#KPMG josh

KPMG

Assessment of Potential Benefits of Cross Border Electricity Trade & Framework for Ancillary Services Market in South Asia

Integrated Research and Action for Development (IRADe)

February 2023

KPMG.com/in

Table of Contents

Objective of the Study

Assessing the Potential Benefits of Cross Border Electricity Trade for Affordable Supply of Electricity, Facilitating, Grid Balancing of Renewable Energy Integration, and Suggesting a Framework for Ancillary Service Market in the South Asia

Uniqueness of the study

- *Detailed Modelling of power system operations of BBINS over 8760 hours*
- *Nuanced Cost Sensitivity Analysis for transmission enhancement, regional supply balance, and cross border sharing of reserves*
- *Convexification of non-linear unit startup/ shutdown decision modelling*
- *Computation of capacity credits of RE generation under regional cooperation*

Scope of Work

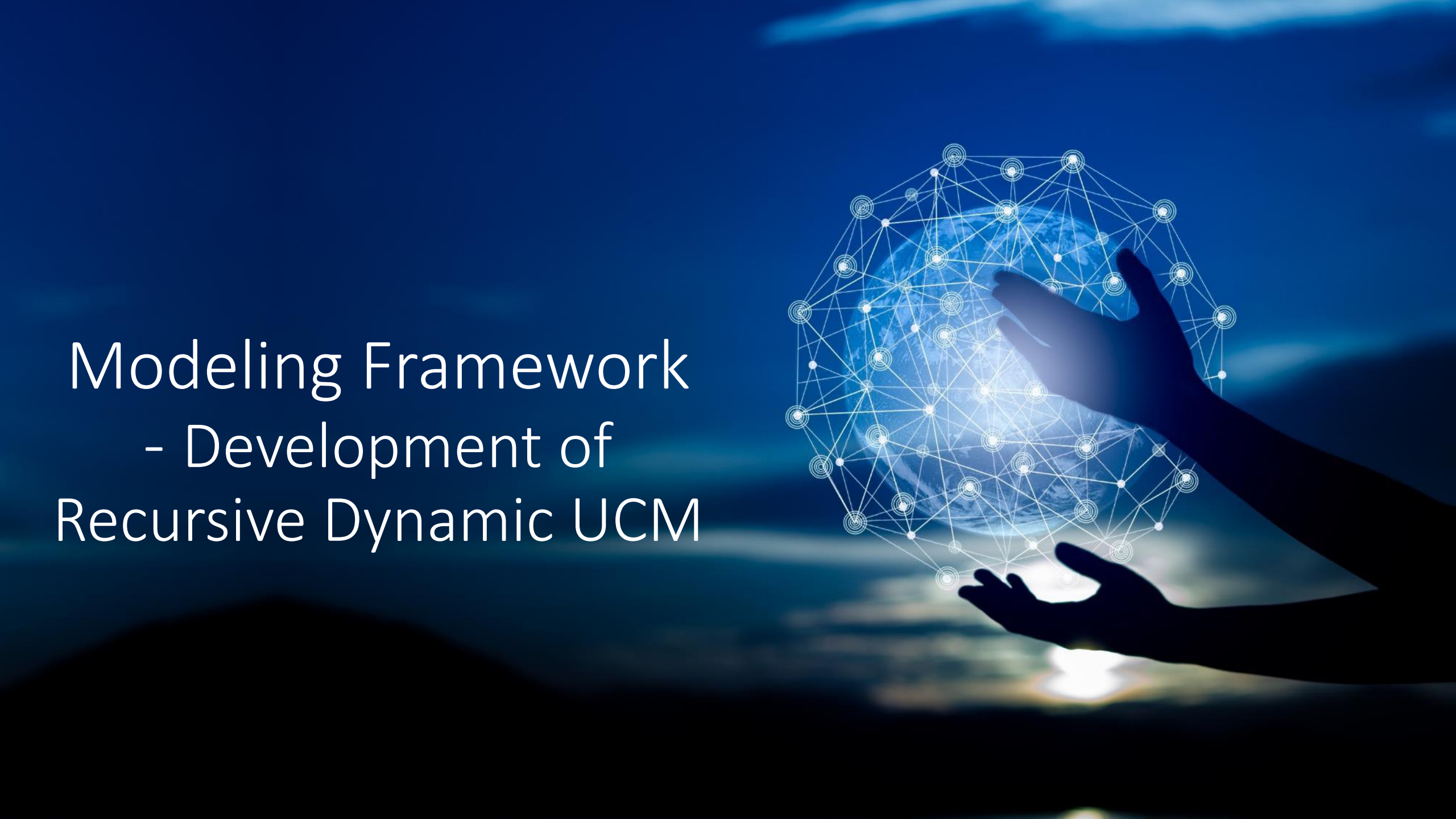
Scope of Work

Quantification of the economic benefits of enhanced South Asian regional cooperation and integration

Objective 1	Review and Analyze the current and future demand – supply positions of each South Asian country, including growth of renewables, for the next 15 years
Objective 2	Carry out comprehensive energy modelling exercise to assess the impact of various constraints on power system operations (Taking the reserve requirements into consideration)
Objective 3	Review and analyze the existing market mechanism related to grid balancing in each country and the region and its associated policy, regulatory, legal and technical frameworks.
Objective 4	Suggest a draft roadmap (regional and country wise) as well as an action plan for implementation of the regional framework for ancillary services market in the region.

Methodology & Approach

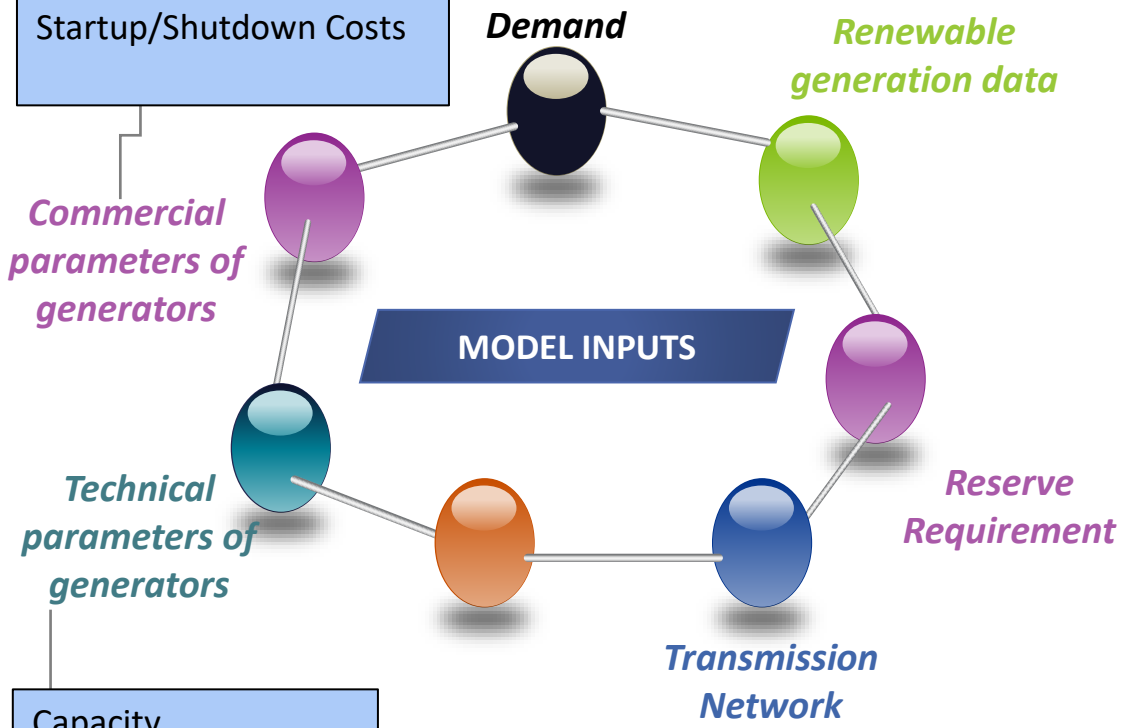
Modeling Framework - Development of Recursive Dynamic UCM



Methodology: Unit Commitment Modelling for 2019-20

UCM runs for 10 days at a time, in a recursive dynamic way (where the final "state" of the power system for the previous day would be assumed as a "start point" for the following day), summing up to model runs for 8760 hours in a year

Variable costs
Fixed costs
Startup/Shutdown Costs



Capacity
Ramp Rates
Technical minimum output
Minimum up/down time

Optimization Engine

Mixed Integer Linear Programming

(Convexification)

MODEL Outputs

- Optimal schedules of generators
- Optimal quantum of power to be bought or sold
- Transmission flows
- Optimal reserves to be maintained

Model Size

Component	Unit Commitment for 2019
Total generators	775
Zones	33
Transmission lines	60 interzonal connections
Number of Hours Considered	8760
Number of Variables in the Model	85-95 Lakhs per quarter
Number of Constraints	85-95 Lakhs per quarter
Number of Scenarios	7

Model Characteristics	Unit Commitment for 2019
Software Used	GAMS
Maximum RAM Utilized per quarter	30 GB
Processor Speed	2.39 GHz
Model Run Time	3-5 hours per quarter per scenario on 256 GB RAM Machine
Number of Simulations	28 (4 simulations per scenario, one for each quarter)

Scenarios considered for the study

Scenario	Assumption on Inter Country Transmission	Assumption of Reserve Management
Scenario 1	No Transmission	Local Management of Reserves for each zone
Scenario 2	Existing Transmission (Constrained)	Local Management of Reserves for each zone
Scenario 3	Existing Transmission (Constrained)	At least 50% of reserves to be maintained locally in each zone
Scenario 4	Existing Transmission (Constrained)	No restriction on import of reserves
Scenario 5	Unconstrained Transmission	Local Management of Reserves for each zone
Scenario 6	Unconstrained Transmission	At least 50% of reserves to be maintained locally in each zone
Scenario 7	Unconstrained Transmission	No restriction on import of reserves

Key Analysis & Findings

How does 2019 analysis shed light on the next steps for enhanced cooperation?

- What are the cost savings from South Asian regional integration?
- How sensitive are the costs to
  - Regional Trading of Electricity (Merit Order Dispatch)
  - Cross border Transmission Enhancement
  - Cross border sharing of reserves

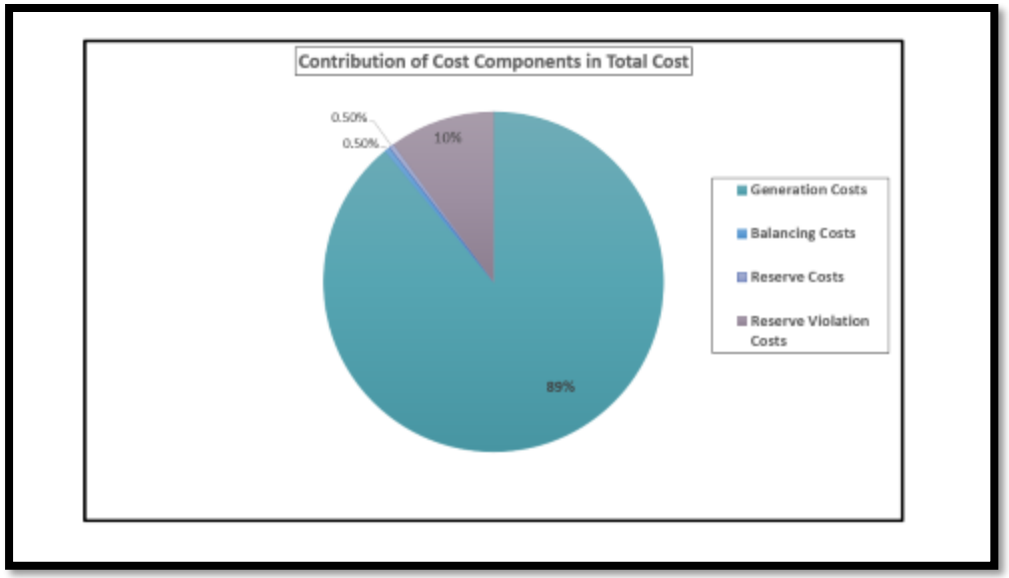
TOTAL COST COMPARISON IN 2019 - 2020

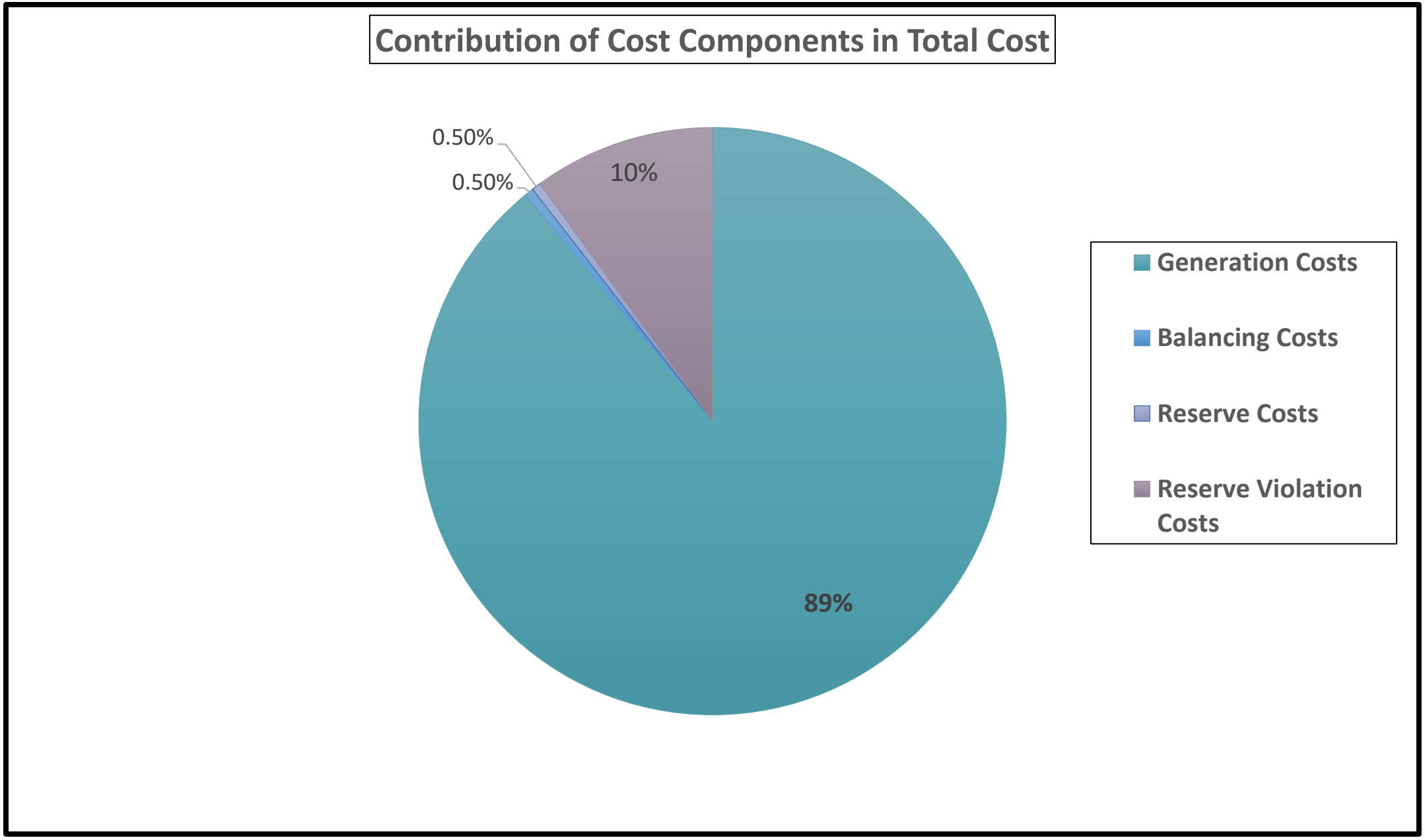
Scenario	BANGLADESH	BHUTAN	INDIA	NEPAL	SRI LANKA	TOTAL	BENEFIT OF REGIONAL COOPERATION (%)
No Transmission	2386	1752	30096	1671	1052	36957	-
Constrained Transmission, Local Reserves	1853	1752	30387	1557	1051	36600	1%
Constrained Transmission, Imported Reserves (50%)	1842	1752	30235	1554	1053	36435	1.5%
Constrained Transmission, Imported Reserves (100%)	1841	876	29956	690	1051	34415	7%
Unconstrained Transmission, Local Reserves	1185	876	30923	699	406	34089	8%
Unconstrained Transmission, Imported Reserves (50%)	1201	0	30746	79	420	32446	12%
Unconstrained Transmission, Imported Reserves (100%)	1211	0	30620	0	431	32262	13%

