Institutions, Conflicts, and Political Economy in Renewable Energy Integration: Case of China, and Thoughts for India

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Brookings India
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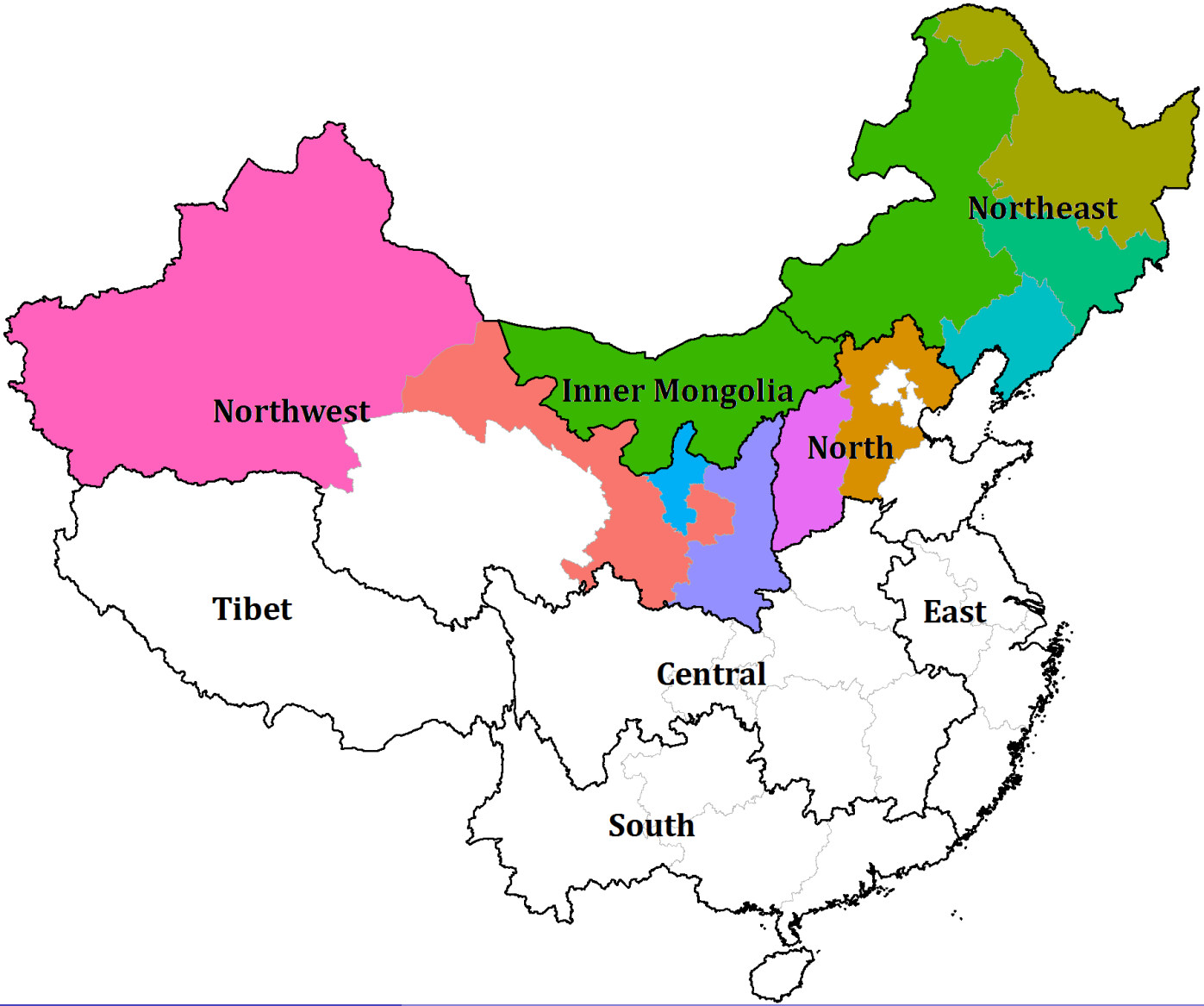
China's wind integration challenges



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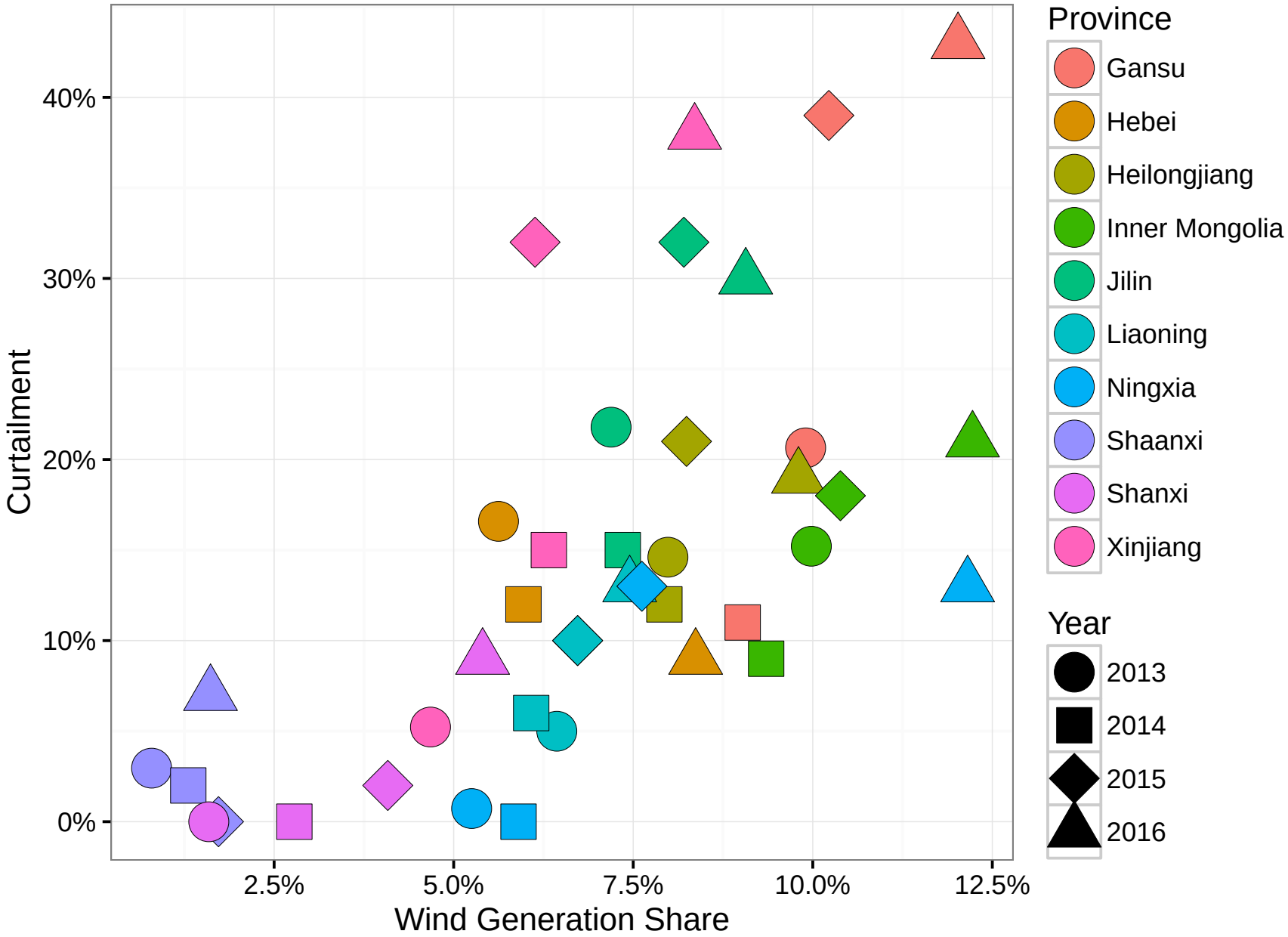

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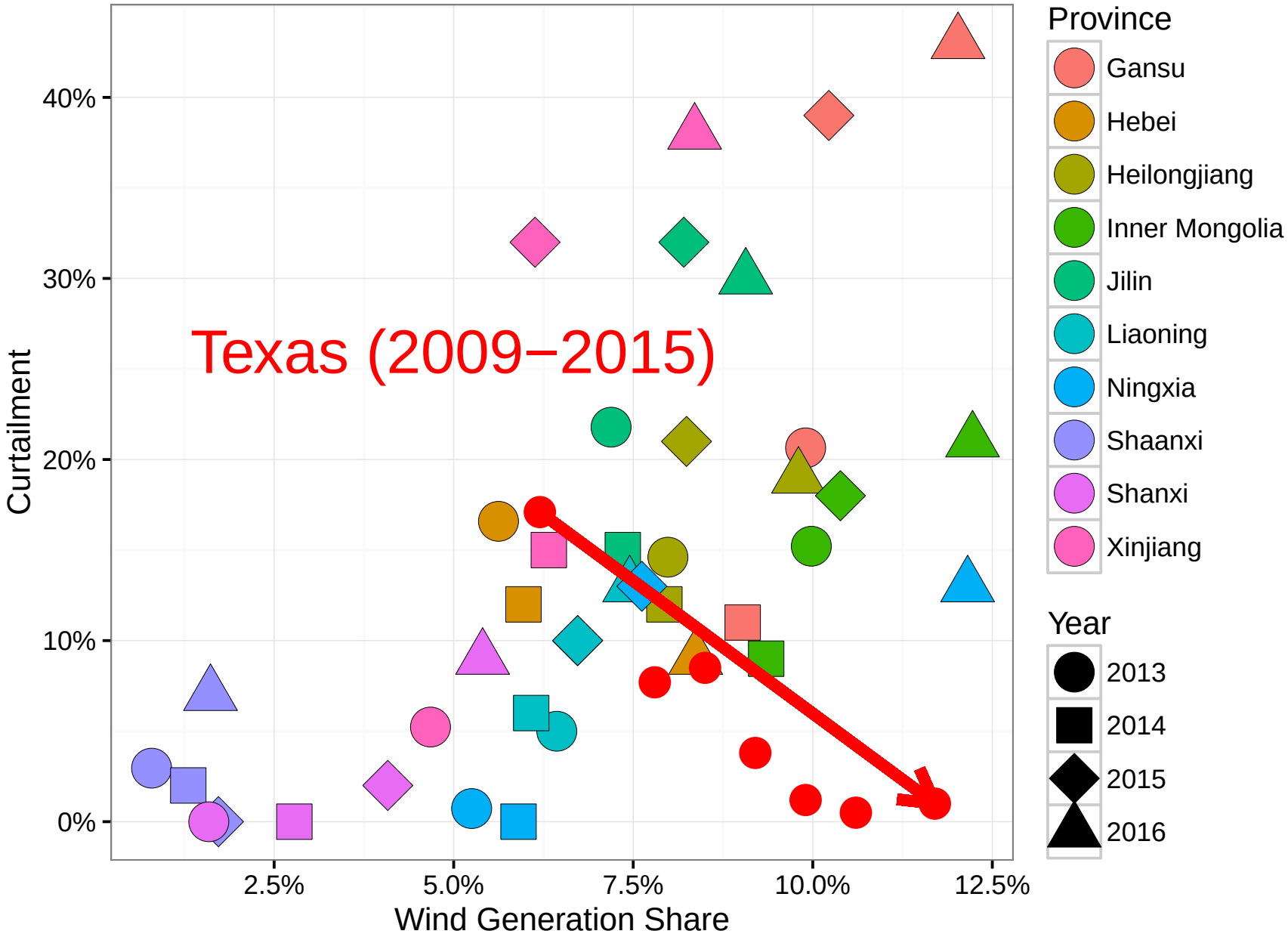

