CEYLON ELECTRICITY BOARD

INTEGRATION OF RENEWABLE BASED GENERATION INTO SRI LANKAN GRID 2018-2028

Dr. H.M Wijekoon
Chief Engineer (Transmission Planning)

Randika Wijekoon
Electrical Engineer (Generation Planning)

Generation and Transmission Planning Branch
Ceylon Electricity Board

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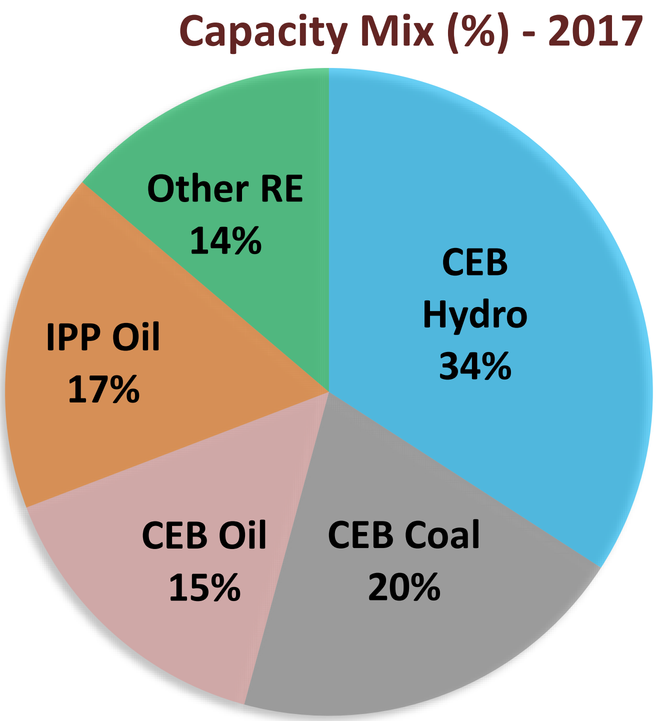
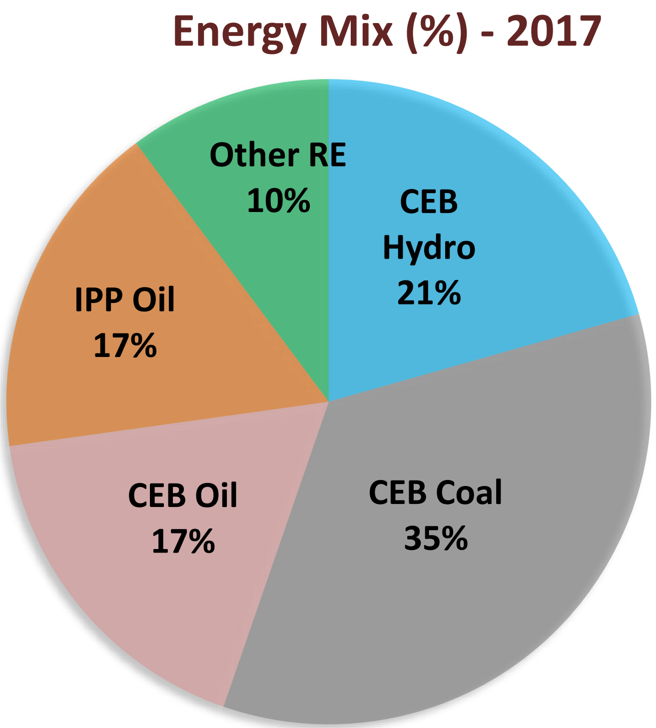
Sri Lanka- Country Information

Population	21.2 million
GDP per capita	3,835 USD (2016)
Area	65610 km^2
Installed Capacity	4036 MW
Peak Demand	2523 MW
Annual Electricity Demand	14,620 GWh
Electrification Level	99%
Per Capita Electricity Consumption	603 kWh per yr
CO2 emissions	0.886 (metric tons per capita)

Capacity Mix and Energy Mix

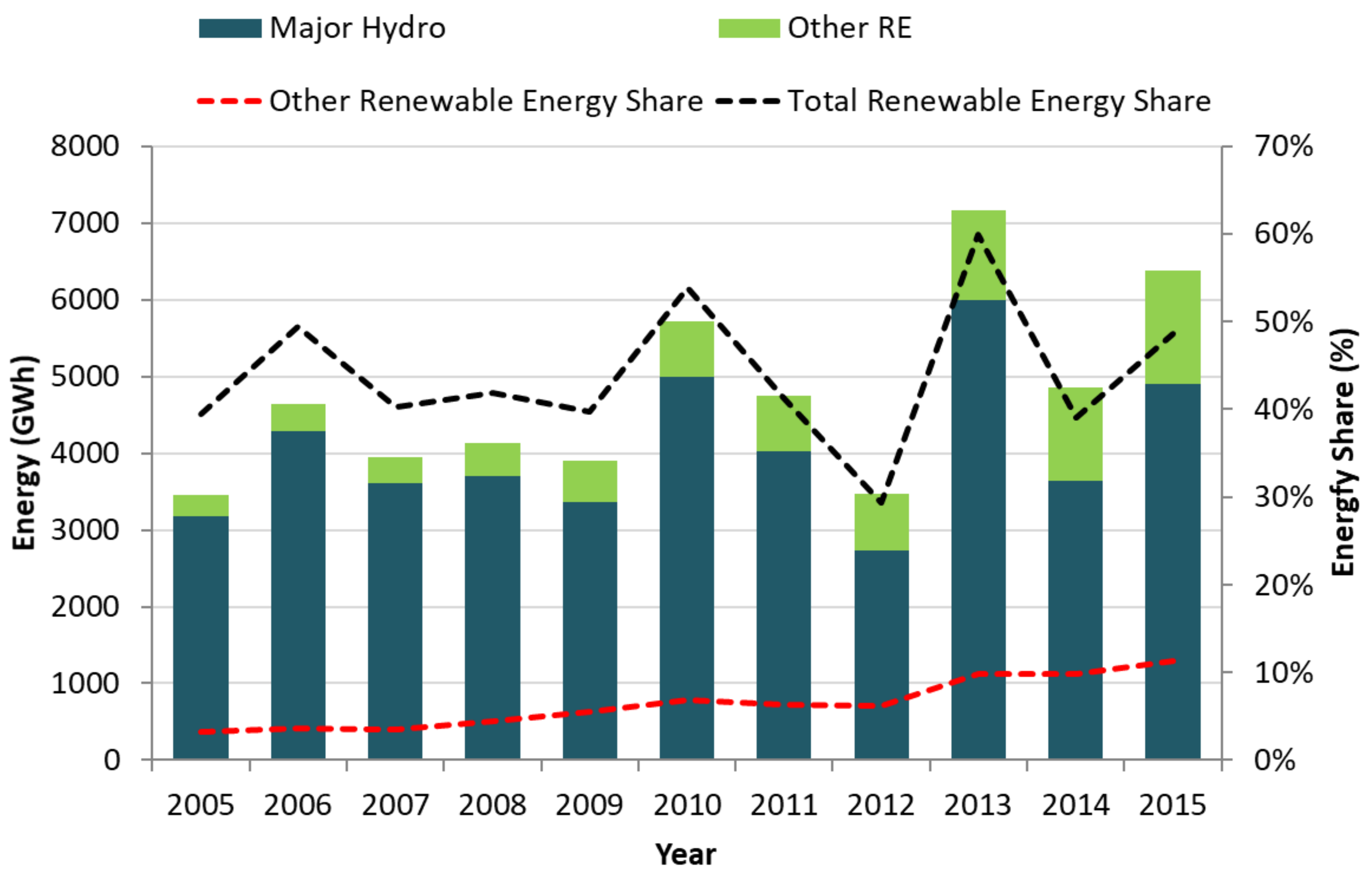




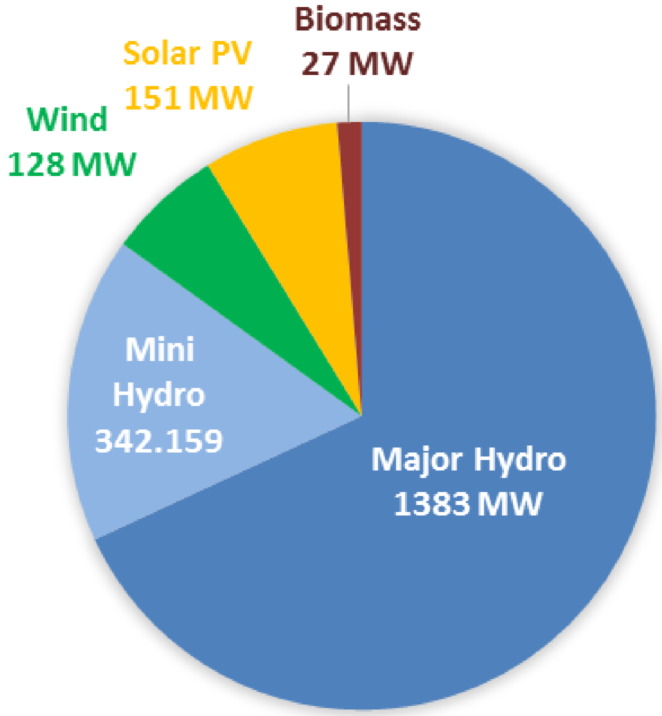
	Capacity (MW)	Energy (GWh)
CEB Hydro	1377	3014
CEB Thermal - Coal	810	5071
CEB Thermal - Oil	604	2560
IPP Thermal - Oil	687	2485
Other RE	558	1489
Total	**4036**	**14620**

RE Development

Energy (GWh)

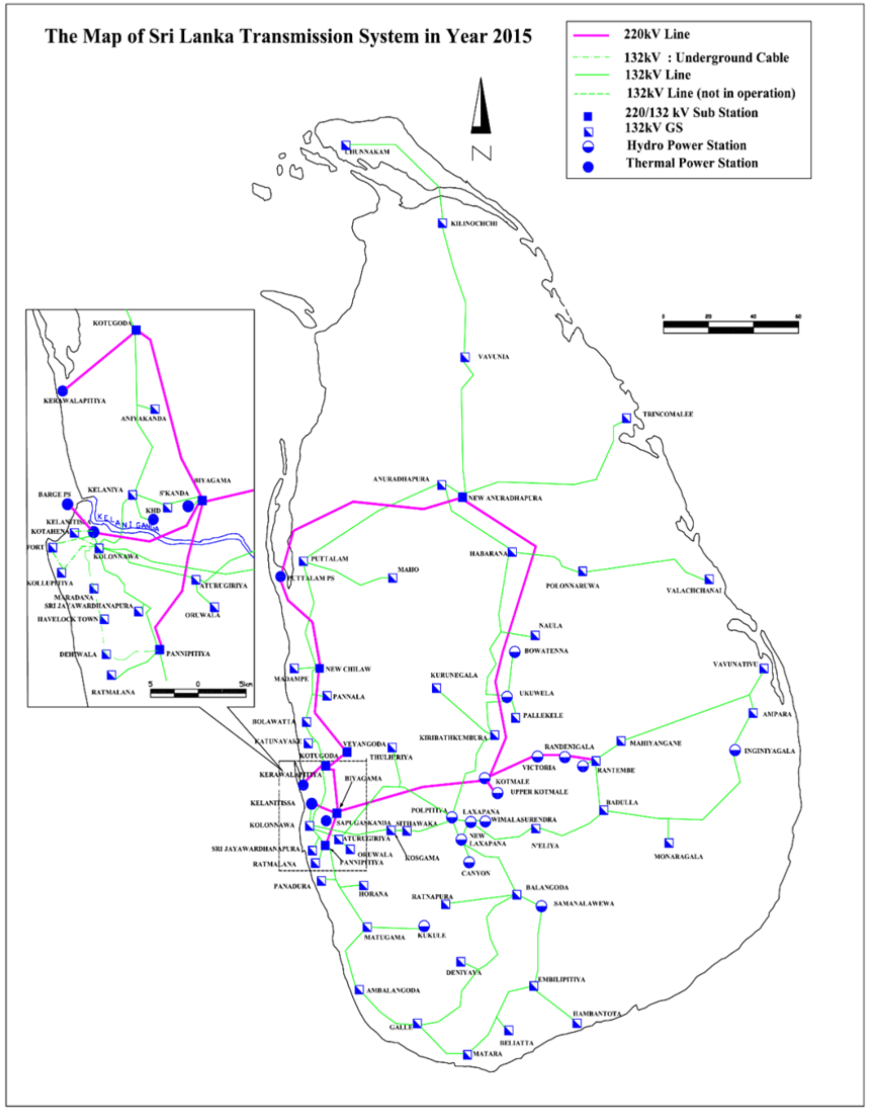


Installed Capacity (MW)

