Grid Scale Renewable Energy Community of Practice

Online Session 4: Grid Integration Studies for Variable Renewable Energy

Date: August 29, 2018

www.ledsgp.org
www.asialeds.org

AGENDA

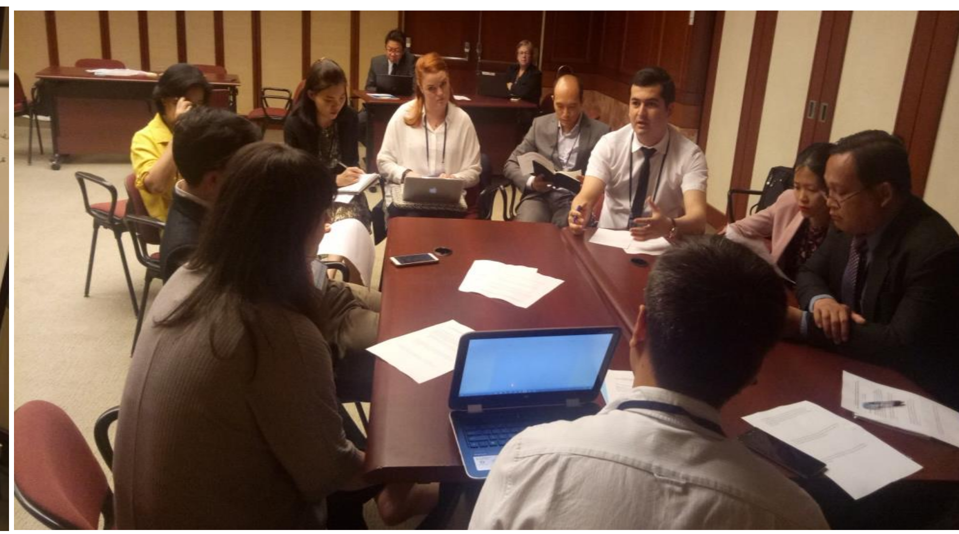
5 min	Welcome and Recap of GRE CoP session at Asia Clean Energy Forum 2018	Carishma Gokhale-Welch, LEDS GP EWG, NREL; Nikhil Kolsepatil, ALP
15 min	Round robin: country participant introductions	All
20 min	Grid Integration studies: basics, best practices, data and analysis	Ilya Chernyakhovskiy, LEDS GP EWG, NREL
15 min	Sri Lanka Grid Integration study	Randika Wijekoon, Ceylon Electricity Board
30 min	Open discussion	All
5 min	Closing and next steps	Carishma Gokhale-Welch, LEDS GP EWG, NREL

ALP GRE CoP at Asia Clean Energy Forum 2018 - Recap

- GRE CoP peer-learning session on ‘Integrating Renewable Energy into the Grid: Opportunities, Challenges and the Way Forward’
- Deep-dive workshops
  - ‘Grid Integration of Variable Renewable Energy’ by USAID, GIZ and NREL
  - ‘Renewable Energy Auctions: A New Paradigm for Asia’ by USAID
- ~30 new members joined the CoP

ALP GRE CoP Peer-Learning Session at ACEF 2018

- Attended by representatives from Bangladesh, Bhutan, India, Indonesia, Kazakhstan, Laos PDR, Nepal, Sri Lanka, and Thailand
- Working Session
    - Policy and Technical groups – existing country-specific grid integration work, challenges, and needs
    - Most important steps and possible actions recommended for advancing RE grid integration in each country



ALP GRE CoP Peer-Learning Session at ACEF 2018

Key topics of interest:

- Grid integration and distribution system studies
- Grid codes: establishment, timely updates to requirements, and enforcement of grid codes
- Competitive auctions for renewable energy procurement
- Implementation of incentives and compensation mechanisms to promote flexibility in grid operation

Deep-dive workshops at ACEF 2018

- Summary report of both deep-dive training workshops on Grid Integration and RE Auctions available on GRE COP webpage under 'Activities':

http://www.asialeds.org/grid-renewable-energy/

- Useful Resources from Grid Integration and RE Auctions deep-dive workshops:
  - Status of Power System Transformation 2018
  - Toolbox for coal power plant flexibility (includes 40 technical retrofit measures for main systems of the power plant)
  - Greening the Grid
  - Modeling study for distributed rooftop solar PV in Indian cities
  - Renewable energy auctions: Cases from sub-Saharan Africa
  - Renewable Energy Auctions: Analyzing 2016
  - Renewable Energy Auctions: A Guide to Design
- Presentations from ACEF deep-dive workshops

NATIONAL RENEWABLE ENERGY LABORATORY

Introduction to Grid Integration Studies

Ilya Chernyakhovskiy, NREL

August, 2018

What is a Grid Integration Study?