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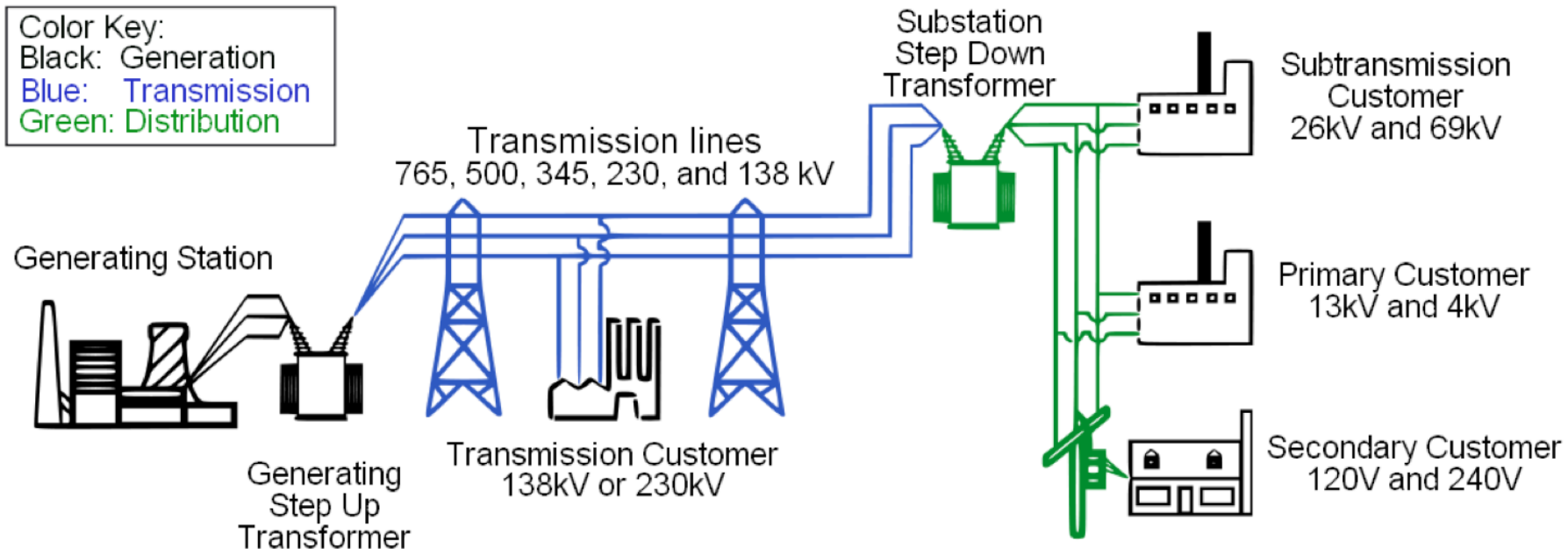
Power system primer



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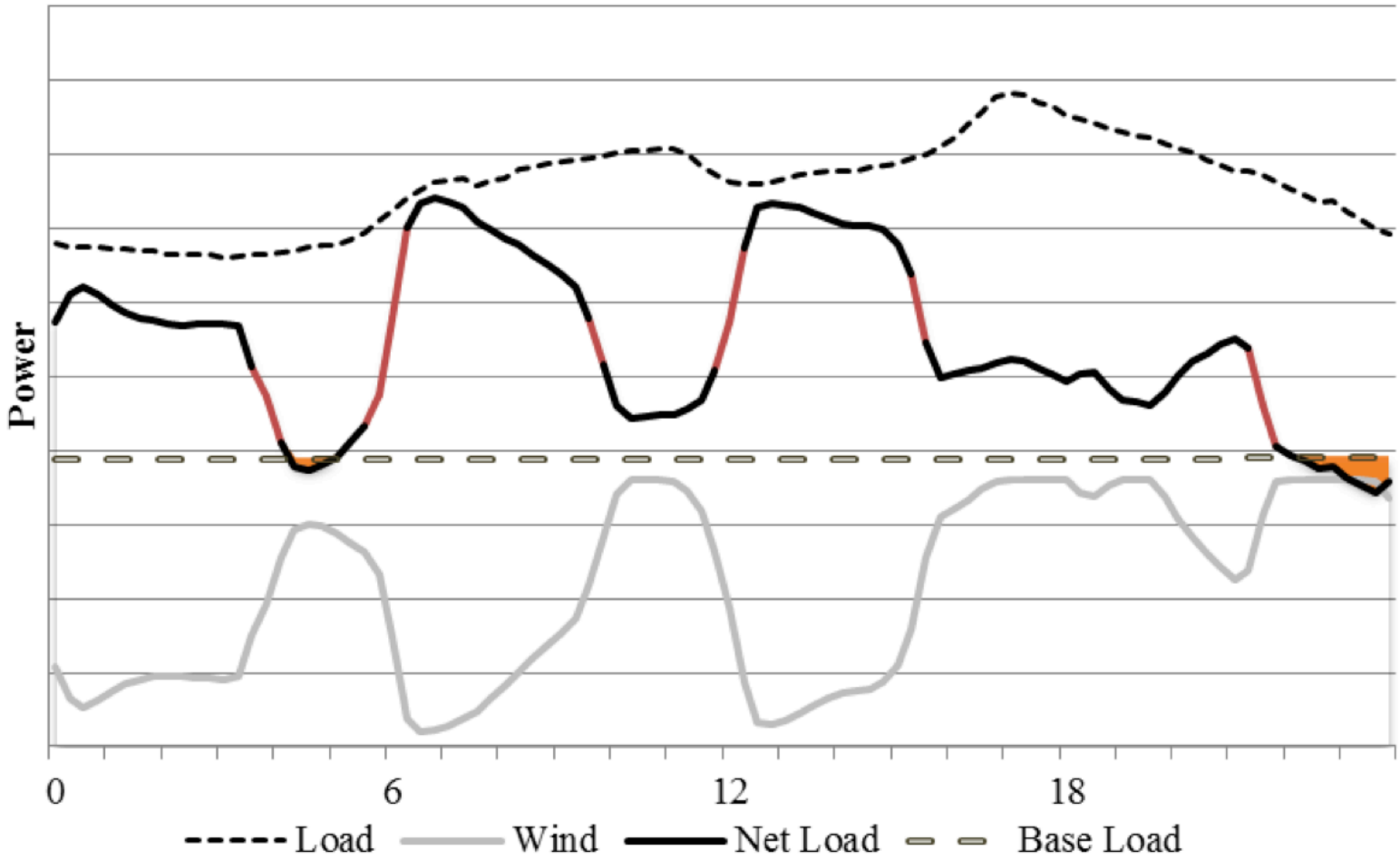
- Additional impacts on frequency and voltage balancing

Indicative Daily Load Profile With Wind



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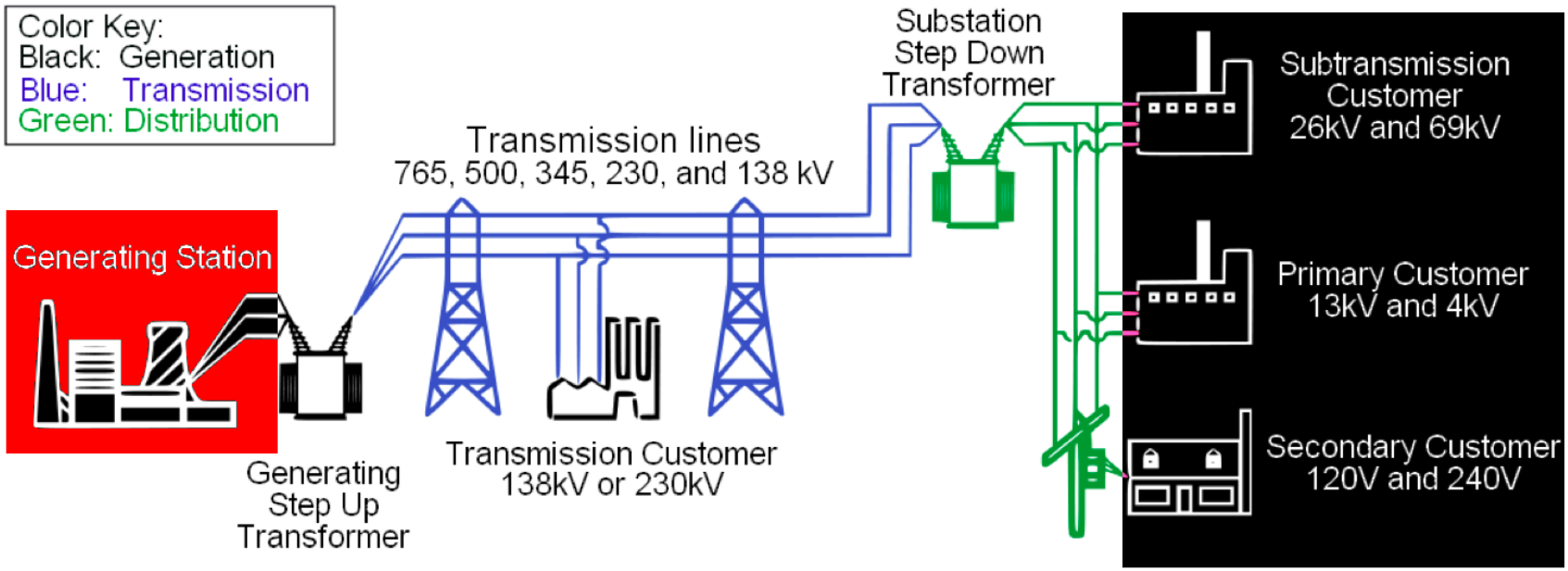
- Additional services and investments bring in new actors
- Need for coordination shifts decision-making power (e.g. setting conventional generation schedules)

Backdrop of market restructuring = "deregulation"



