

ELECTRICITY GENERATION AND TRANSMISSION IN INDIA

OPTIMIZING INFRASTRUCTURE FOR ECONOMIC GROWTH

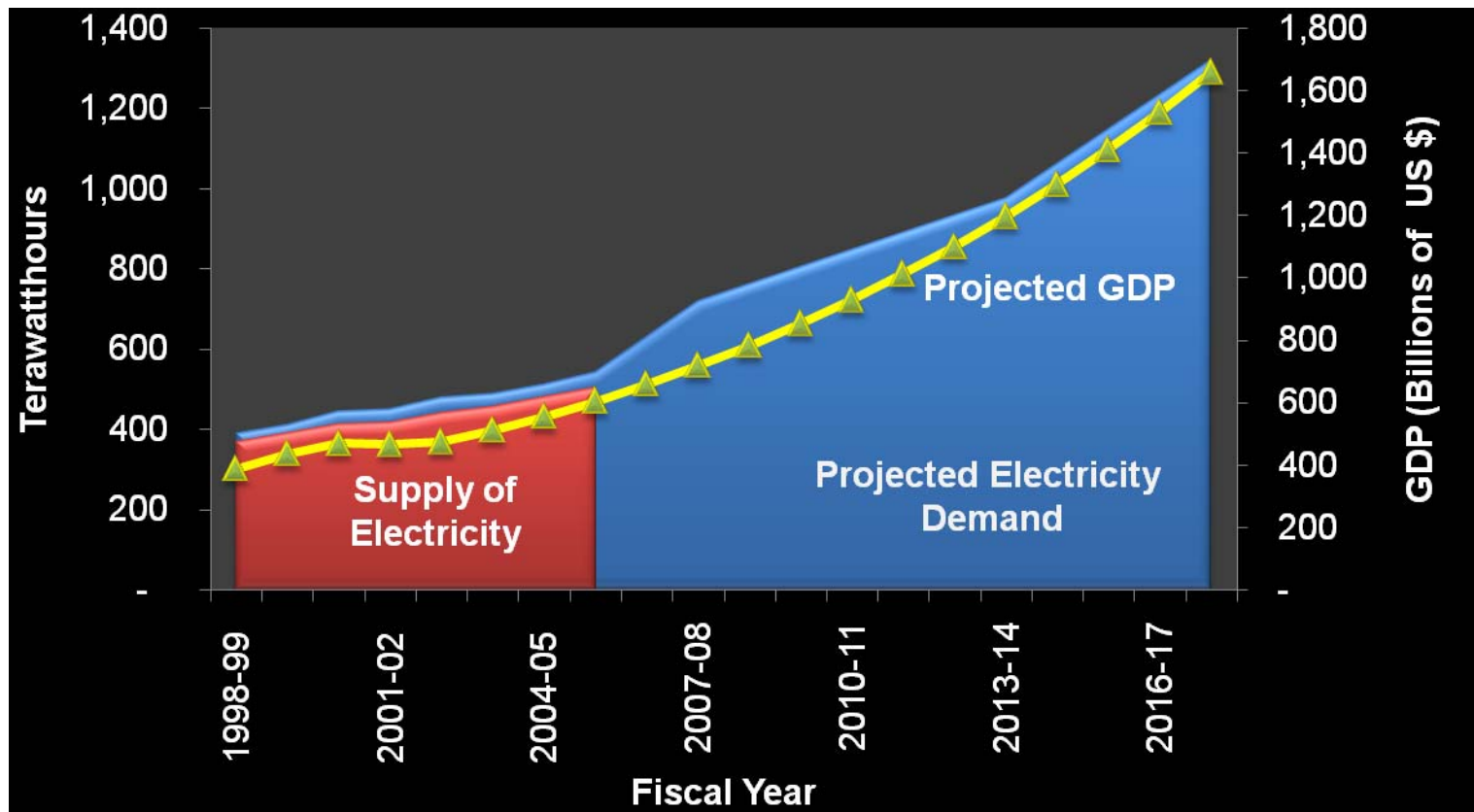
Devendra Canchi

**Energy Center at Discovery Park
Purdue University**

Global Partnerships Program Committee Meeting

June 29, 2007

India's Economic Growth and Demand for Electricity



Sources

GDP Projection: Dominic Wilson and Roopa Purushothaman, "Dreaming with BRICs: the path to 2050"

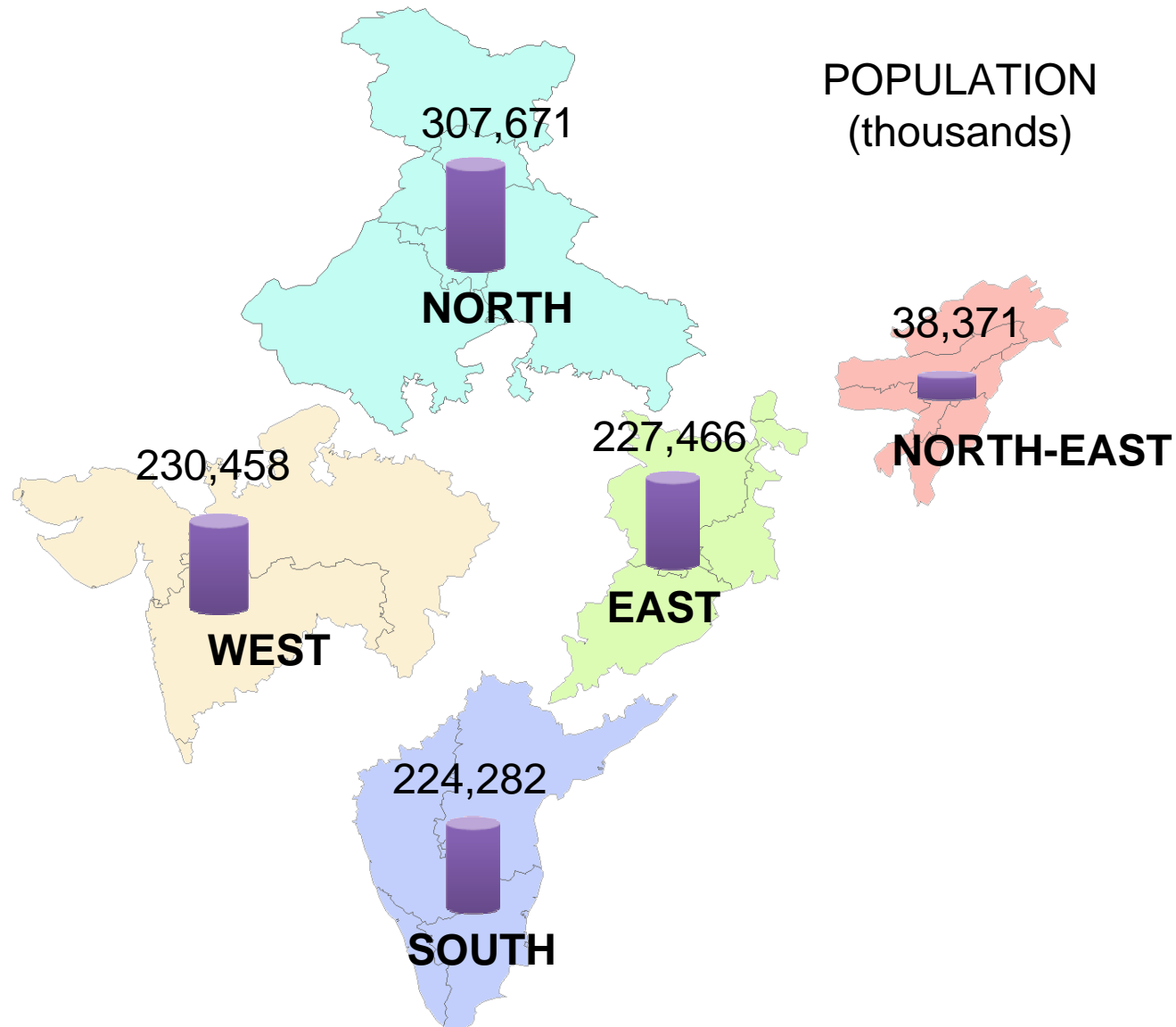
Global Economics Paper No 99, Goldman Sachs, 1st October 2003.

Electricity Demand Projection: Central Electricity Authority, Govt. of India, 16th Electric Power Survey, 2001.

