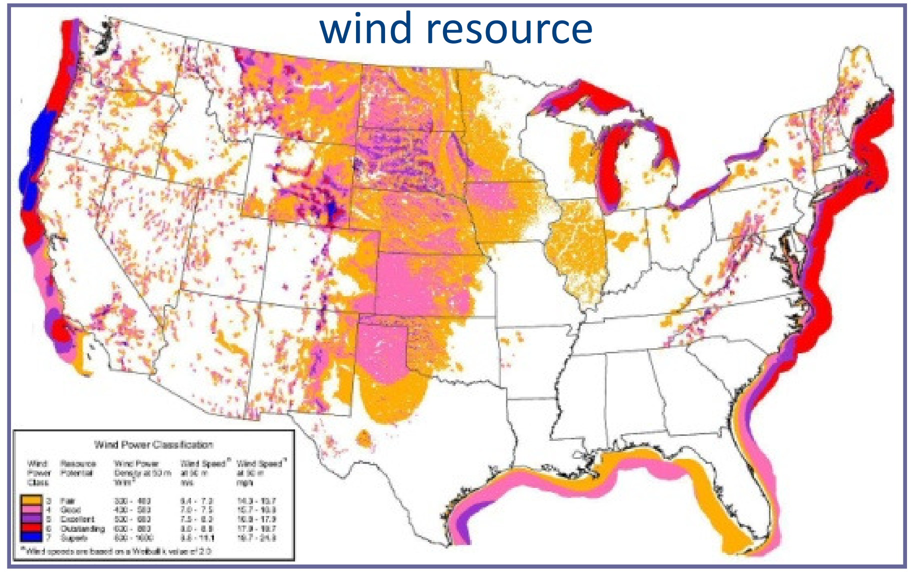
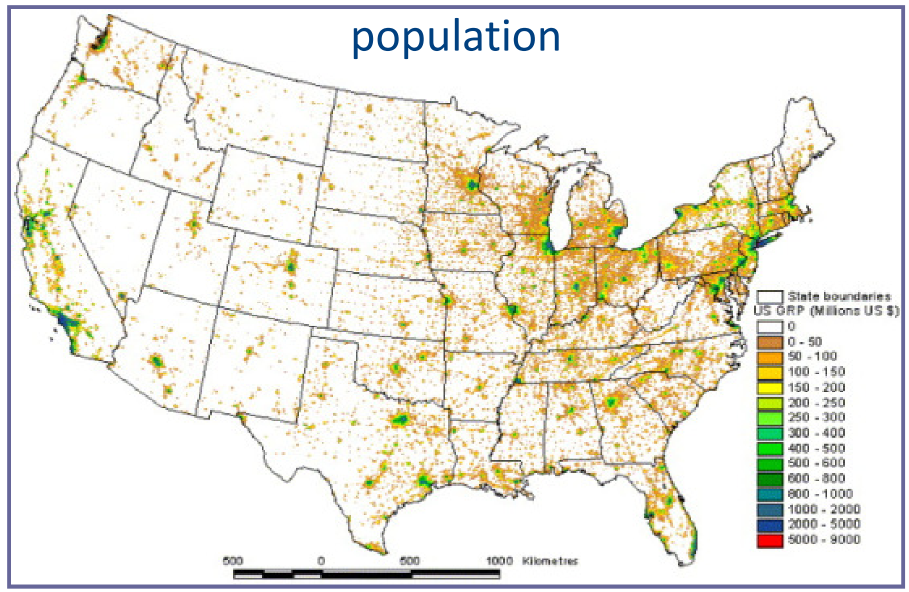
Challenge and Opportunities

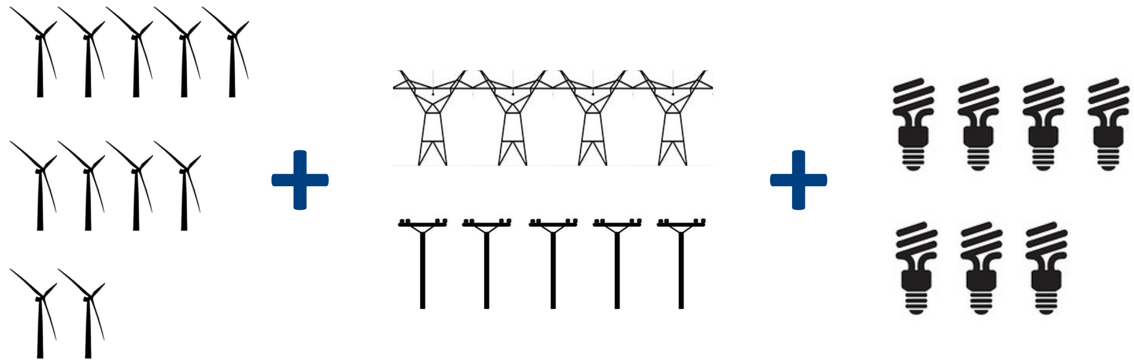
- Targeting 10 times today's wind capacity by 2030
- Need to optimally develop and connect resources
- Major infrastructure improvements needed
- Regional transmission planning: FERC 1000, etc.