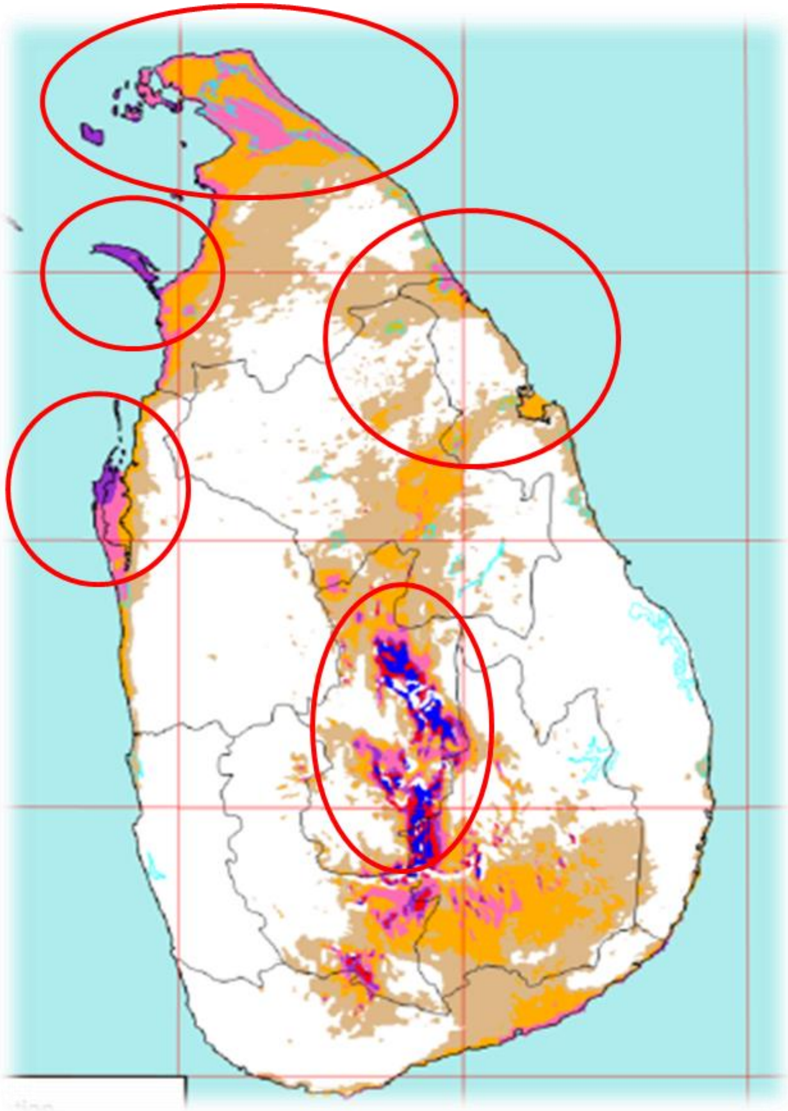


Wind - 128MW
Solar Rooftop - 100MW
<u>Solar Grid Scale - 50MW</u>
Total VRE - 278MW

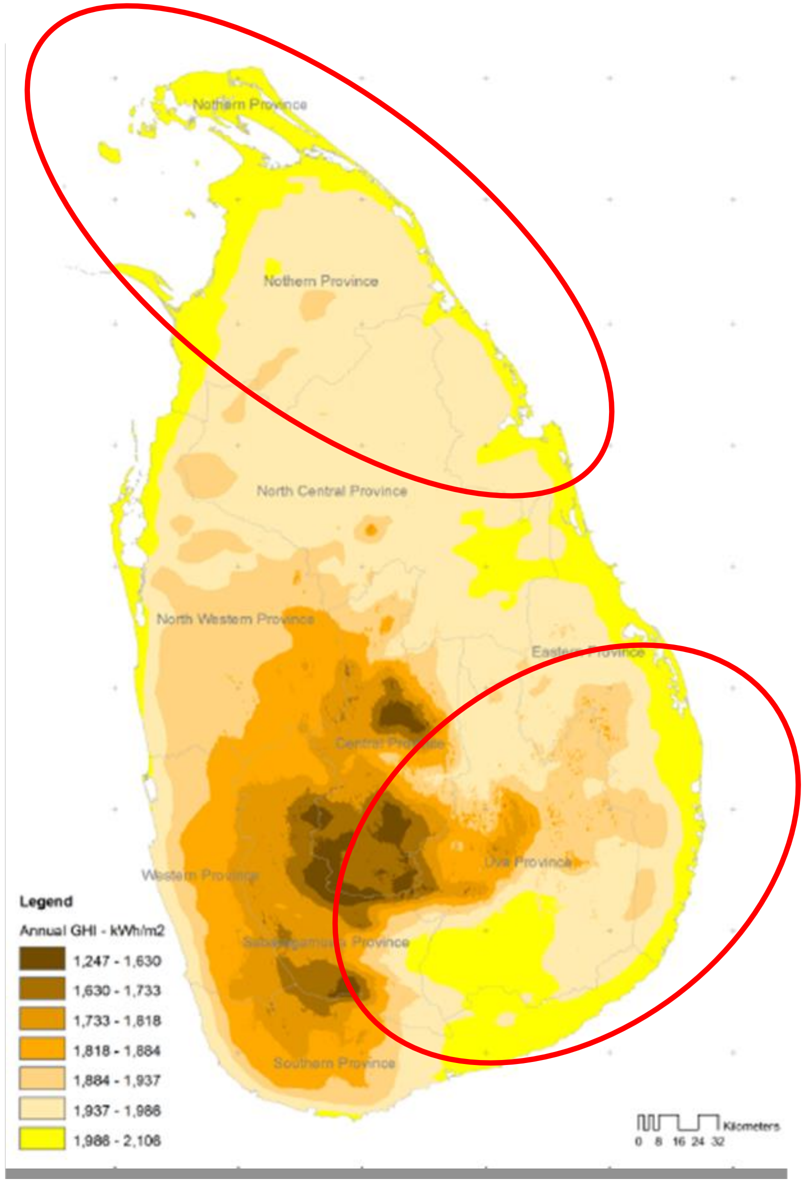
Network and Resource Locations



Transmission Network



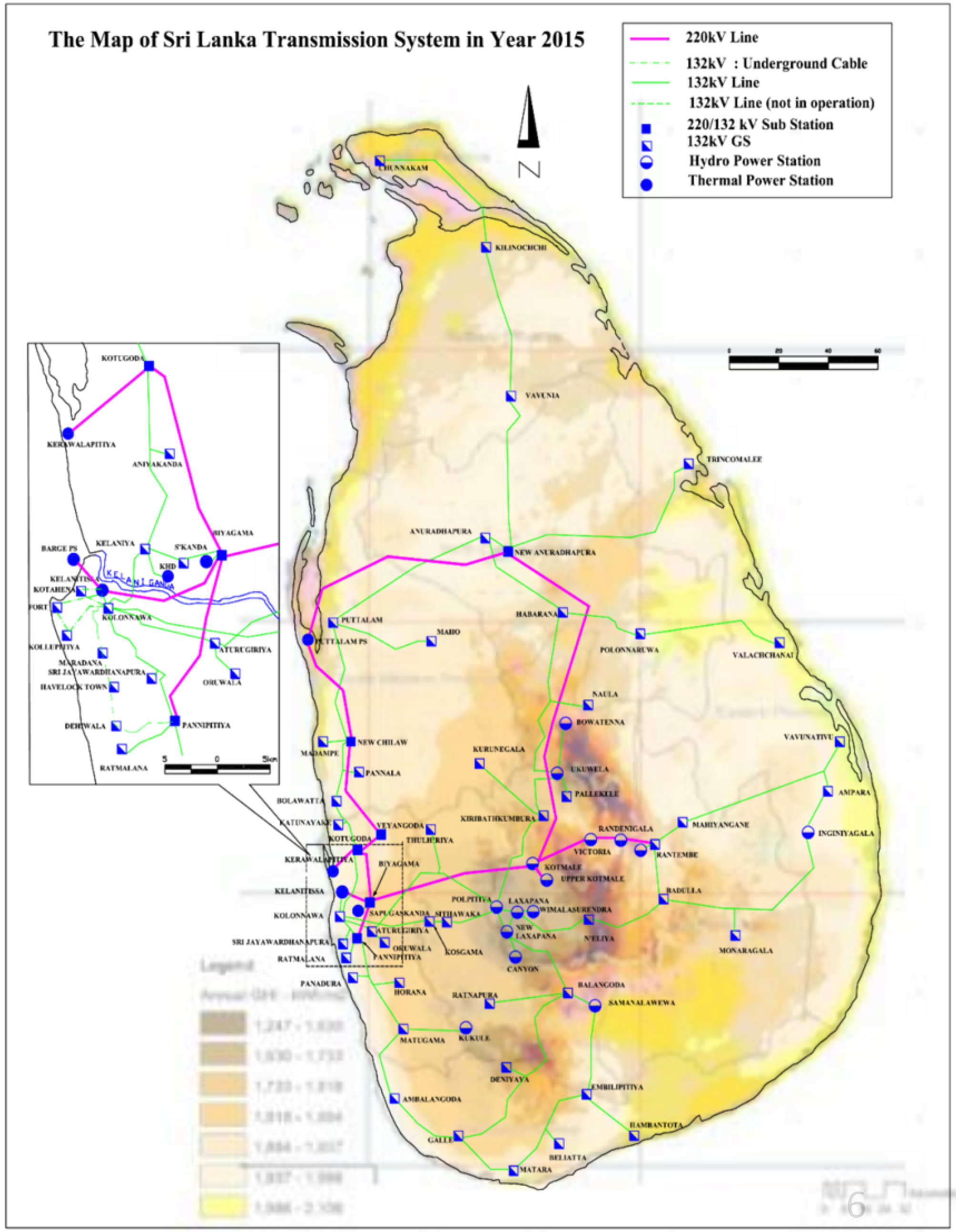
Wind Resources



Solar Resources

VRE Development Challenges

- Infrastructure development for RE resources
- High Seasonality of RE resources
- Ensuring System Stability
- Constraints in existing network
- Daily Load Variation pattern
- Ensuring adequate Operational flexibility
- Impact of DG on distribution system
- Accurate system modelling
- National Policy on energy mix



Overall Study Methodology

Renewable Energy Resource Assessment

Major Hydro, Mini Hydro, Wind , Solar, Biomass

Renewable Energy Development Projection

Future capacity additions and energy contribution

Resource availability & quality , Infrastructure availability , Technology costs

Optimization of Long Term Planning

Optimized Generation Expansion plan, 20 year planning period , Multiple scenarios

Transmission Network Study

Steady State Analysis,

Dynamic Analysis

Short term frequency stability Analysis

Medium to Short term operational study

Medium term Hydro Thermal Optimization,

Economic Dispatch in 30min time steps

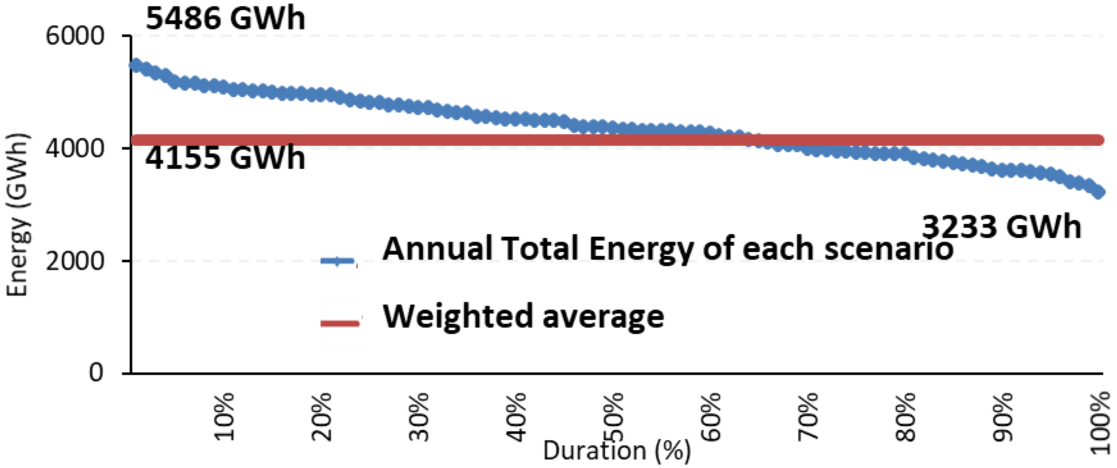
Operational Constraints, curtailments

Results and Analysis

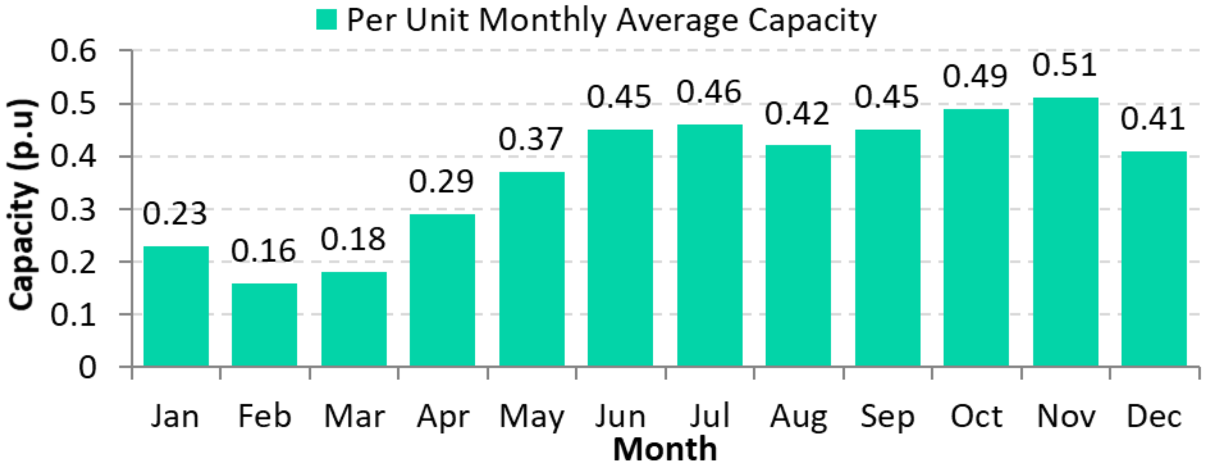
- Energy and Capacity Contribution
- Stability and Curtailments
- Economic Analysis of Integration scenarios