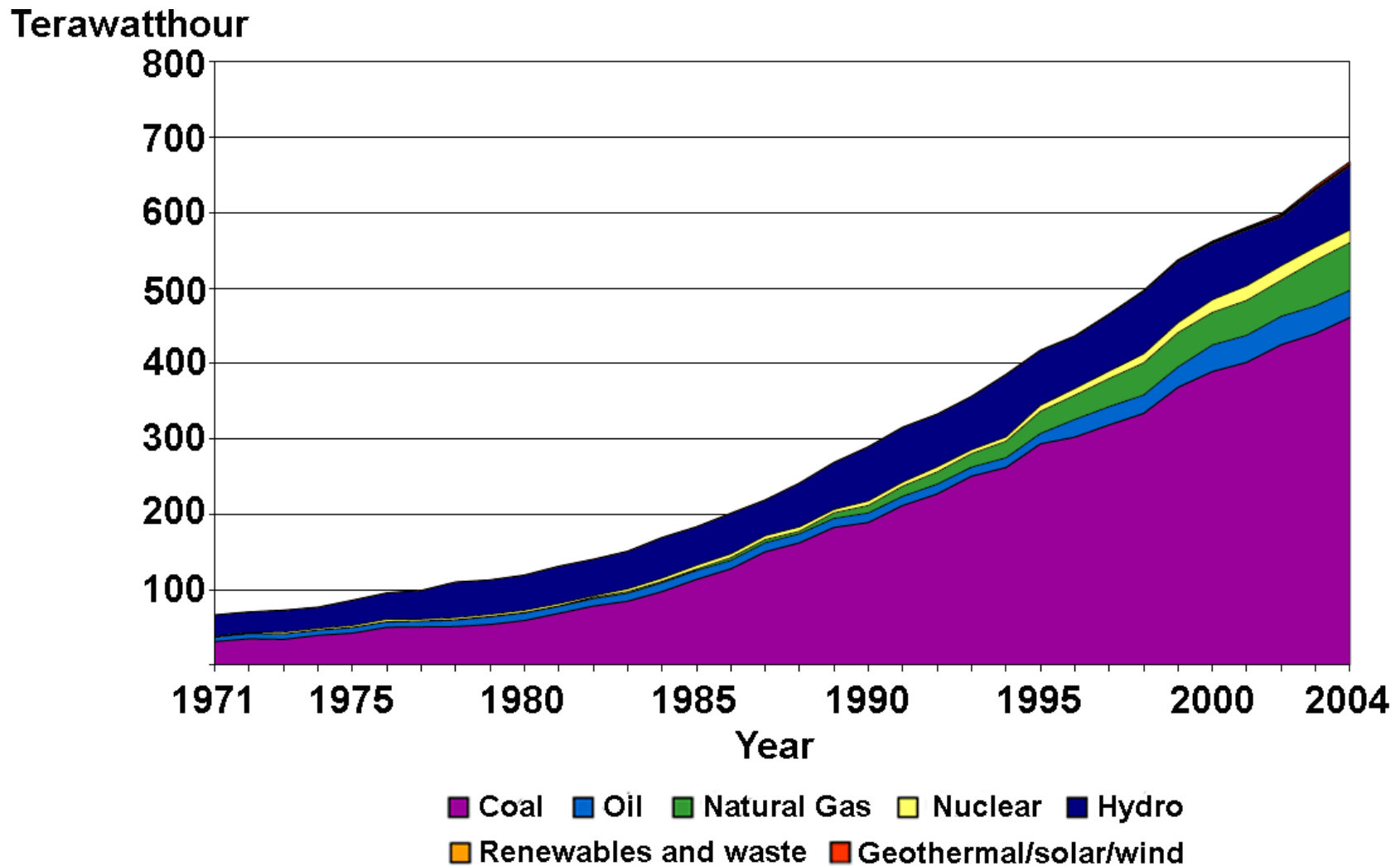
India's Electricity Per Capita

Country	Electricity Consumption per Capita 2004 (kWh)
India	457
China	1,585
Germany	7,029
USA	13,351

India - Regions and Population



India's Electricity Generation by Fuel Historical Trends



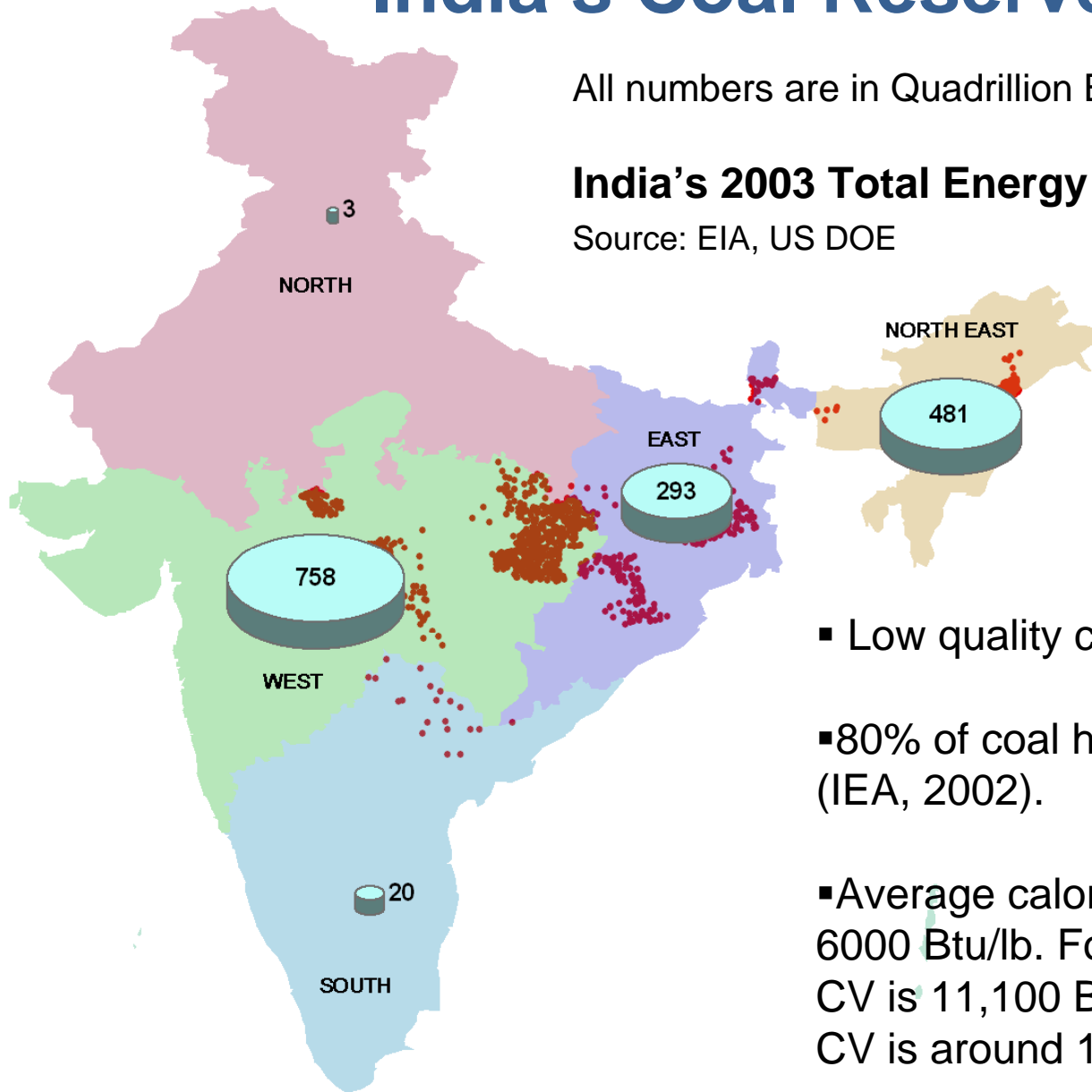
Source: IEA Energy Statistics, http://www.iea.org/textbase/stats/pdf_graphs/INELEC.pdf

India's Coal Reserves (Quads)

All numbers are in Quadrillion Btu, 1 Quad = 10^{15} Btu

India's 2003 Total Energy Consumption = 14 Quads

Source: EIA, US DOE



- Low quality coal with high ash content.
- 80% of coal has ash content of 30 to 50% (IEA, 2002).
- Average calorific value (CV) is around 6000 Btu/lb. For comparison, Indiana coal CV is 11,100 Btu/lb and Appalachian coal CV is around 13,000 Btu/lb.