Cost Components

The benefits of regional cooperation have been assessed in terms of variable costs of generation, balancing costs, costs of maintaining reserves and cost of reserve violations.

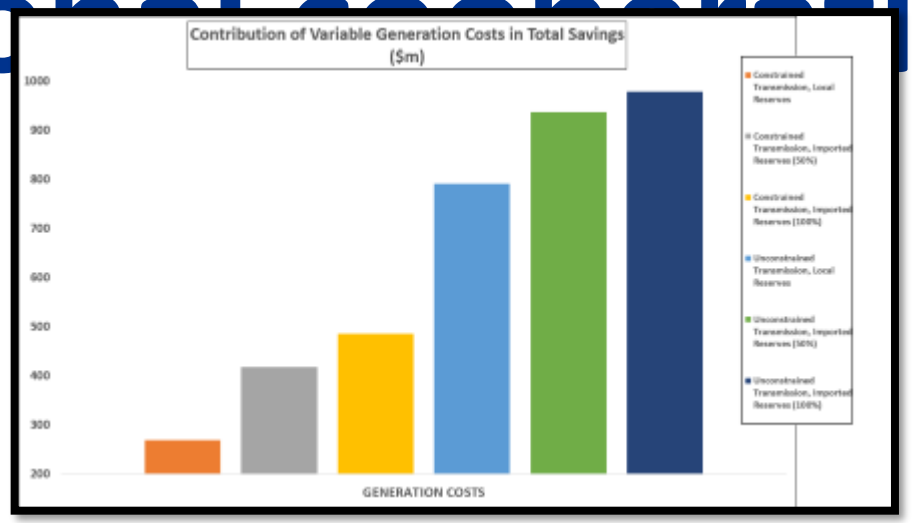
Generation Costs	The variable costs per unit of production of energy.
Balancing Costs	The startup and the shutdown costs of the generators.
Reserve Costs	The costs incurred while maintaining a quantum of reserves.
Reserve Violation Costs	The costs/penalty incurred for meeting the unmet reserves.

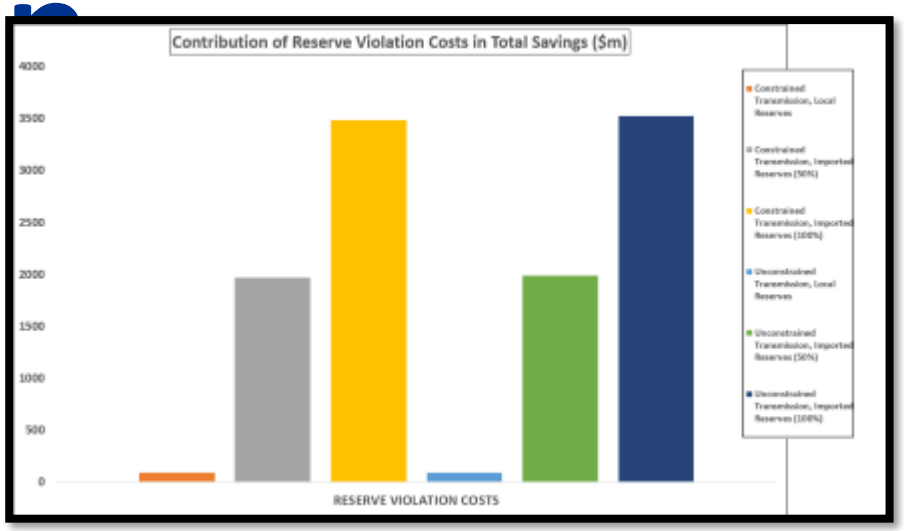



Contribution of Cost Components in Total Cost
0.50%
0.50%
10%
89%
Generation Costs
Balancing Costs
Reserve Costs
Reserve Violation Costs

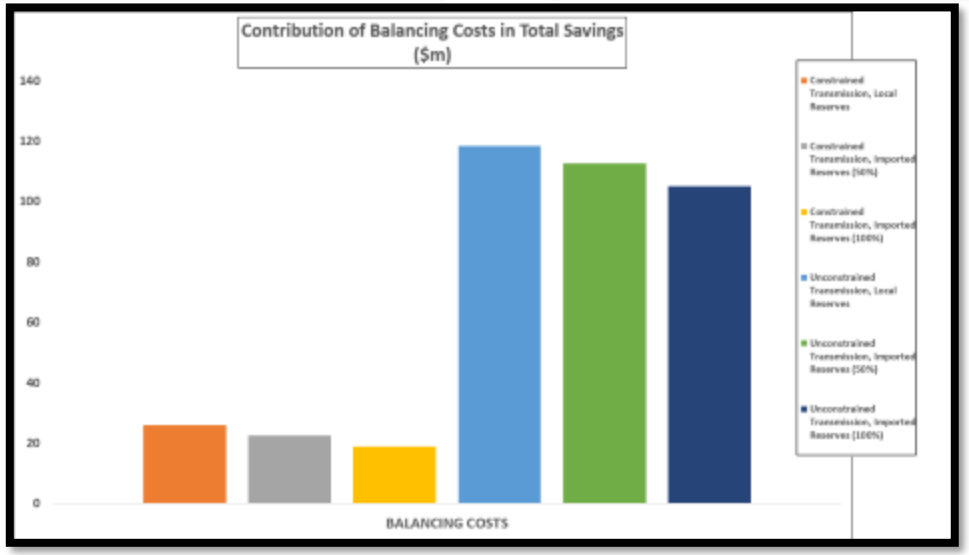
Savings in Cost Components via regional cooperation