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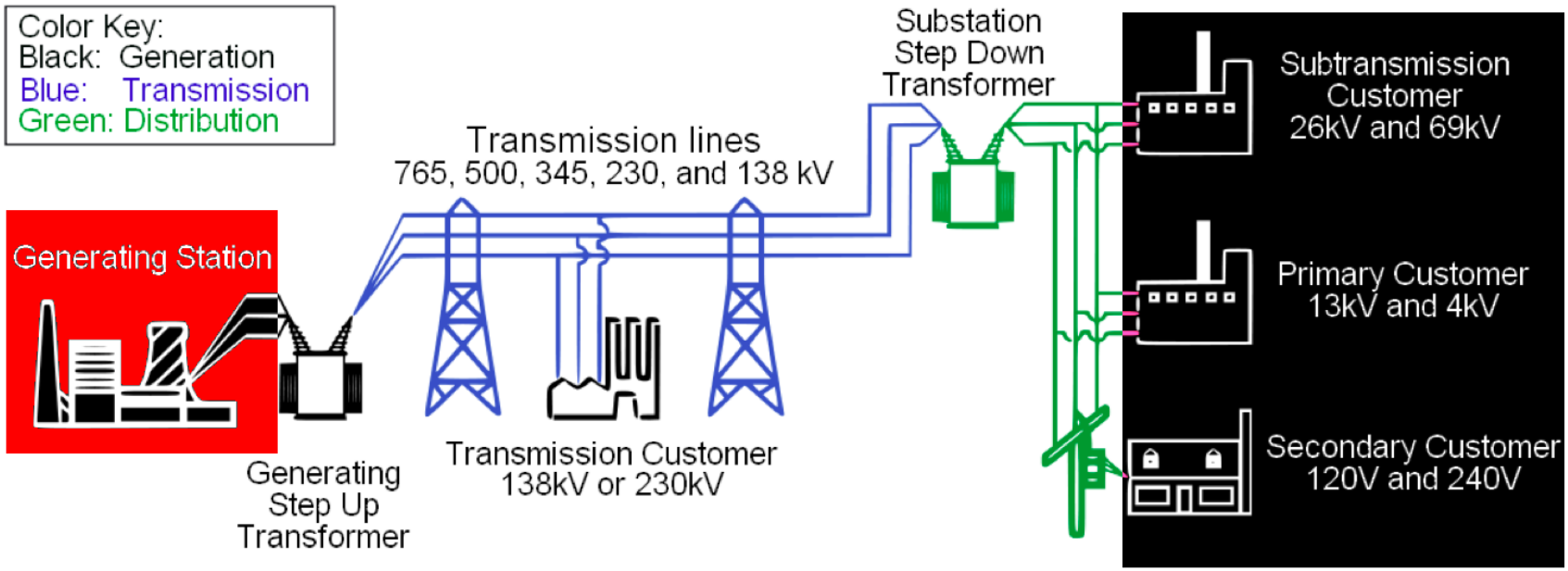

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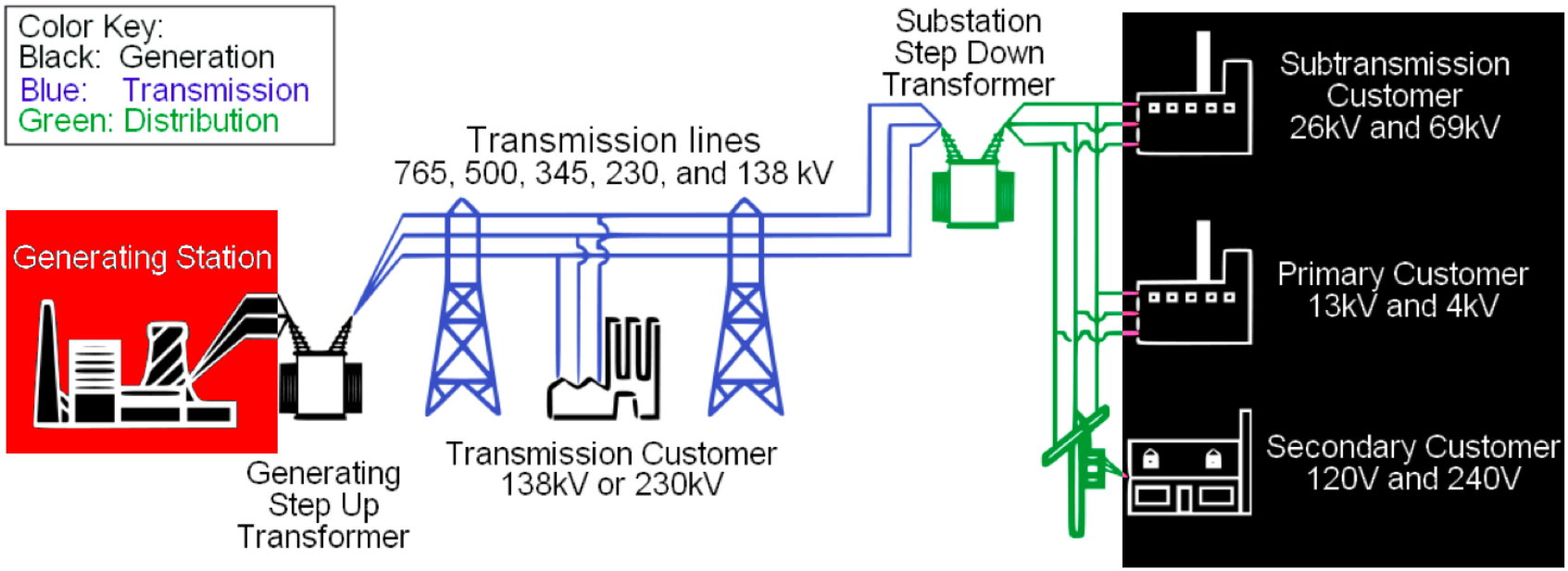

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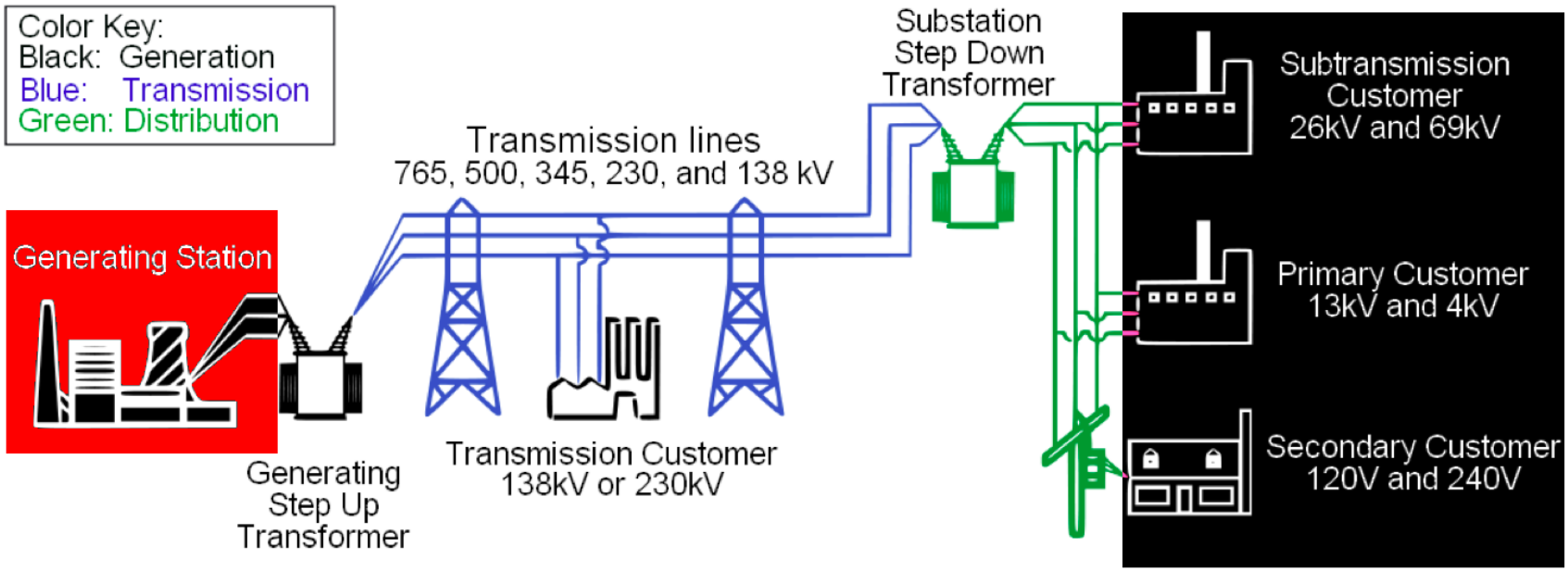

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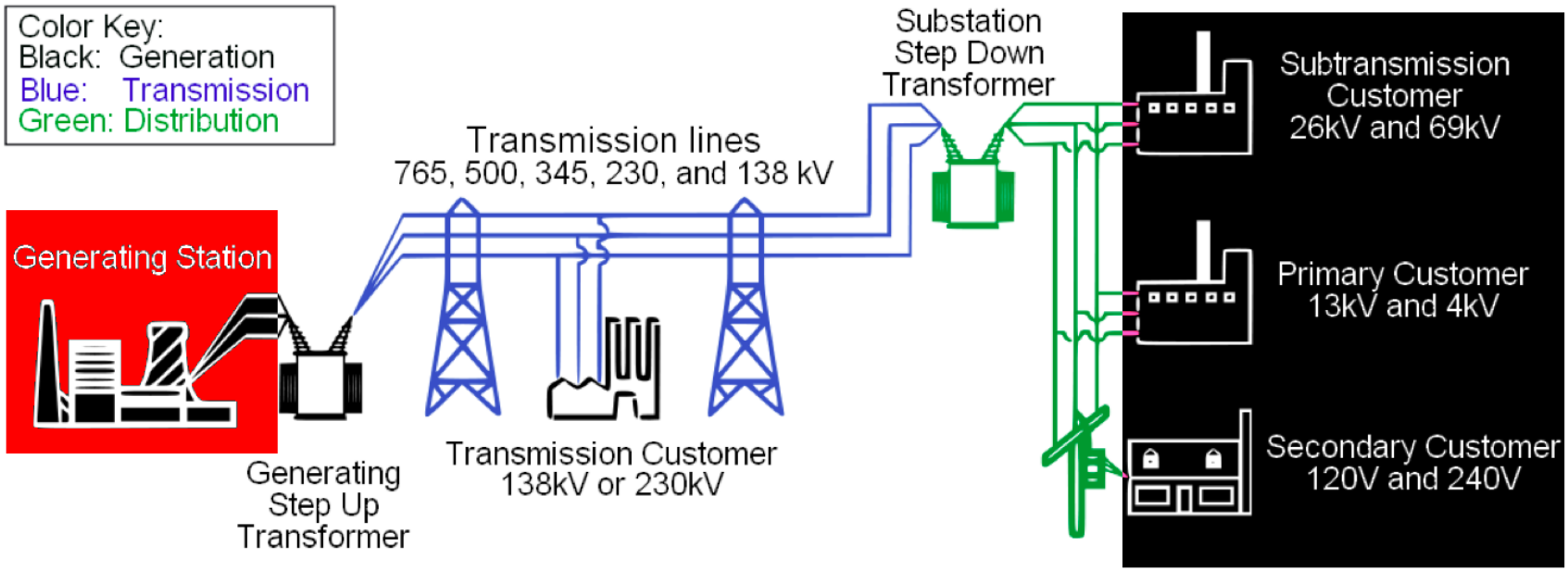