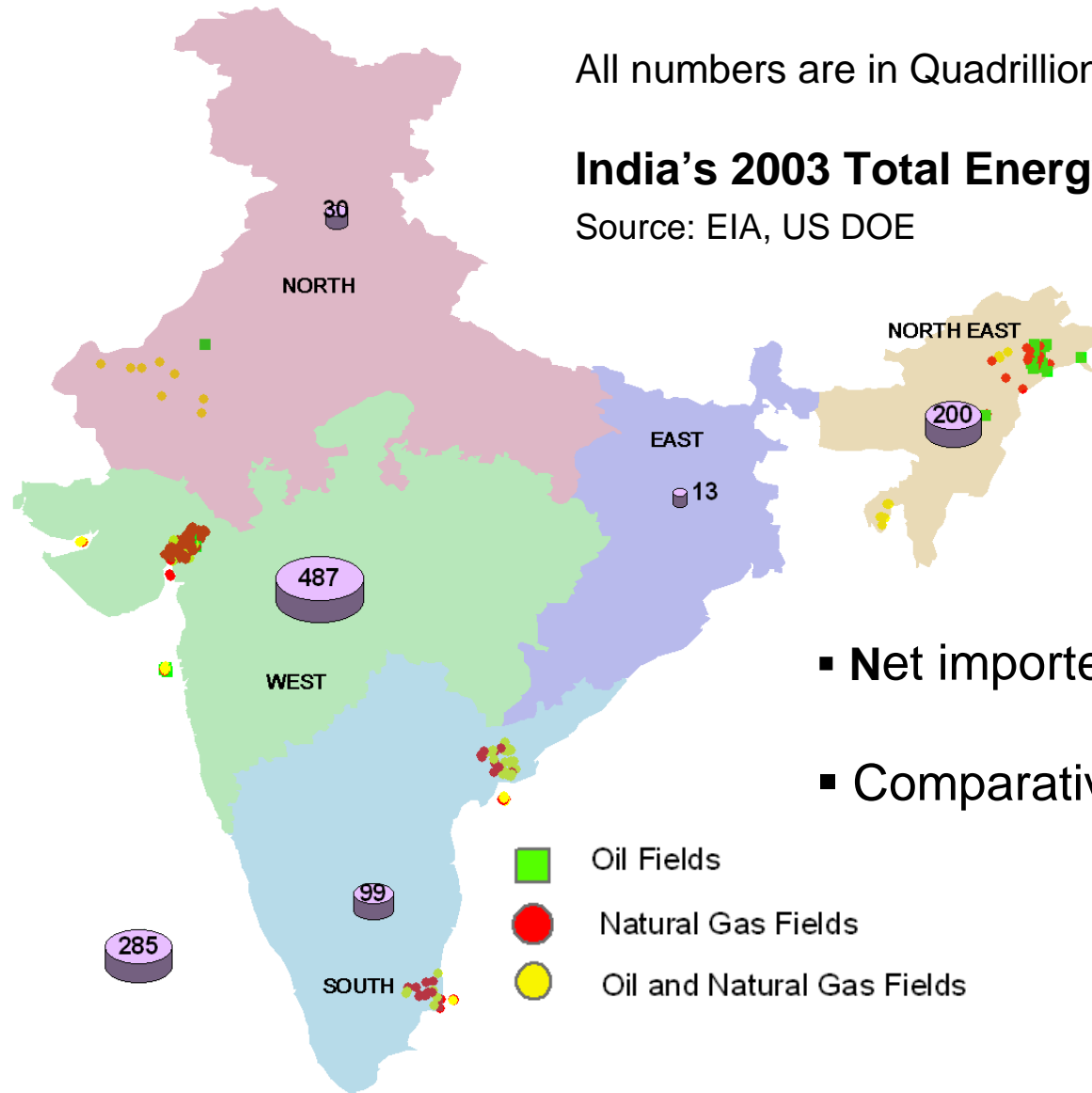
Source: Coal wing, Geological Survey of India, Calcutta

India's Oil and Natural Gas Reserves (Quads)

All numbers are in Quadrillion Btu, 1 Quad = 10^{15} Btu

India's 2003 Total Energy Consumption = 14 Quads

Source: EIA, US DOE



- Net importer of Oil and Natural gas.
- Comparatively cheaper to import

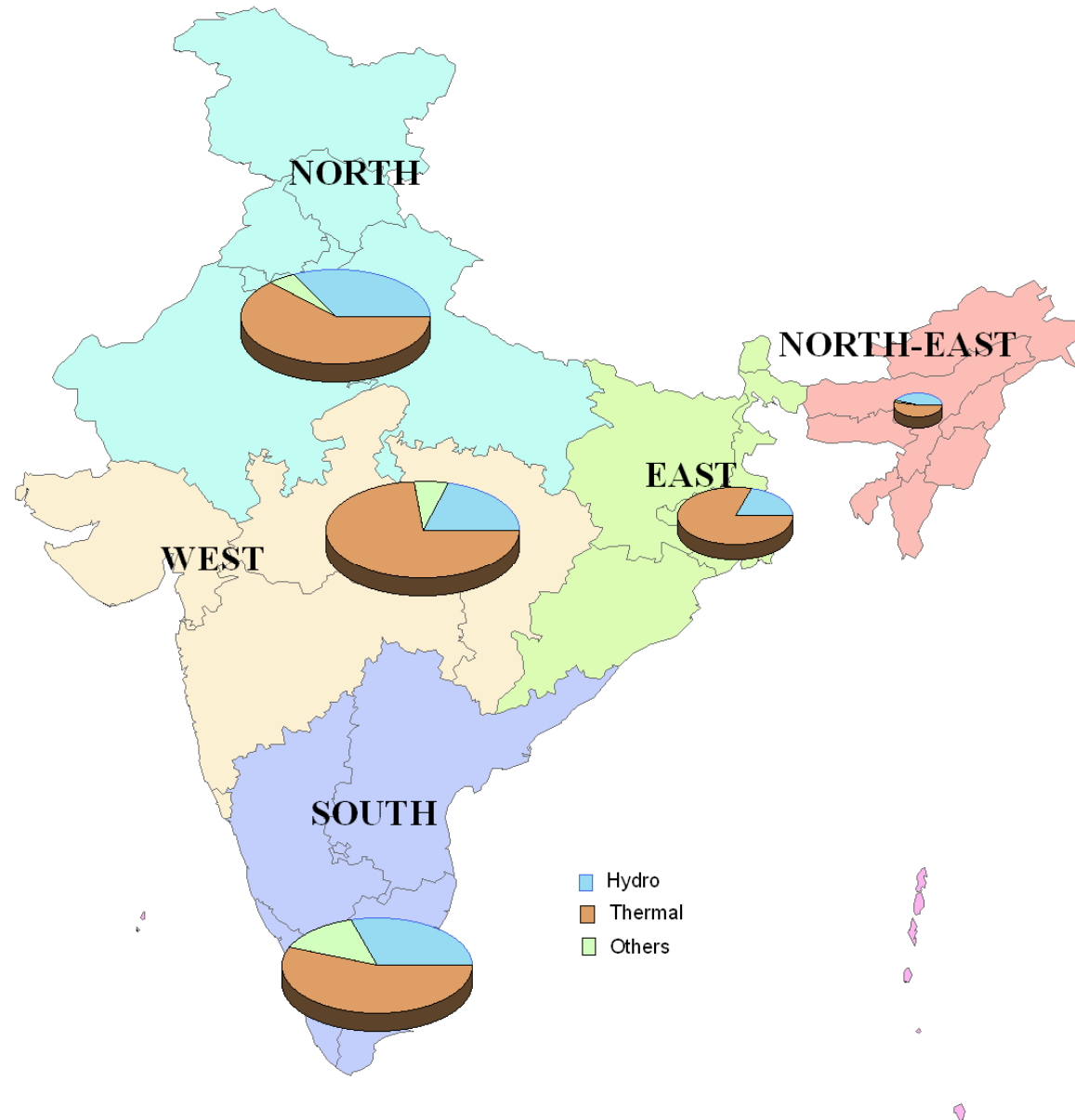
Source: Directorate General of Hydrocarbons, Ministry of Petroleum and Natural Gas

Electricity – Generation Capacity (MW)