SimWIND Approach: Generation, Transmission, Delivery



Unique algorithm to devise a candidate network of all possible least-cost network arcs

Simultaneously optimize for a given wind power target:

- Location and amount of power to generate
- Location and capacities of transmission lines

Quantitative, discrete spatial accounting of:

- Geographical (land slope, roughness, etc.) and Social (land use, population, politics, etc.) costs
- Transmission losses

SimWIND Mixed integer-linear program

- Candidate network defined by nodes (*i,j*) and arcs (*ij*) with capacities (*c*)
- Model "builds" wind farms (w_i, capacity factor β_i) and transmission lines (t_{ijc}, loss α_{ijc}) to serve loads (l_{kj}) with a power delivery *Target*
- Network and solution are optimized over a weighted cost surface

Minimize:

$$\overbrace{\sum_{i\in A} F_i^w w_i}^{(a)} + \overbrace{\sum_{i\in I}\sum_{j\in N_i}\sum_{c\in C} F_{ijc}^t t_{ijc}}^{(b)} + \overbrace{\sum_{j\in B}\sum_{k\in K} F_{jk}^l l_{jk}}^{(c)} \quad (1)$$

Subject to

$$e_{ijc} \le Q_c^{max} t_{ijc} \quad \forall i\in I, \forall j\in N_i, \forall c\in C \quad (2)$$

$$e_{ijc} \ge Q_c^{min} t_{ijc} \quad \forall i\in I, \forall j\in N_i, \forall c\in C \quad (3)$$

$$\sum_{j\in N_i}\sum_{c\in C} e_{ijc} - \sum_{j\in N_i}\sum_{c\in C} \alpha_{jic} e_{jic} = \begin{cases} \beta_i a_i & \text{if } i\in A \\ -b_i & \text{if } i\in B \\ 0 & \text{otherwise} \end{cases} \quad \forall i\in I \quad (4)$$

$$a_i \le Q_i^w w_i \quad \forall i\in A \quad (5)$$

$$w_i \le W_i \quad \forall i\in A \quad (6)$$

$$b_j \le \sum_{k\in K} Q_k^l l_{jk} \quad \forall j\in B \quad (7)$$

$$b_j \le Q_j^b \quad \forall j\in B \quad (8)$$

$$\sum_{j\in B} b_j \ge Target \quad (9)$$

$$w_i \in \{0,1,2,\ldots,n\} \quad \forall i\in A \quad (10)$$

$$t_{ijc} \in \{0,1\} \quad \forall i\in I, \forall j\in N_i, \forall c\in C \quad (11)$$

$$l_{jk} \in \{0,1\} \quad \forall j\in B, \forall k\in K \quad (12)$$

$$e_{ijc} \ge 0 \quad \forall i\in I, \forall j\in N_i \quad (13)$$

$$a_i \ge 0 \quad \forall i\in A \quad (14)$$

$$b_j \ge 0 \quad \forall j\in B \quad (15)$$

Decision variables

- e_{ijc} amount of electricity transported from node *i* to node *j* with transmission capacity *c* (MW)
- t_{ijc} $\begin{cases} 1, & \text{if a transmission line is built on arc } ij \text{ with capacity } c \\ 0, & \text{otherwise} \end{cases}$
- w_i number of wind turbines built at source *i*
- l_{jk} $\begin{cases} 1, & \text{if a load center of capacity } k \text{ is built at node } j, \\ 0, & \text{otherwise} \end{cases}$
- a_i generation capacity installed at node *i* (MW)
- b_j electricity delivered to load center *j* (MW)

Inputs

F^w, F^t, F^l	fixed cost for opening constructing a wind turbine$^{(w)}$, constructing a transmission line$^{(t)}$, and building a load center$^{(l)}$ ($)
Q^w, Q^t, Q^l, Q^b	capacity of one wind turbine$^{(w)}$, a transmission line$^{(t)}$, a load center$^{(l)}$, and the node demand$^{(b)}$ (MW)
α_{ijc}	transmission loss between *i* and *j* with capacity *c* (MW)
β_i	capacity factor for wind farm at node *i*
Target	amount of system-wide electricity to deliver (MW)
W_i	maximum number of wind turbines at each site *i*