RE Resource Assessment and modelling

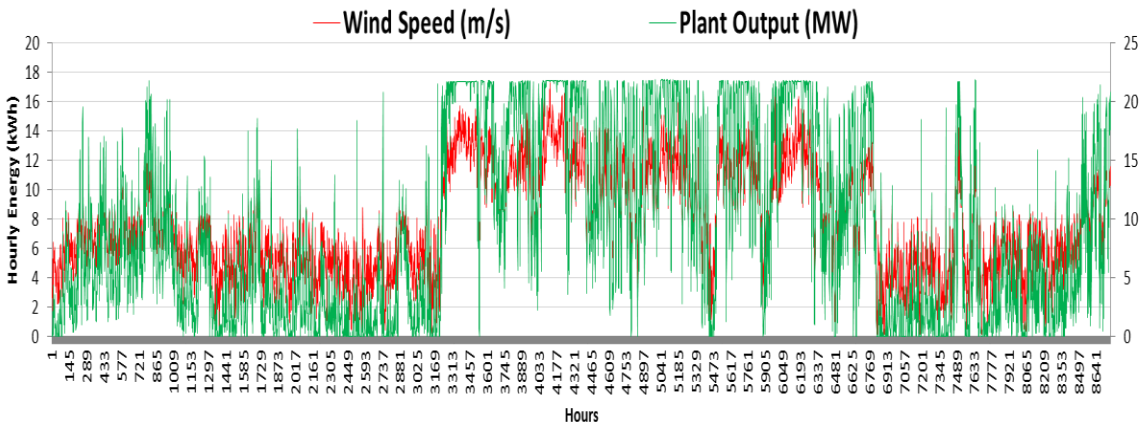
Major Hydro



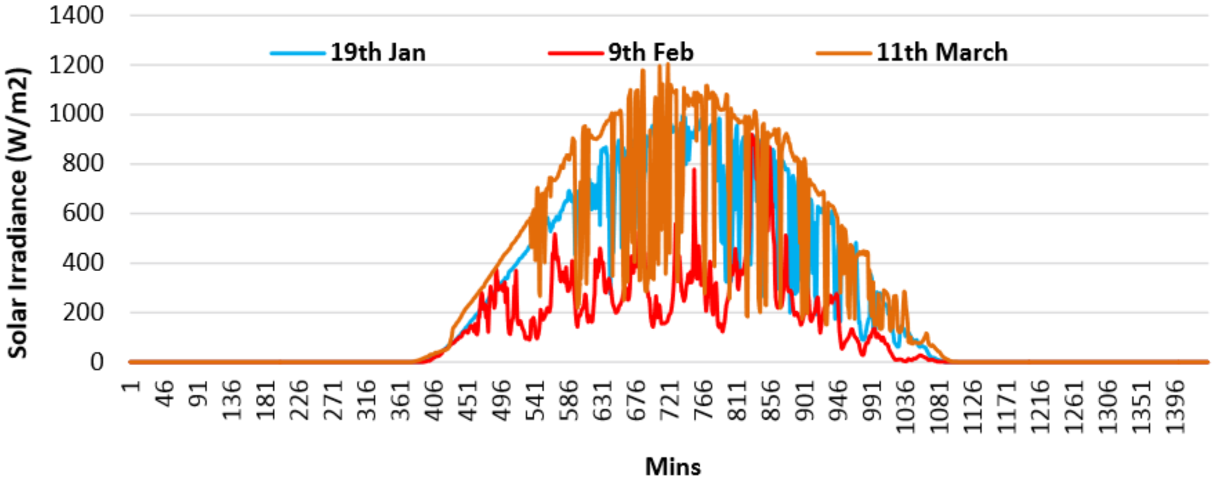
Mini Hydro



Wind

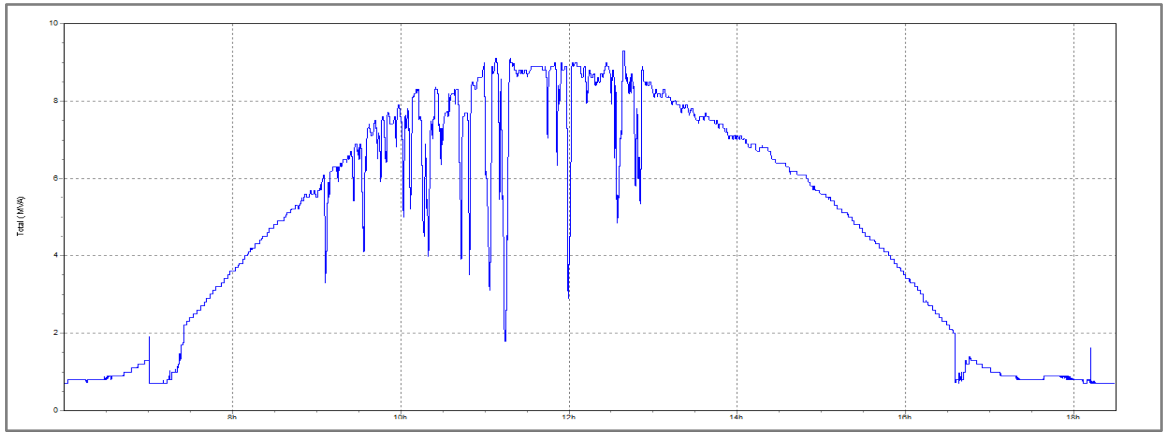


Solar PV

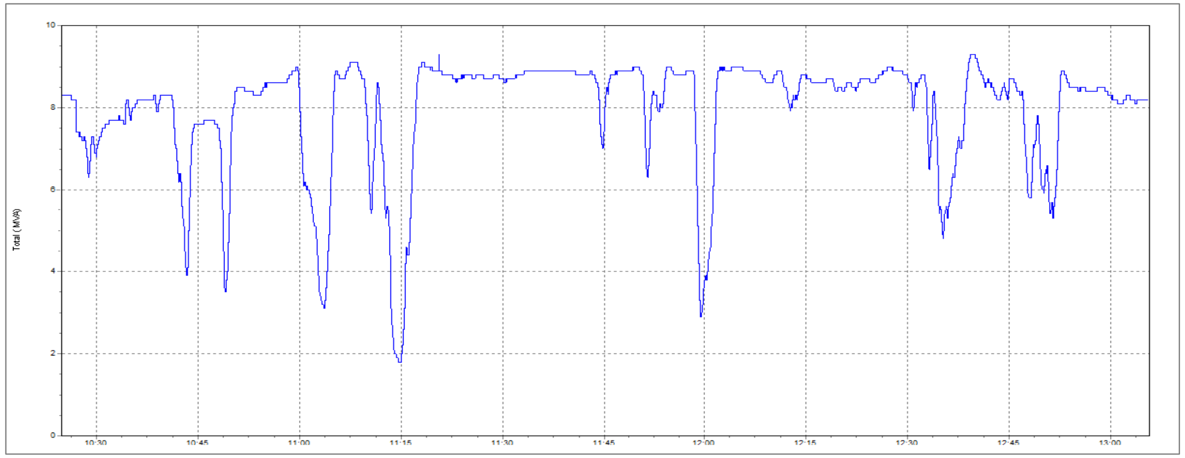


Transmission Network Study

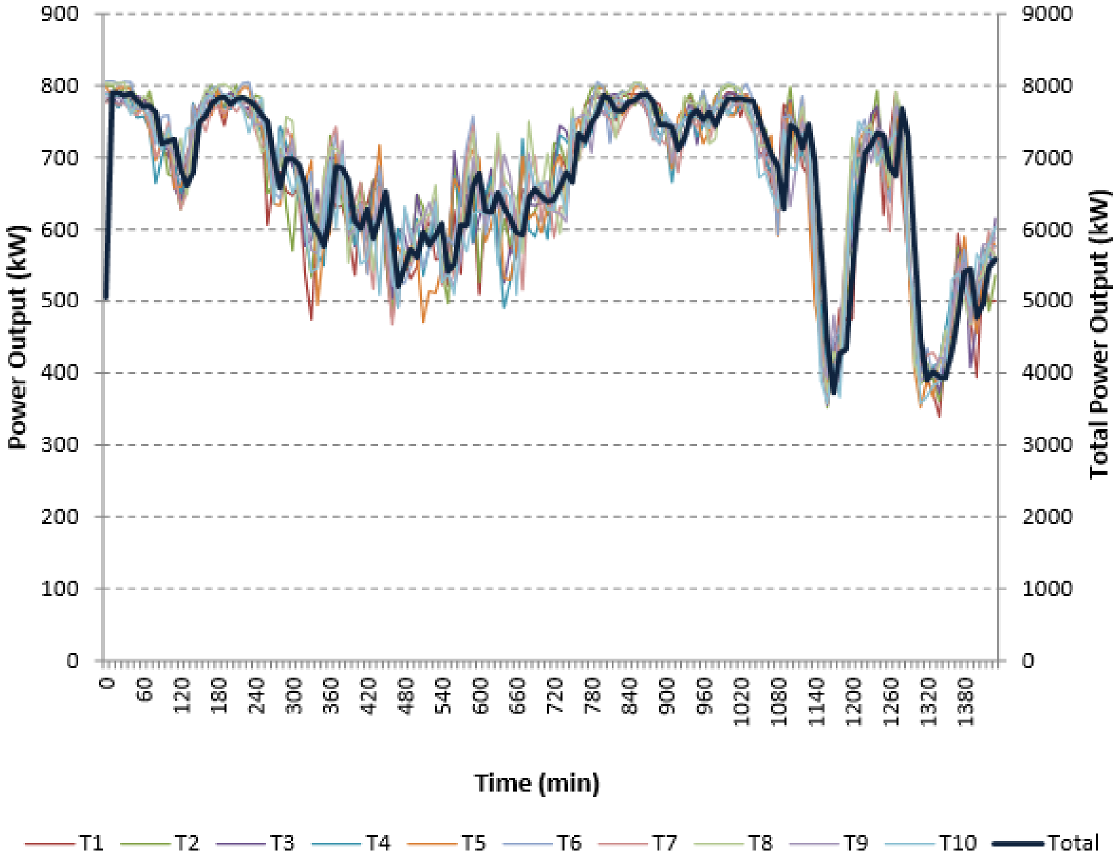
Power System Stability Studies -VRE Variability