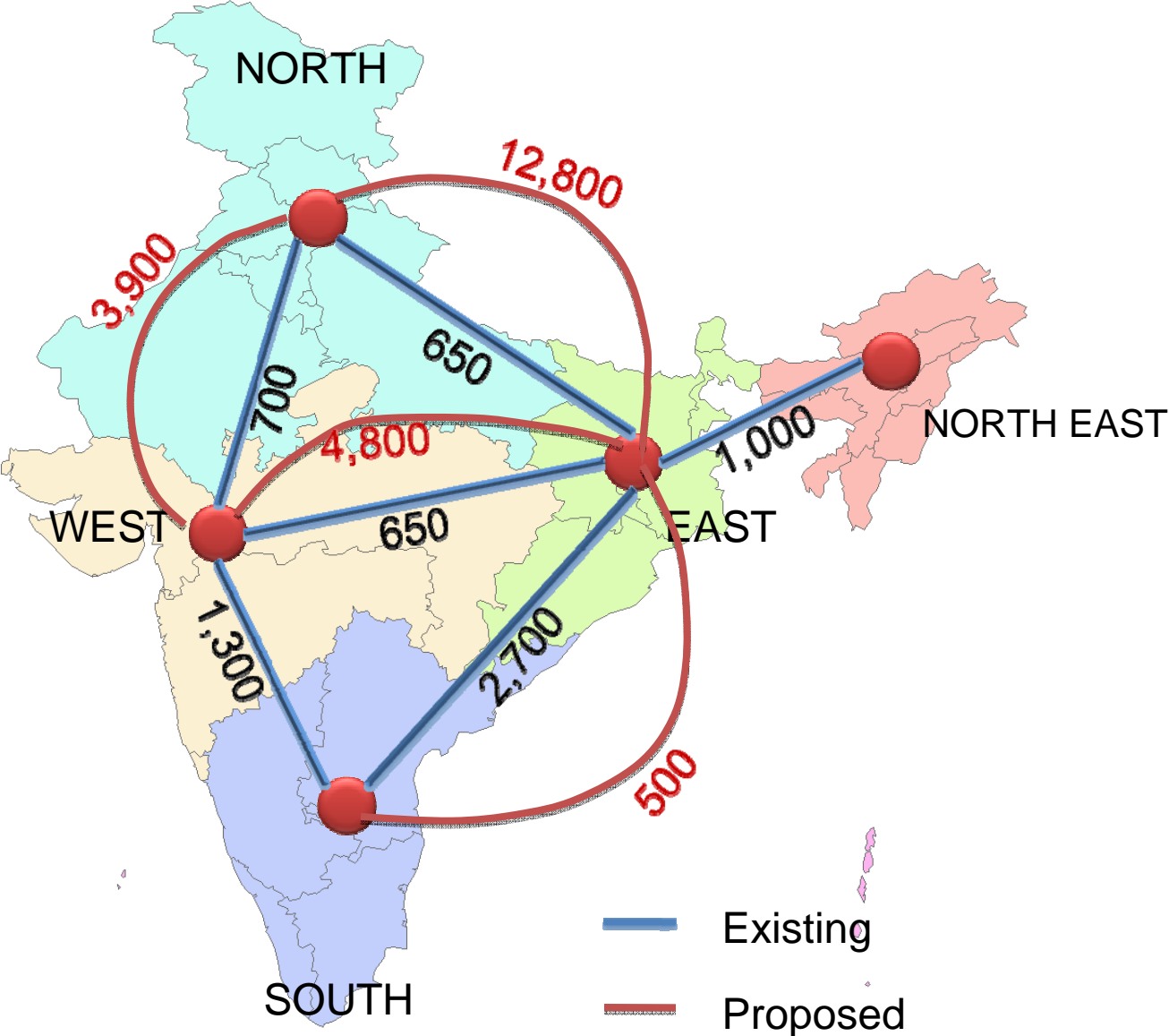
Region	Installed Capacity (MW) as of Dec 2006			
	Hydro	Thermal	Others	Total
NORTH	12,042	20,941	1,745	34,728
	34.7%	60.3%	5.0%	100.0%
WEST	6,919	26,361	2,872	36,152
	19.1%	72.9%	7.9%	100.0%
SOUTH	10,997	19,323	5,029	35,349
	31.1%	54.7%	14.2%	100.0%
EAST	1,035	1,188	47	2,270
	45.6%	52.3%	2.1%	100.0%
NORTH-EAST	1,035	1,188	47	2,270
	45.6%	52.3%	2.1%	100.0%
TOTAL	32,029	69,003	9,741	110,773
	28.9%	62.3%	8.8%	100.0%

Source: Ministry of Power, Govt. of India

Electricity- Generation Capacity (contd.)

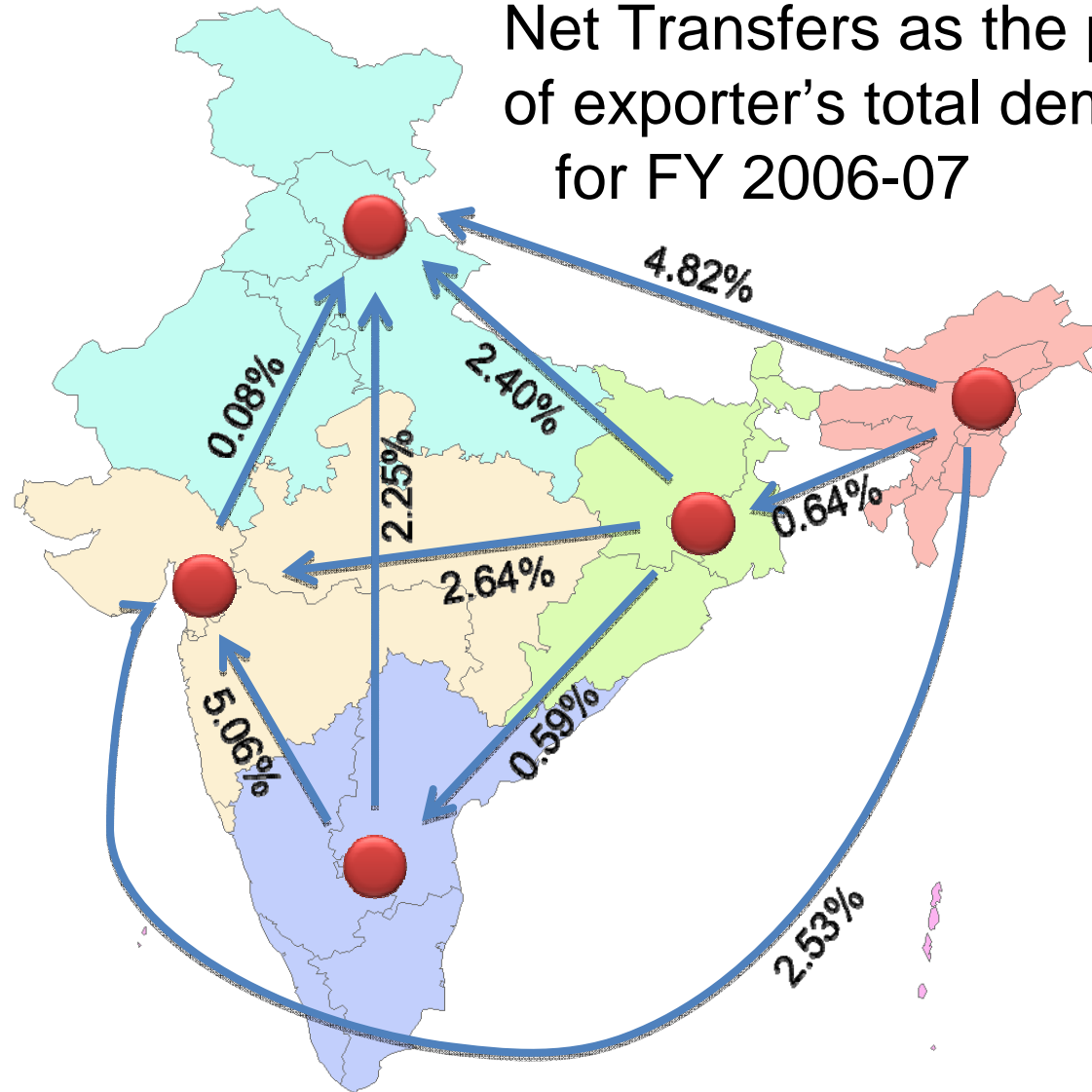


Inter-regional Transmission Capacity (MW)