GENERATION COSTS

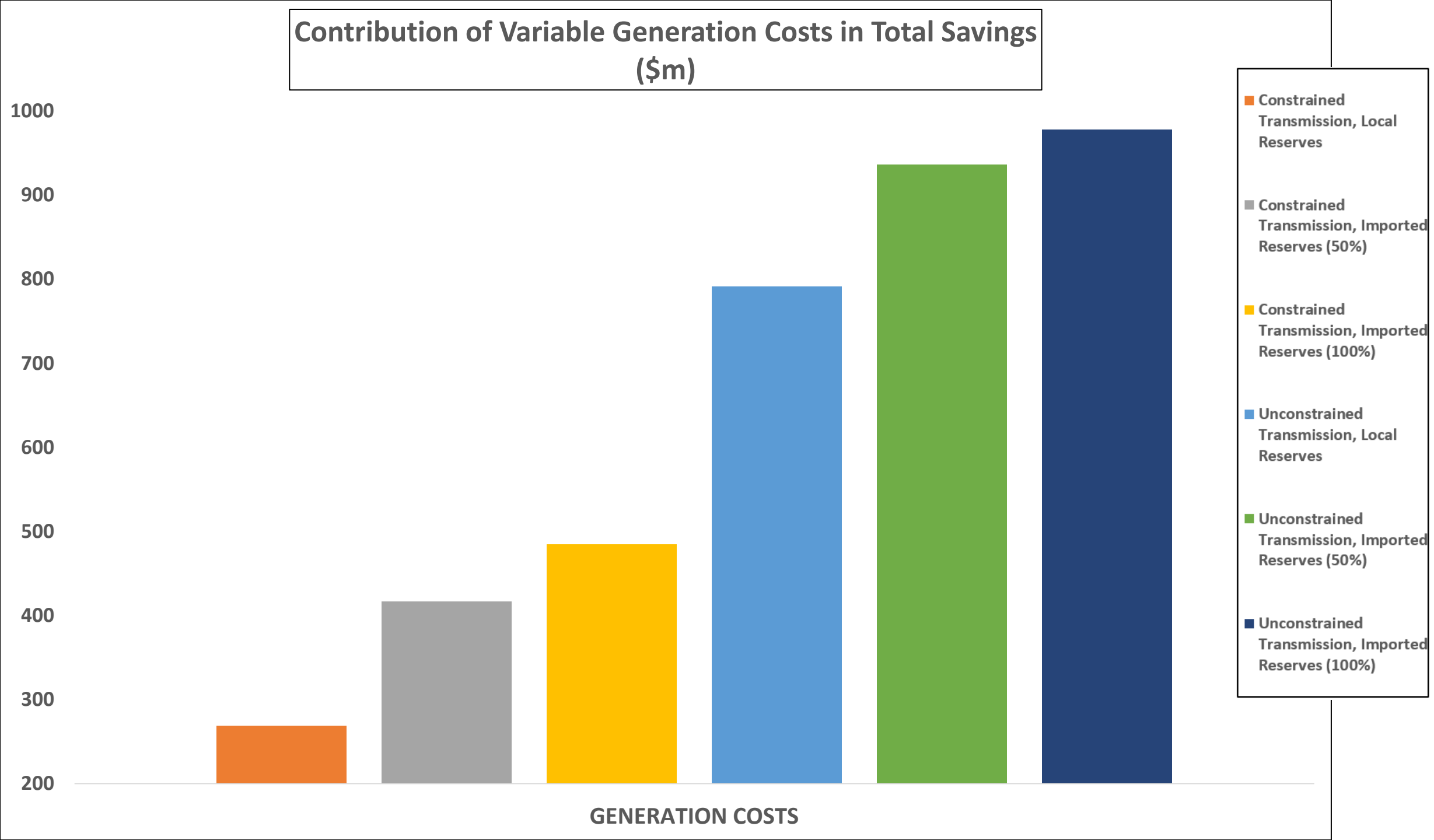


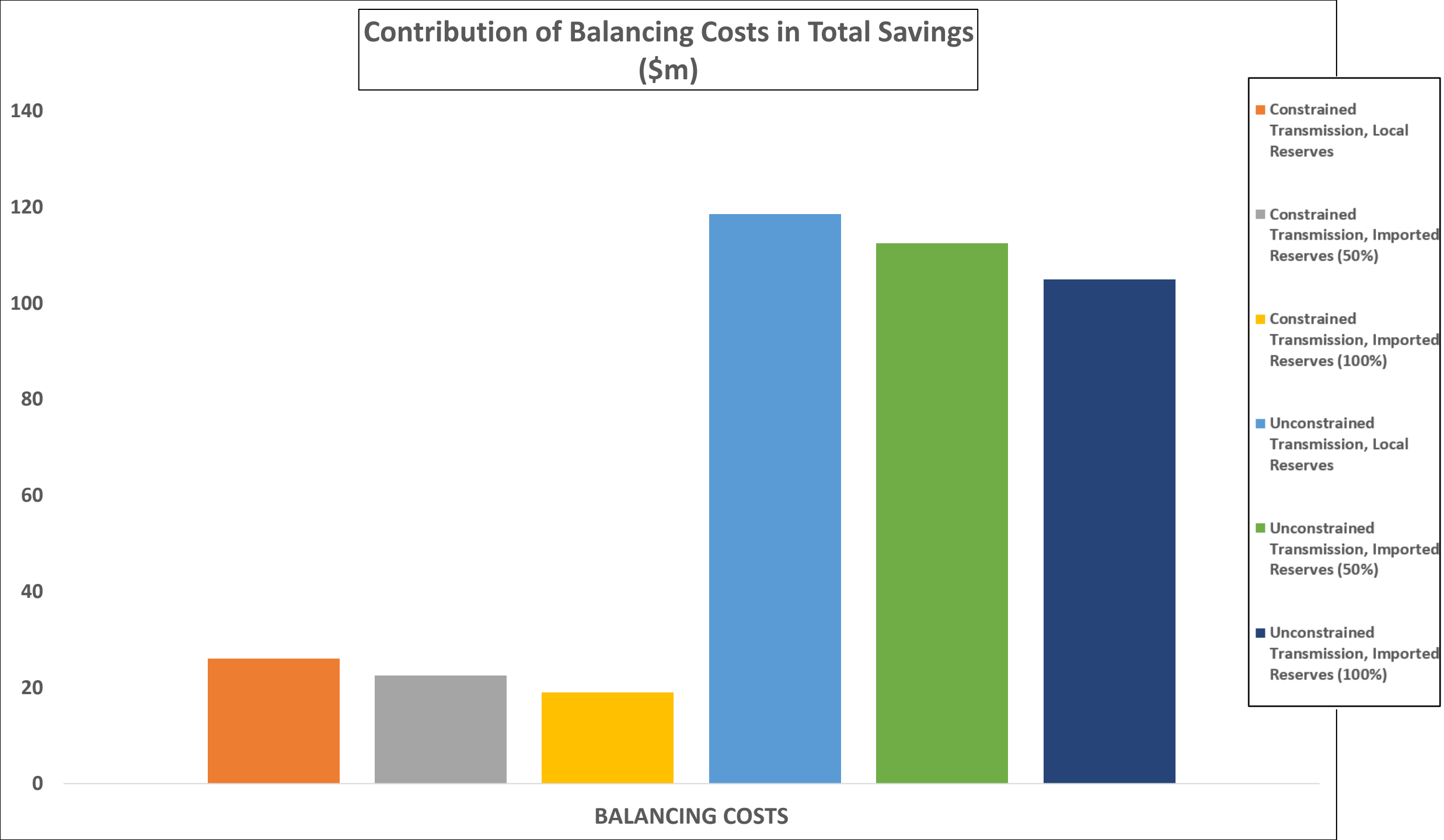


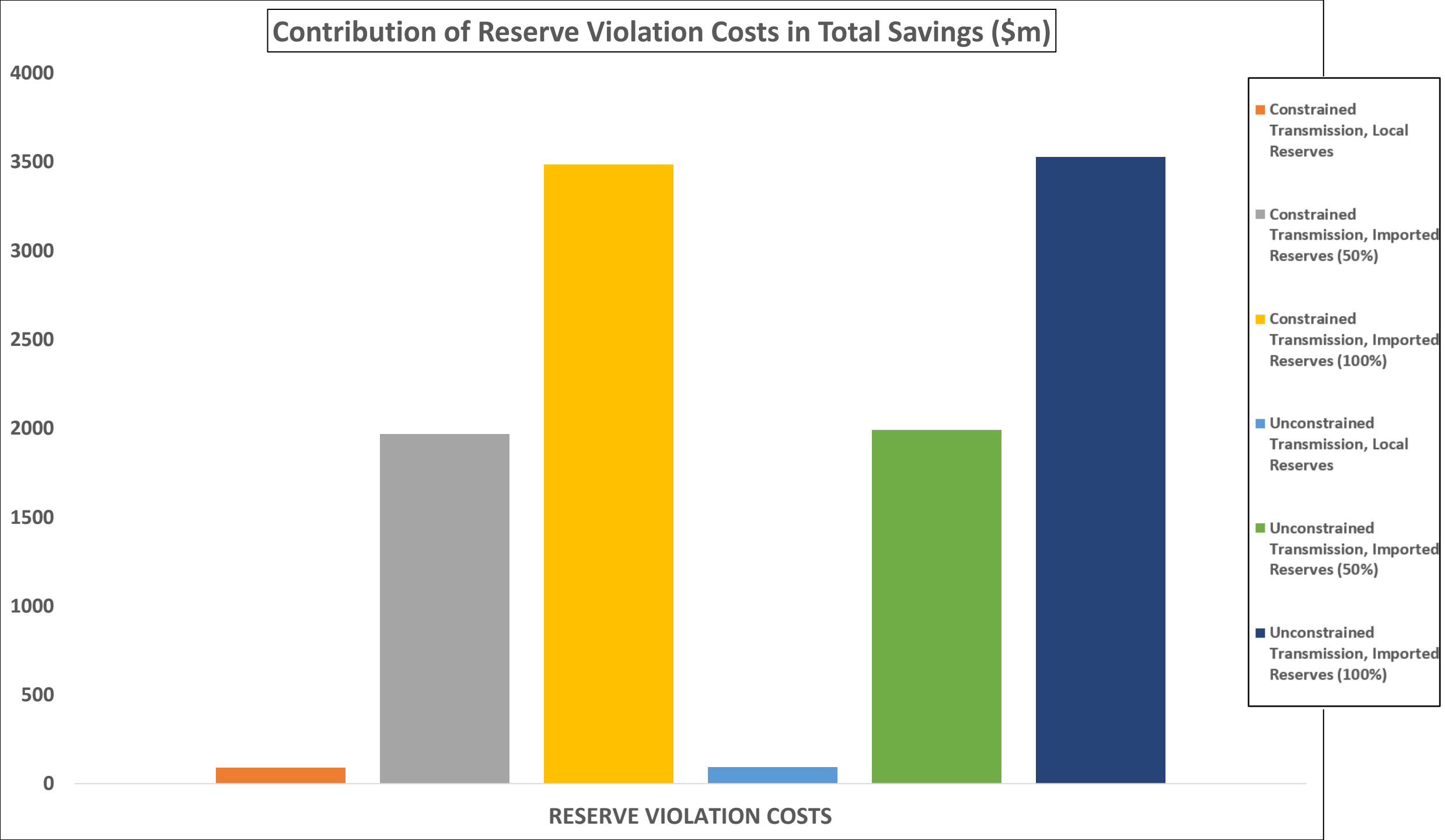
RESERVE VIOLATION COSTS



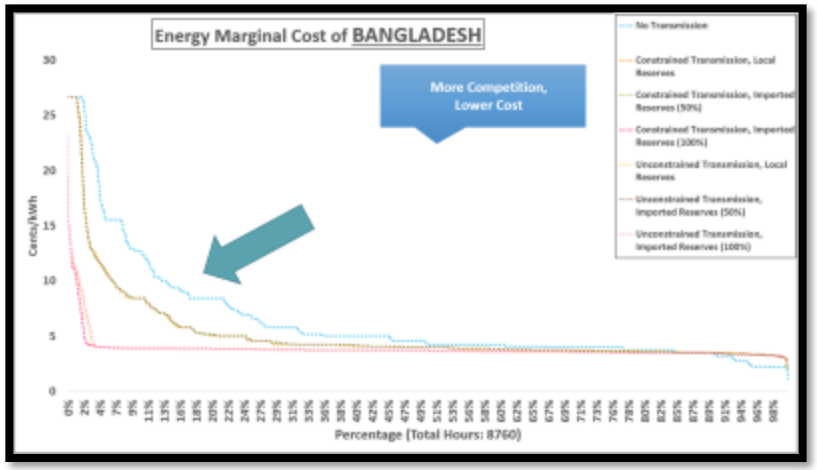
BALANCING COSTS


Contribution of Variable Generation Costs in Total Savings ($m)
1000
900
800
700
600
500
400
300
200
GENERATION COSTS
Constrained Transmission, Local Reserves
Constrained Transmission, Imported Reserves (50%)
Constrained Transmission, Imported Reserves (100%)
Unconstrained Transmission, Local Reserves
Unconstrained Transmission, Imported Reserves (50%)
Unconstrained Transmission, Imported Reserves (100%)

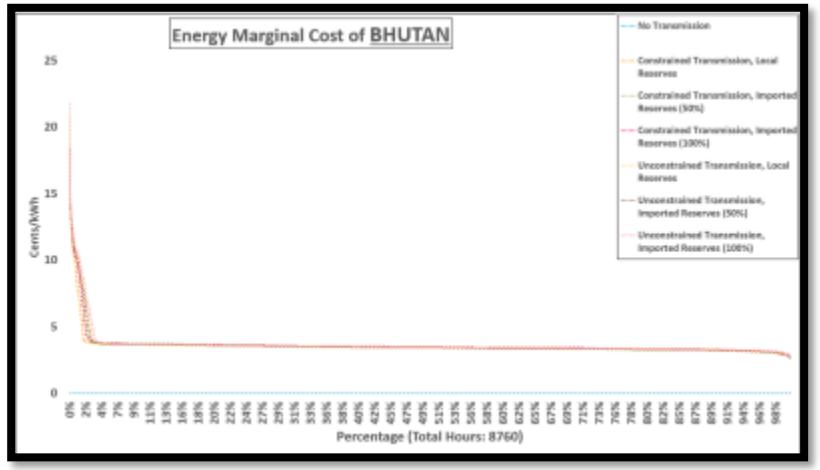

Contribution of Balancing Costs in Total Savings ($m)
140
120
100
80
60
40
20
0
BALANCING COSTS
Constrained Transmission, Local Reserves
Constrained Transmission, Imported Reserves (50%)
Constrained Transmission, Imported Reserves (100%)
Unconstrained Transmission, Local Reserves
Unconstrained Transmission, Imported Reserves (50%)
Unconstrained Transmission, Imported Reserves (100%)


Contribution of Reserve Violation Costs in Total Savings ($m)
4000
3500
3000
2500
2000
1500
1000
500
0
RESERVE VIOLATION COSTS
Constrained Transmission, Local Reserves
Constrained Transmission, Imported Reserves (50%)
Constrained Transmission, Imported Reserves (100%)
Unconstrained Transmission, Local Reserves
Unconstrained Transmission, Imported Reserves (50%)
Unconstrained Transmission, Imported Reserves (100%)

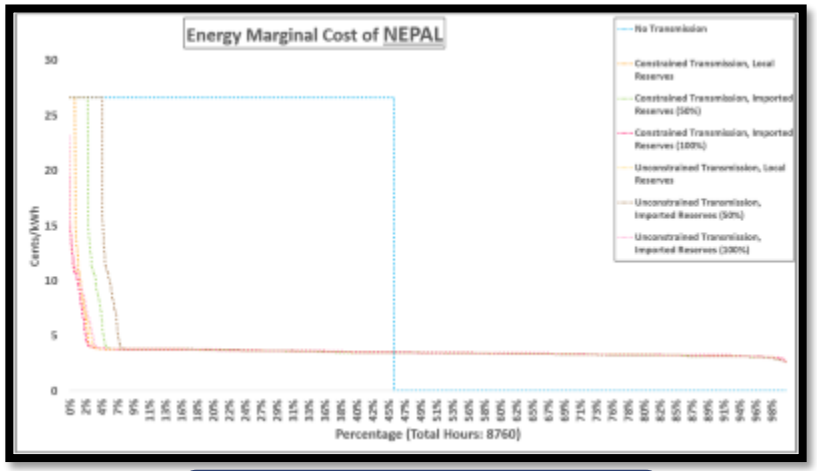
How sensitive are the costs to regional electrical energy cooperation?