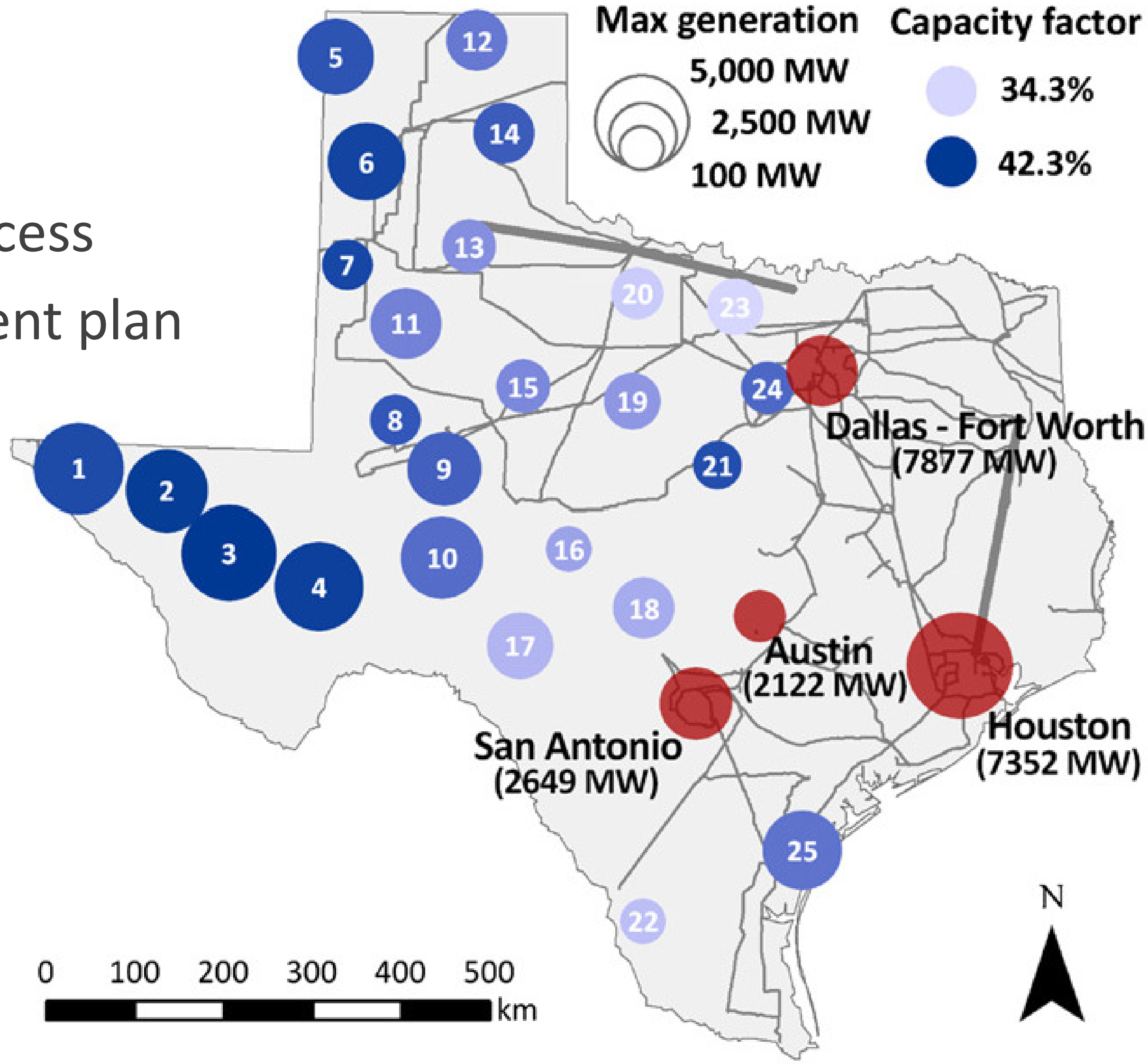
Sets

I, A, B	set of all nodes, wind farm sites nodes, and load centers
N_i	set nodes adjacent to node *i*
C, K	set of discrete transmission line and load center capacities

ERCOT Wind Resource Zones

ERCOT case study

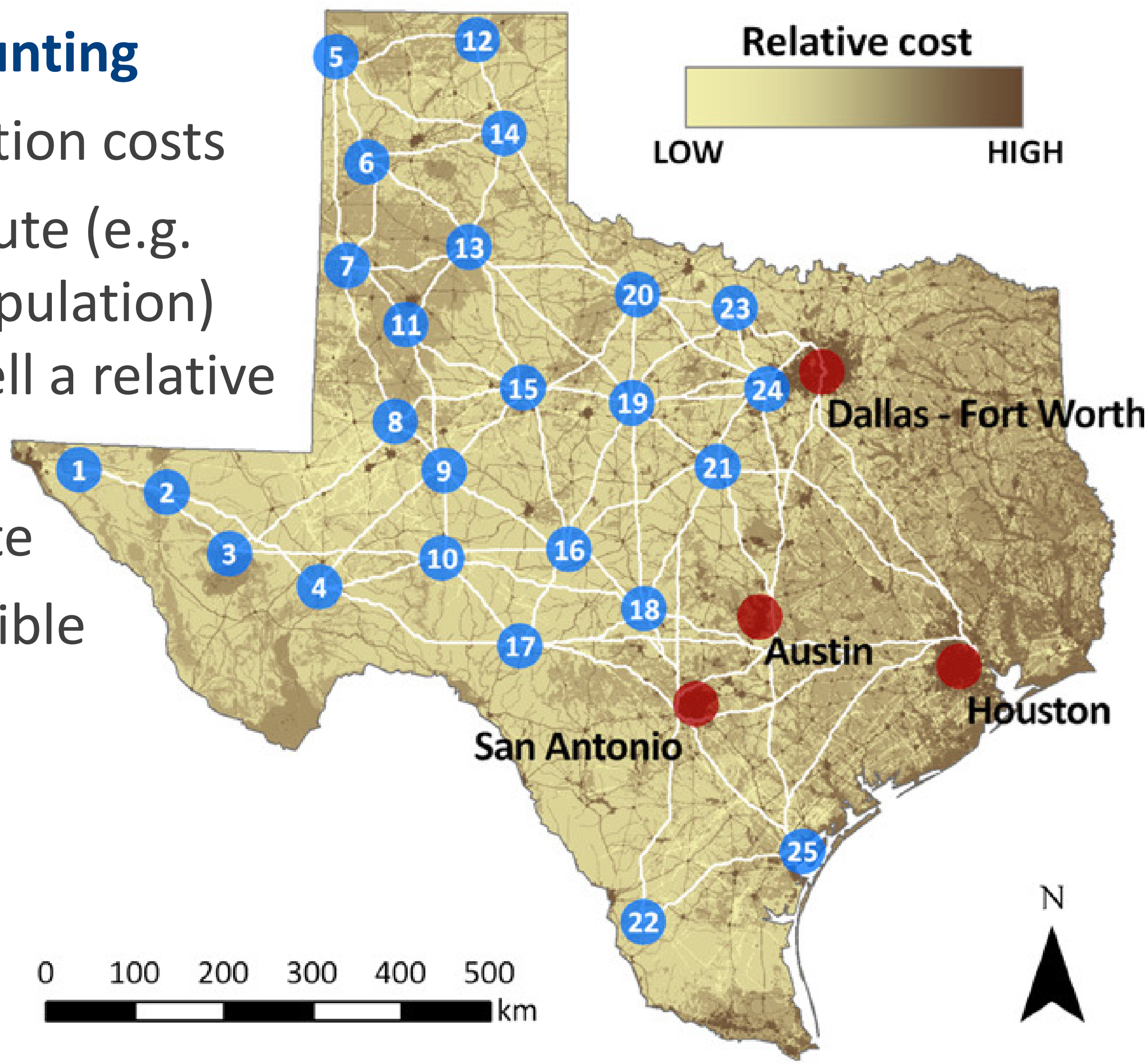
- Isolated system
- CREZ selection process
- Existing development plan
- Clear disparity between quality resource and demand locations