Power output variation in a day of 10 MW Hambantota plant



Enlarged view of time period 10.30 hrs to 13.00 hrs



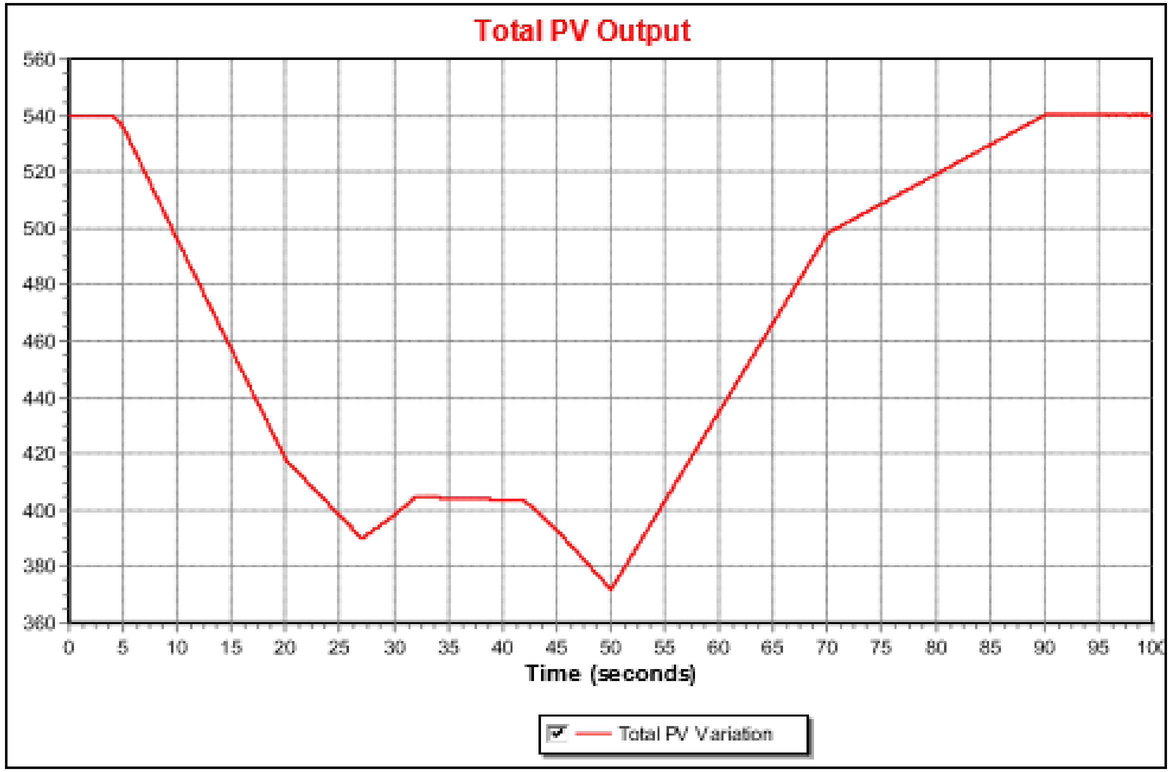
Aggregated output off Wind Turbines

Power System Stability Studies

Short term frequency stability analysis

100 seconds duration

Defined ramp event



Ramp Rate defined for 540 kW Solar PV Plant

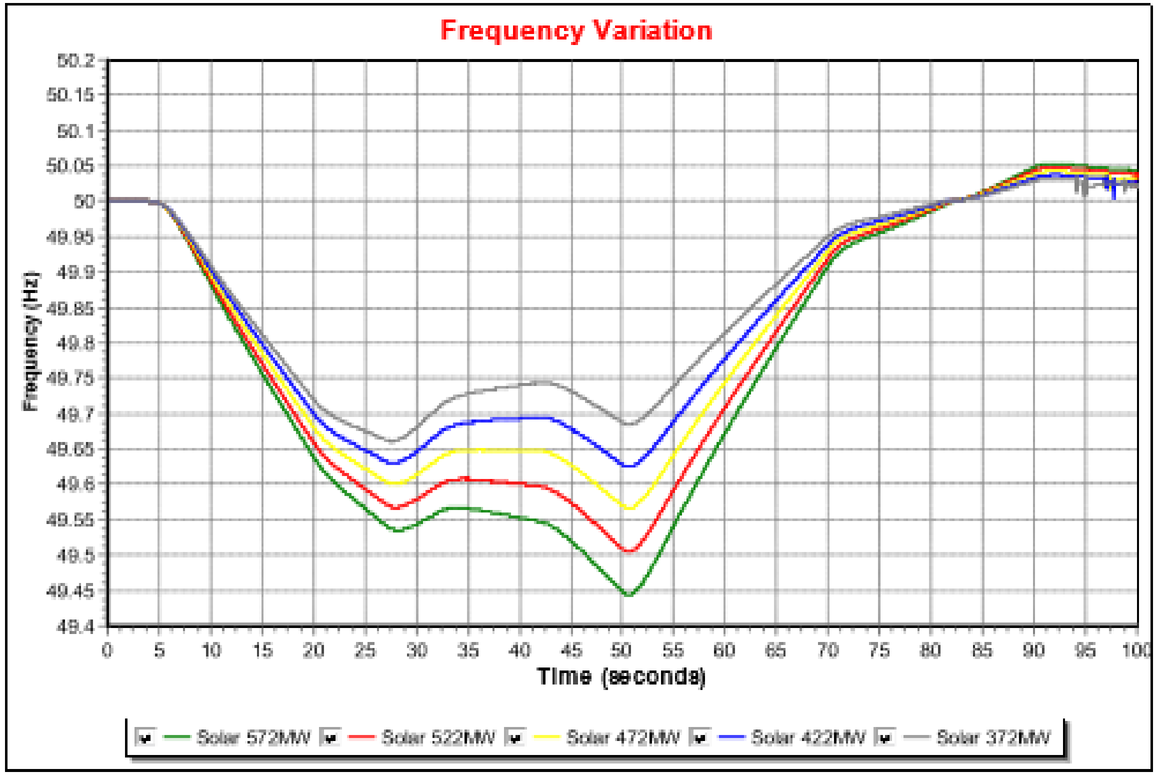
Study Scenarios

Year	
2018	▪ Case 1: Only swing machine is used for free governor ▪ Case 2: Swing machine + GT7 used for free governor ▪ Case 3: Swing machine + KCCP used for free governor ▪ Case 4: With All Hydro Governor (Victoria, Kotmale, Upper Kotmale, N'Lax) ▪ Case 5: Swing machine + KCCP + GT7 + 2x35MW GTs used for free governor
2020	▪ Case 1: With All Hydro Governor (Victoria, Kotmale, Upper Kotmale, N'Lax) used for free governor ▪ Case 2: Swing machine + KCCP + GT7 used for free governor ▪ Case 3: Swing machine + KCCP + GT7 + LNG used for free governor ▪ Case 4: Swing machine + KCCP + GT7 + LNG + 2x35MW GTs used for free governor
2020, 2025, 2028	▪ LNG + GTs + Hydro (Victoria, Kothmale, Upper Kothmale)

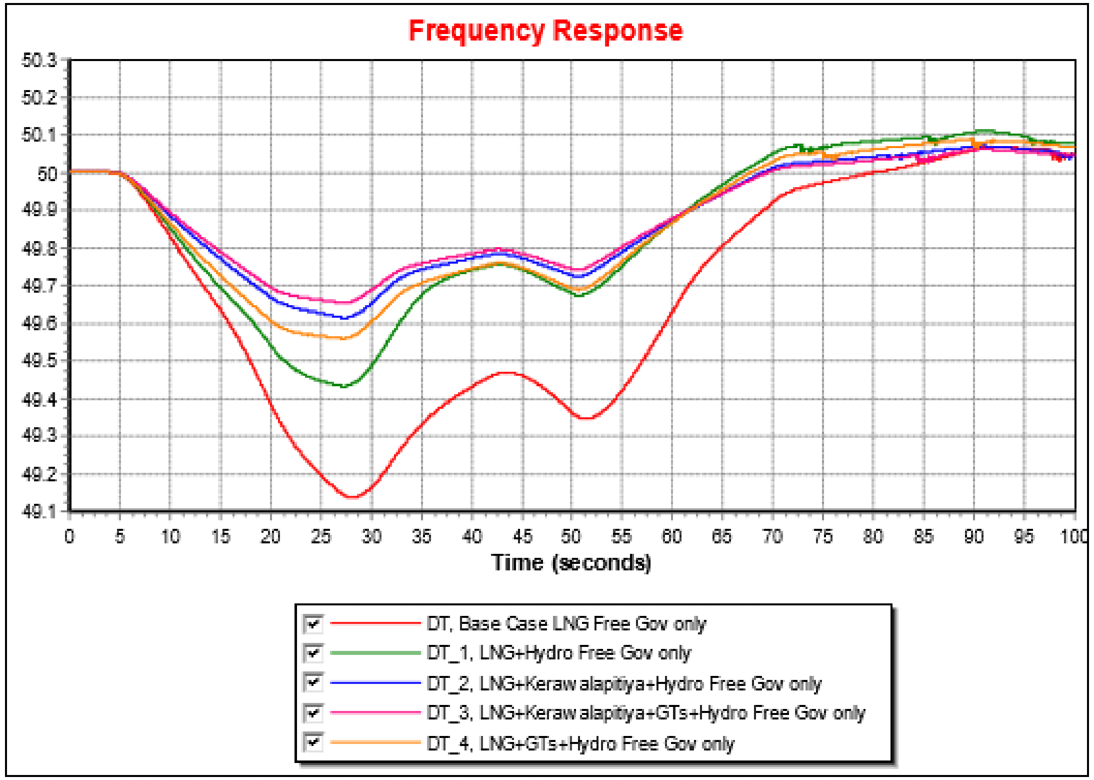
Power System Stability Studies

Short term frequency stability analysis

Different Solar Penetration Levels



Different Regulating scenarios



Studied years-2018,2020,2022,2025,2028

Power System Stability Studies

Short term frequency stability - Results

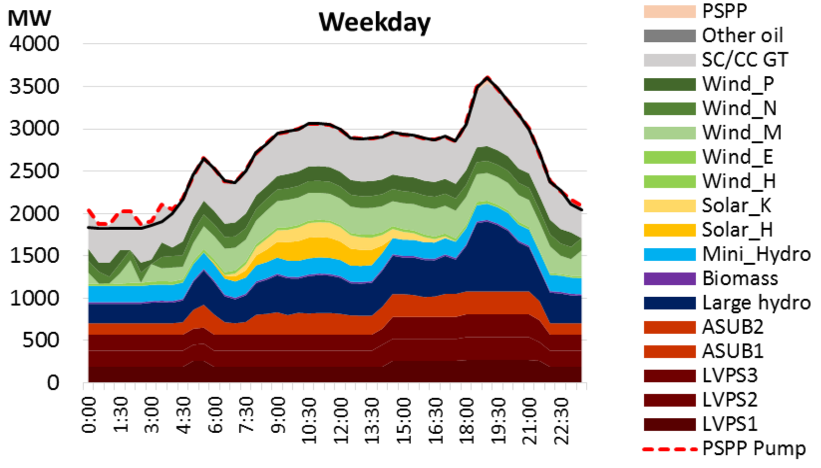
Scenario	State
Hydro Maximum Day Peak – DH	System Stable with Load Shedding
Thermal Maximum Day Peak - DT	System Stable with Load Shedding
Minimum ORE Day Peak – ORE_DP	System Stable
Hydro Maximum Night Peak - NH	System Stable with Load Shedding
Thermal Maximum Night Peak - NT	System Stable
Minimum ORE Night Peak – ORE_NP	System Stable
Hydro Maximum Off Peak - HMOP	System Stable with Load Shedding
Thermal Maximum Off Peak - TMOP	System Stable

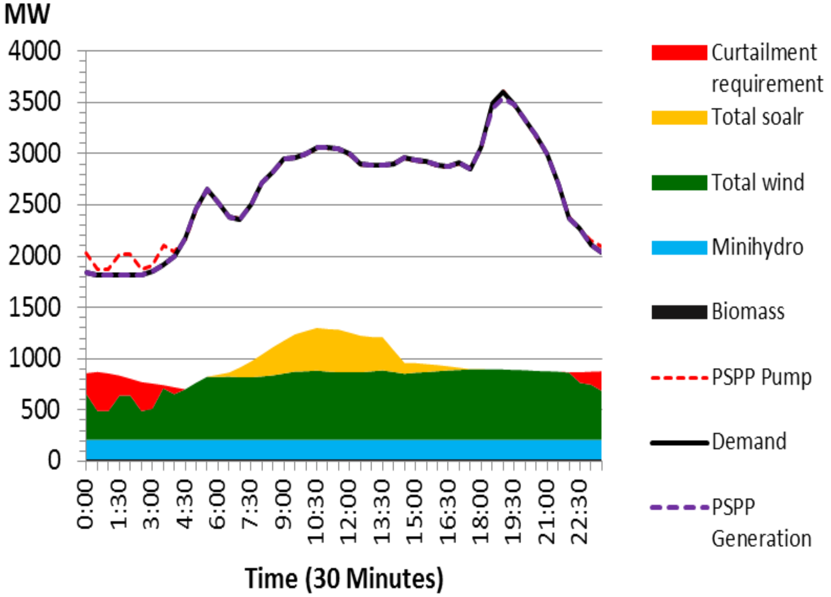
System Operation Study

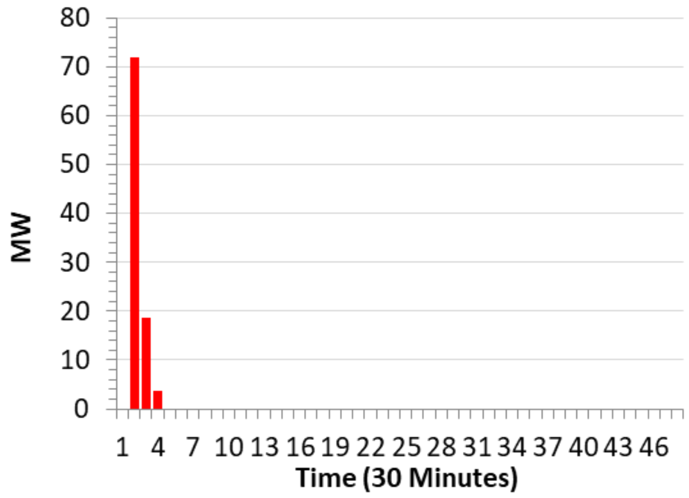
- Medium term hydro thermal optimization and operational analysis with the tool SDDP
- Short term economic dispatch and operational analysis with the tool NCP

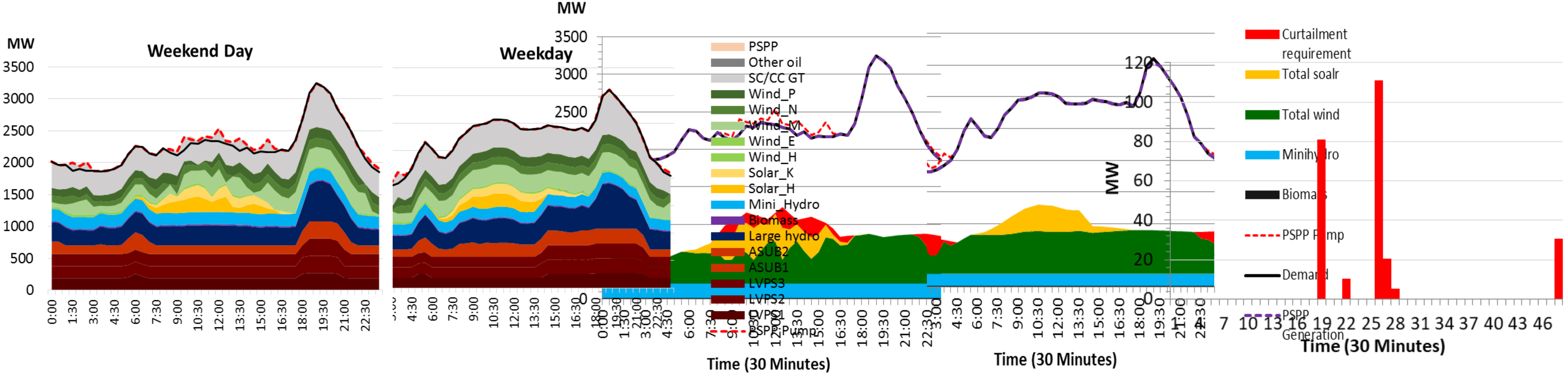
- Time series demand data
- Hydrological Inflow Data
- Hydro/ Thermal plant technical parameters
- Hydro/ Thermal plant operational constraints
- Hydro inflow forecasting methodology
- Fuel Prices and O&M cost of thermal plants
- Annual power plant additions/retirements
- Plant maintenance and outages
- Annual Renewable capacity development
- Time Series RE resource profiles
- operating reserve requirements
- System operational constraints