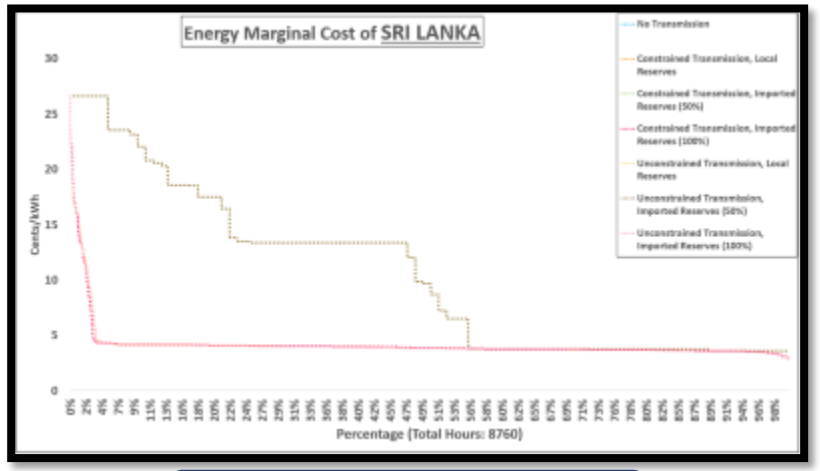
BANGLADESH



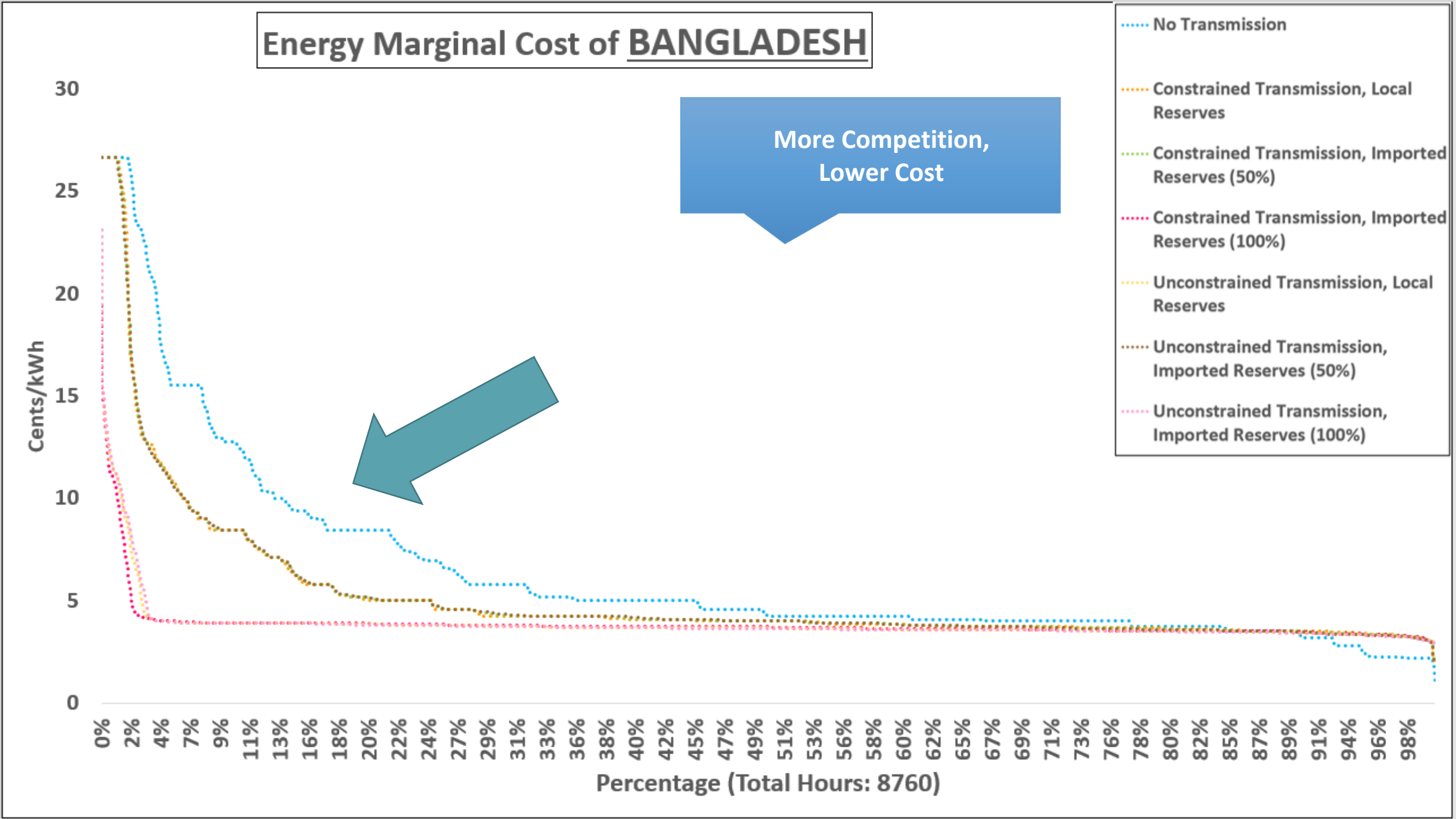
BHUTAN

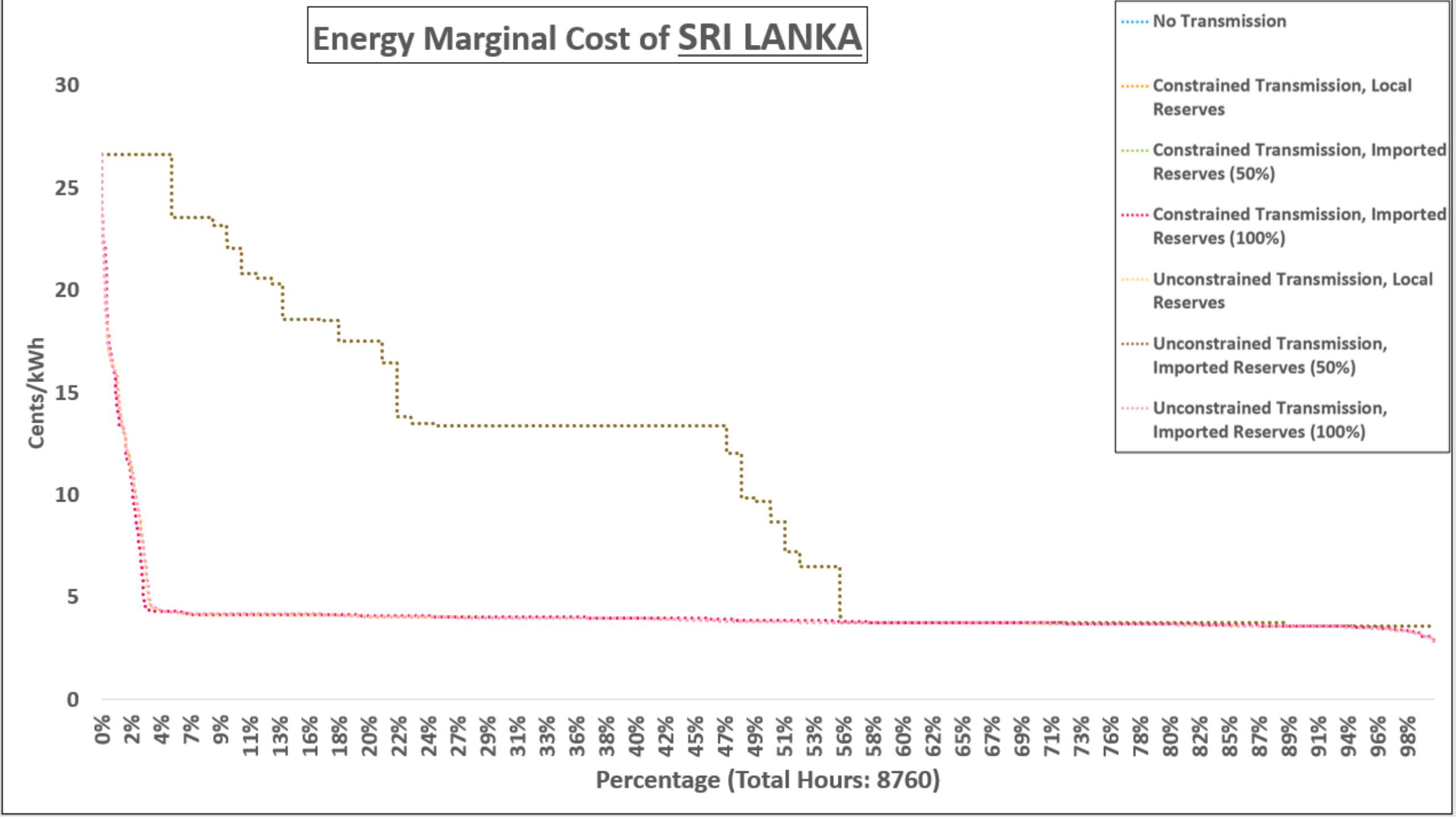


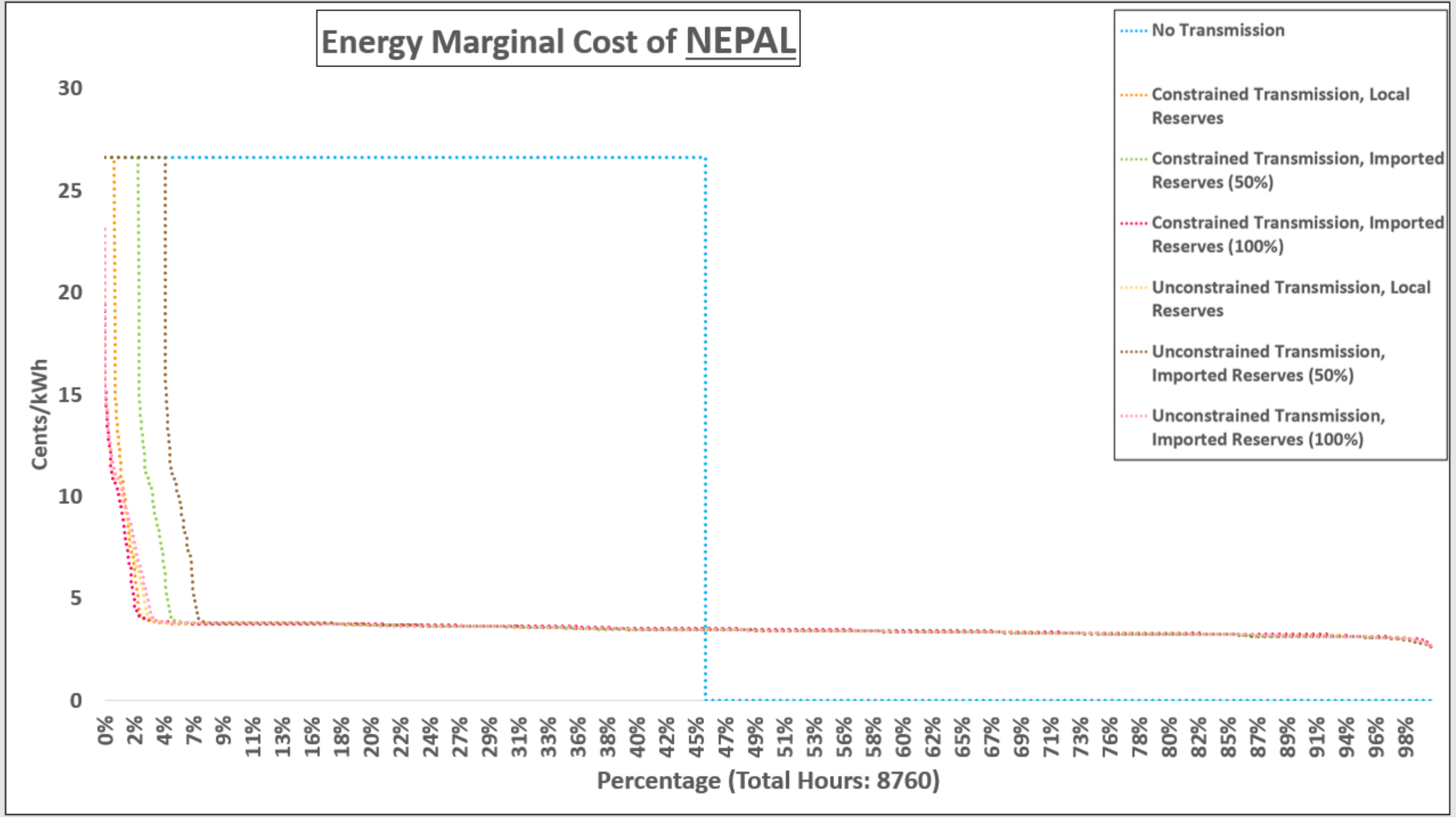
NEPAL

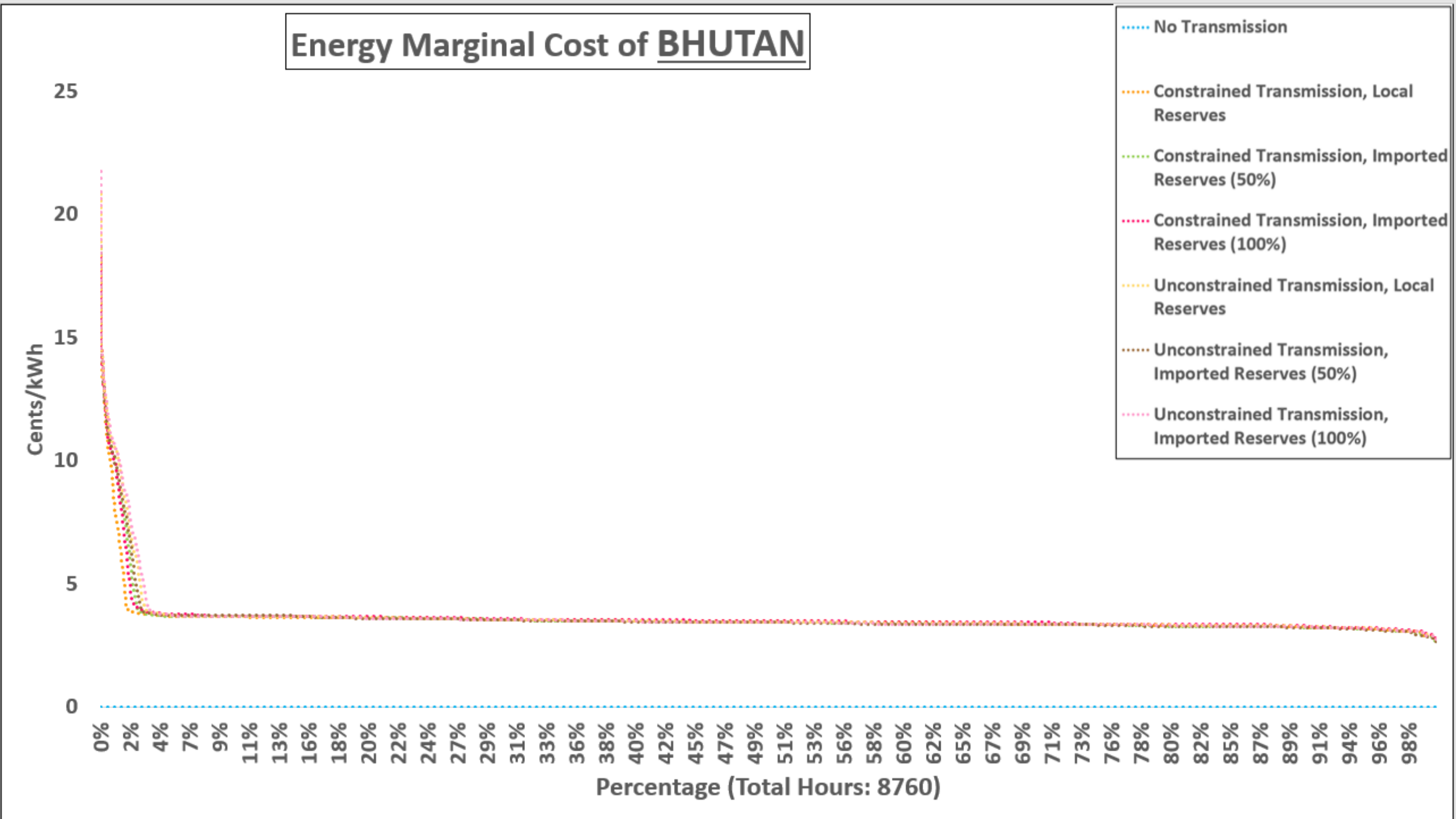


SRI LANKA

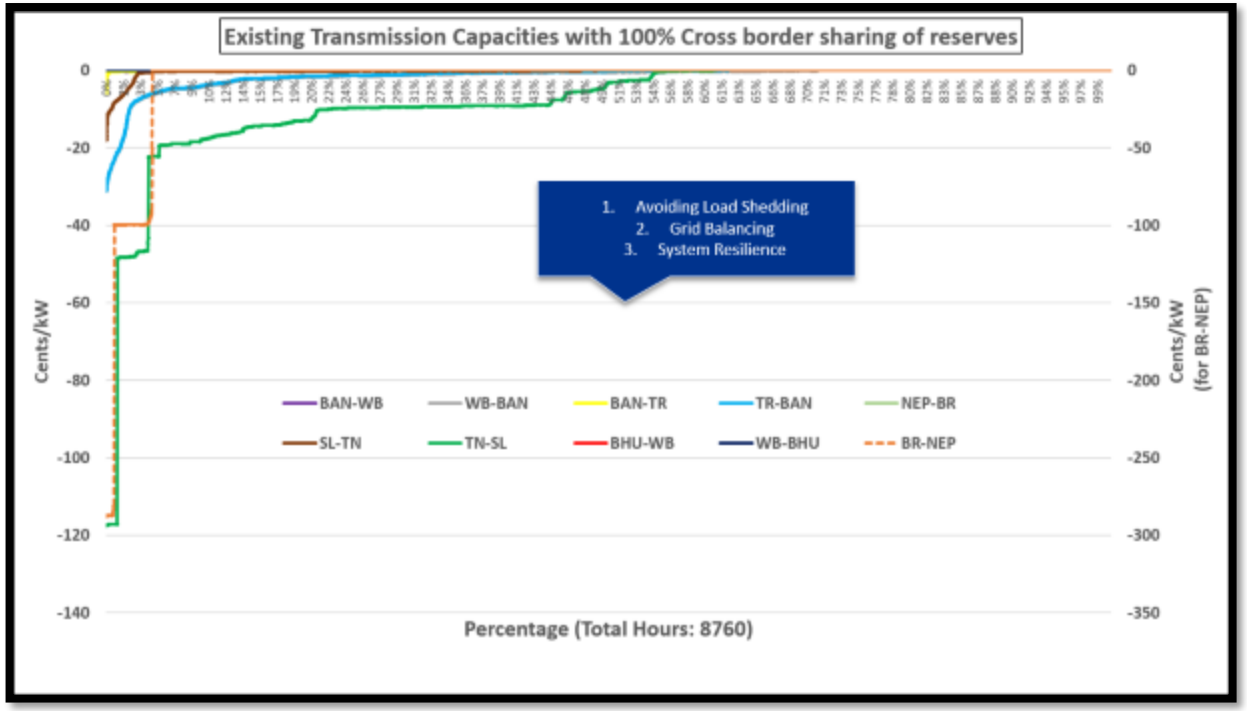

Energy Marginal Cost of BANGLADESH
More Competition, Lower Cost
No Transmission
Constrained Transmission, Local Reserves
Constrained Transmission, Imported Reserves (50%)
Constrained Transmission, Imported Reserves (100%)
Unconstrained Transmission, Local Reserves
Unconstrained Transmission, Imported Reserves (50%)
Unconstrained Transmission, Imported Reserves (100%)
Cents/kWh
30
25
20
15
10
5
0
0% 2% 4% 7% 9% 11% 13% 16% 18% 20% 22% 24% 27% 29% 31% 33% 36% 38% 40% 42% 45% 47% 49% 51% 53% 56% 58% 60% 62% 65% 67% 69% 71% 73% 76% 78% 80% 82% 85% 87% 89% 91% 94% 96% 98%
Percentage (Total Hours: 8760)