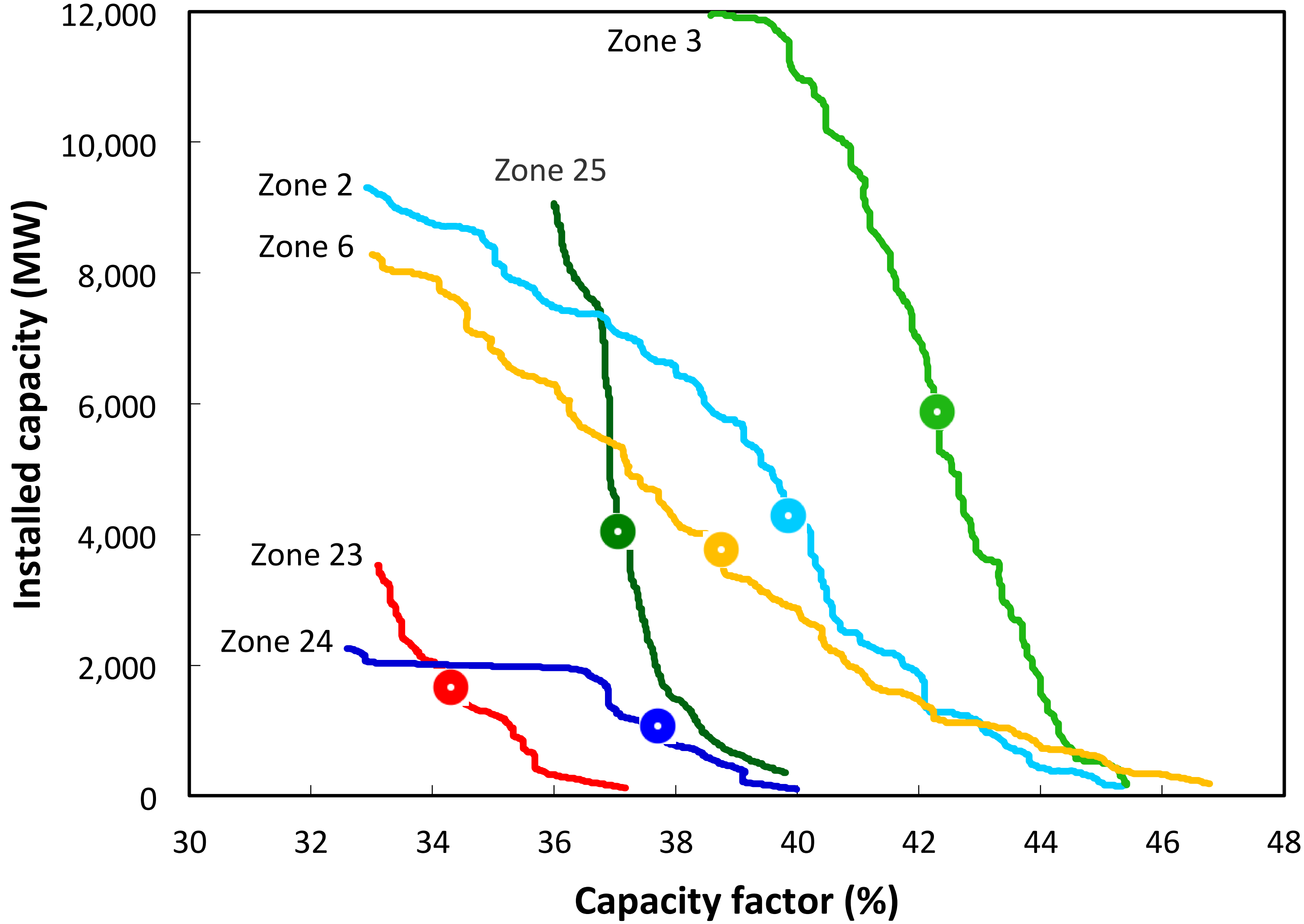
SimWIND Cost Surface and Candidate Network

Geospatial cost accounting

- ROW and construction costs
- Weight each attribute (e.g. slope, land use, population) to give each grid cell a relative cost
- Develop a candidate network of all possible least-cost arcs