OPERATIONAL STUDY (Dispatch Results 2025- High wind season)







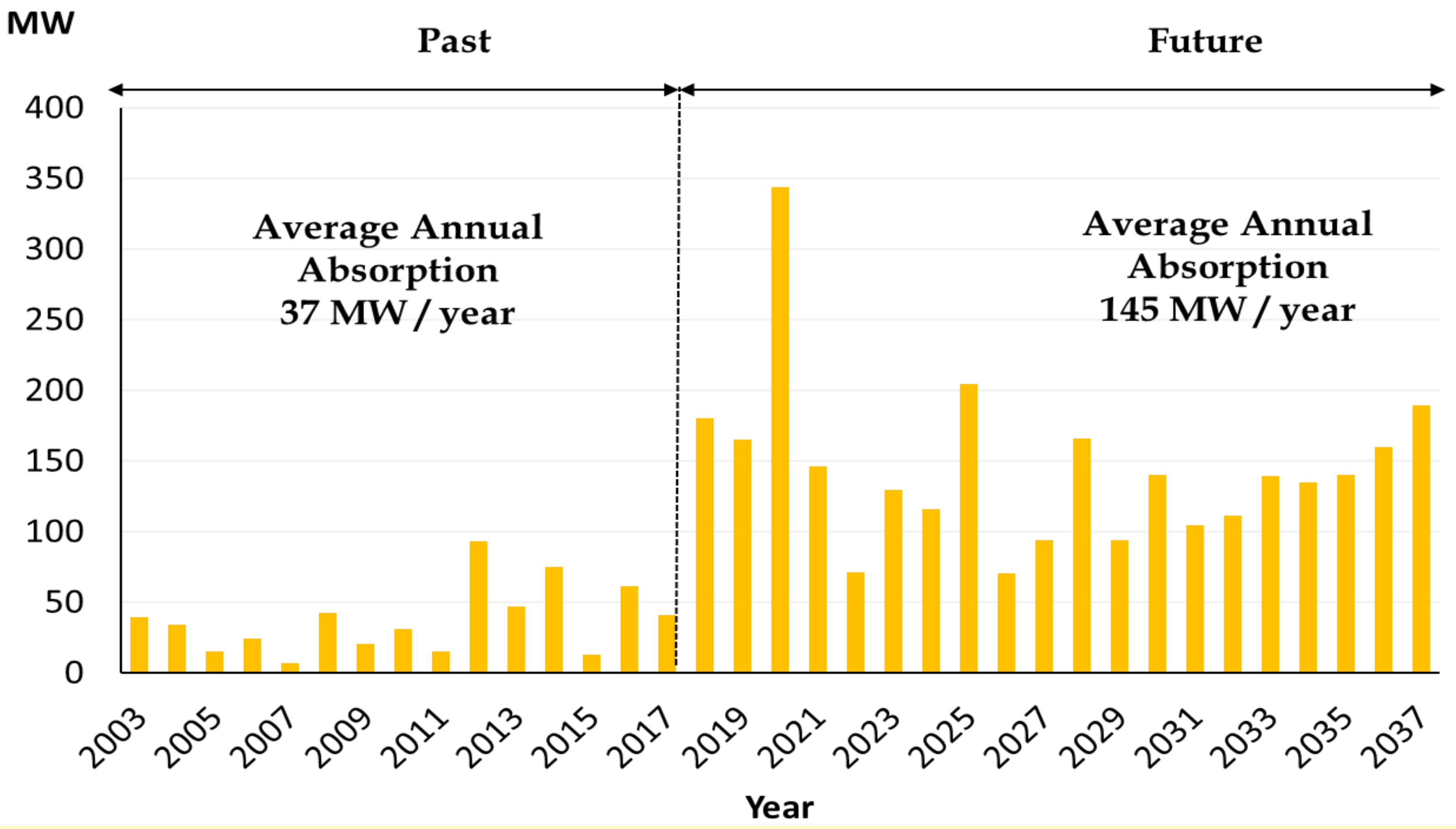


Variable Renewable Energy Curtailment

Year	Maximum NCRE Curtailment Requirement					
	Dry Period		High Wind Period		Wet period	
	Weekday -Offpeak -Daytime	Weekend -Offpeak - Daytime	Weekday -Offpeak - Daytime	Weekend -Offpeak - Daytime	Weekday -Offpeak - Daytime	Weekend -Offpeak - Daytime
Case 1: With Future Coal Power, LNG and Pump Storage Development						
2020	None	None	150MW None	80 MW 50 MW	170MW None	140MW None
2022	None	None	220MW None	140MW 100MW	None	None
2025	None	None	380MW None	330MW 280MW	70MW None	20MW None
2028	-	-	70MW None	30MW 111MW	-	-
Case 2: With No Future Pump Storage and Coal Power Development						
1. With new combined cycle minimum load operation constraint at 50%						
2025	None	None	445MW None	380MW 430MW	None	None
2028	None	None	80MW None	200MW 276MW	None	None
1. With new combined cycle minimum load operation constraint at 30%						
2025	None	None	215MW None	175MW 160MW	None	None
Case 3: LNG Development Restricted to Western Province only						
2028	-	-	70MW None	60MW 185MW	-	-

Study Outcome

Provisions for Annual RE Capacity Additions



The study enabled the Average Annual Absorption of Other Renewables to be nearly four times higher than the past.

Ongoing Work

Understanding System Flexibility

Flexibility Requirement

- Flexibility Reserve
- Ramp characteristics

Sources of Flexibility

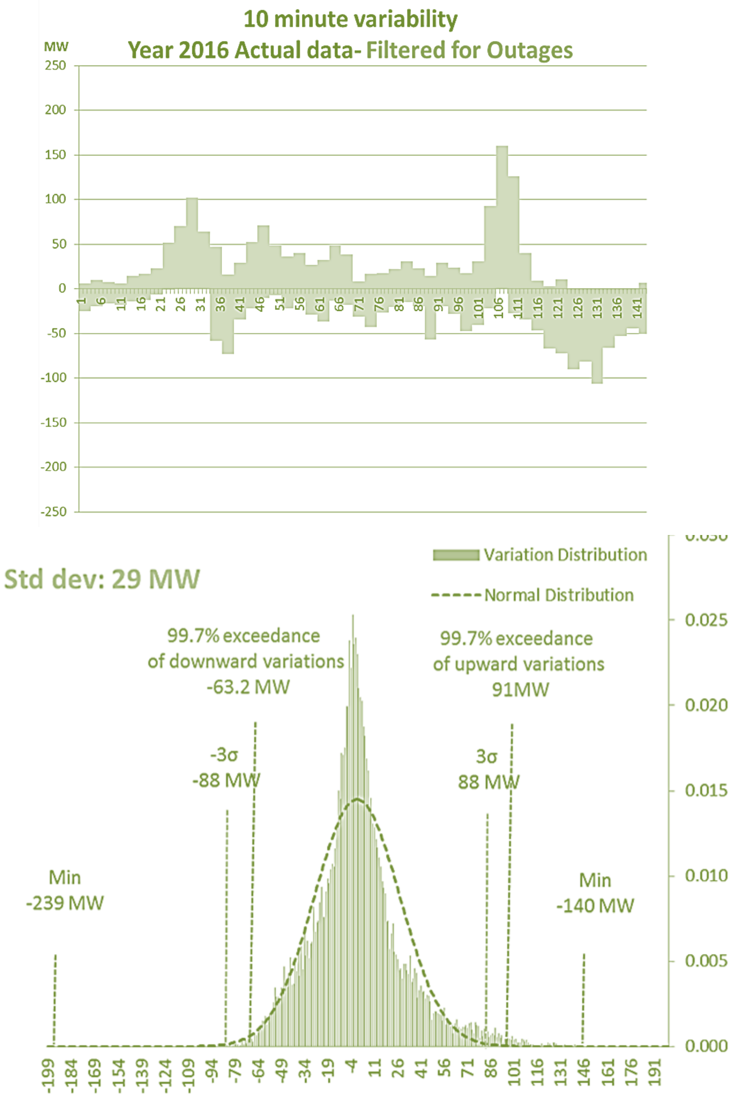
- Dispatchable Generation
- Storage
- Demand Side activities
- Interconnections

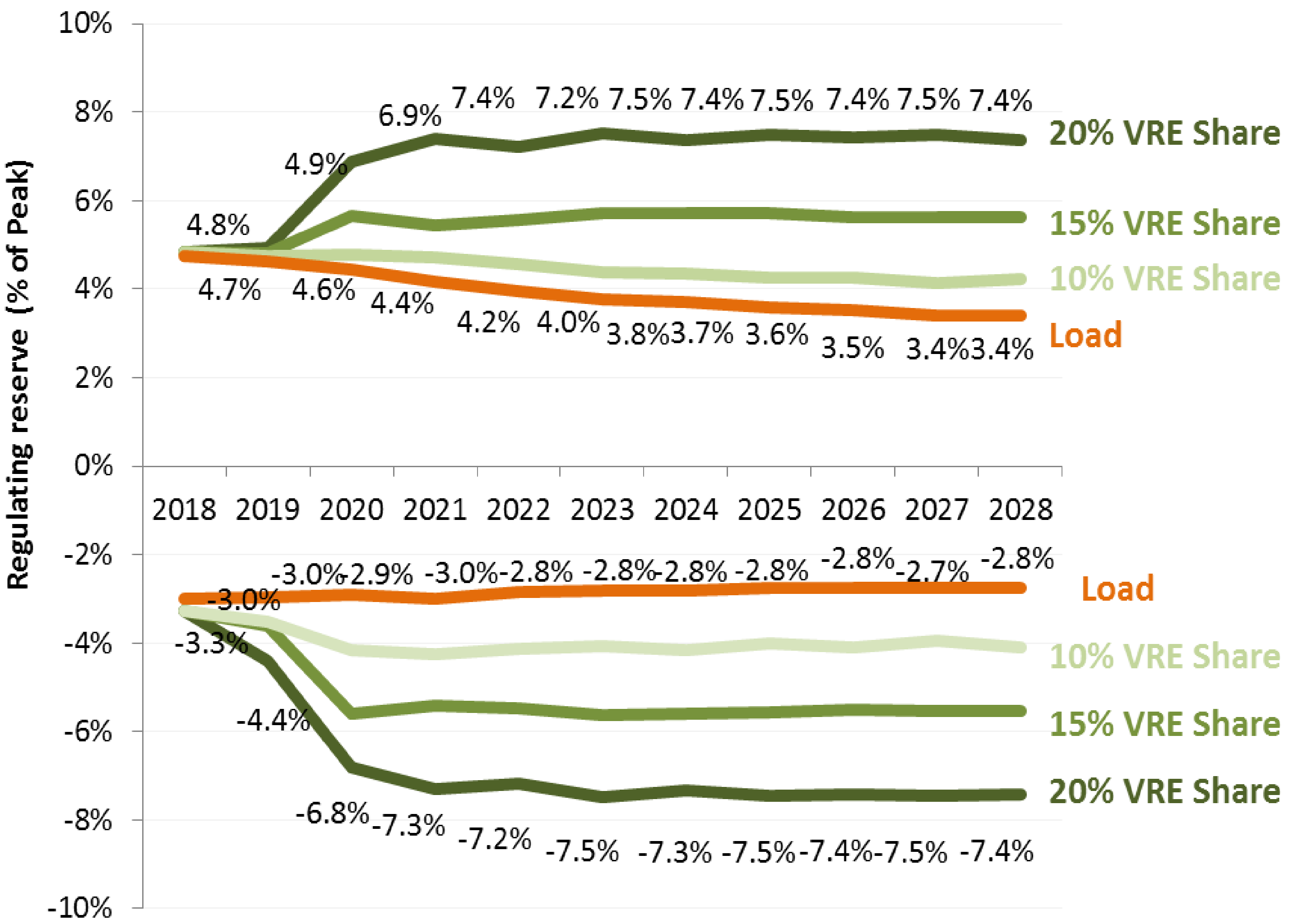
Minimizing Flexibility

- Geographical Spread

Assessing Flexibility Reserve Requirement with VRE

Regulating Reserve Estimation for VRE development





Evaluating Flexibility requirement

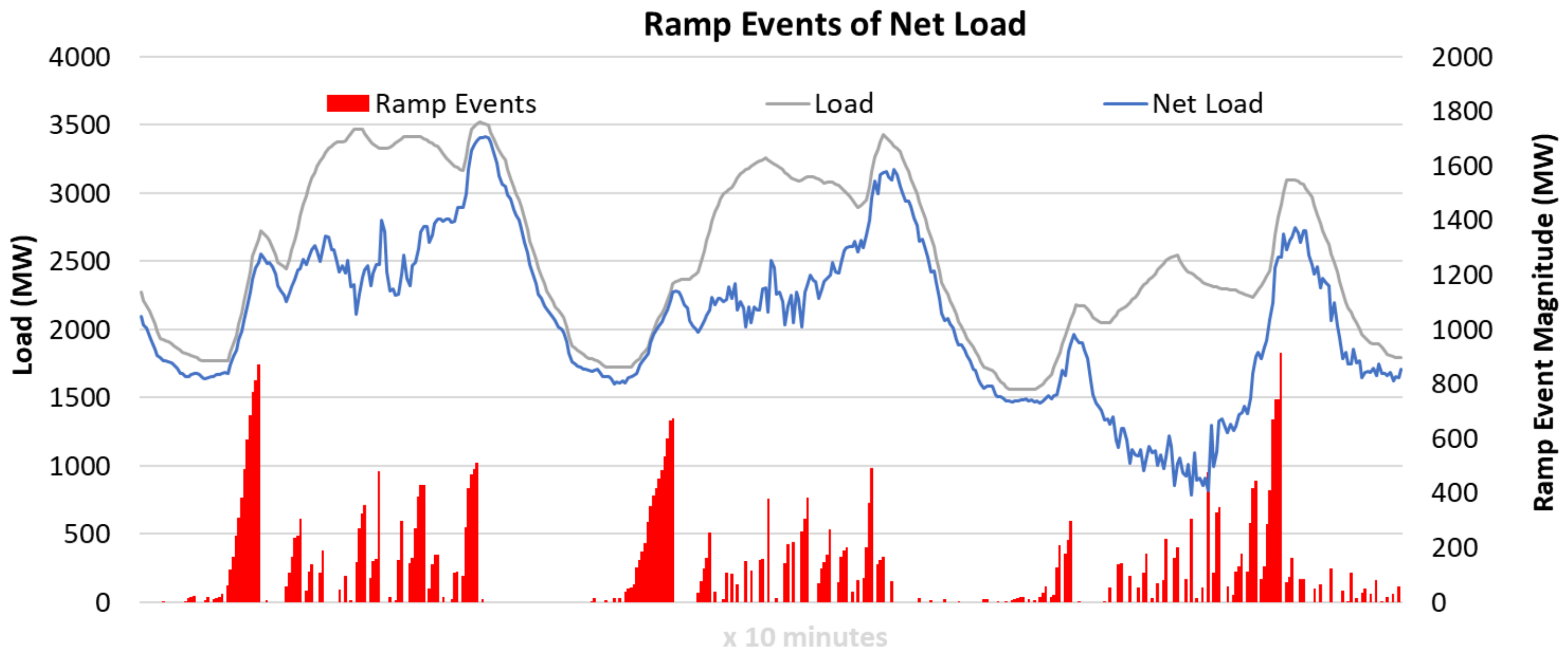
Main attributes of the flexibility requirement