Energy Marginal Cost of SRI LANKA
No Transmission
Constrained Transmission, Local Reserves
Constrained Transmission, Imported Reserves (50%)
Constrained Transmission, Imported Reserves (100%)
Unconstrained Transmission, Local Reserves
Unconstrained Transmission, Imported Reserves (50%)
Unconstrained Transmission, Imported Reserves (100%)
Cents/kWh
30
25
20
15
10
5
0
0%
2%
4%
7%
9%
11%
13%
16%
18%
20%
22%
24%
27%
29%
31%
33%
36%
38%
40%
42%
45%
47%
49%
51%
53%
56%
58%
60%
62%
65%
67%
69%
71%
73%
76%
78%
80%
82%
85%
87%
89%
91%
94%
96%
98%
Percentage (Total Hours: 8760)


Energy Marginal Cost of NEPAL
No Transmission
Constrained Transmission, Local Reserves
Constrained Transmission, Imported Reserves (50%)
Constrained Transmission, Imported Reserves (100%)
Unconstrained Transmission, Local Reserves
Unconstrained Transmission, Imported Reserves (50%)
Unconstrained Transmission, Imported Reserves (100%)
Cents/kWh
30
25
20
15
10
5
0
0%
2%
4%
7%
9%
11%
13%
16%
18%
20%
22%
24%
27%
29%
31%
33%
36%
38%
40%
42%
45%
47%
49%
51%
53%
56%
58%
60%
62%
65%
67%
69%
71%
73%
76%
78%
80%
82%
85%
87%
89%
91%
94%
96%
98%
Percentage (Total Hours: 8760)

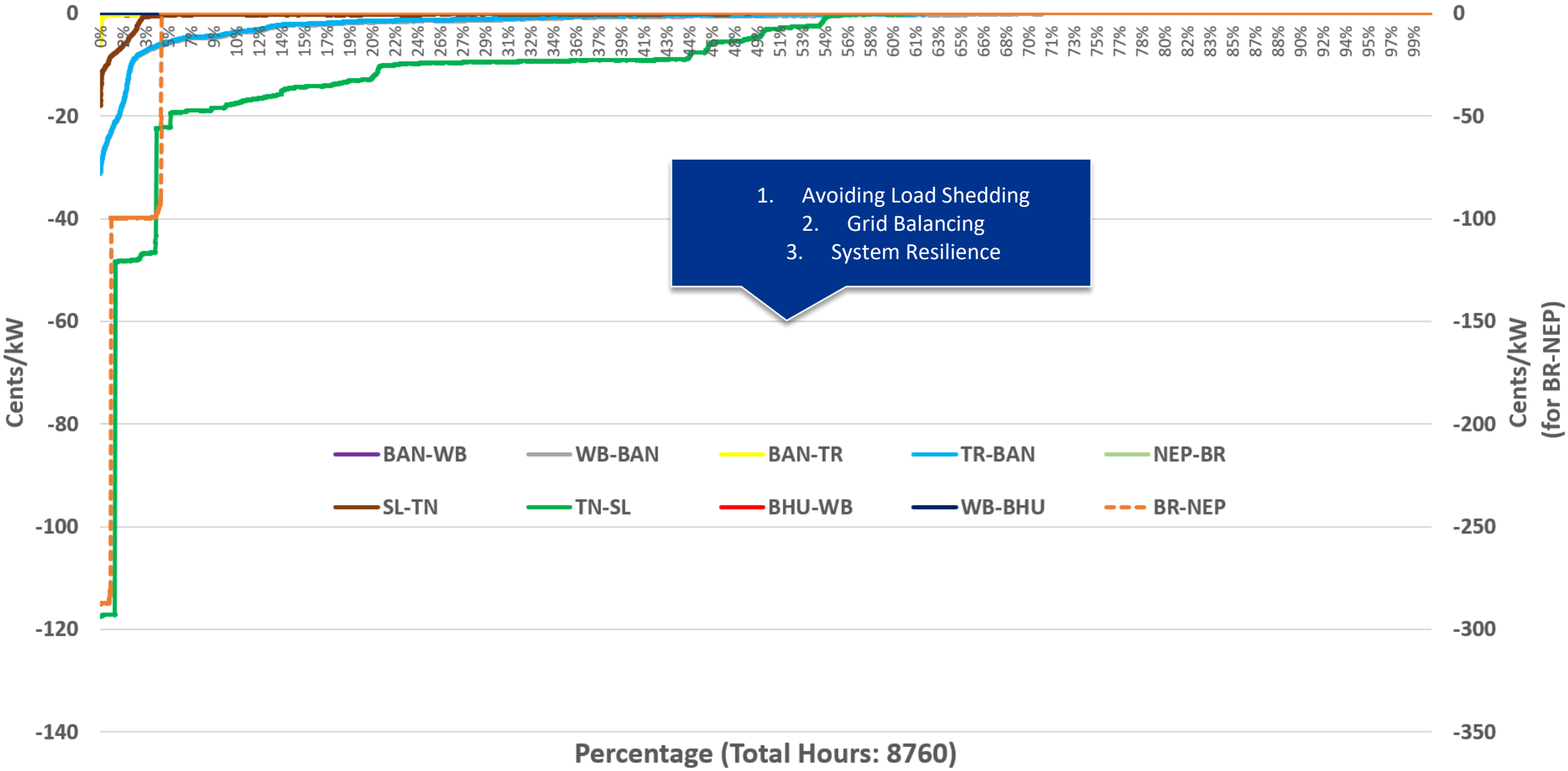

Energy Marginal Cost of BHUTAN
No Transmission
Constrained Transmission, Local Reserves
Constrained Transmission, Imported Reserves (50%)
Constrained Transmission, Imported Reserves (100%)
Unconstrained Transmission, Local Reserves
Unconstrained Transmission, Imported Reserves (50%)
Unconstrained Transmission, Imported Reserves (100%)
Cents/kWh
25
20
15
10
5
0
0%
2%
4%
7%
9%
11%
13%
16%
18%
20%
22%
24%
27%
29%
31%
33%
36%
38%
40%
42%
45%
47%
49%
51%
53%
56%
58%
60%
62%
65%
67%
69%
71%
73%
76%
78%
80%
82%
85%
87%
89%
91%
94%
96%
98%
Percentage (Total Hours: 8760)

How sensitive is the cost to transmission enhancement between various nations?

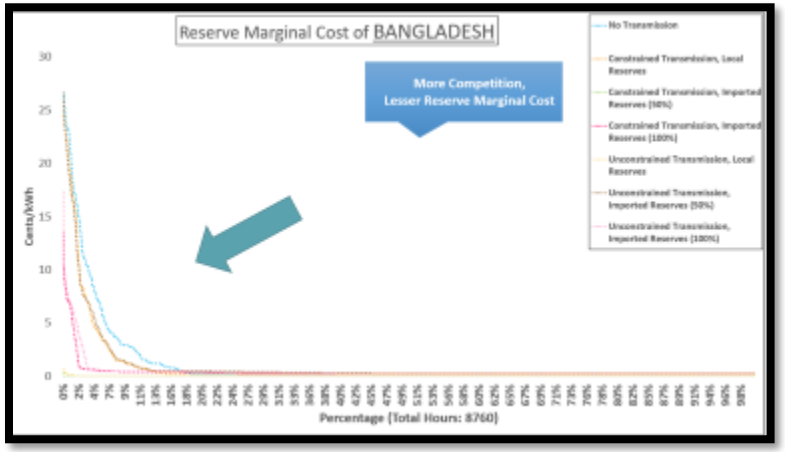


Existing Transmission Capacities with 100% cross border sharing of reserves

Existing Transmission Capacities with 100% Cross border sharing of reserves

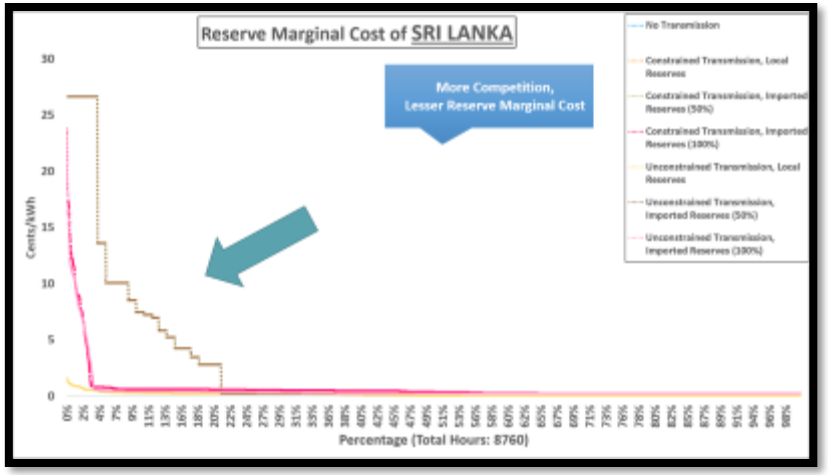


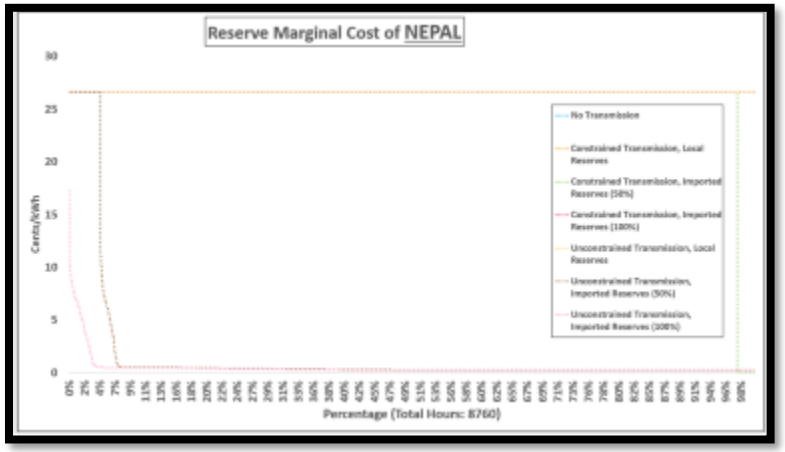
How sensitive are the costs to regional cooperation in ancillary services?