Wind Resource Curves



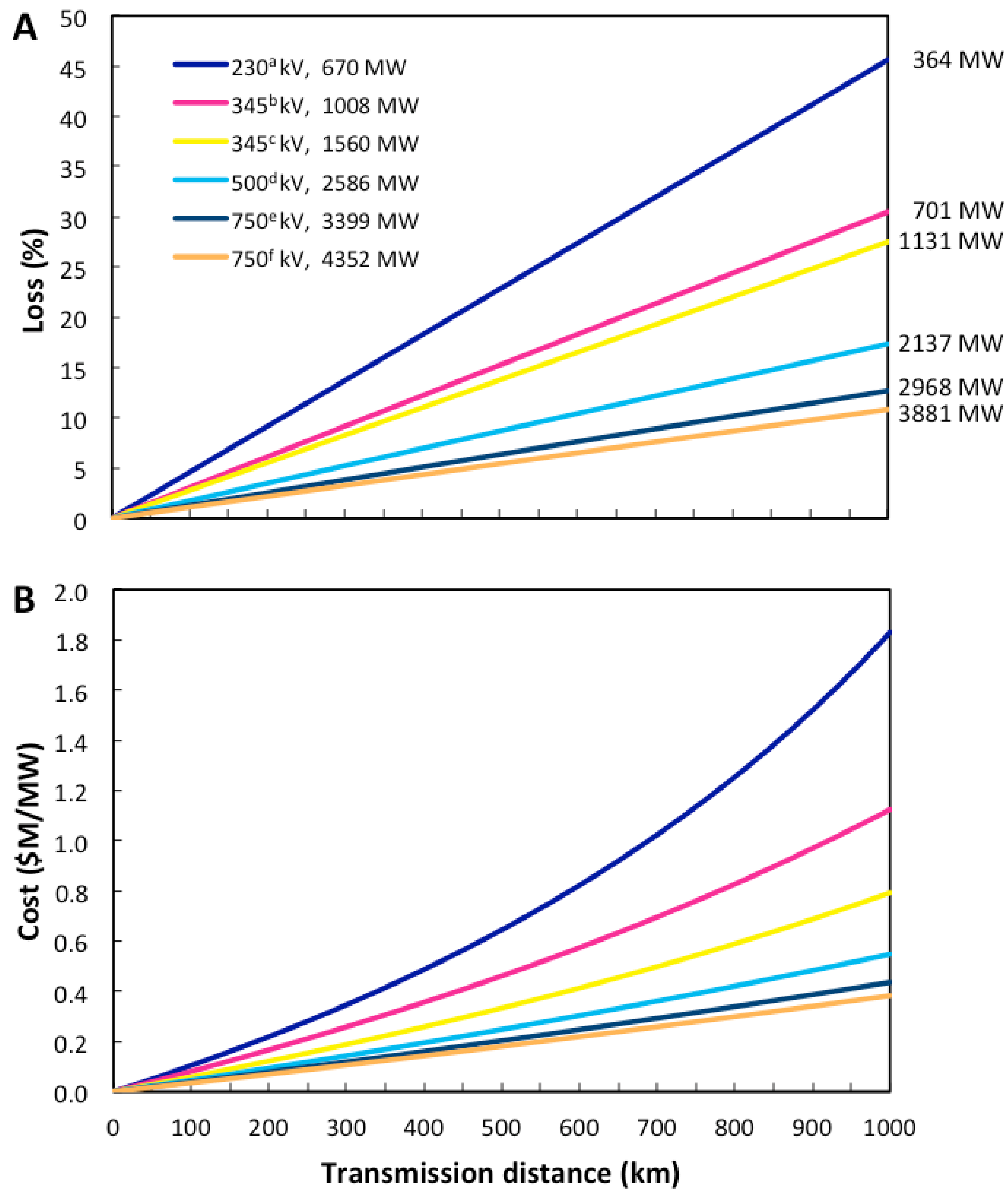
Adapted from ERCOT, 2006

Resistive Losses and Transmission Cost

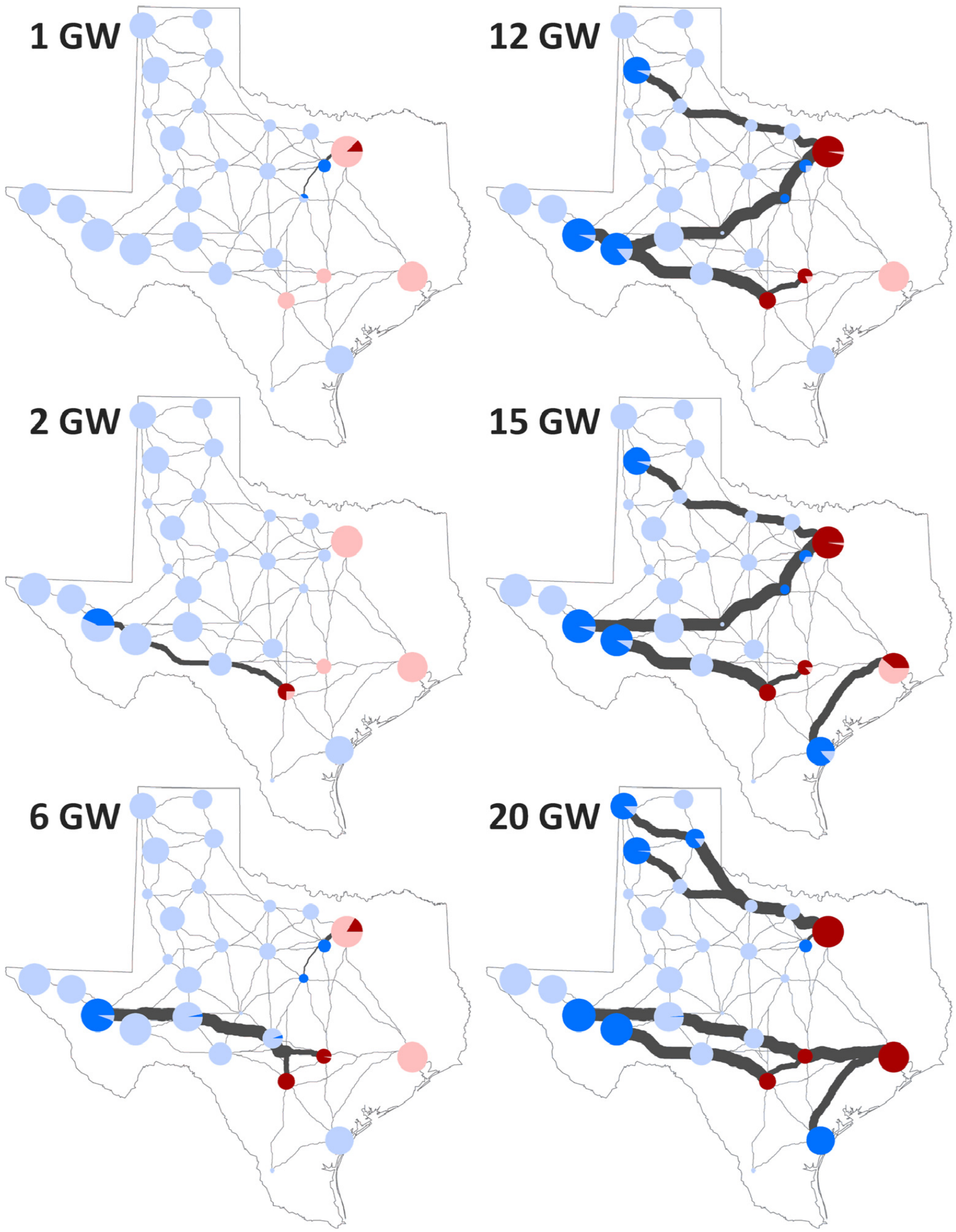
$$\text{Loss} = \frac{Q\sigma d}{V^2}$$

Q	(MW)	total electricity generated
σ	(Ω/phase)	conductor resistance
d	(km)	distance from source to load
V	(kV)	line voltage