- **Magnitude of the ramp**
- **Ramp duration**
- **Ramp rate**
- **Frequency of occurrence**

Analytical techniques

- **Impact of Plant minimum operating level**

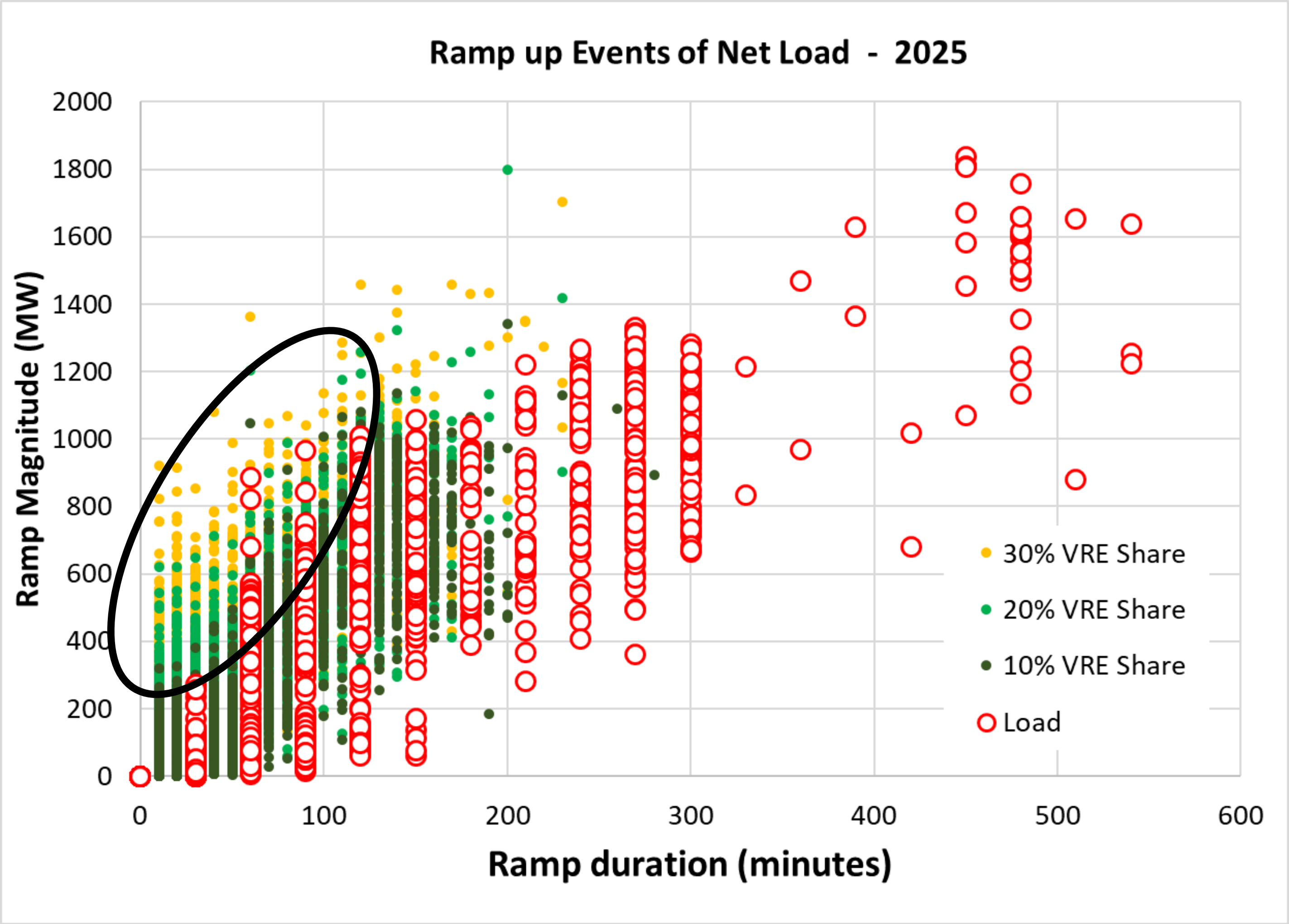
Production simulation



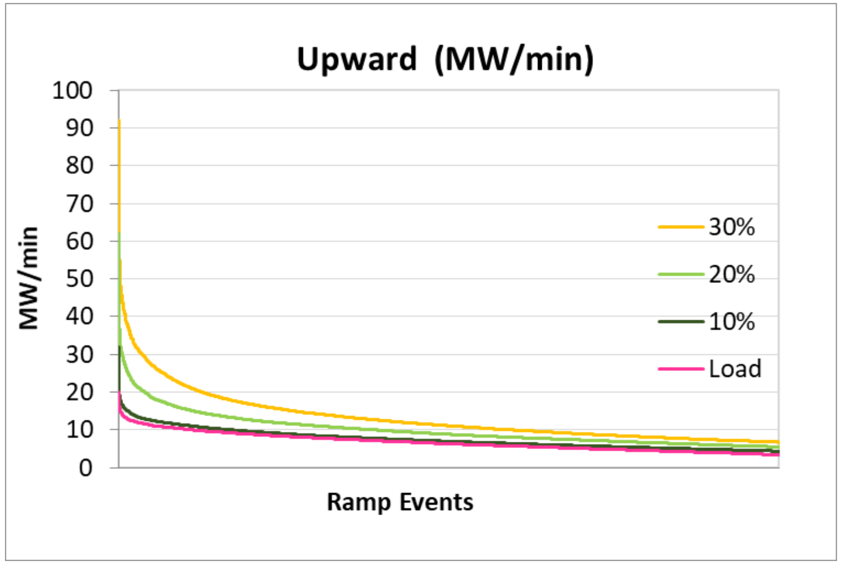
- **Ramp Magnitude**
- **Ramp Duration**
- **Ramp rate**

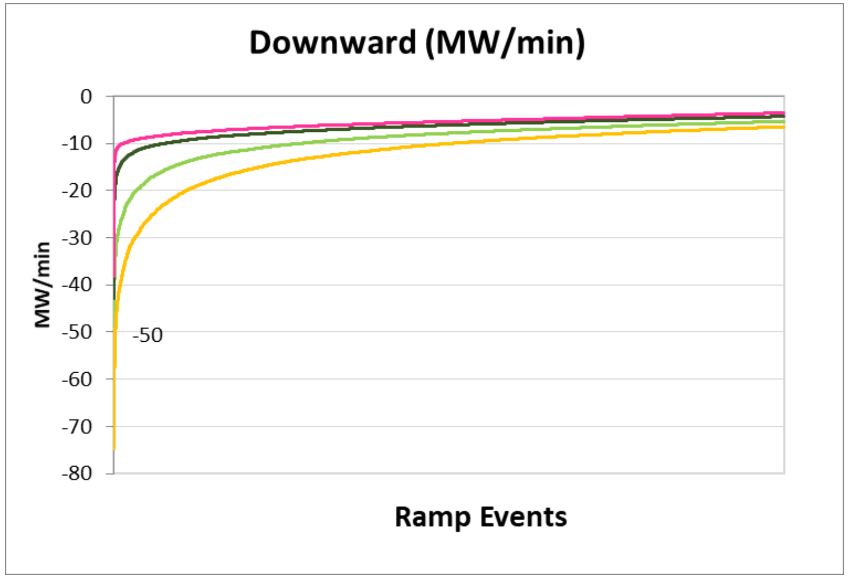
Assessing Flexibility requirement

Ramp events in VRE development scenarios



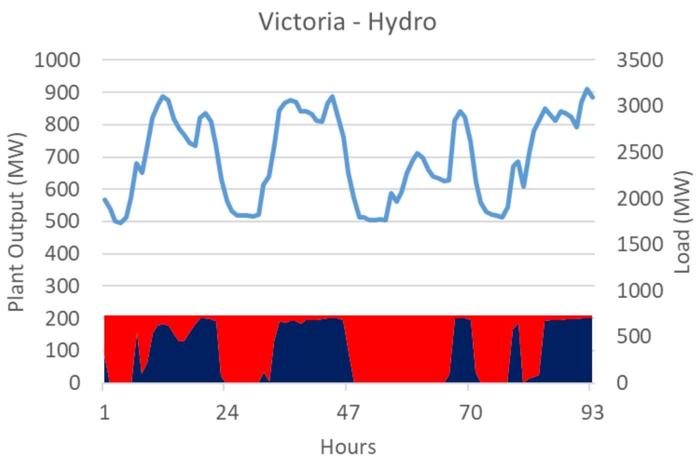
Duration curves of Ramp Rate Requirement