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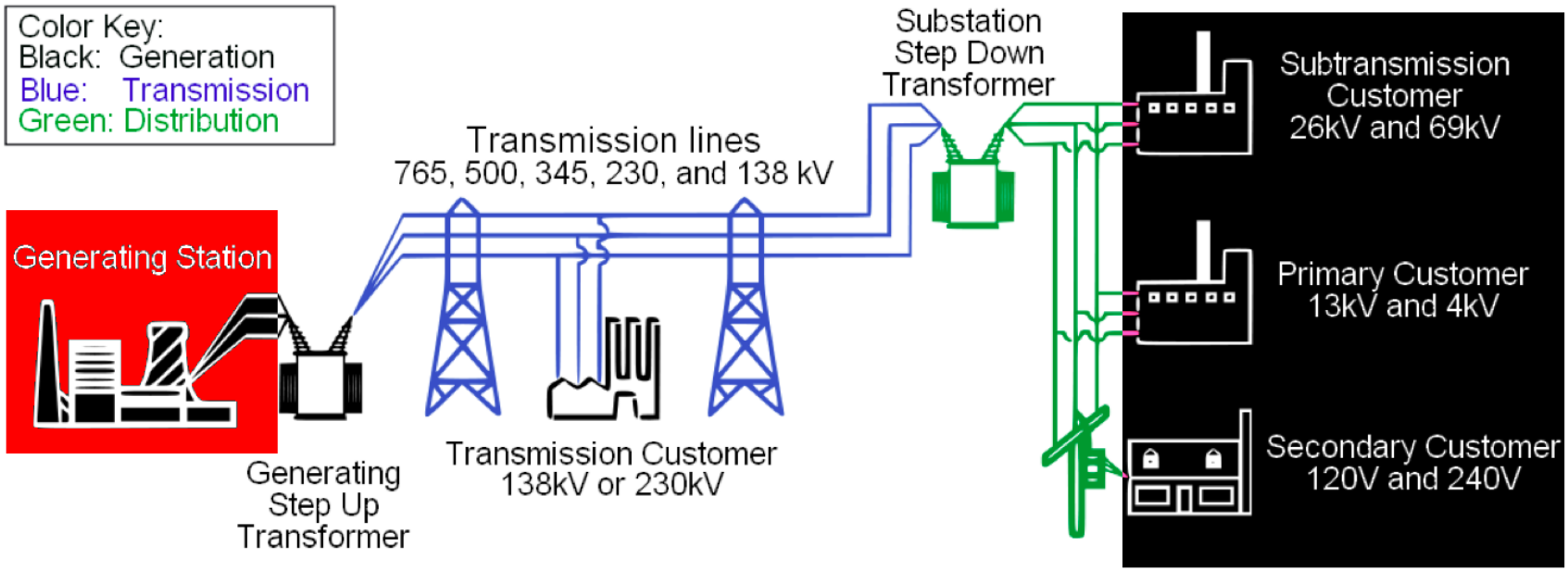

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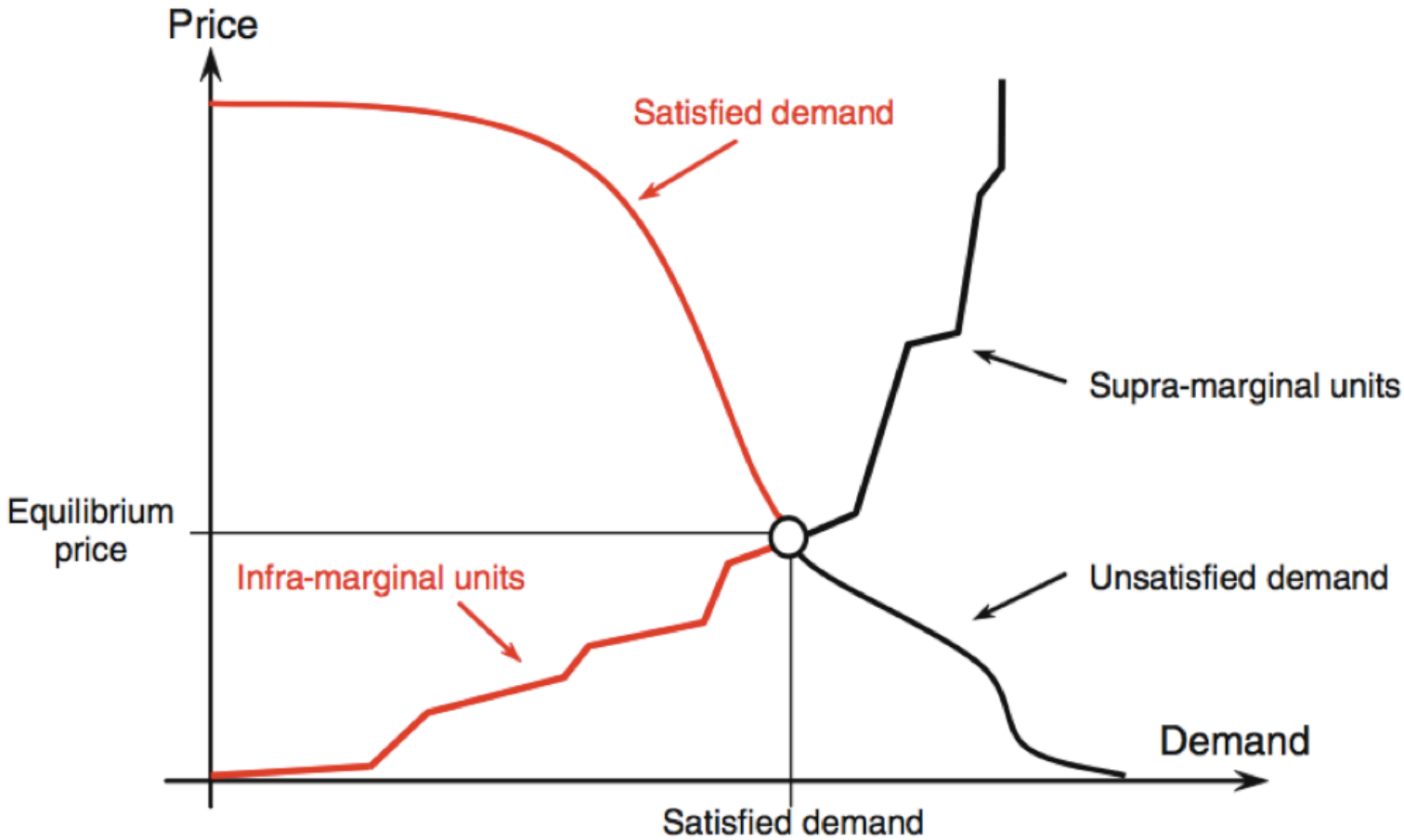
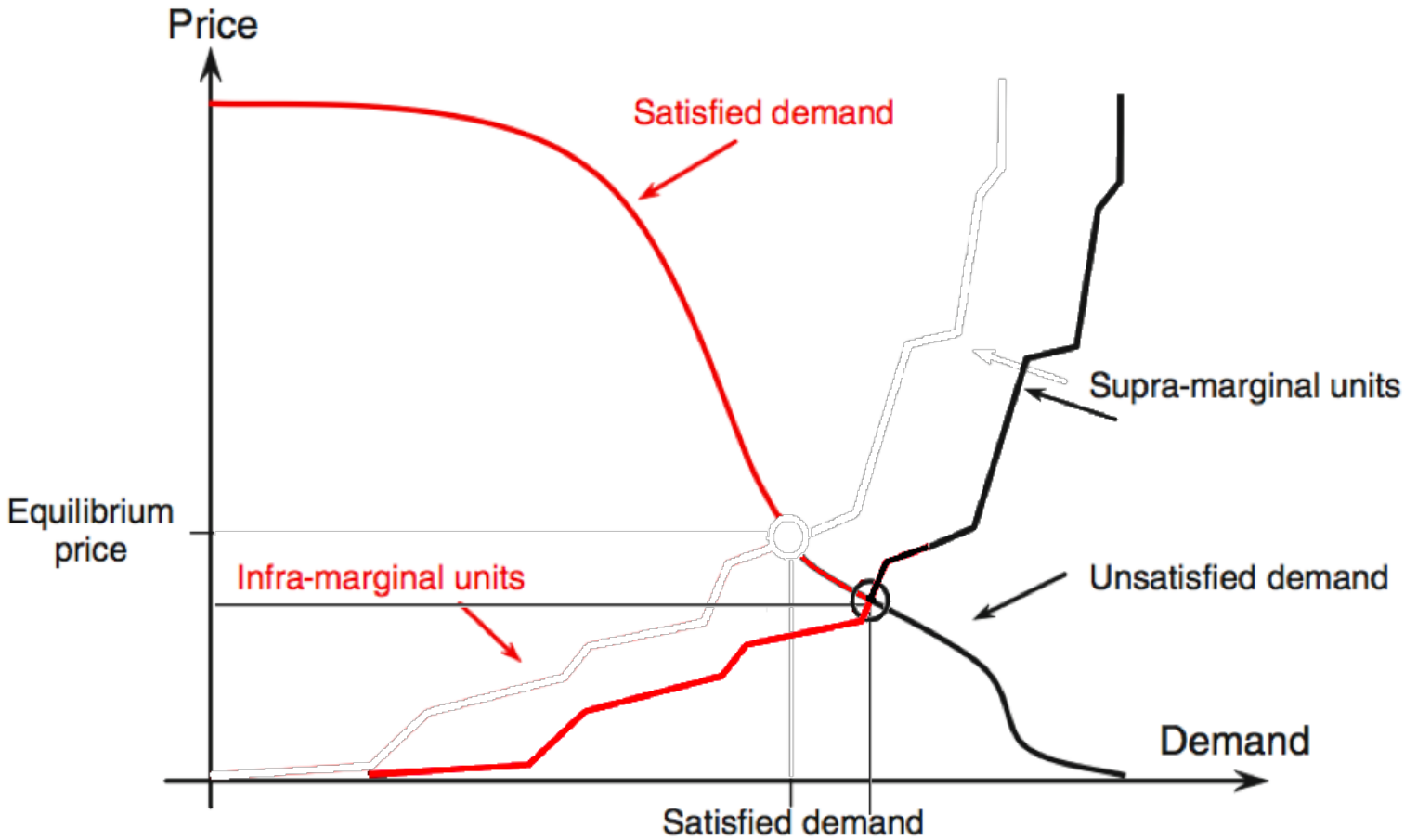
Market functioning: Matching supply and demand



In electricity, the market is naturally differentiated by both **location** (e.g., substation) and **time** (minutes to hour) $\rightarrow$ **Locational Marginal Price (LMP)** (Schweppe et al. 1988)