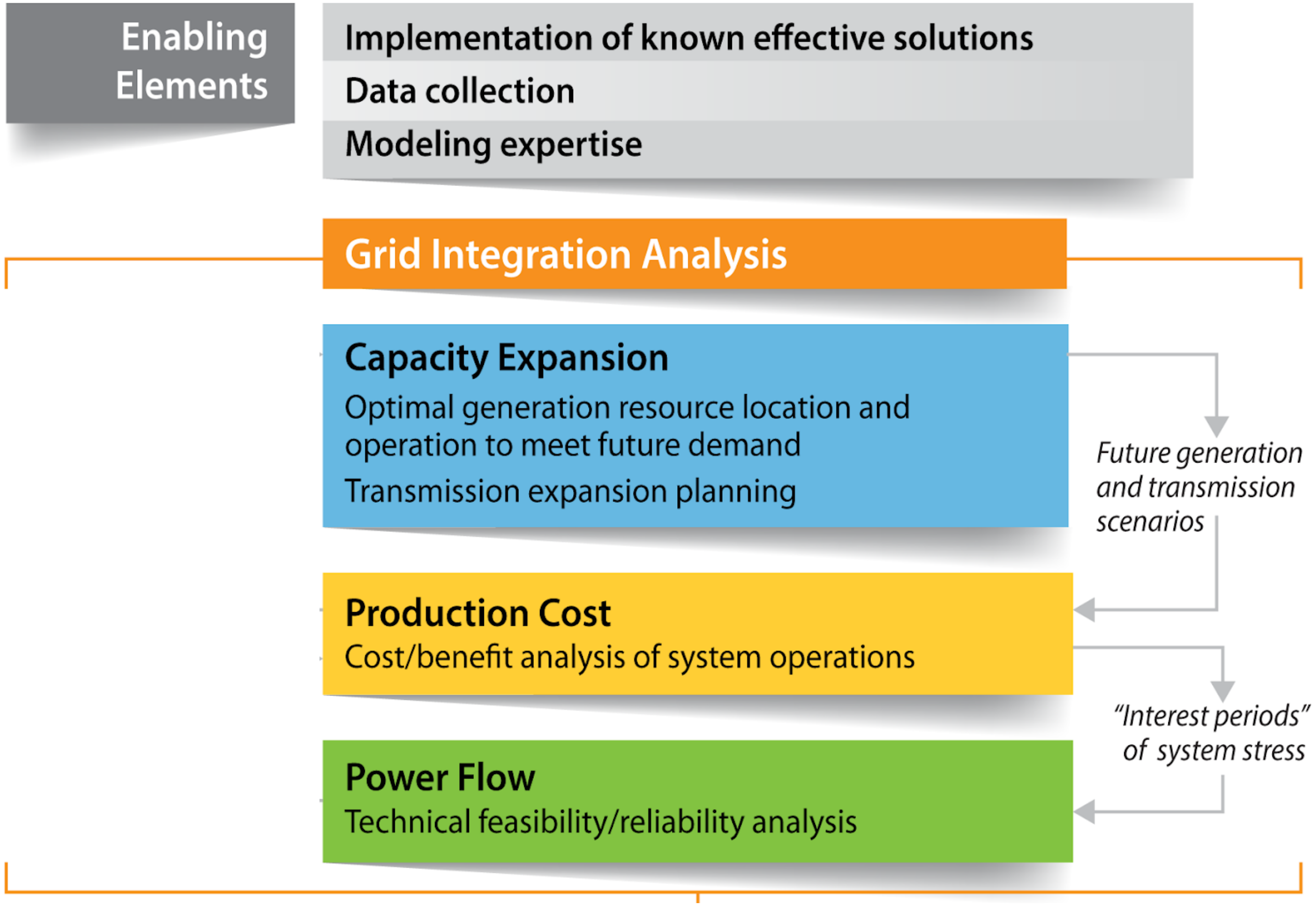
A grid integration study represents a comprehensive examination of the technical challenges and potential solutions associated with integrating significant variable RE generation to an electricity grid.

- How much capacity do I need to reliably meet future demand? What the operational impacts of increasing shares of variable RE?
- What is the least-cost capacity mix?
  - Impact of gas price swings on the future energy mix?
  - Impact of more stringent environmental regulations?
- How do we achieve specific energy goals?
  - How do we achieve #% amount of RE? Where should projects be sited? What are the T&D constraints?
  - How do we achieve other energy sector goals, such as emissions reductions or reduced water consumption?
- What is the government’s commitment to development of the energy sector?