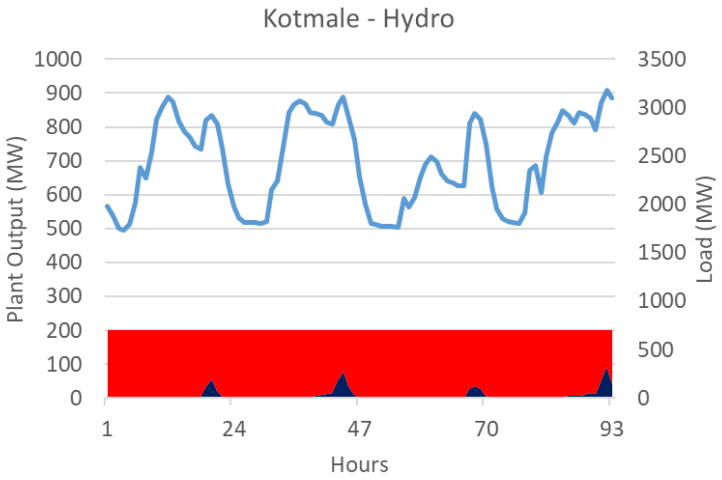


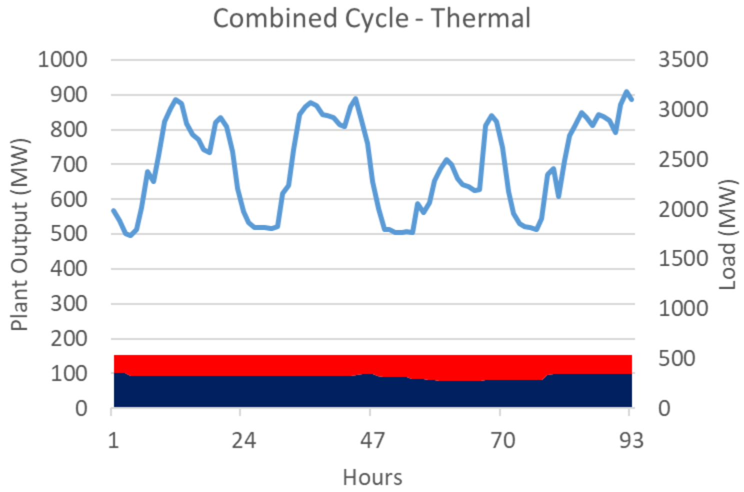


Flexibility of Generating Units

Flexible contribution of future regulating units

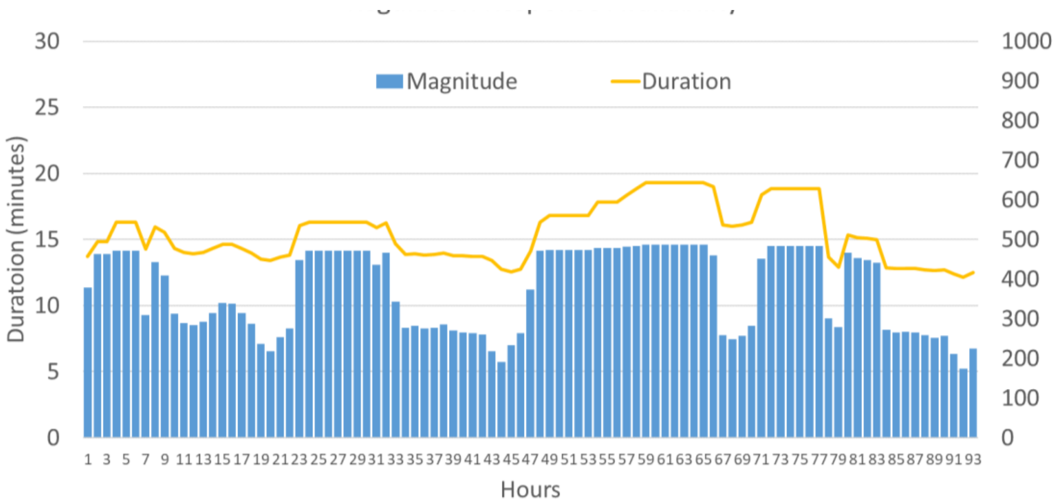




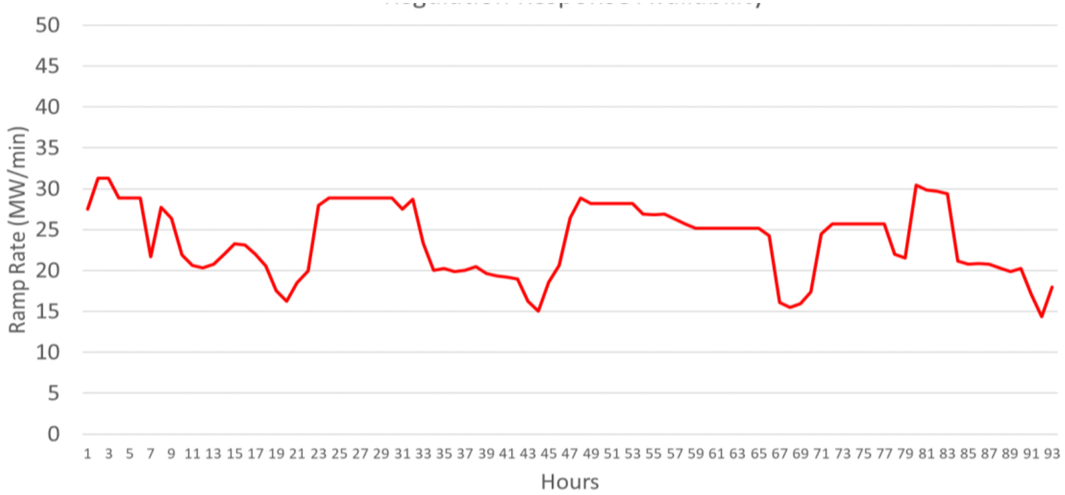


Aggregated Regulation Response Availability

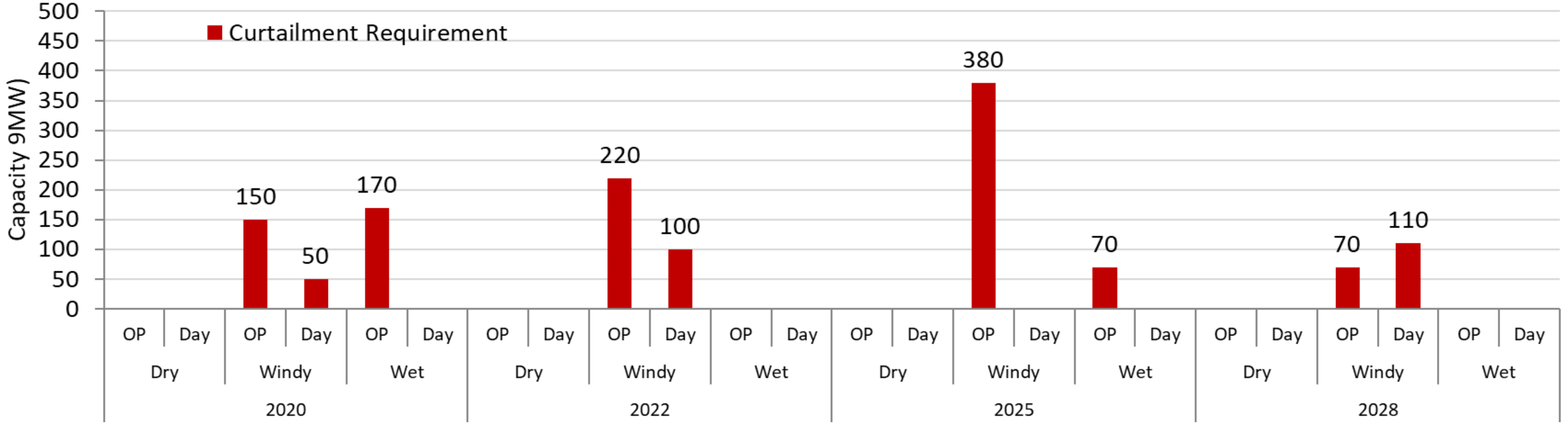
Reserve Magnitude and Duration



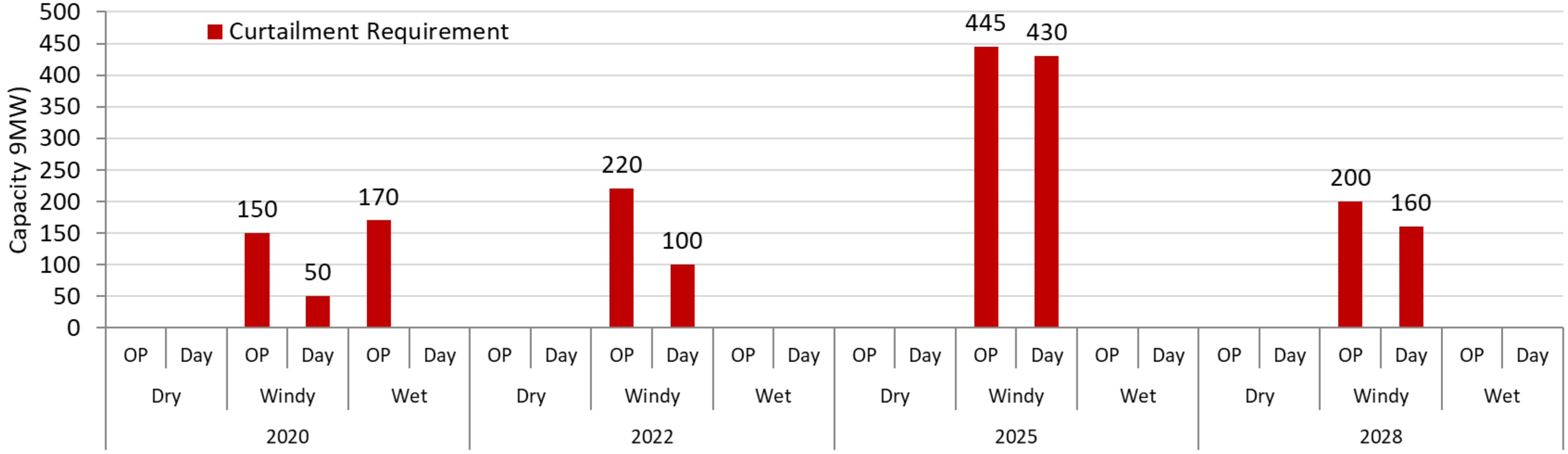
Ramp Rate of Reserve



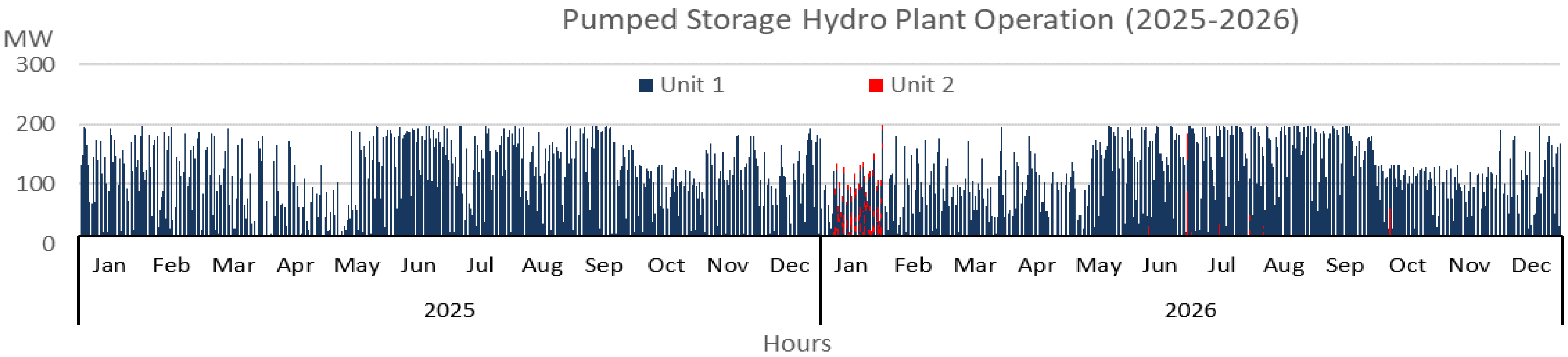
With Coal, Combined Cycle and Pumped Hydro units



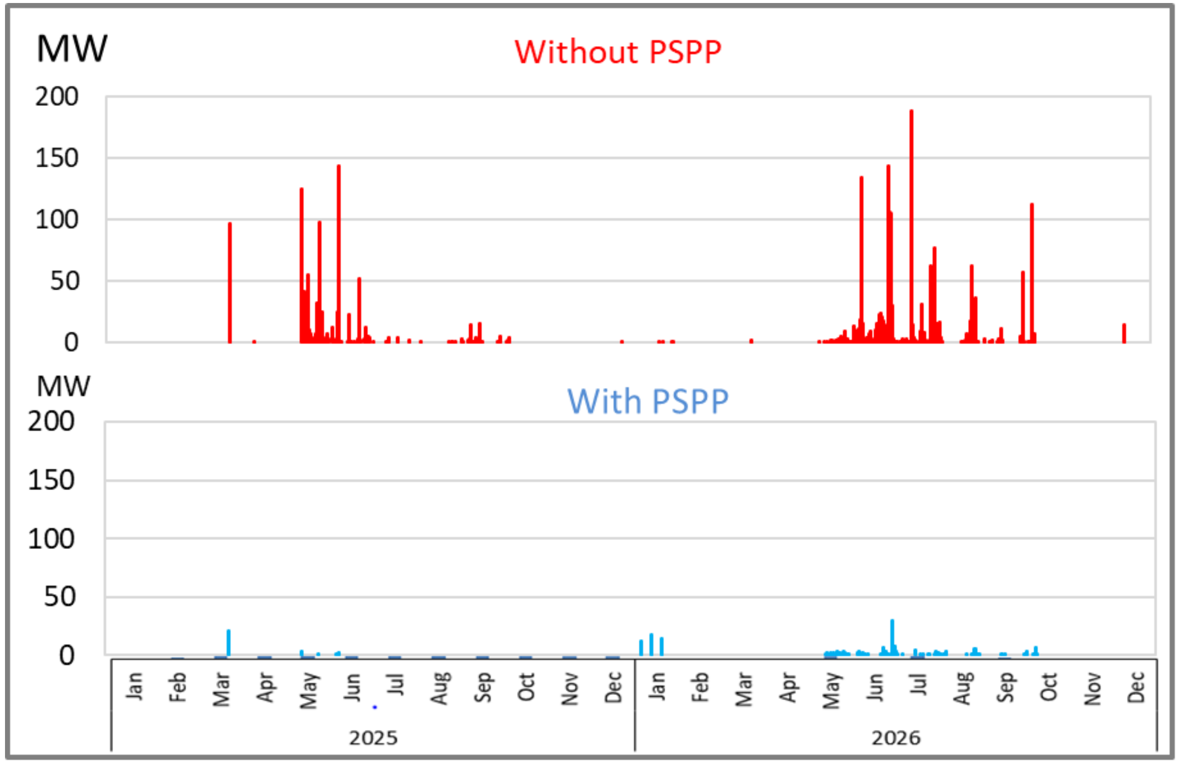
With only combined cycle units



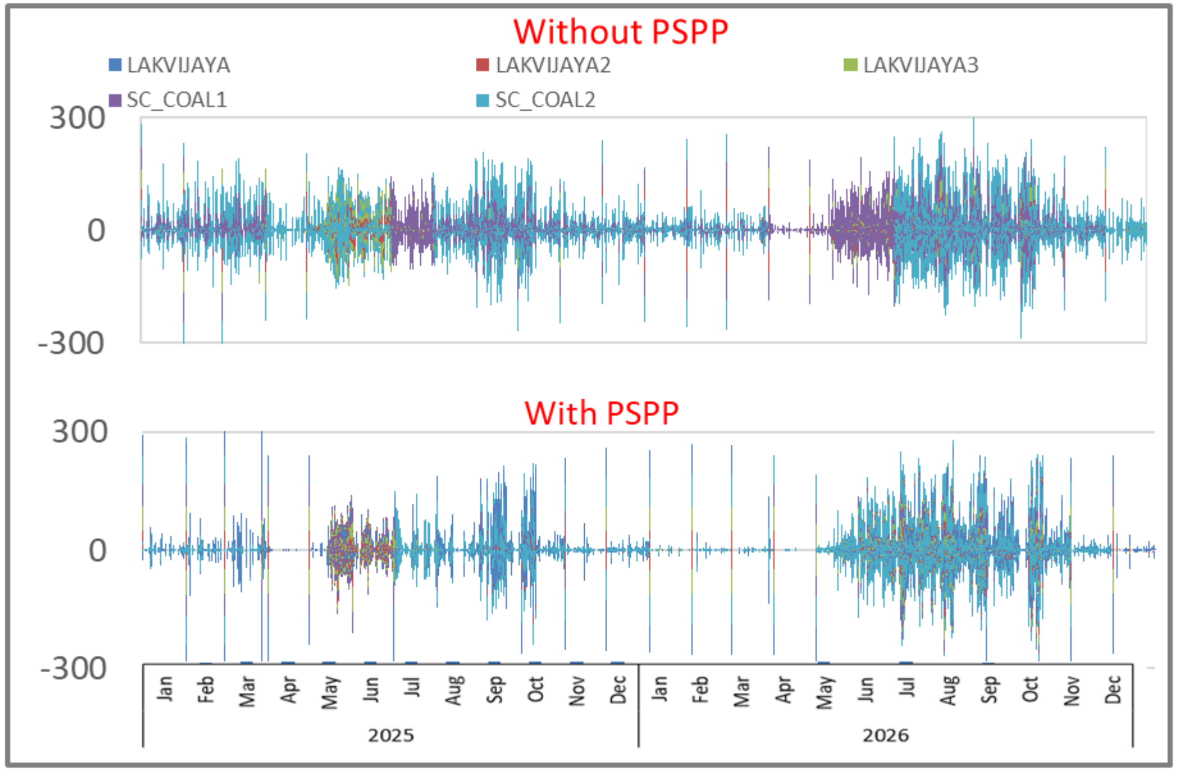
Impact of Pumped Storage Hydro Plant Operation