Market functioning with renewables



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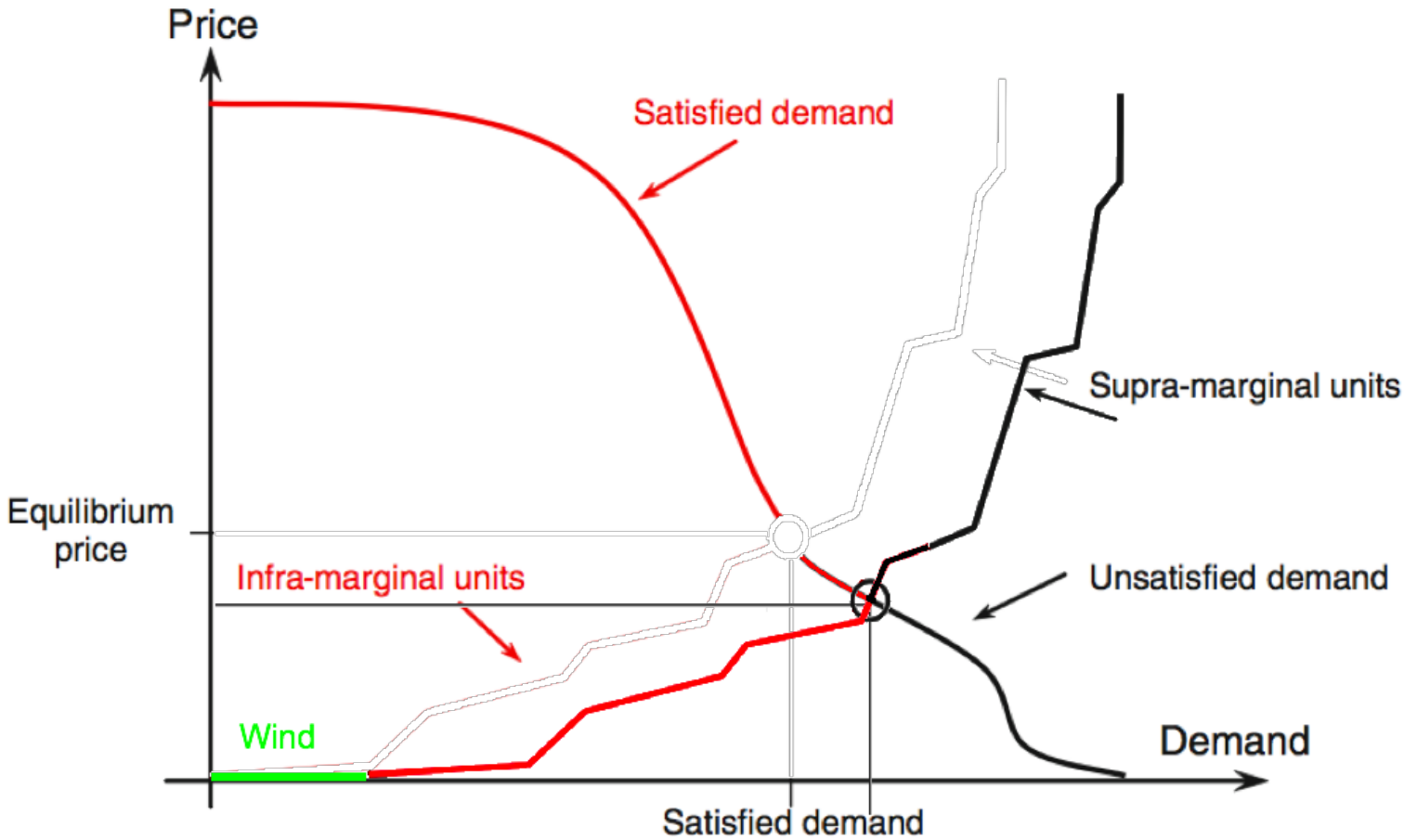

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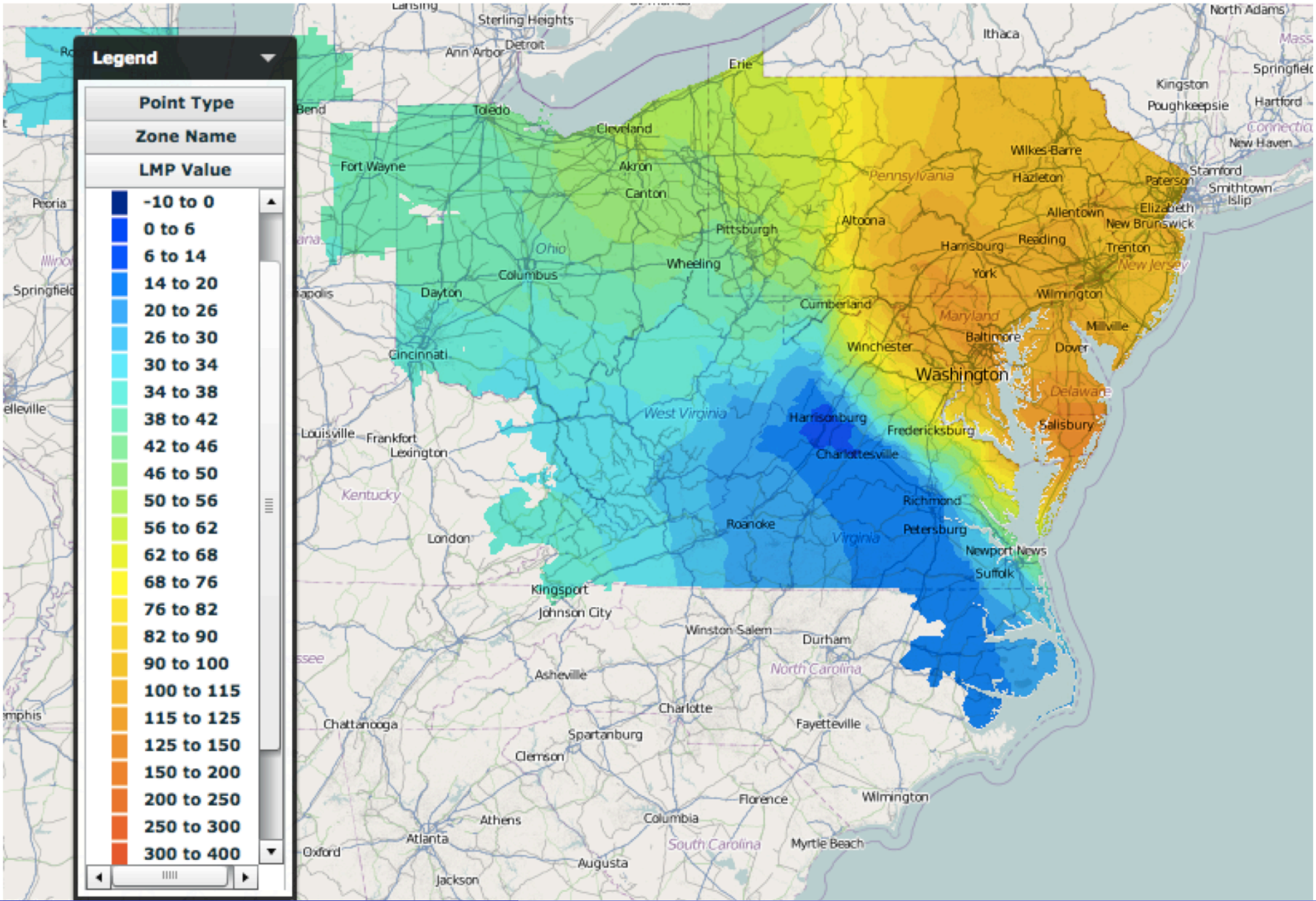
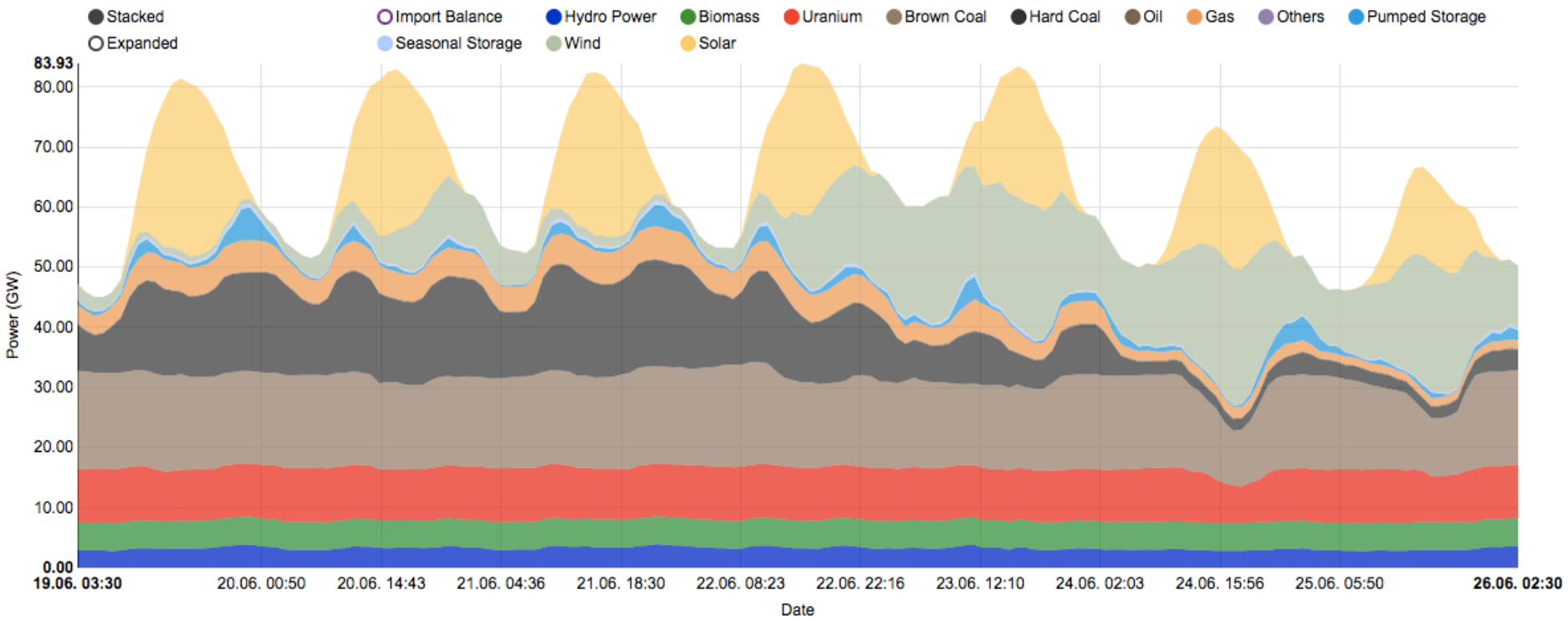
Locational signals (PJM 5-minute prices)



Time signals (Germany generation profile: June 19-26, 2017)