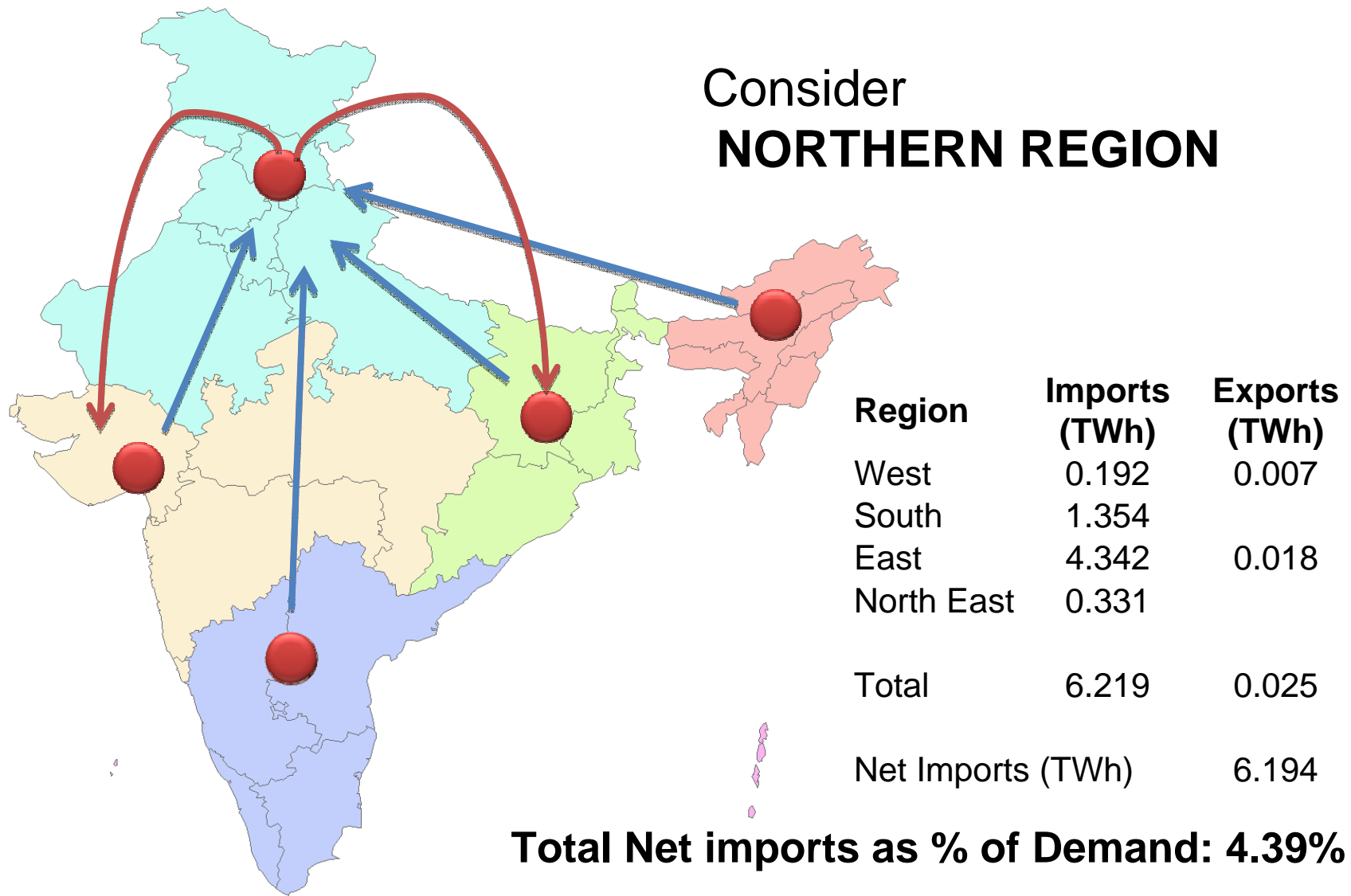
Inter Regional Transfers in FY 2006-07

Net Transfers as the percentage of exporter's total demand for FY 2006-07



Source: Central Electricity Authority

Inter Regional Transfers in FY 2006-07



Source: Central Electricity Authority

Major Issues

- Gap between supply and demand leads to frequent outages
- States preferred to invest on generation capacity instead of inter-regional transmission capacity (IEA, 2002)
- No market based tariff system to facilitate supply-demand adjustments (IEA, 2002)

Major Issues (contd.)

- Large industries generate their own electricity at substantially higher cost to compensate for unreliable power supply
- Several state owned distribution companies went bankrupt, therefore unable to make essential investments on their own (IEA, 2002)
- Little private sector participation

IEA, 2002, "Electricity in India: Providing Power for Millions", International Energy Agency, Paris, 2002.

Power Pool Modeling

- Facilitates optimal investment on generation and transmission capacity over a period of time
- Global cost minimization for a group of trading regions (nodes)
- Demand driven (season-day-hour)
- Supply is built up to meet the demand
- Both energy and reserves are traded

Power Pool Modeling (contd.)

- Opportunity costs are taken into account
- Autonomy factors allow for constraining the possible magnitude of trade

8 Node, India Demonstration Model, 2007-2017

- 8 Nodes include five regions in India with three neighboring countries: Pakistan, Bangladesh and Nepal.
- Two scenarios:
 1. **Complete Autonomy** – Each node is independent (no actual energy flows (MWh) but reserves trading (MW) is allowed when in excess at a node)
 2. **Free Trade** – No restrictions on trade, in essence the group acts as one node

Demonstration Model Results 2007-2017

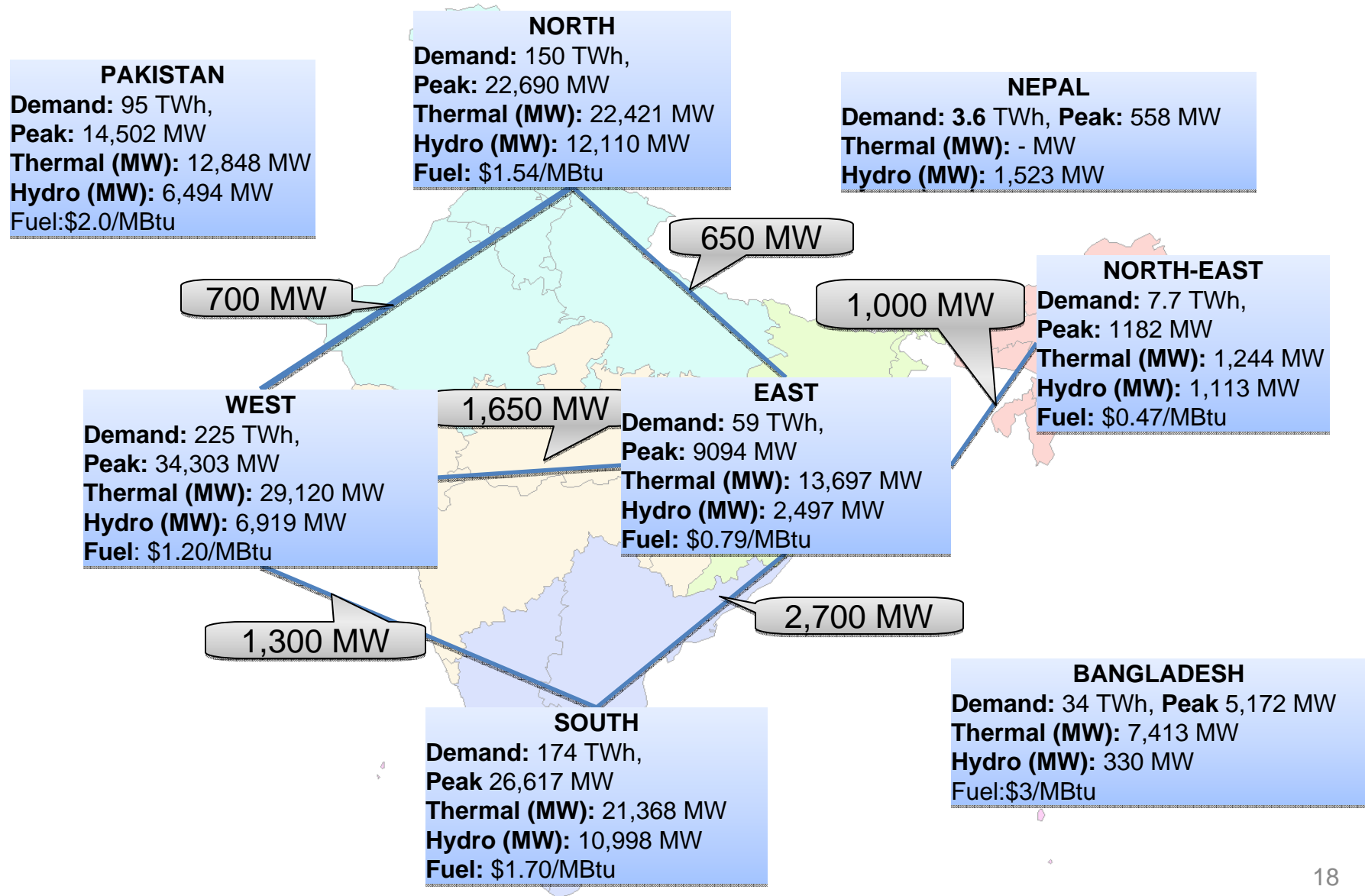
Optimal Total Cost (capital & operational)

- | | |
|----------------------|-----------------------|
| 1. Complete Autonomy | US \$ 60.030 Billions |
| 2. Free Trade | US \$ 53.411 Billions |