VRE Curtailment

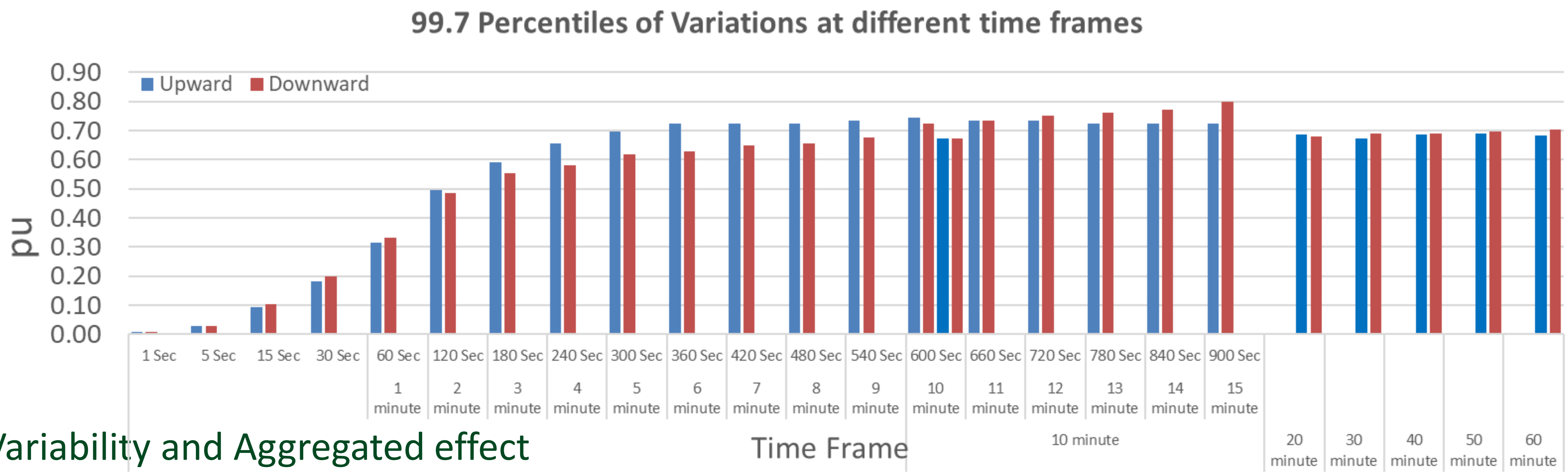


Baseload Plant Cycling

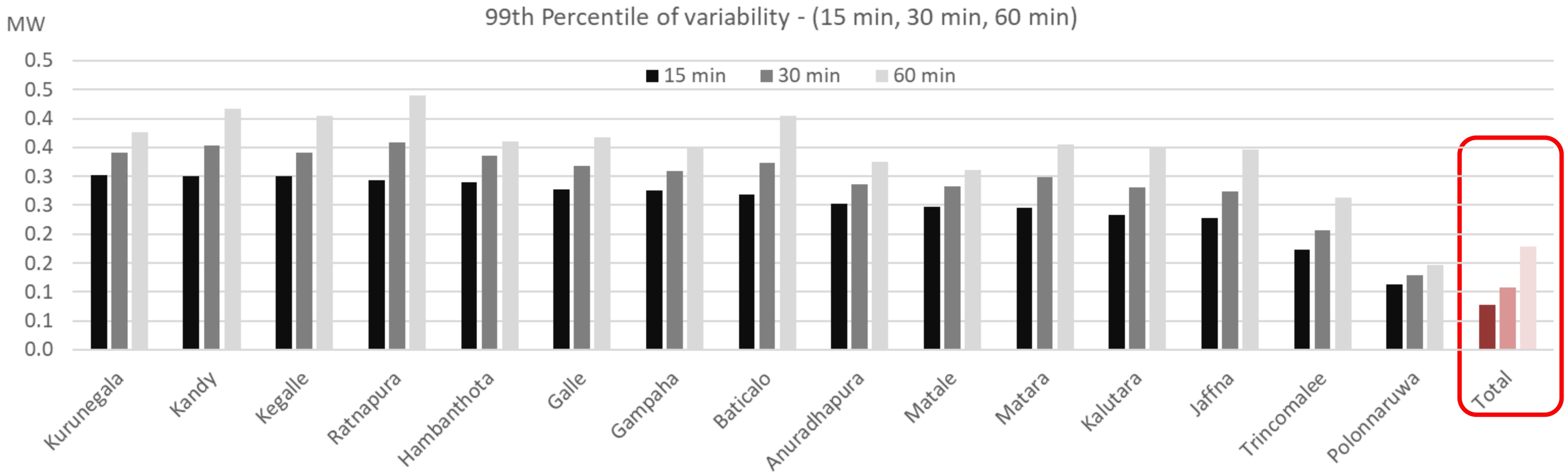


Assessing the Variability of Distributed Solar PV

Temporal Variability

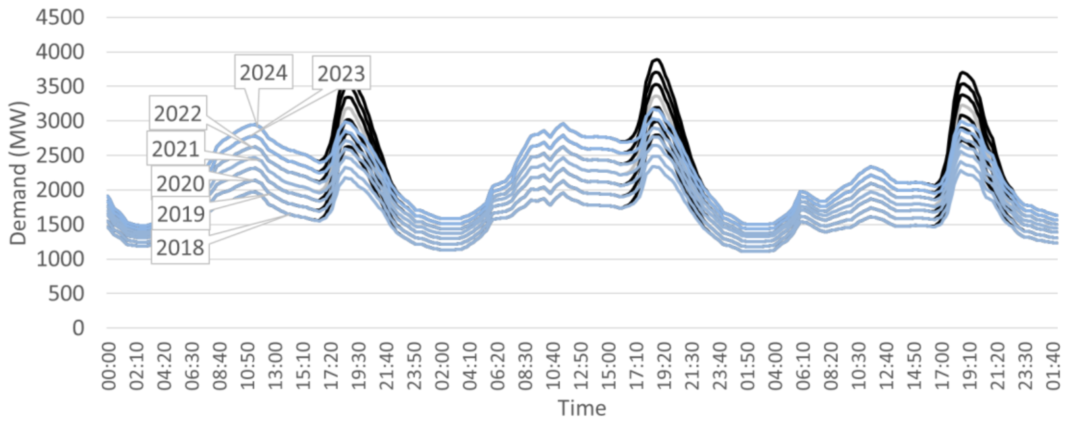


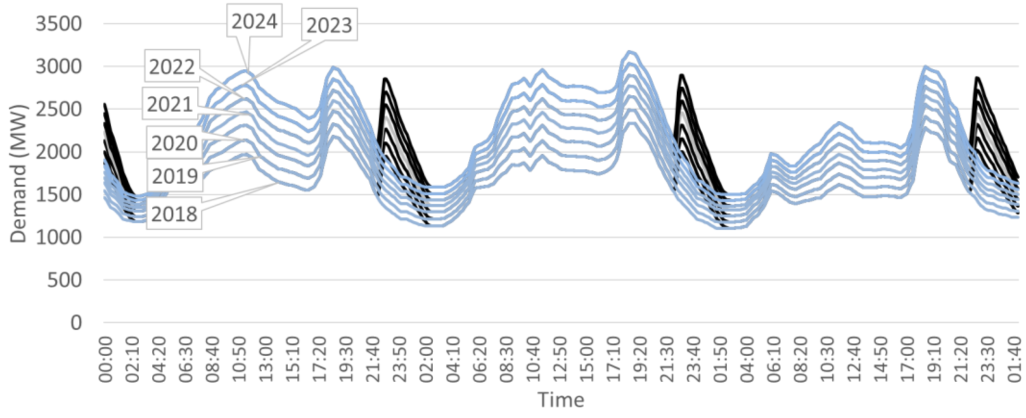
Spatial Variability and Aggregated effect



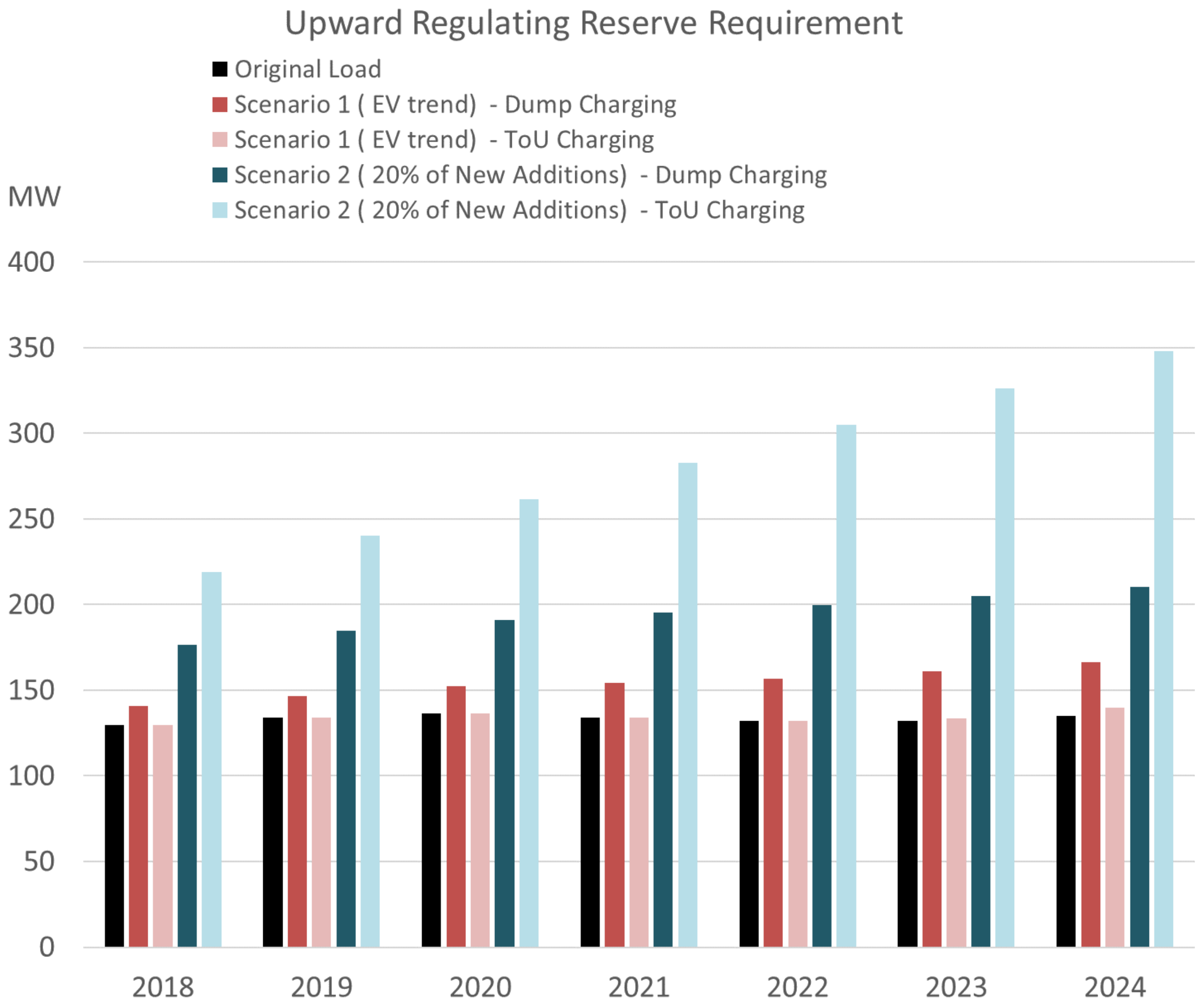
Analyzing Demand Side activities

Impact of EV charging load on the flexibility Requirement





Upward Regulating Reserve Requirement



Way Forward

- **Diversified and Prioritized** resource locations for VRE
- Establishing **wind and solar forecasting systems** to the national dispatch center.
- Providing Variable Renewable Energy (VRE) **curtailment rights** to system operator
- Base load power plants with **increased flexibility.**
- Utilizing **Demand side management and response** to provide flexibility
- **Continuous upgrades to RE integration studies**
- Proper and **timely implementation** of VRE and other major power plants

Thank You