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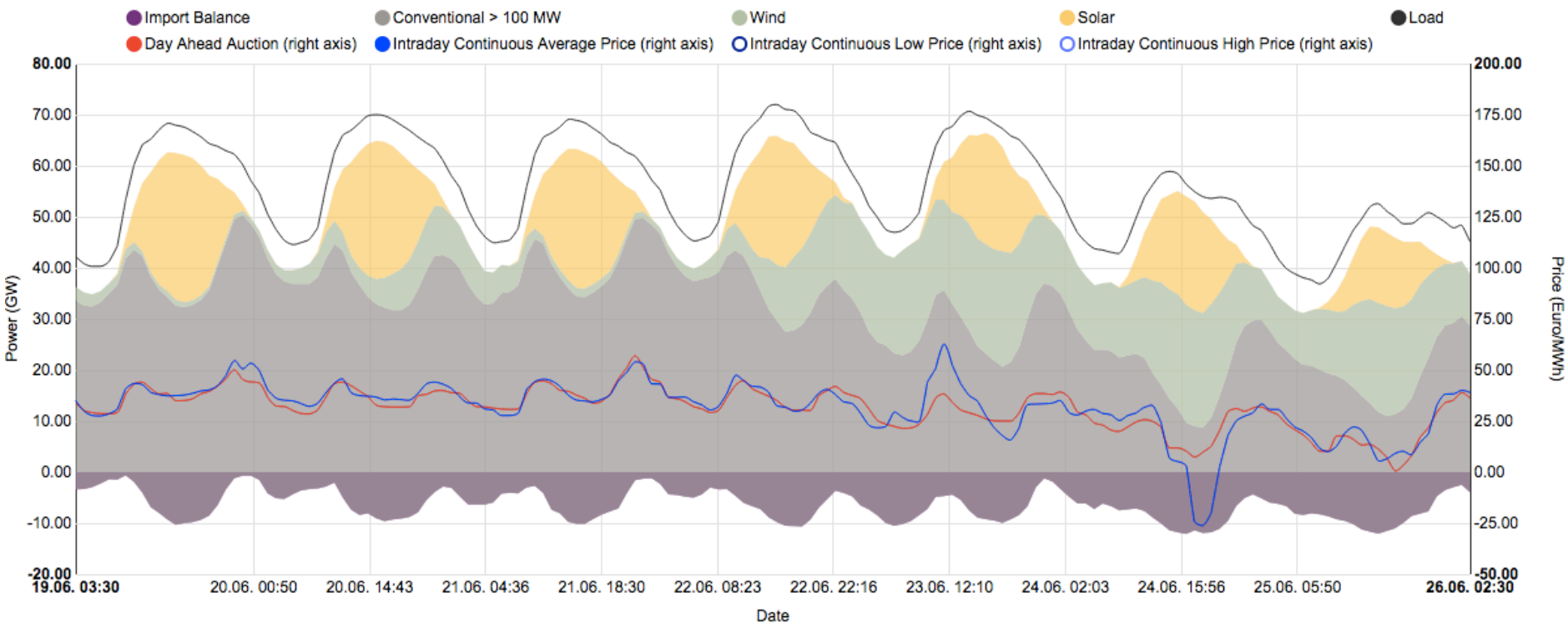

Figure: Day-ahead price. Real-time (hourly) price.

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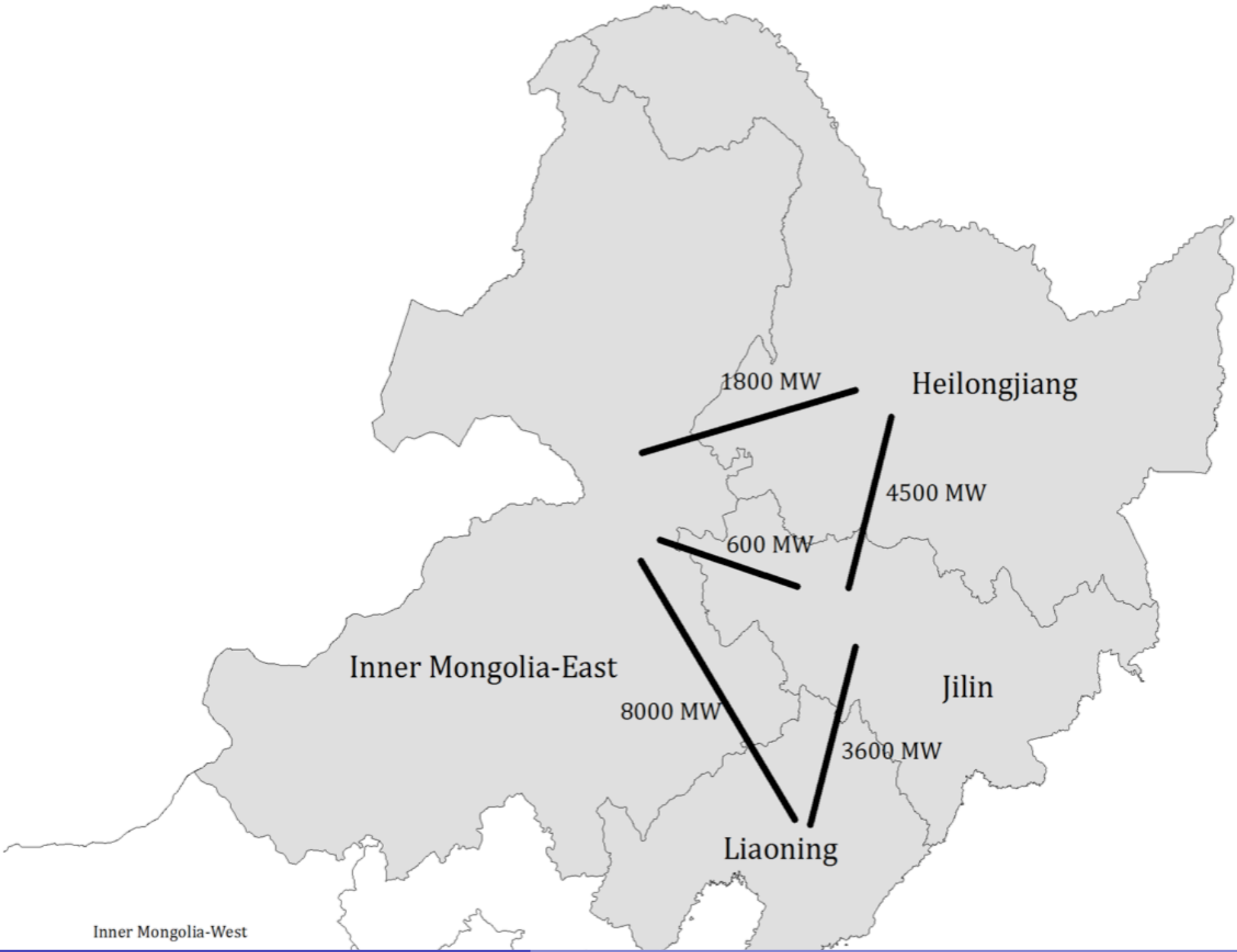
- Market experiments overseen and, in some cases, directed by local governments

Modeling wind curtailment in Northeast



Modeling wind curtailment in Northeast

Unit commitment optimization (typical daily scheduling tool in most power systems):

$$Z = \min_{x,y} \quad \sum_{p,k,t} \left(\mathbf{c}^\top \boldsymbol{x}_{p,k,t} + \mathbf{d}^\top \boldsymbol{y}_{p,k,t} \right) \tag{1}$$

$$\text{s.t.} \quad \begin{aligned} &\text{Supply/demand balance} \\ &\text{Network losses} \\ &\text{Generator output/ramping limits} \\ &\text{Commitment constraints} \\ &\text{District heating requirements} \\ &\text{Reserve requirements} \\ &\text{Quota constraint} \end{aligned}$$

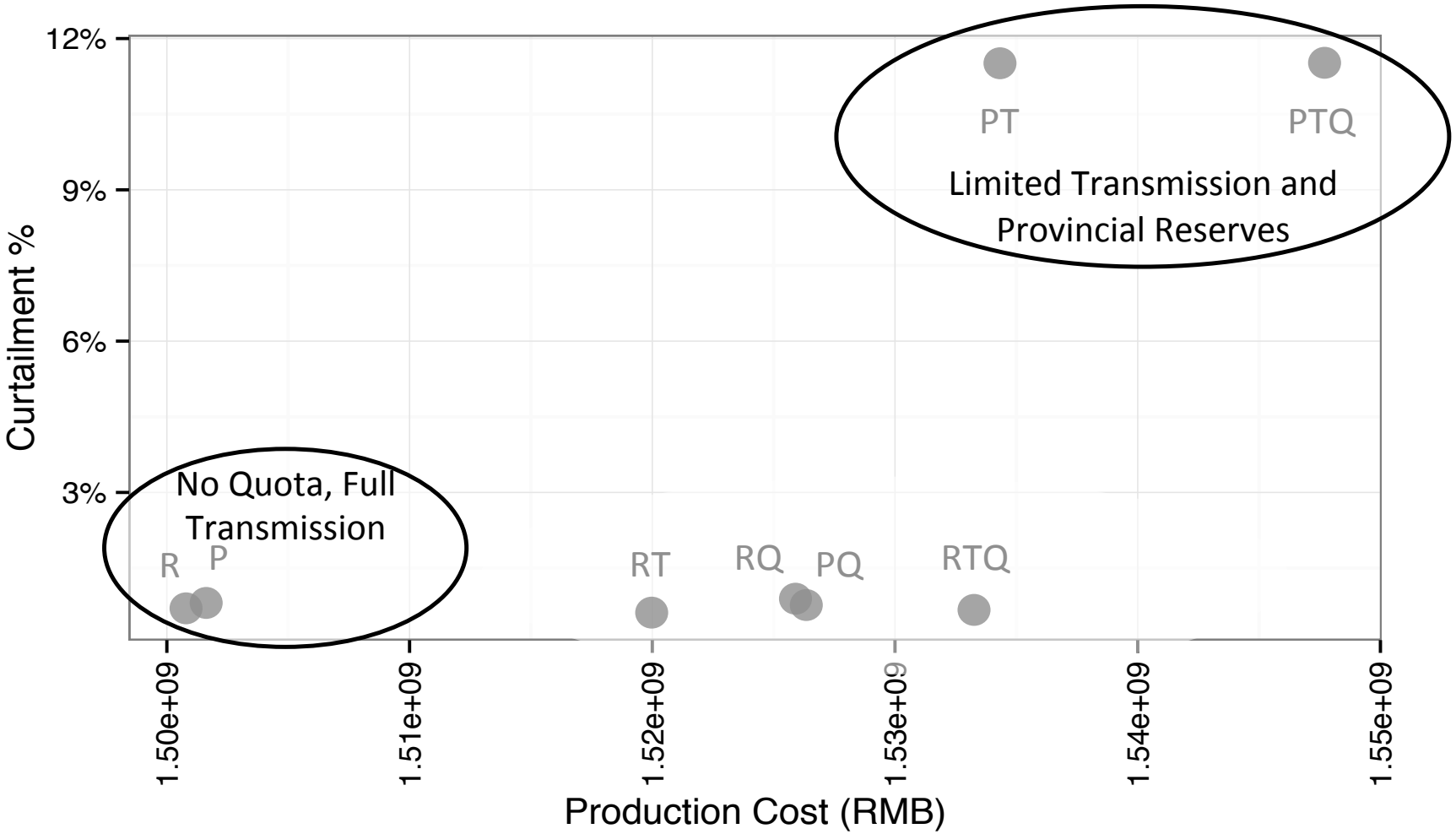
$\boldsymbol{x} \in \{0..N_{p,k}\}$: commitments $\boldsymbol{y}$: outputs $\boldsymbol{c}$: start up costs $\boldsymbol{t}$: time steps (1 hour)
$\boldsymbol{d}$: variable operation costs $\boldsymbol{p}$: provinces $\boldsymbol{k}$: generator clusters
Full model formulation in: (M. R. Davidson and Pérez-Arriaga 2017)

Three key political conflicts

Quota (Q)	**Limited Transmission (T)**	**Provincial Reserves (P)**
Minimum generation allowance to coal-fired generators. Implemented as minimum constraint on total generation for each type of generator.	Planned total transfers between provinces. Implemented as reduction in interconnection capacity and restricted flow directions between provinces.	Provinces cannot share reserve generation. Hence, must have adequate reserves available *within* province.