Cost savings = \$ 6.6 Billion = 7%

8 Node Complete-Autonomy India Model, 2007-2017

Existing Infrastructure



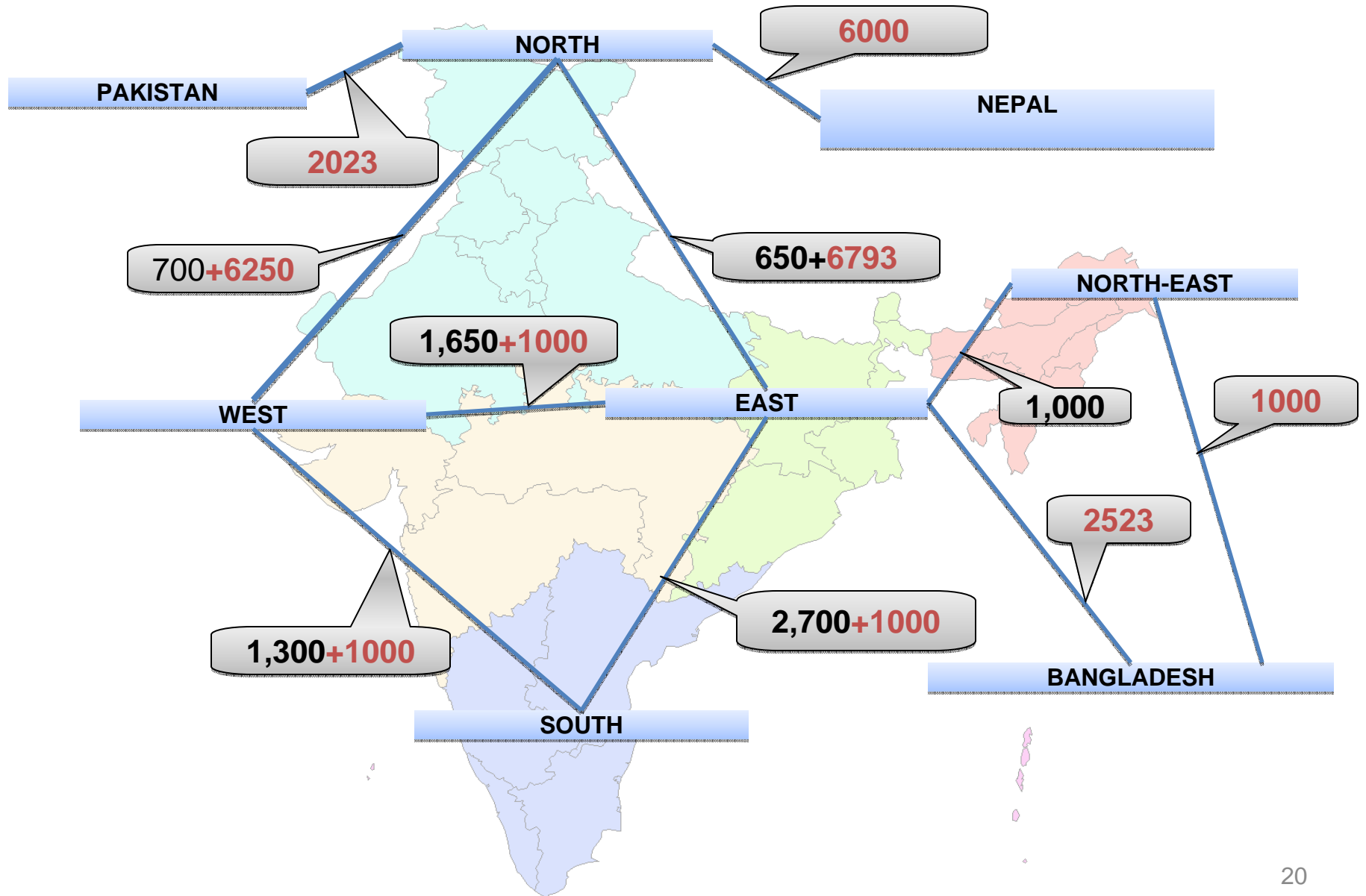
8 Node Complete-Autonomy India Model, 2007-2017 Demonstration Cost Summary

Total Cost: US \$ 60.030 Billions

	Generation Capital costs (Millions of US \$)	Total Fuel Costs (Millions of US \$)
North	913	2,505
West	7,611	9,481
South	4,456	9,434
East	999	1,939
North East	644	8
Pakistan	4,170	2,459
Bangladesh	223	1,417
Nepal	1,243	0
Total	20,258	27,243

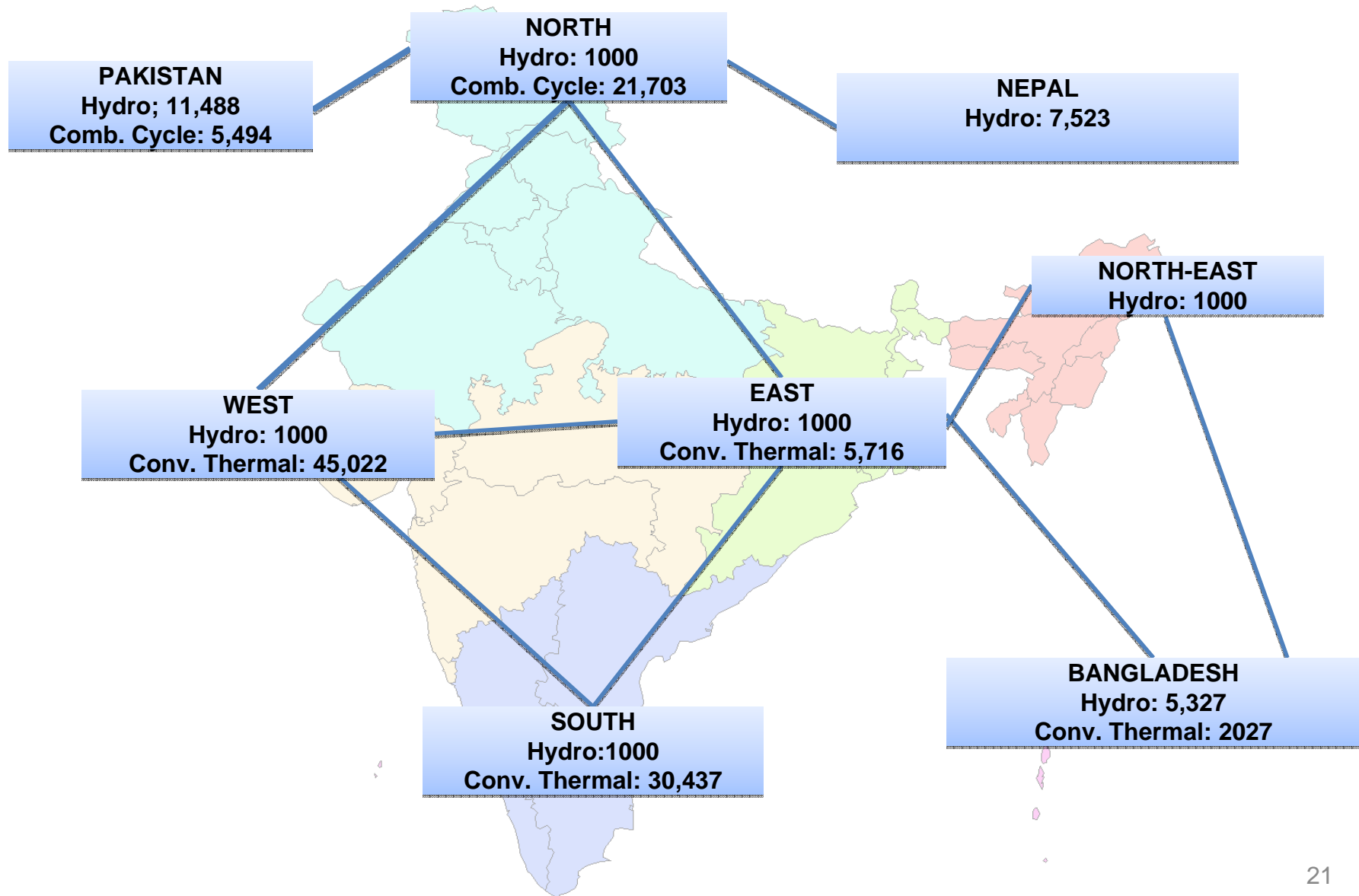
8 Node Complete-Autonomy India Model, 2007-2017