BANGLADESH

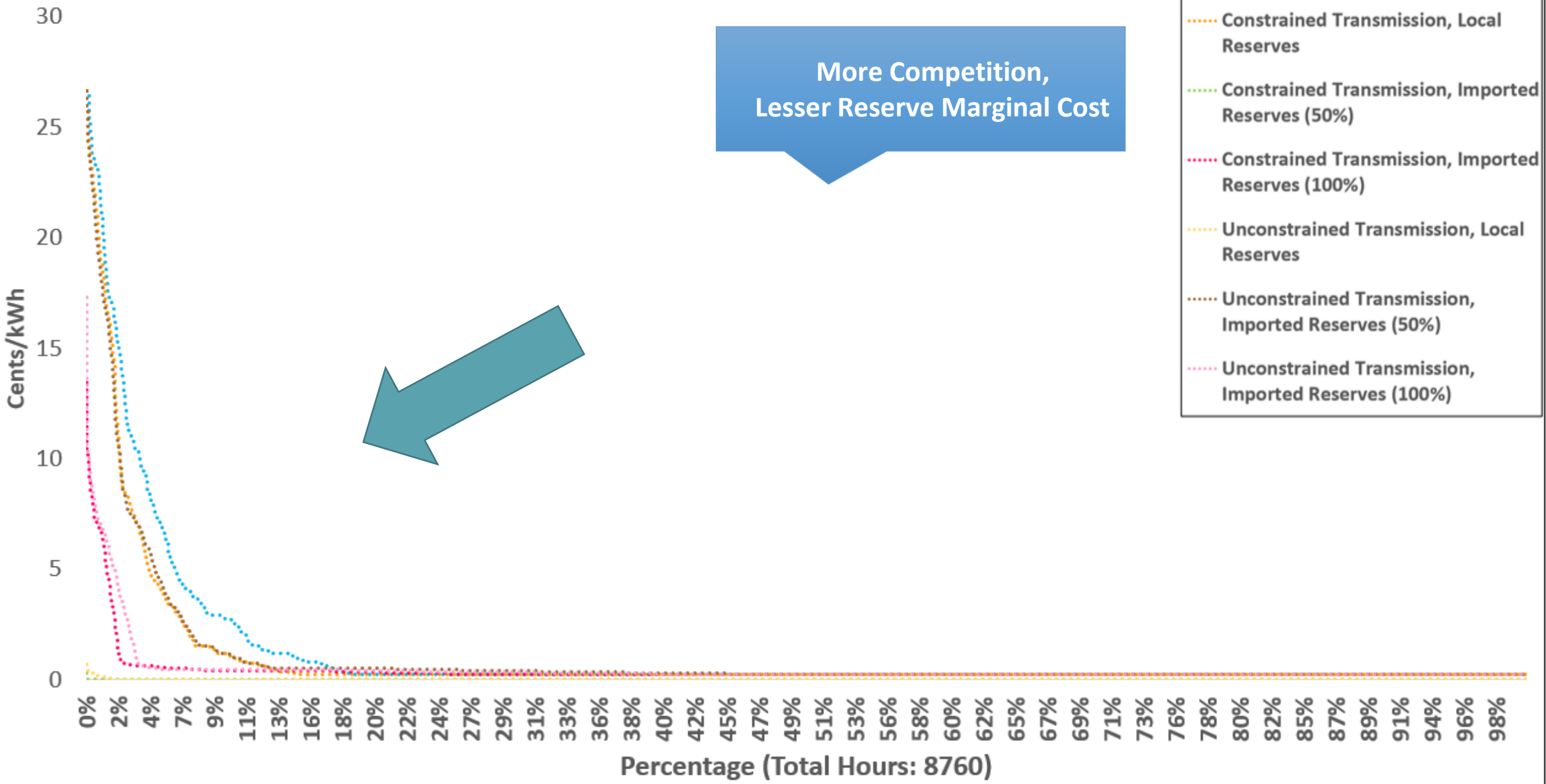
SRI LANKA



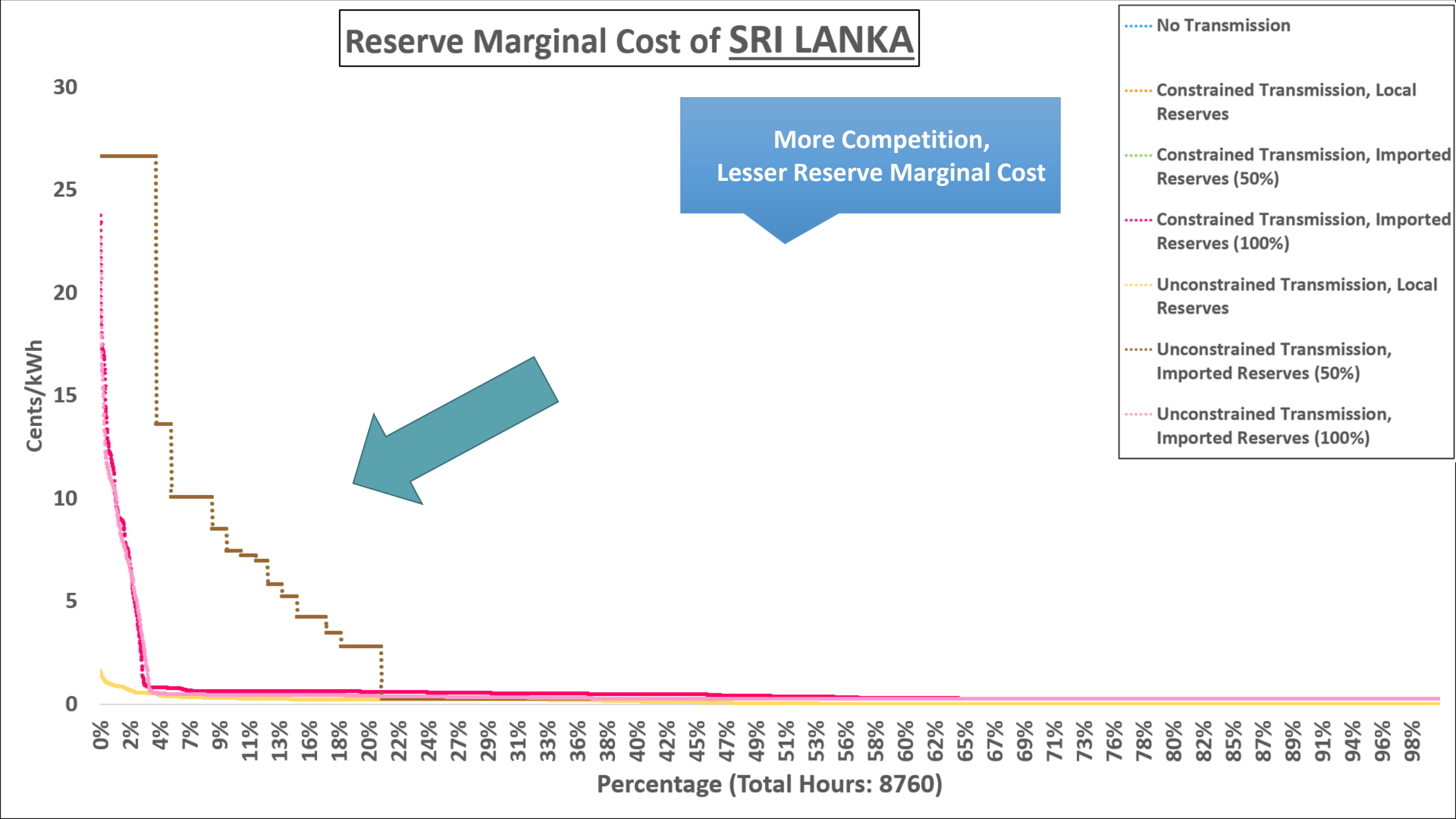


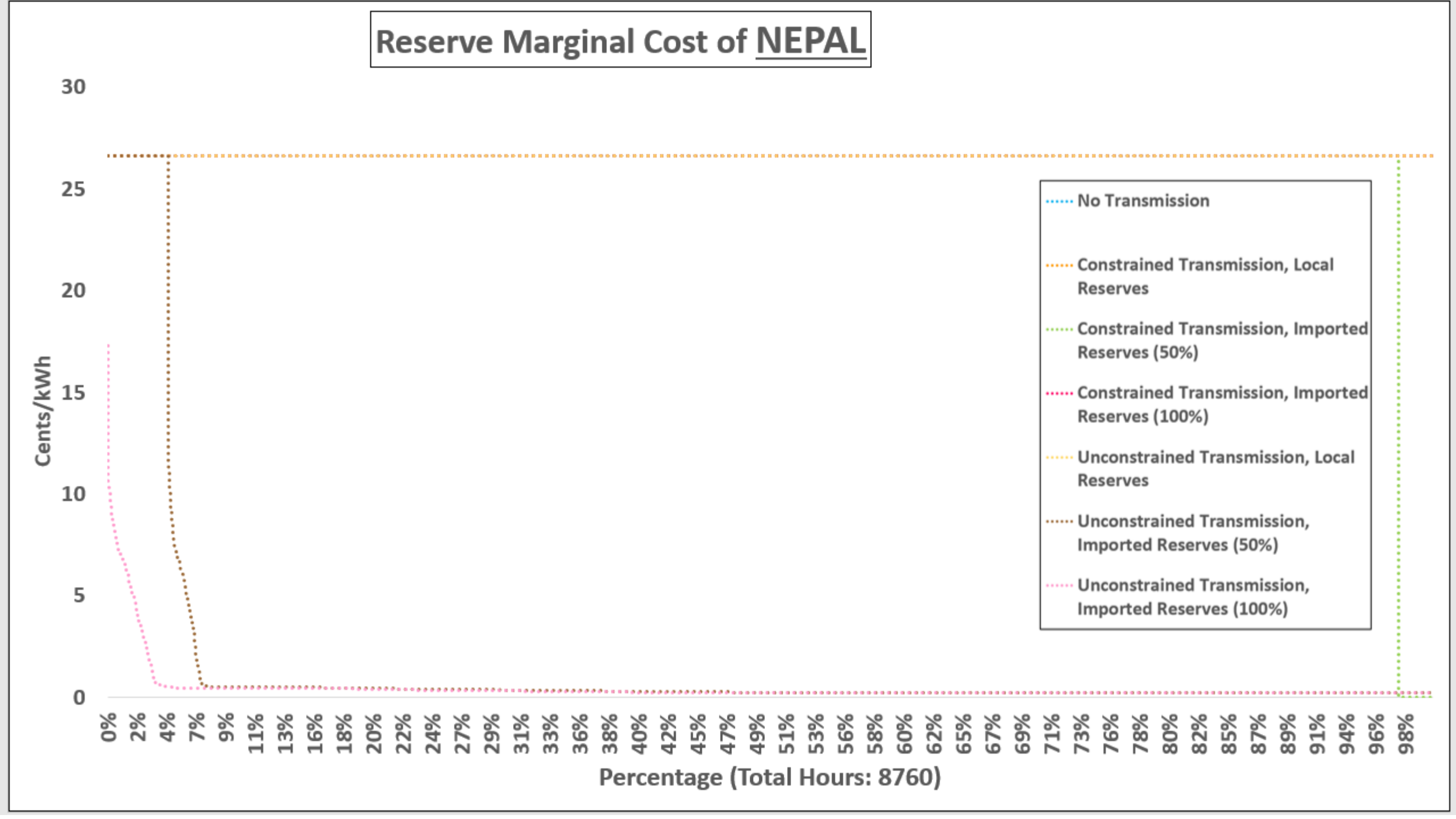
NEPAL

Reserve Marginal Cost of BANGLADESH

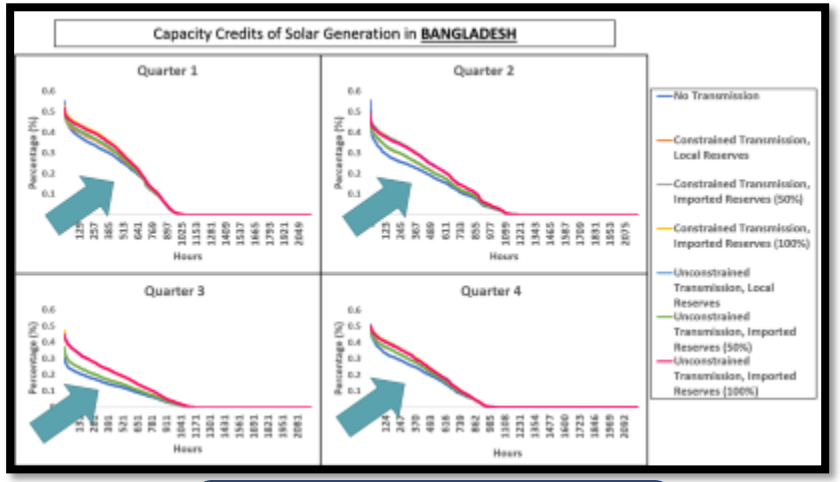


Reserve Marginal Cost of SRI LANKA

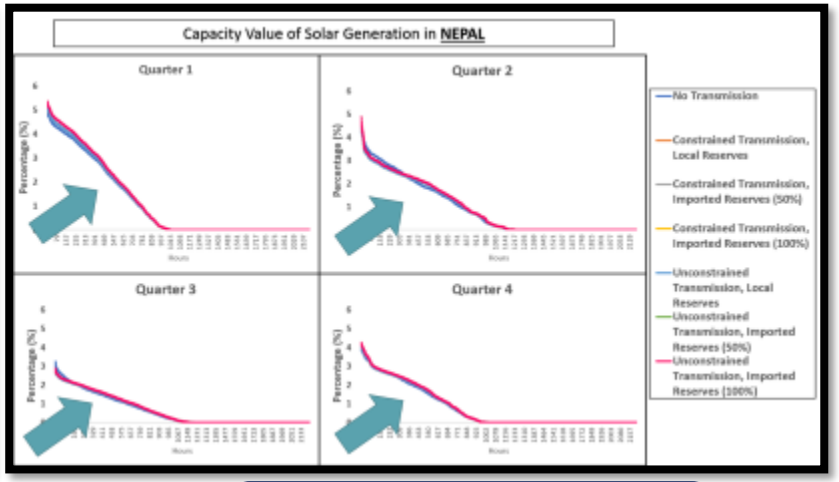



Reserve Marginal Cost of NEPAL
30
25
20
15
10
5
0
Cents/kWh
0%
2%
4%
7%
9%
11%
13%
16%
18%
20%
22%
24%
27%
29%
31%
33%
36%
38%
40%
42%
45%
47%
49%
51%
53%
56%
58%
60%
62%
65%
67%
69%
71%
73%
76%
78%
80%
82%
85%
87%
89%
91%
94%
96%
98%
Percentage (Total Hours: 8760)
No Transmission
Constrained Transmission, Local Reserves
Constrained Transmission, Imported Reserves (50%)
Constrained Transmission, Imported Reserves (100%)
Unconstrained Transmission, Local Reserves
Unconstrained Transmission, Imported Reserves (50%)
Unconstrained Transmission, Imported Reserves (100%)

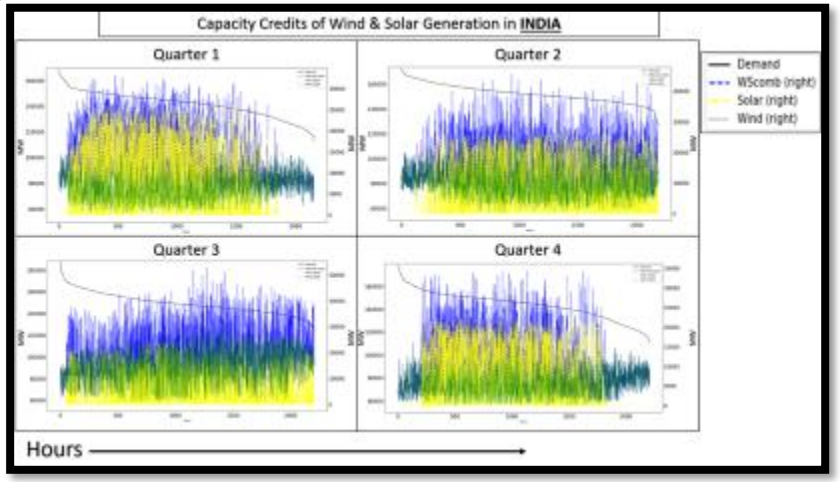
Capacity Credits of Solar & Wind Power Generation