Northeast results

R=Regional reserves, P=Provincial reserves (i.e., no inter-provincial sharing)
Q=Quota, T=Limited transmission (i.e., long-term contract restrictions)



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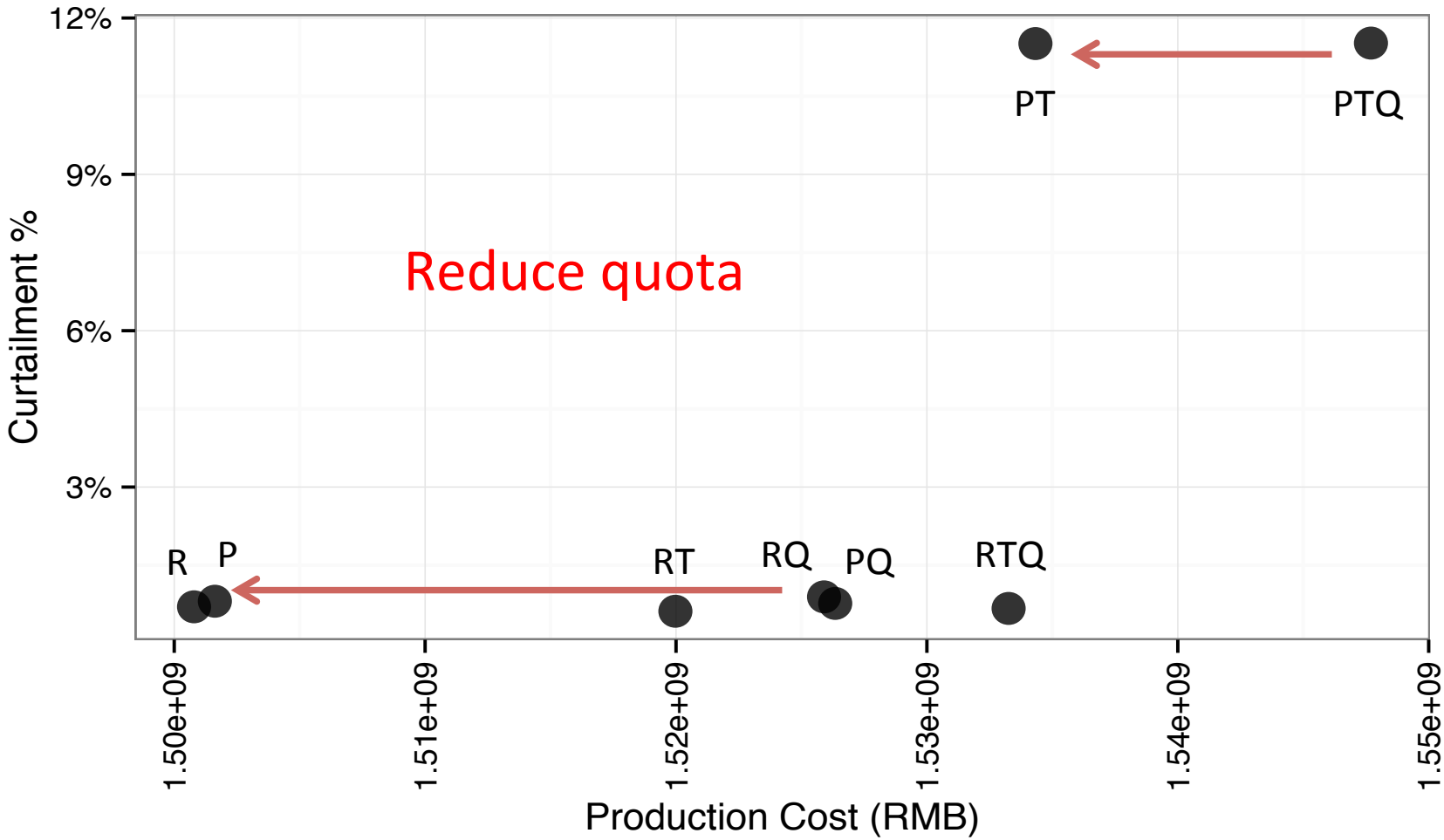

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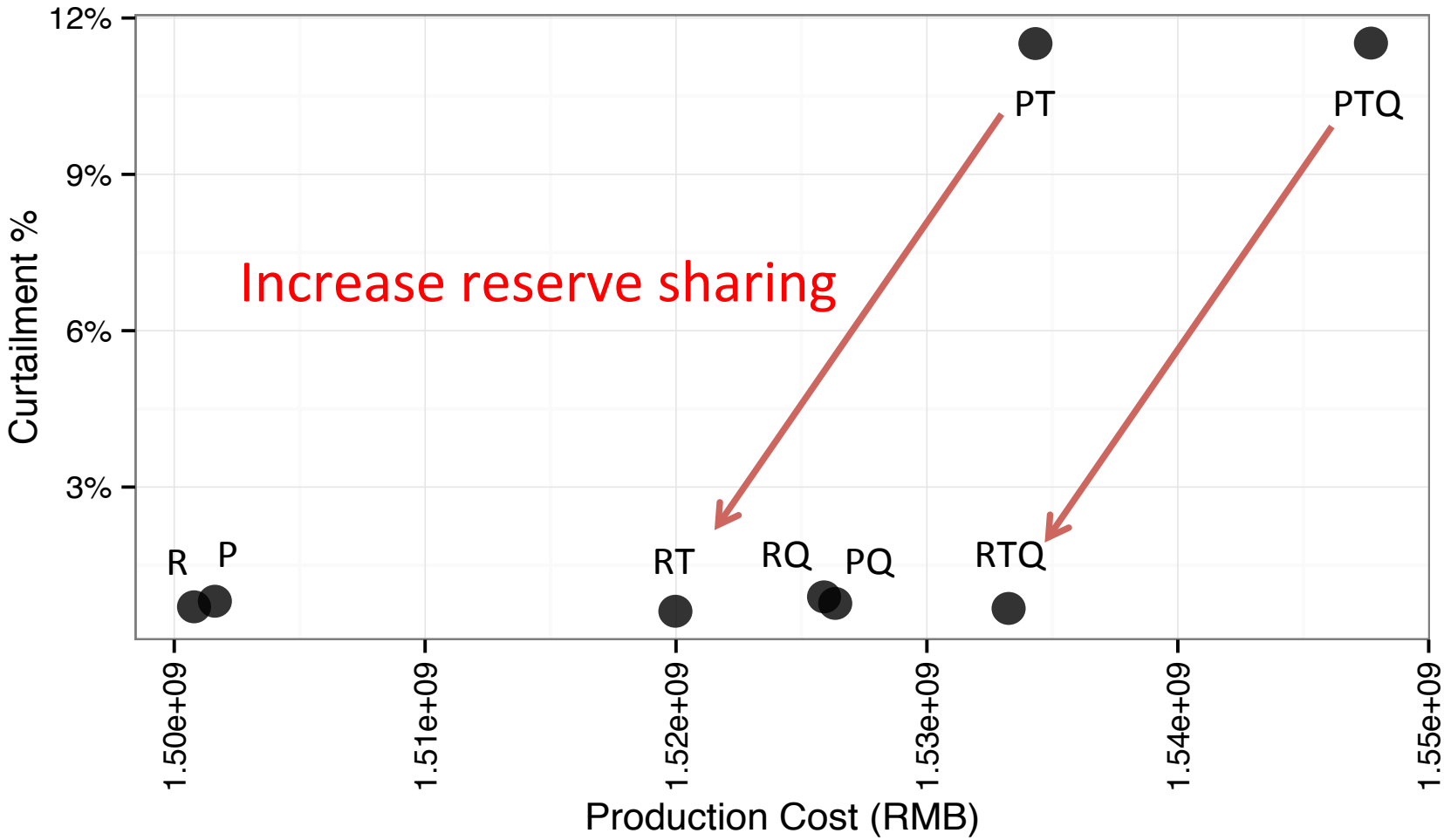

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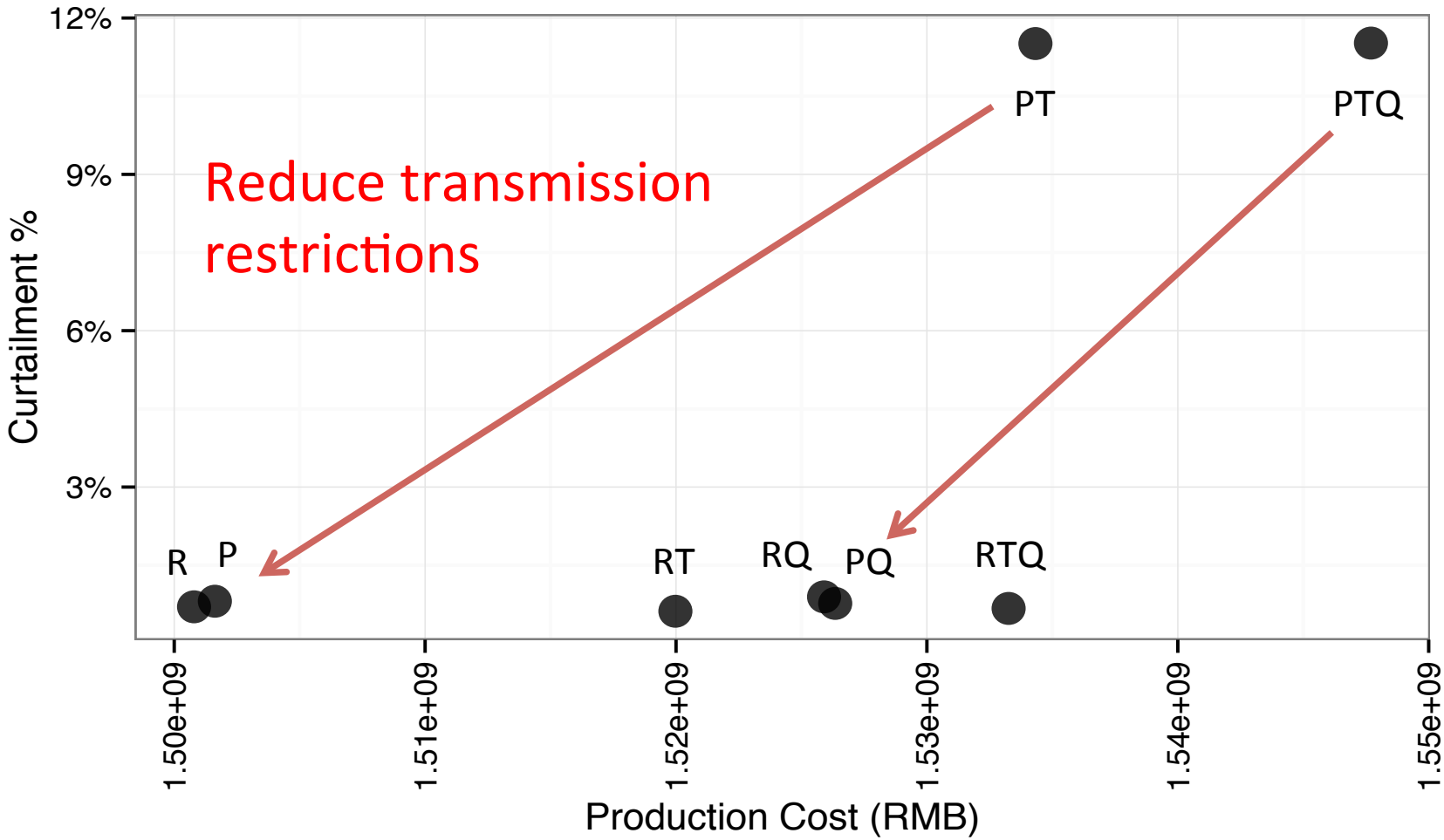