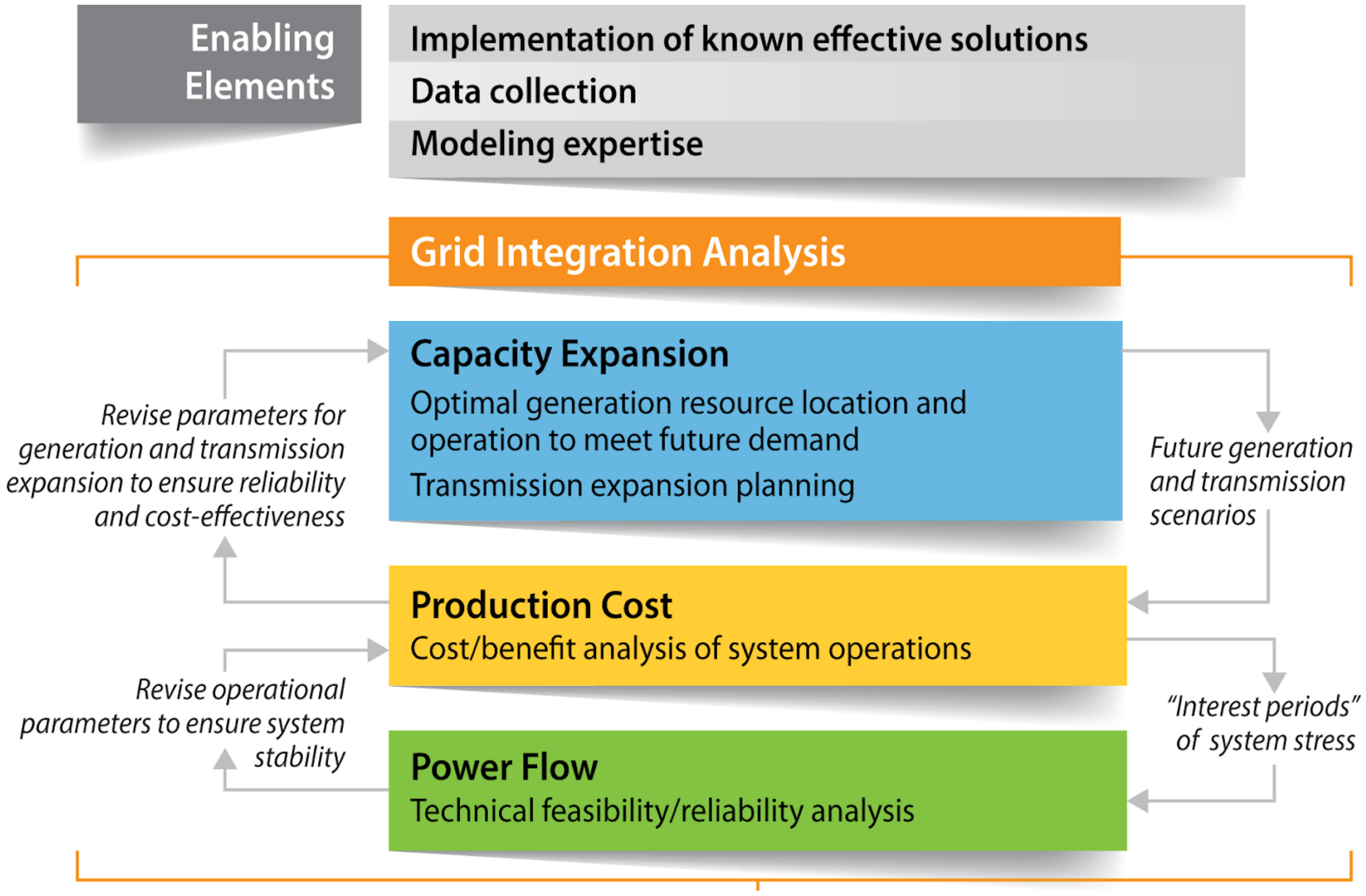
The Role of Grid Integration Studies

Enabling Elements	Implementation of known effective solutions
	Data collection
	Modeling expertise