Demonstration Expansions of Transmission Capacity



8 Node Complete-Autonomy India Model, 2007-2017

Demonstration Expansions of Generation Capacity



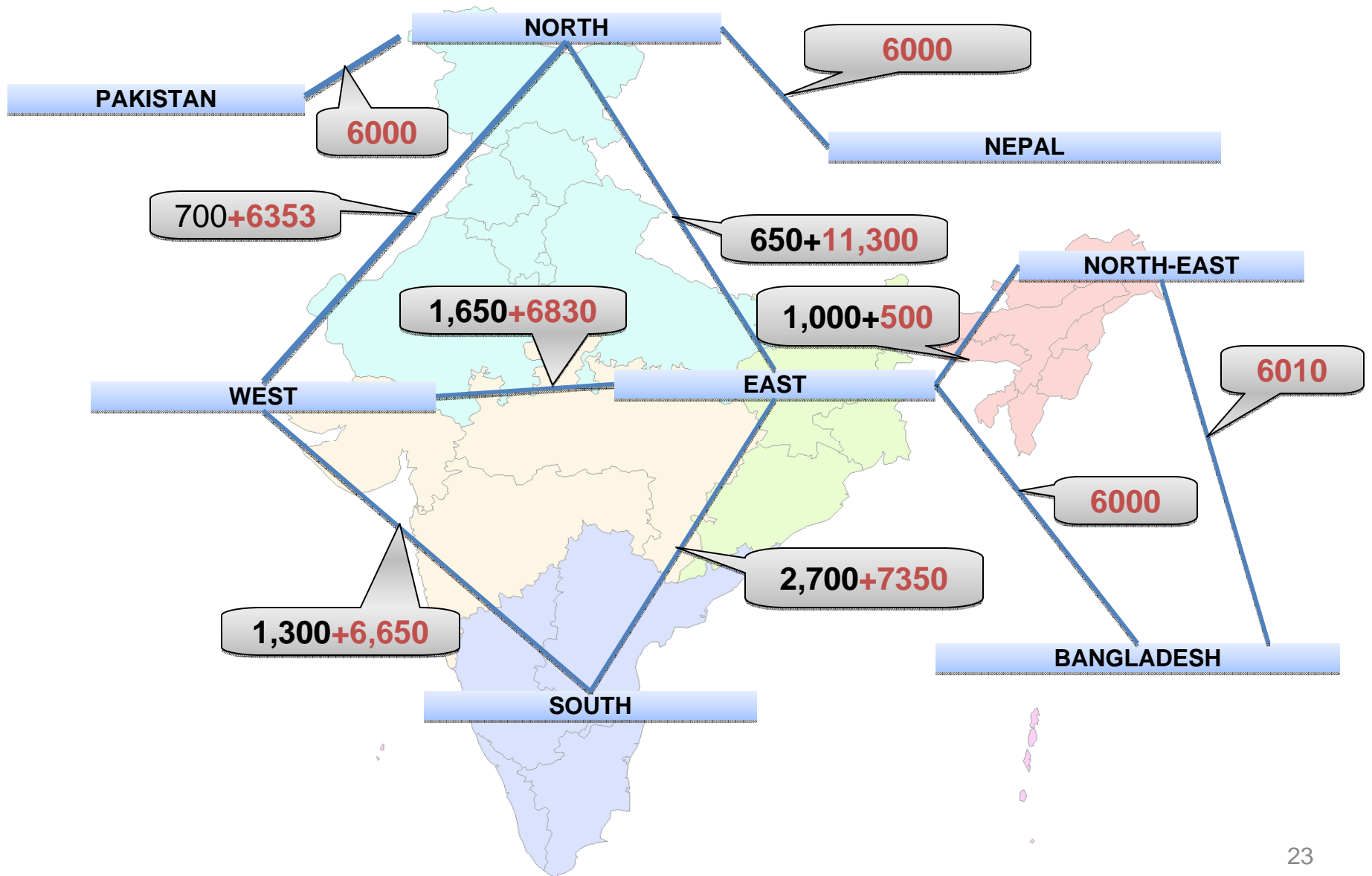
8 Node Free-Trade India Model, 2007-2017 Demonstration Cost Summary

Total Cost: US \$ 53.411 Billions

	Generation Capital costs (Millions of US \$)	Total Fuel Costs (Millions of US \$)
North	1,415	4,127
West	5,219	10,318
South	1,758	5,598
East	1,305	2,145
North East	1,280	336
Pakistan	1,503	2,622
Bangladesh	259	1,614
Nepal	1,243	0
Total	13,983	26,759

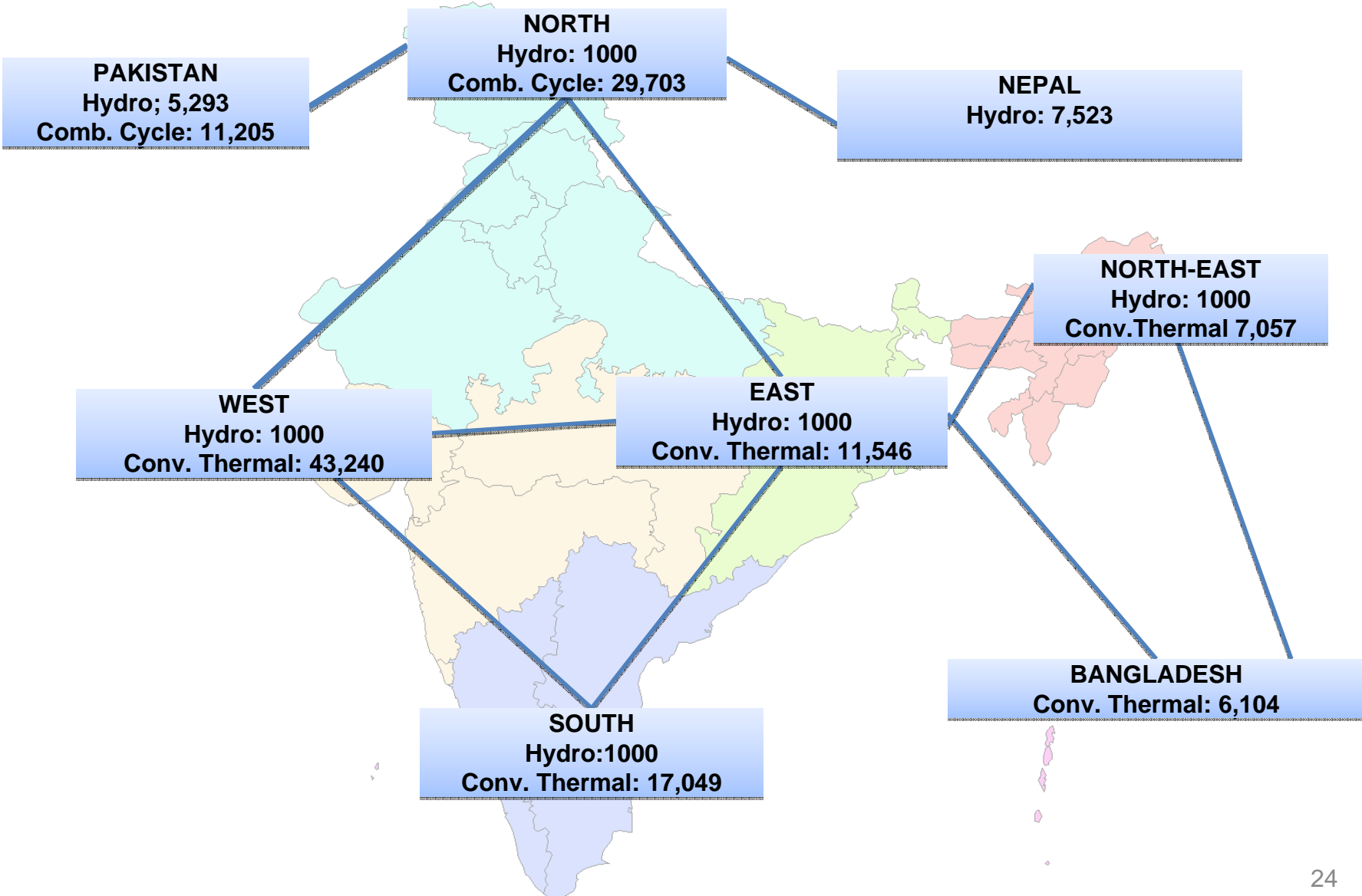
8 Node Free-Trade India Model, 2007-2017

Demonstration Expansions of Transmission Capacity (MW)