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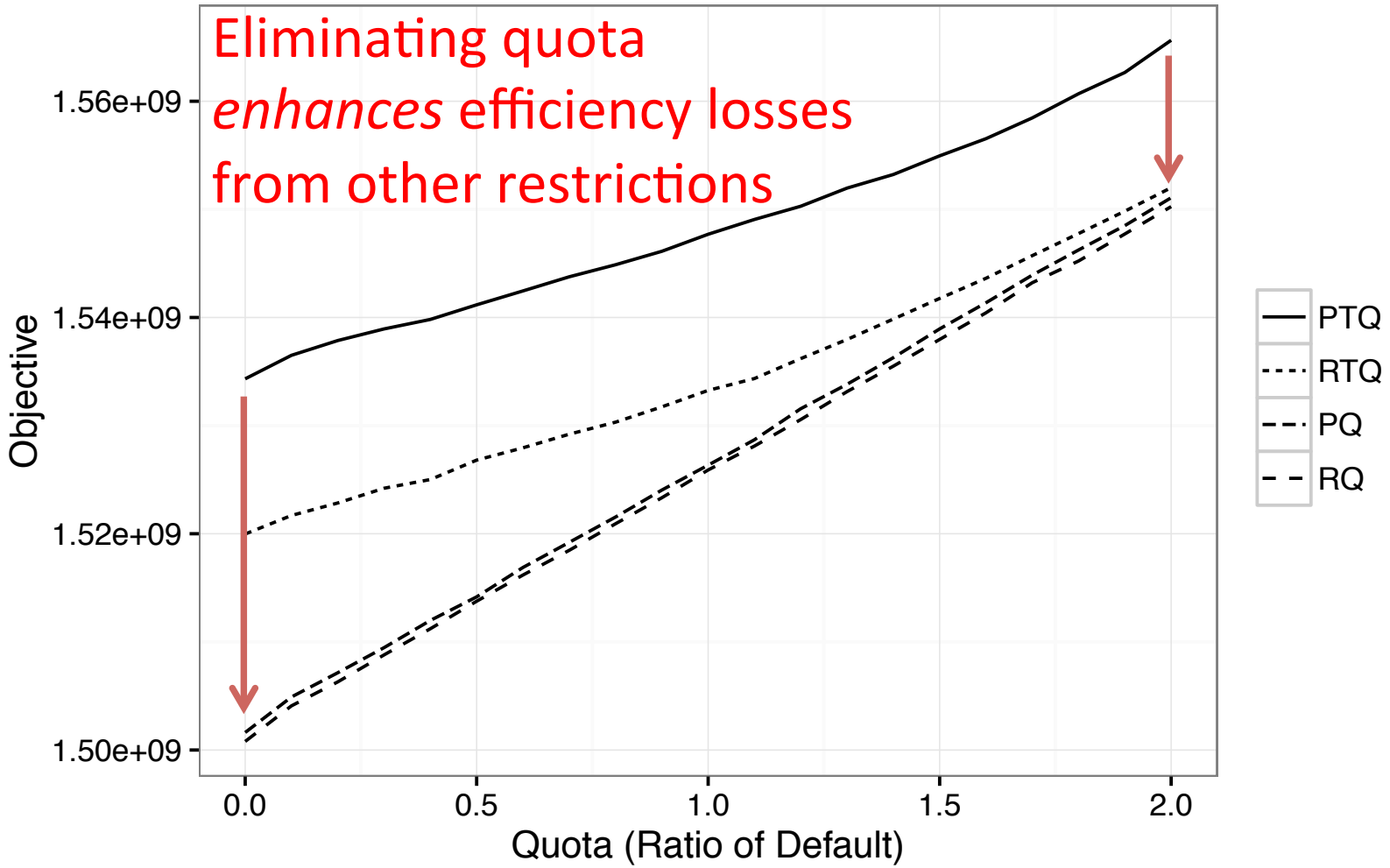

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- Modeling institution interactions can uncover "2nd-best" policies

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Emerging electricity markets

- Short-term exchange transactions: 3% of total generation (CERC, 2017)

Thoughts for India (2)

Long-term $\rightarrow$ Short-term

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- What combination of market (e.g. exchange) vs. administrative (e.g. UI, PPA provisions) pricing is appropriate?
- What will be the new balance of power between centre and state in scheduling and operation?

Thank you

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Modeling wind curtailment in Northeast II

Experimental setup

- NE grid relatively isolated, with pronounced coal overcapacity and large wind curtailment (15-30%), winter highest
- Historical network and generator data from 2011 winter (CEC 2011)
- Fixed **one-week demand** in winter season, and **six wind scenarios** to capture variability
- Cogeneration units as must-run and higher minimum outputs (sensitivity on commitments)
- Measure effects and interactions of three political conflicts

Outcomes of interest

- Total production cost
- Wind curtailment

Model I

$$\min \quad \sum_{g \in G} \sum_{t \in T} \left(p_g^{su} \boldsymbol{v}_{g,t}^{up} + p_g^{var} \boldsymbol{y}_{g,t} \right) \tag{2}$$

$$\text{s.t.} \quad \sum_{g \in G_p} \boldsymbol{y}_{g,t} - \sum_{p' \neq p} [\boldsymbol{f}_{p,p',t} + \boldsymbol{l}_{p,p',t}/2] = d_{p,t} \tag{3}$$

$$\boldsymbol{f}_{p,p',t} = -\boldsymbol{f}_{p',p,t} \tag{4}$$

$$\boldsymbol{f}_{p,p',t} = \boldsymbol{f}^{+}_{p,p',t} - \boldsymbol{f}^{-}_{p,p',t} \tag{5}$$

$$\sum_{s} \boldsymbol{j}_{p,p',t,s} = \boldsymbol{f}^{+}_{p,p',t} + \boldsymbol{f}^{-}_{p,p',t} \tag{6}$$

$$\boldsymbol{f}_{p,p',t} + \boldsymbol{l}_{p,p',t}/2 \leq \overline{F}_{p,p'} \tag{7}$$

$$\boldsymbol{l}_{p,p',t} = \mu_{p,p'} \sum_{s} \alpha_{p,p',s} \boldsymbol{j}_{p,p',t,s} \tag{8}$$

$$\alpha_{p,p',s} = (2s-1)\,\Delta f_{p,p'}, \qquad \forall s = 1..S \tag{9}$$

$$\Delta f_{p,p'} = \overline{F}_{p,p'}/S \tag{10}$$

$$\boldsymbol{l}_{p,p',t}, \boldsymbol{f}^{+}_{p,p',t}, \boldsymbol{f}^{-}_{p,p',t}, \boldsymbol{j}_{p,p',t,s} \geq 0 \tag{11}$$

Model II

$$\mathbf{U}_{p,k,t} \leq |G_{p,k}| \tag{12}$$

$$\mathbf{U}_{p,k,t} \geq \sum_{t'=t-MU_k}^{t} \mathbf{V}^{up}_{p,k,t'} \tag{13}$$

$$|G_{p,k}| - \mathbf{U}_{p,k,t} \geq \sum_{t'=t-MD_k}^{t} \mathbf{V}^{dn}_{p,k,t'} \tag{14}$$

$$\mathbf{U}_{p,k,t} - \mathbf{U}_{p,k,t-1} = \mathbf{V}^{up}_{p,k,t} - \mathbf{V}^{dn}_{p,k,t} \tag{15}$$

$$\mathbf{W}_{p,k,t} = \mathbf{Y}_{p,k,t} - \underline{P}_k \mathbf{U}_{p,k,t} \tag{16}$$

$$\mathbf{W}_{g,t} - \mathbf{W}_{g,t-1} \leq \mathbf{U}_{p,k,t} RU_k + \mathbf{V}^{up}_{p,k,t} \underline{P}_k \tag{17}$$

$$\mathbf{W}_{g,t-1} - \mathbf{W}_{g,t} \leq \mathbf{U}_{p,k,t} RD_k + \mathbf{V}^{dn}_{p,k,t} \underline{P}_k \tag{18}$$

$$\mathbf{R}_{p,k,t} \leq \mathbf{U}_{p,k,t} RU_k \tag{19}$$

$$\mathbf{S}_{p,k,t} \leq \mathbf{U}_{p,k,t} RD_k \tag{20}$$

Quota parameterization

Table: Modeled minimum winter thermal generation quotas Q_p by province.

	Annual CF	Assumed Max Summer CF	Estimated Min Winter CF	Q_p
HL	47%	80%	14%	14%
JL	39%	80%	-2%	0%
LN	50%	80%	20%	20%
IME	58%	80%	36%	36%

Transmission capacities (physical)

Table: Estimated inter-provincial transmission capacities $\overline{F}_{p,p'}$ (MW) in 2011. (HL = Heilongjiang, JL = Jilin, LN = Liaoning, IME = Eastern Inner Mongolia)

	HL	JL	LN	IME
HL	0	4500	0	1800
JL	4500	0	3600	600
LN	0	3600	0	8000
IME	1800	600	8000	0

Transmission capacities (restricted)

Table: Modeled effective inter-provincial transmission capacities $\overline{F}^*_{p,p'}$ under provincial dispatch (MW). Source of exports (2011): (State Grid 2012).

	Exports (PWh)	Avg. power (MW)	$\overline{F}^*_{p,p'}$ (MW)
HL $\rightarrow$ JL	0.119	14	0
HL $\rightarrow$ LN	5.257	600	600
HL $\rightarrow$ IME	0.426	49	0
JL $\rightarrow$ LN	2.579	294	300
IME $\rightarrow$ LN	10.622	1213	1200

China's wind curtailment