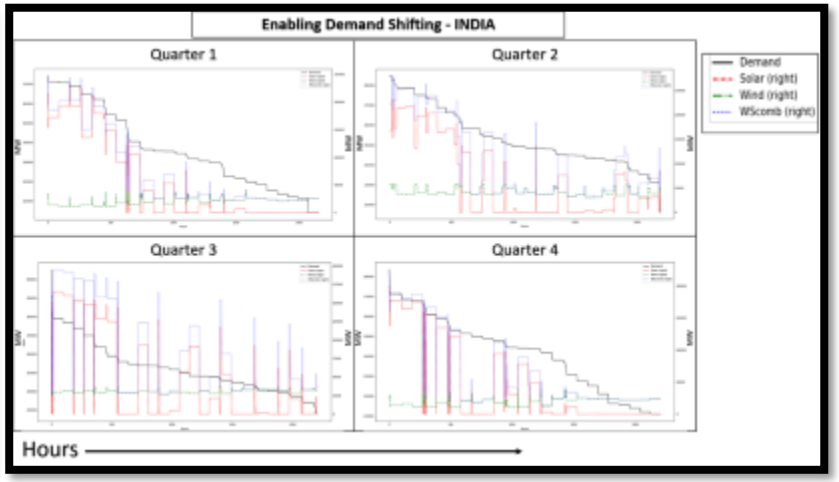
BANGLADESH



NEPAL

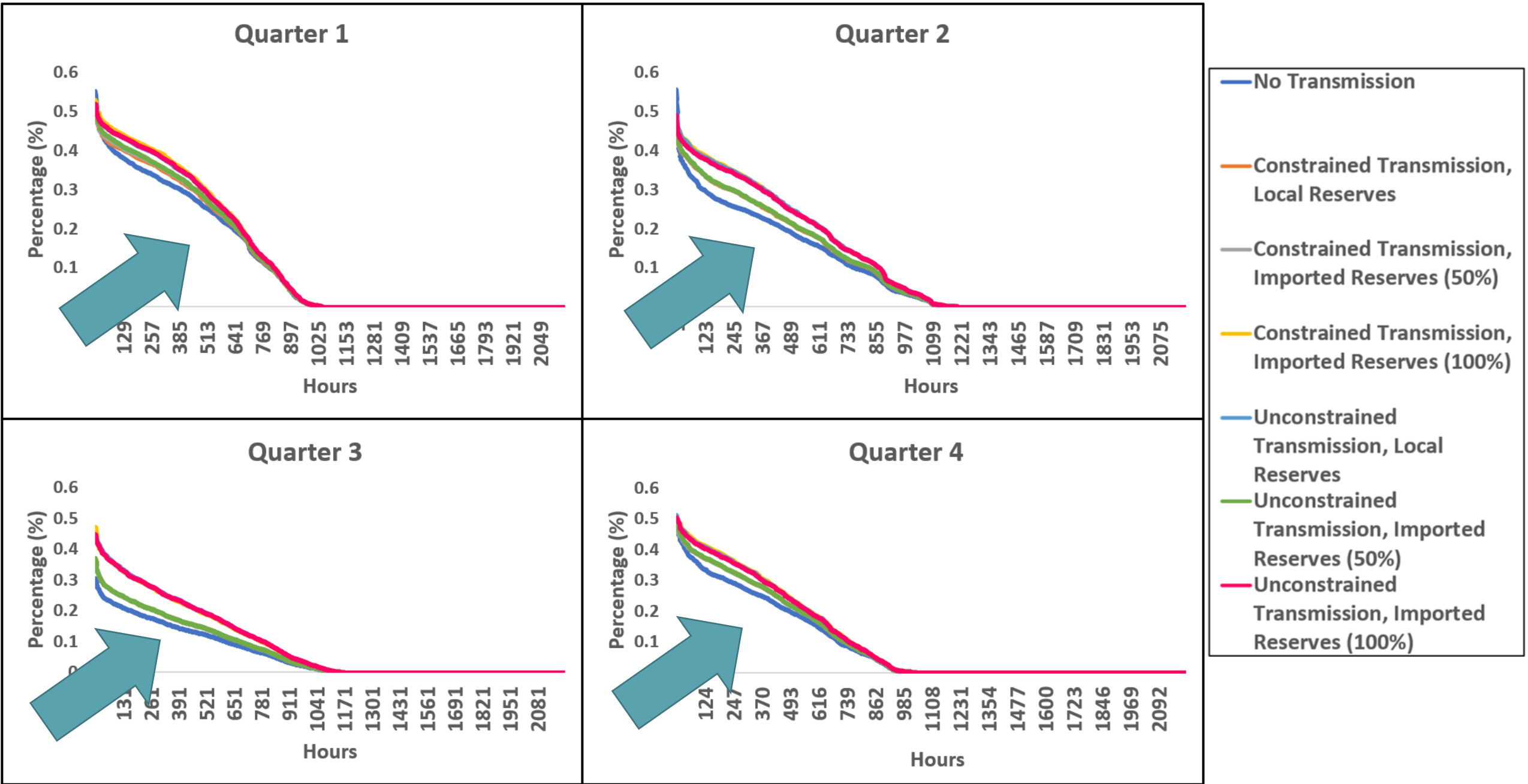


INDIA

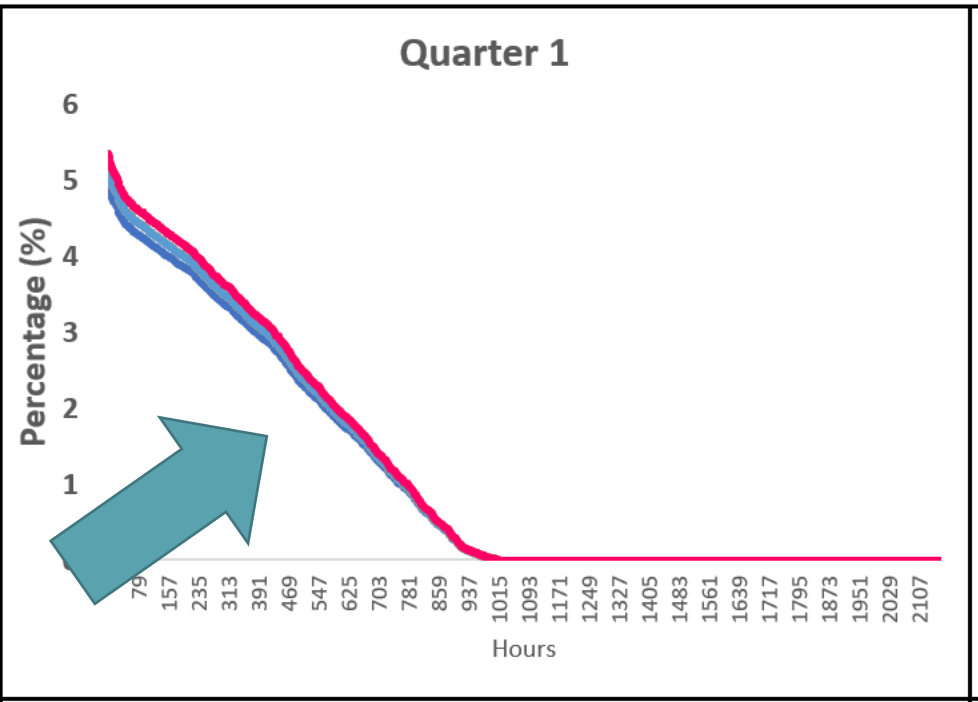


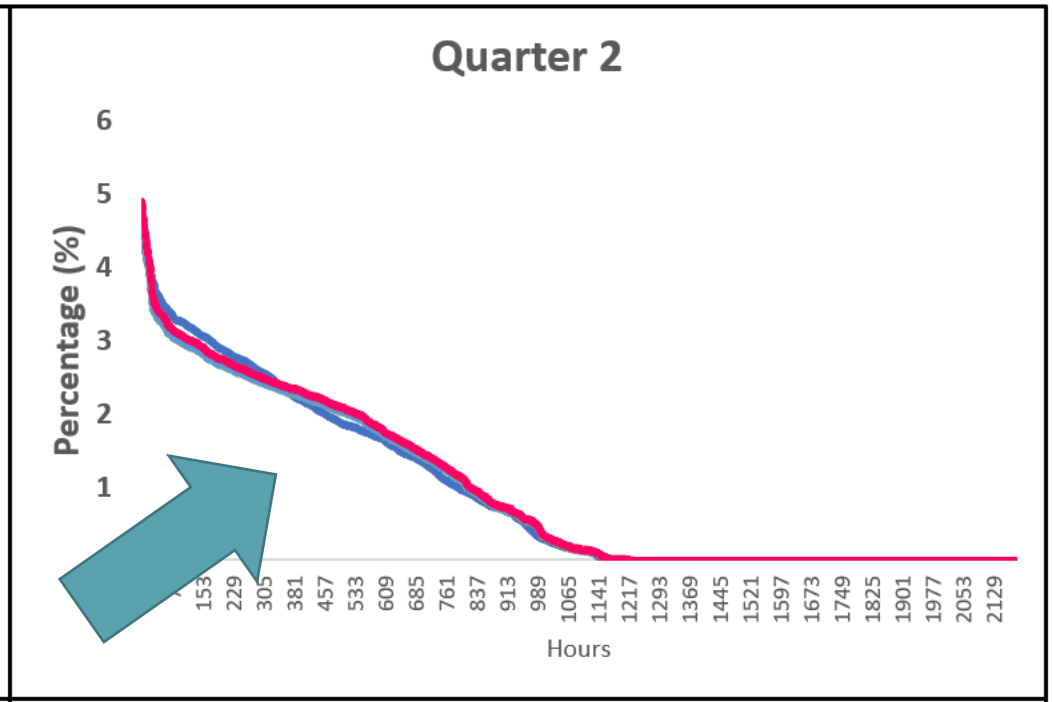
INDIA- ENABLING DEMAND SHIFTING

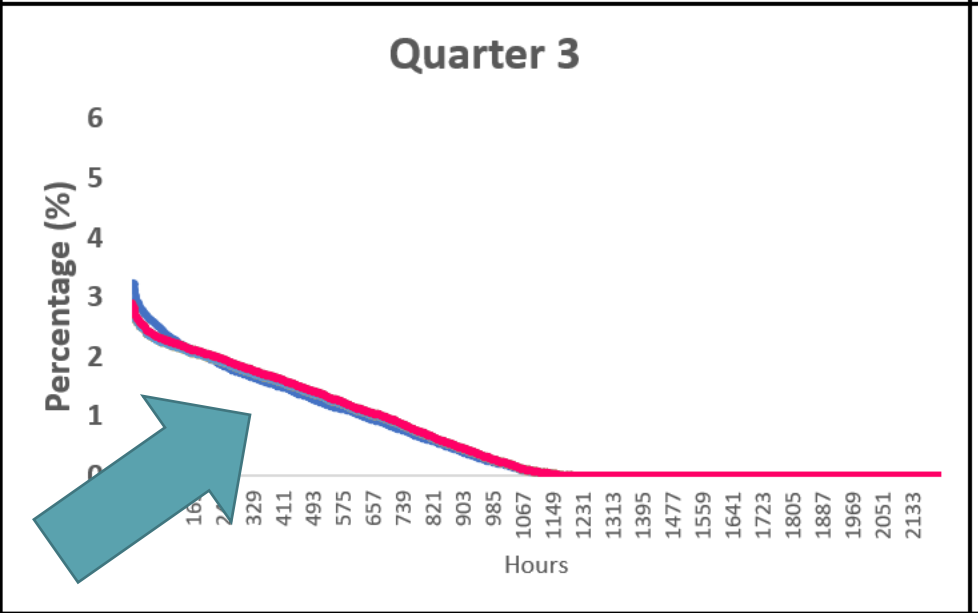
Capacity Credits of Solar Generation in **BANGLADESH**