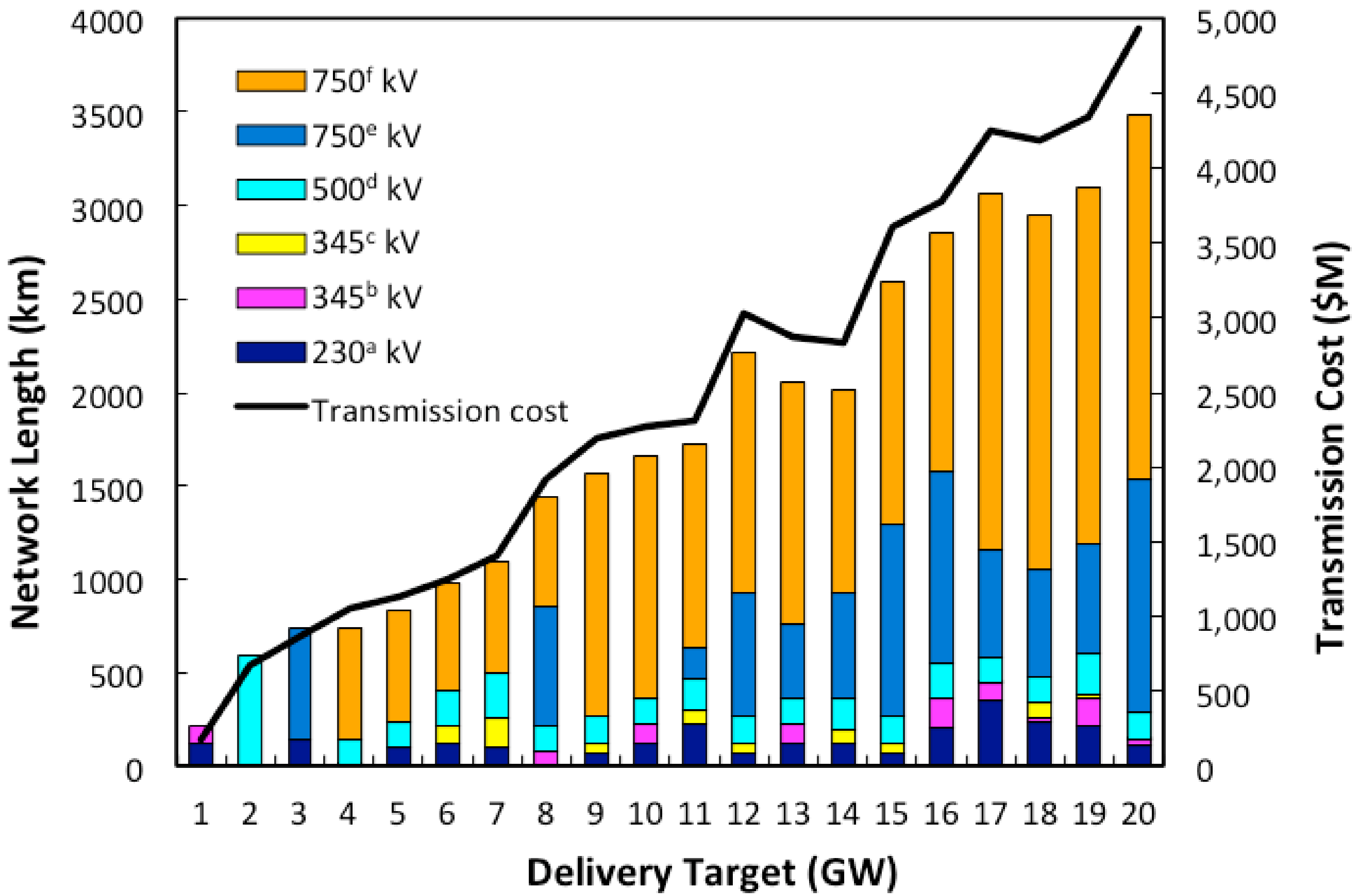
IEAGHG R&D Programme, 2002



SimWIND Example Solutions

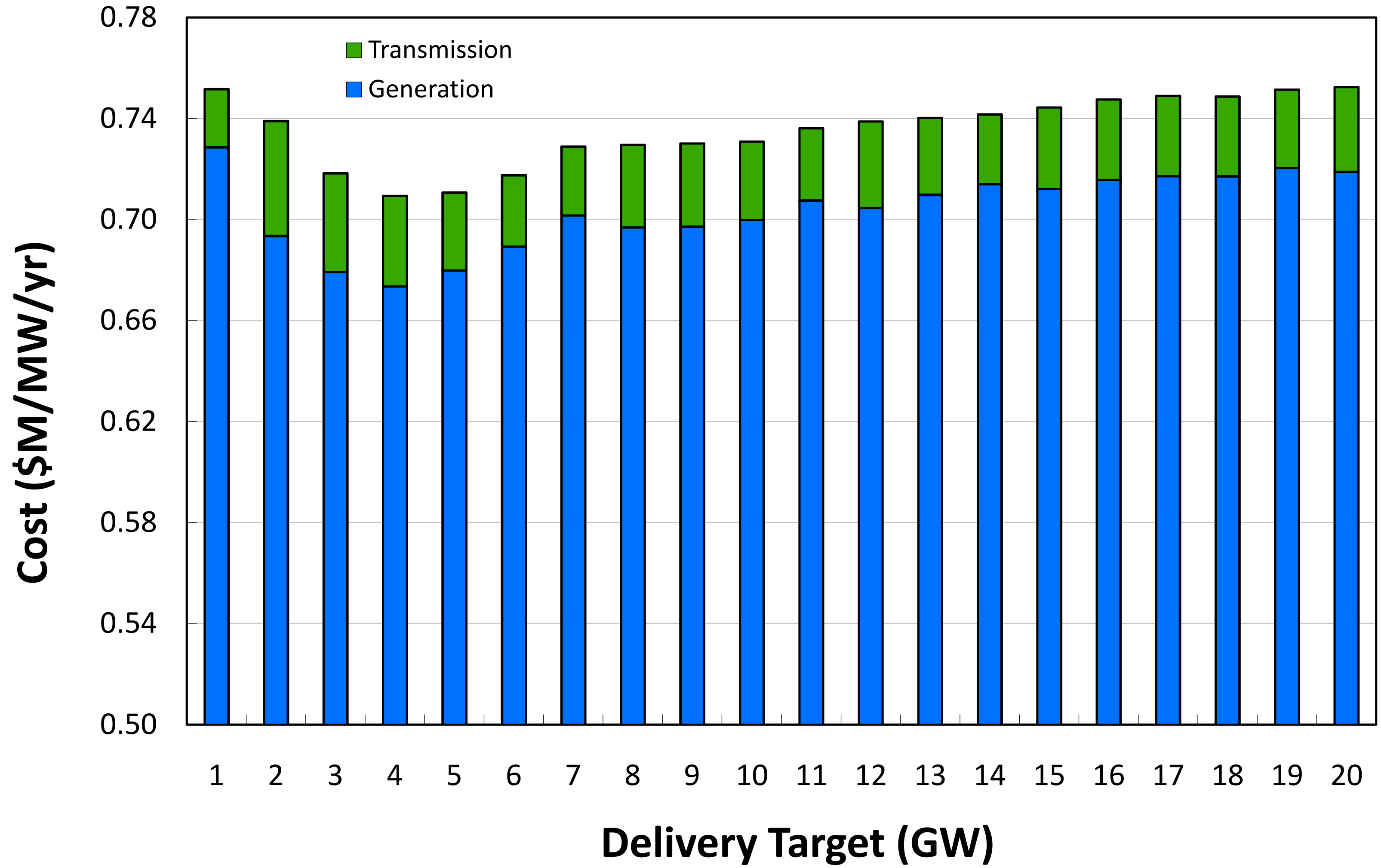


Transmission Network Length and Cost

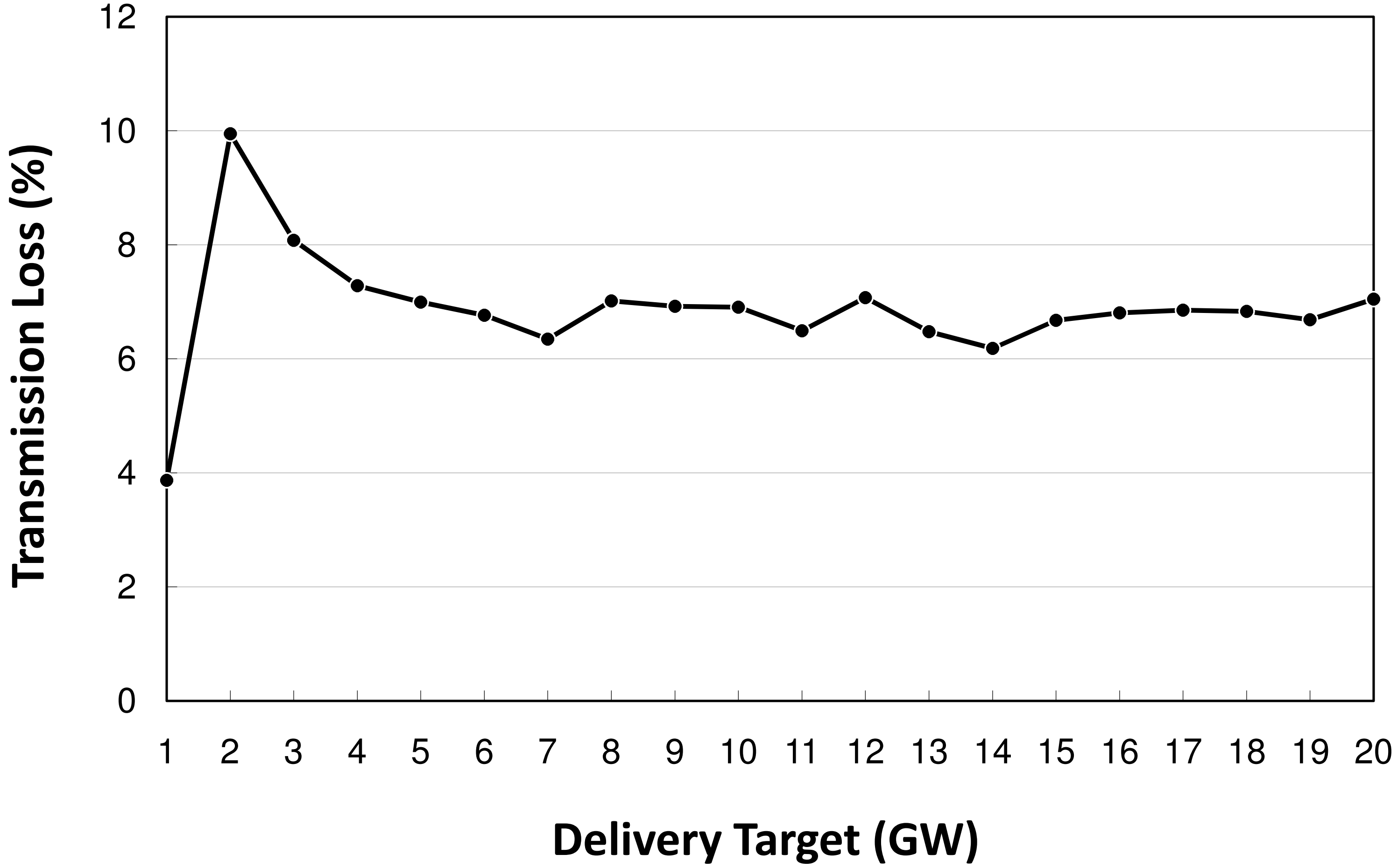


Annualized Costs for Generation and Transmission

- Generation accounts for ~95% of system costs

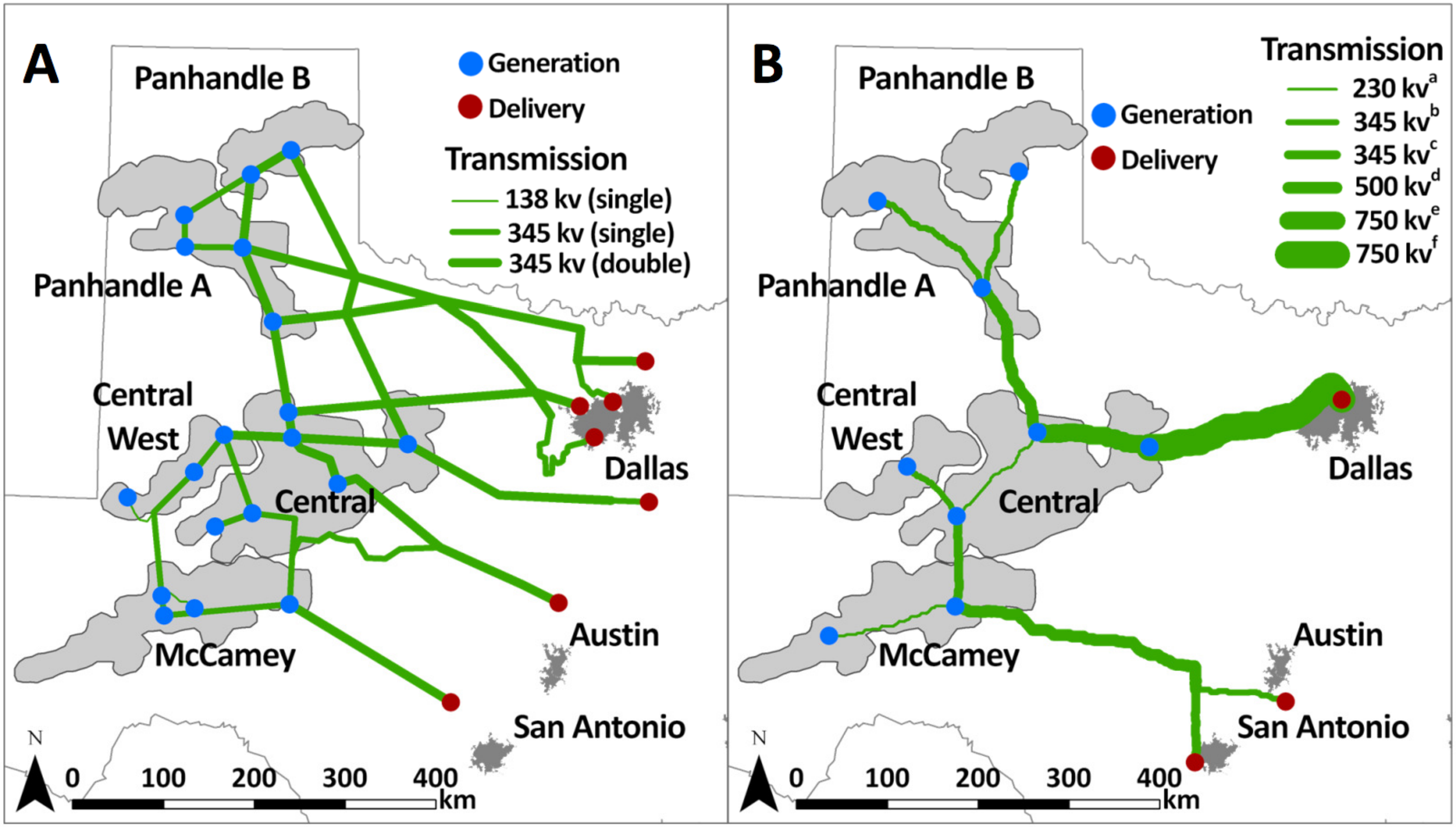


System-Wide Transmission Losses



SimWIND vs. ERCOT Scenarios: 18,456 MW installed

	ERCOT Scenario 2	*SimWIND*
Total Length:	3823 km	1952 km
Total Cost:	4728 $M	2422 $M



Adapted from ERCOT, 2006

Conclusions and Future Directions

Conclusions

- *SimWIND* quantifies potential savings from simultaneous siting of generation and transmission
- These optimal solutions are often non-intuitive
- Accounting for transmission losses amplifies economies of scale
- Offer a flexible platform for translating varied stakeholder interests into costs that are an integral part of the optimization

Priorities

- Coupling with a power-flow model to address system reliability
- Incorporating existing transmission and reserve capacity
- Considering other/multiple generation types and storage
- Incorporating dynamic planning capabilities

Phillips, B.R., Middleton, R.S., 2012, *SimWIND*: A geospatial infrastructure model for optimizing wind power generation and transmission. *Energy Policy* 43, 291–302.