8 Node Free-Trade India Model, 2007-2017

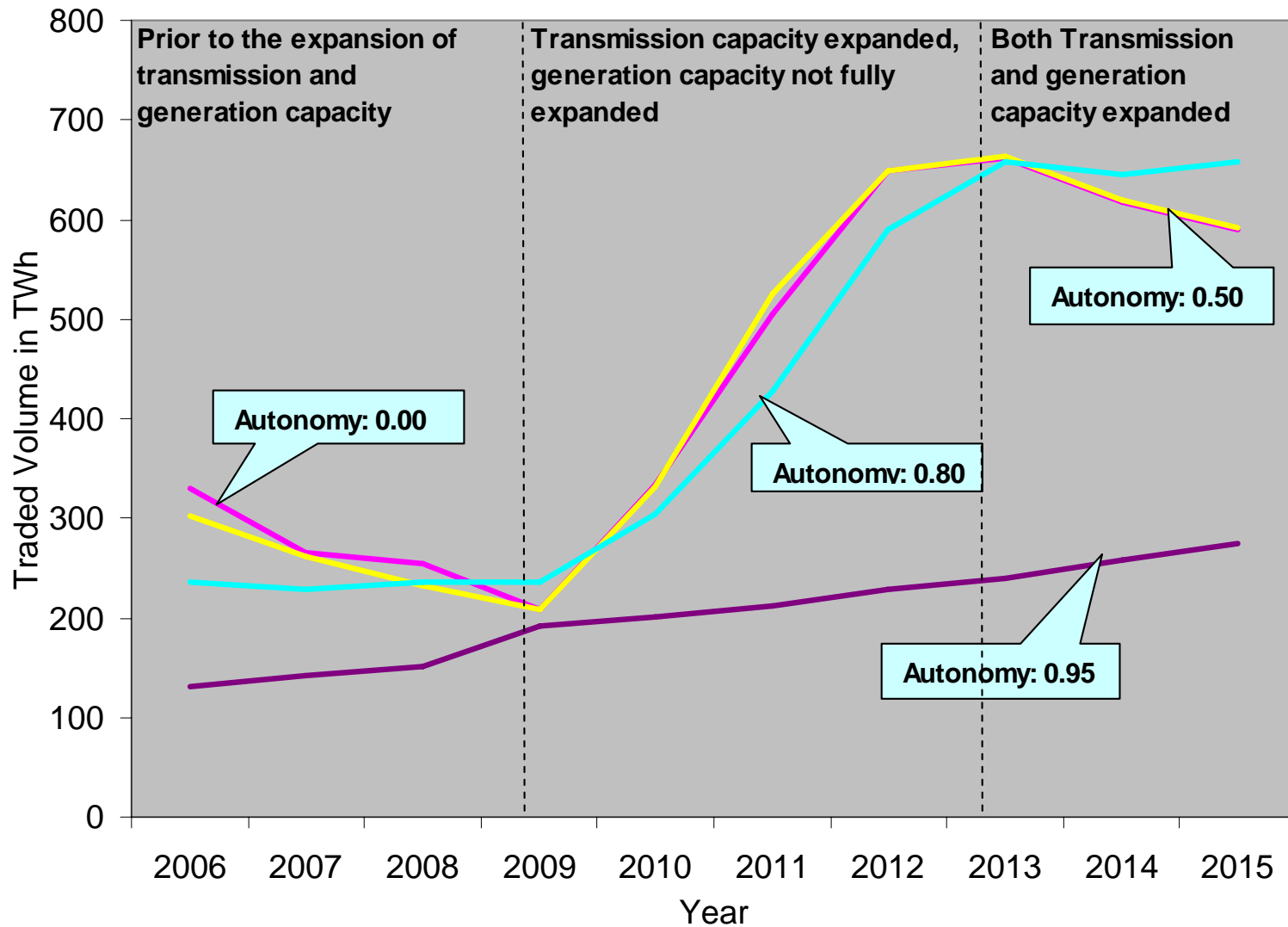
Demonstration Expansions of Generation Capacity (MW)



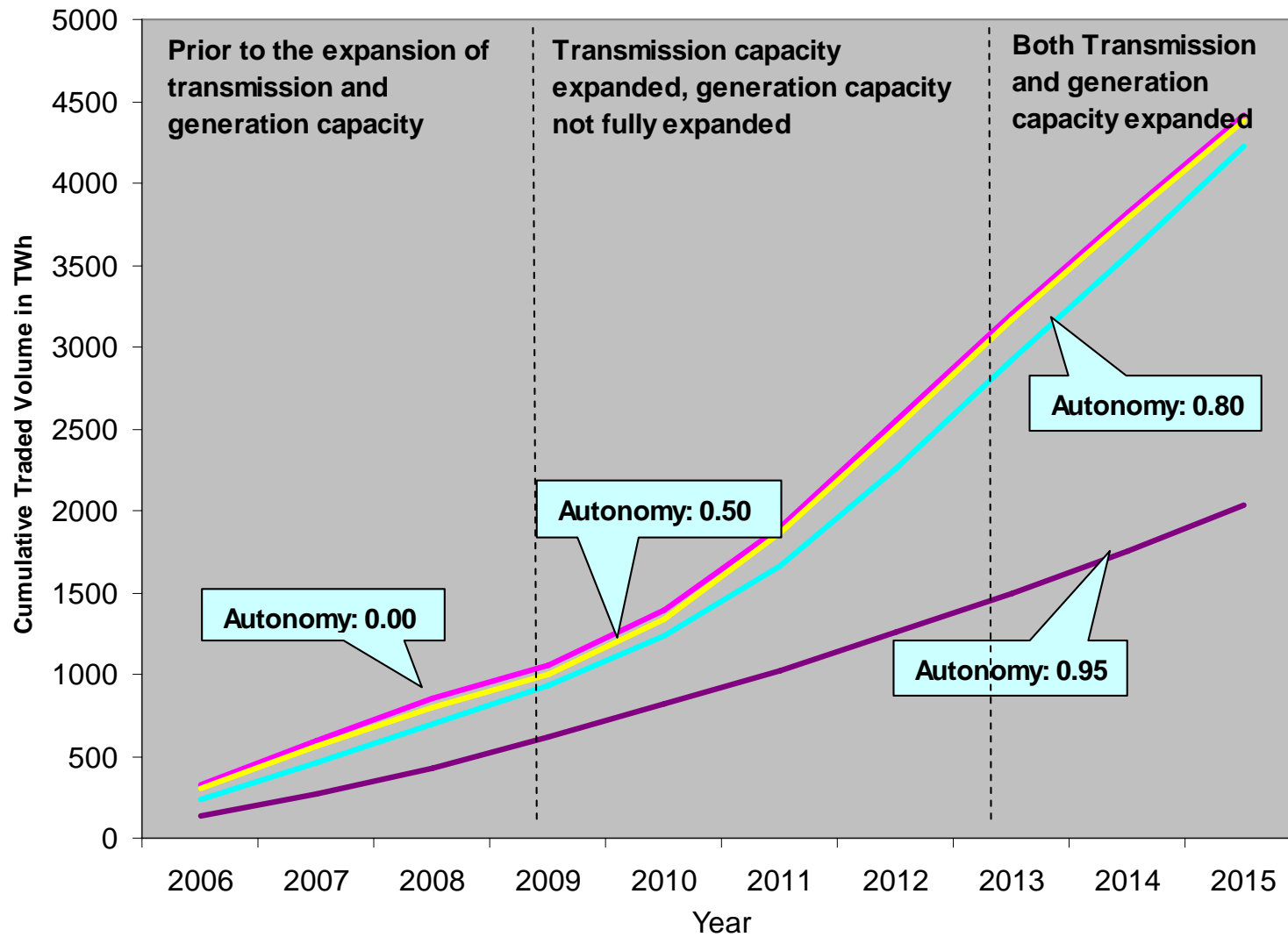
Comparison of Generation Capacity Expansions (MW)

	Conv. Thermal		Hydro		Comb. Cycle	
	Complete Autonomy (MW)	Free Trade (MW)	Complete Autonomy (MW)	Free Trade (MW)	Complete Autonomy (MW)	Free Trade (MW)
North			1,000	1,000	21,703	29,703
West	45,022	43,240	1,000	1,000		
South	30,437	17,049	1,000	1,000		
East	5,716	11,546	1,000	1,000		
North East		7,057	1,000	1,000		
Pakistan			11,488	5,293	5,494	11,205
Bangladesh		6,104	5,327			
Nepal			7,523			

Electricity Trading at Various Degrees of Autonomy-1



Electricity Trading at Various Degrees of Autonomy-2



Future Scenarios

- Weigh the cost and benefits of improving the national transmission system
- Estimate the cost of reliability and the role of reserves
- Technology options for new generation capacity & expansion planning
- Fuel supplies & the impact of international energy trade
- Compare the impact of drought in an integrated & non-integrated India