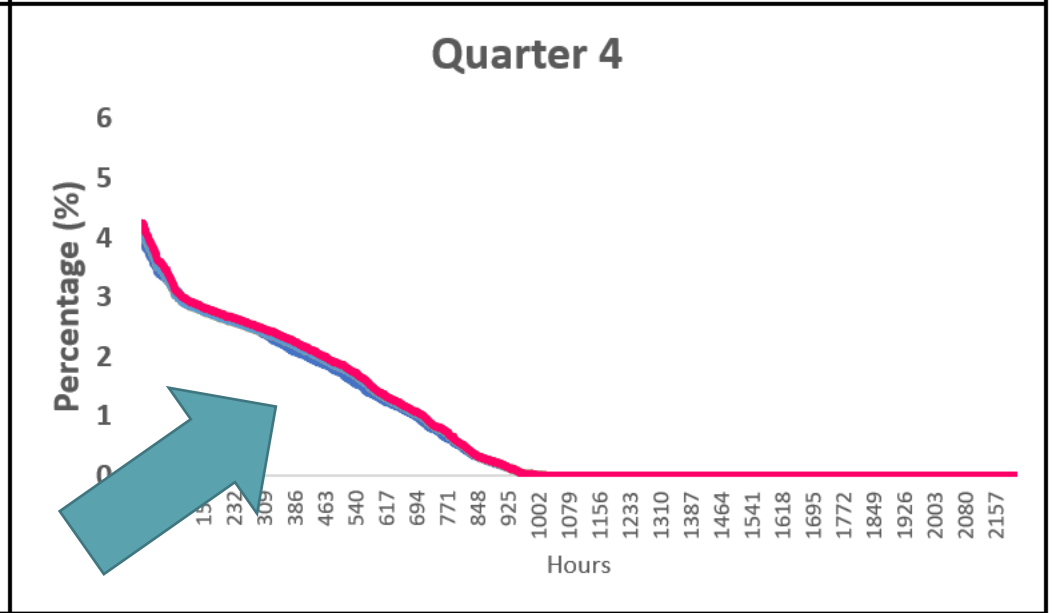


Capacity Value of Solar Generation in **NEPAL**





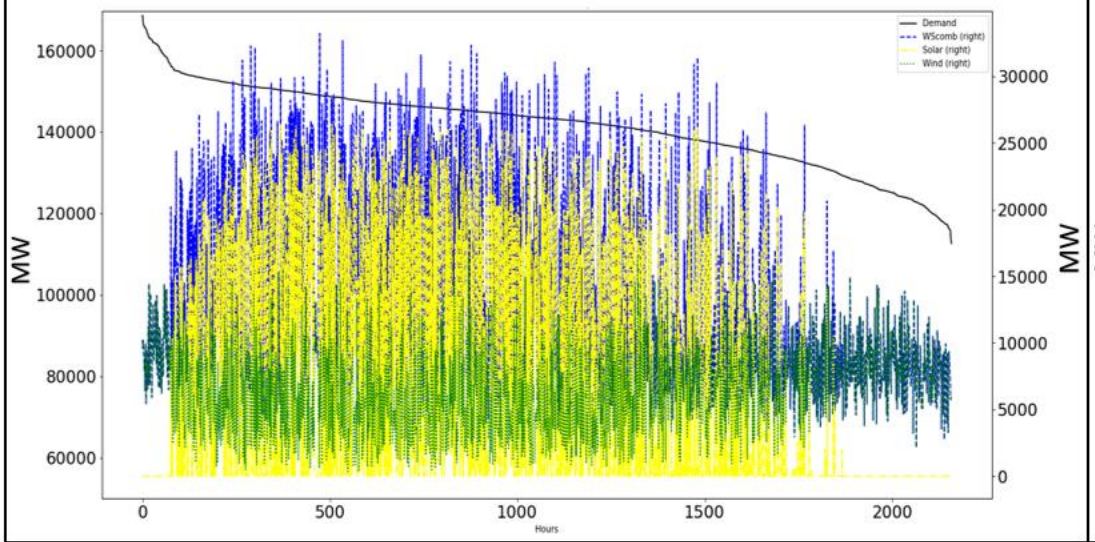




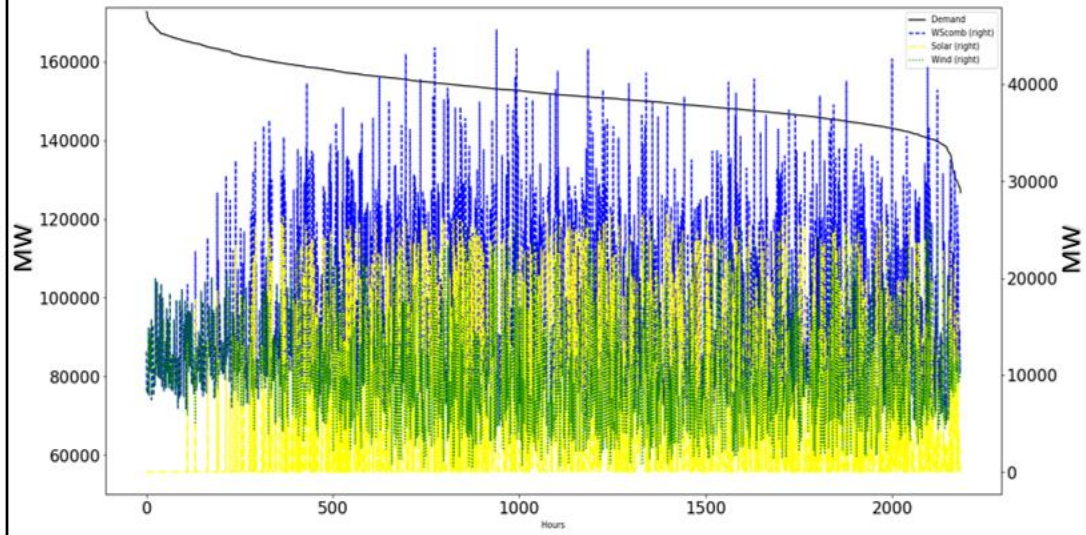
- No Transmission
- Constrained Transmission, Local Reserves
- Constrained Transmission, Imported Reserves (50%)
- Constrained Transmission, Imported Reserves (100%)
- Unconstrained Transmission, Local Reserves
- Unconstrained Transmission, Imported Reserves (50%)
- Unconstrained Transmission, Imported Reserves (100%)

Capacity Credits of Wind & Solar Generation in **INDIA**

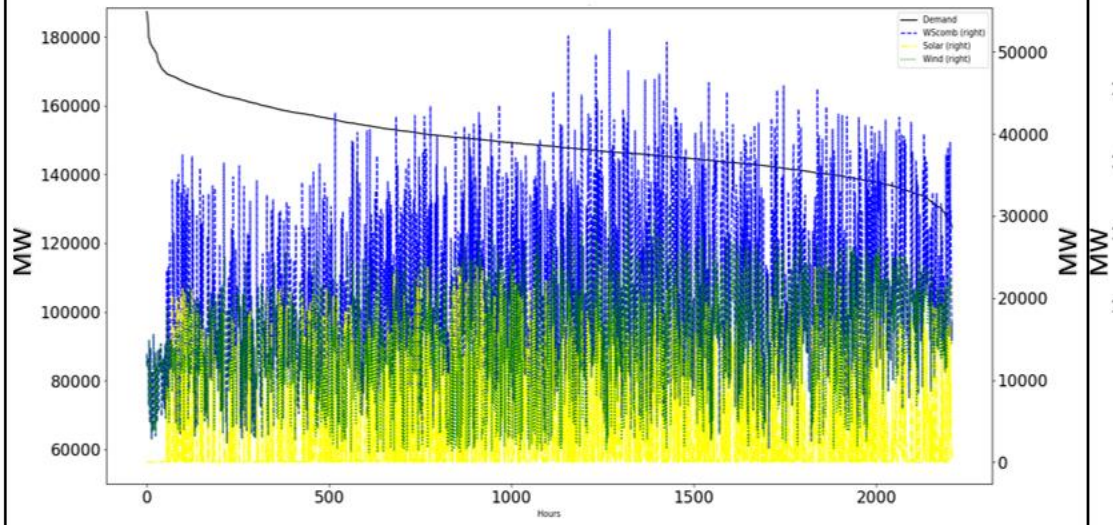
Quarter 1



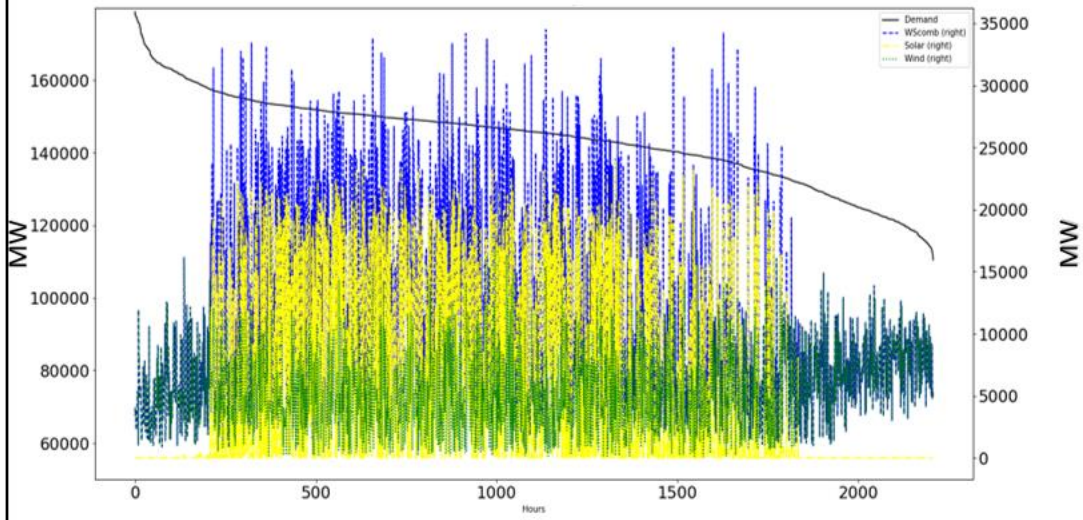
Quarter 2



Quarter 3



Quarter 4

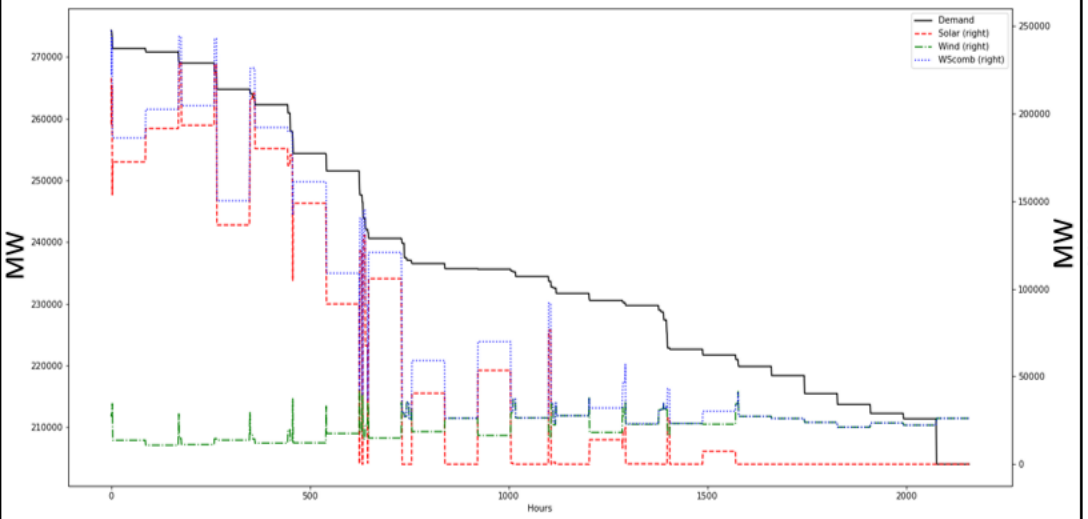


Demand
WScomb (right)
Solar (right)
Wind (right)

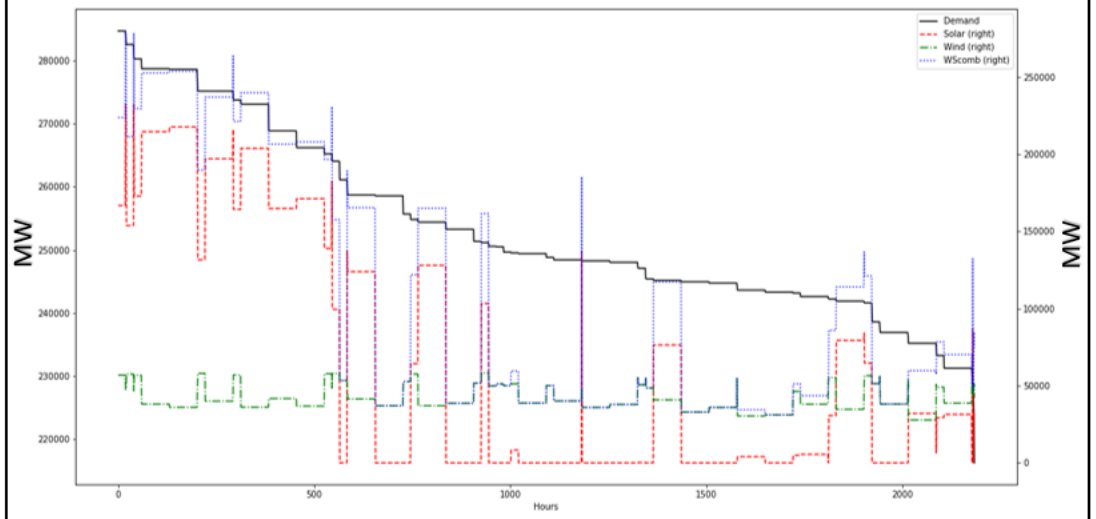
Hours →

Enabling Demand Shifting - INDIA

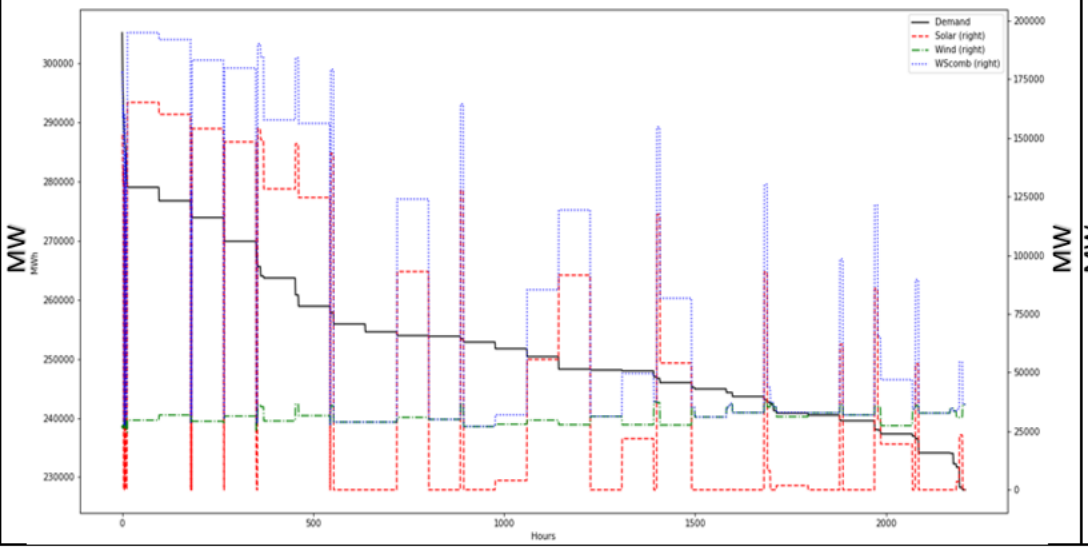
Quarter 1



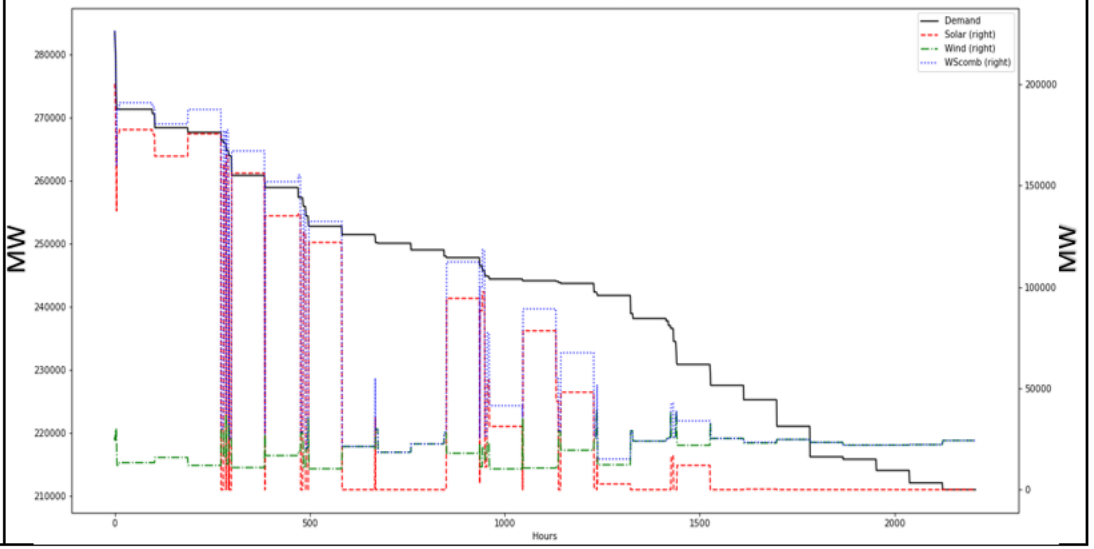
Quarter 2



Quarter 3



Quarter 4



Demand
Solar (right)
Wind (right)
WScomb (right)

Hours →

Conclusions

- Allowance of cross border utilization of reserves, with enhanced transmission capacities can lead to up-to 13% reduction in overall costs
- With enhanced regional cooperation, cheaper resources get better utilized to provide energy and balancing needs
- Enhancement of transmission capacities allows for balancing across large areas and hence, leads to reduction in balancing costs
- Marginal cost of reserves declines with regional cooperation as the opportunity value of reserves are much higher when they are required to be maintained locally
- Enhancement of transmission capacities seems to have the highest benefit in terms of reduction of nodal energy prices as well as the volatility in nodal prices in the South Asian region

Thank You