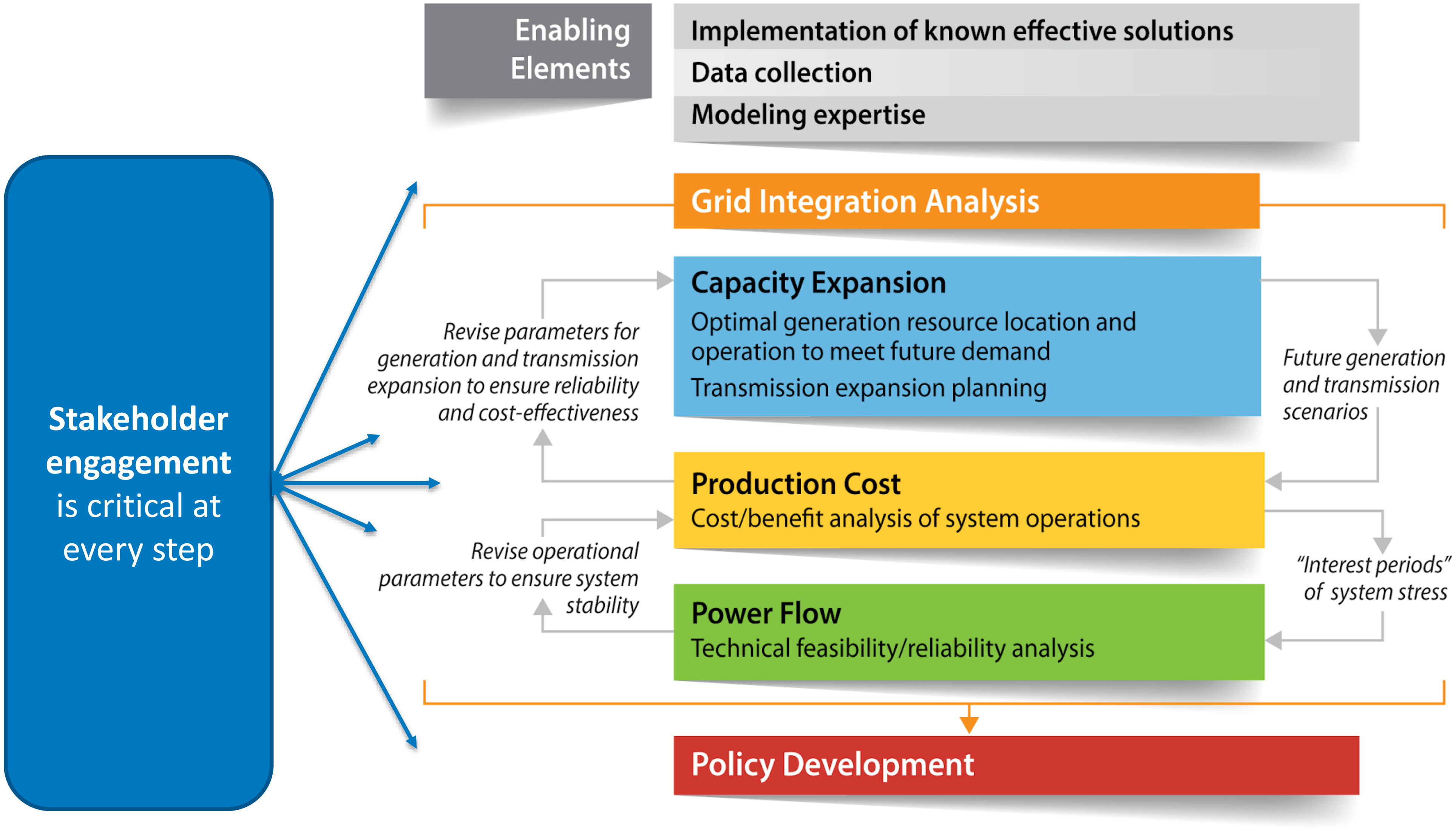
The Role of Grid Integration Studies



The Role of Grid Integration Studies



The Role of Grid Integration Studies



What are the phases of a grid integration study?

Task 1: Data Collection	**Task 2:** Scenario Development	**Task 3:** Analysis	**Task 4:** Facilitation and Reporting
Wind / Solar Profile Development (Resource +Location)	**Resource Scenarios** (wind, solar, conventional, demand response, storage)	**Organize datasets to represent all scenarios and sensitivities**	**Data analysis and output synthesis**
Existing system data (load, grid, power plants, etc.)	**Transmission Scenarios**	**Run the model, analyze initial results, make necessary adjustments**	**Final Report**
	System Management Scenarios (Design/Planning/Reserves/Operational Methods/Markets)		
Stakeholder Meetings	**Stakeholder Meetings**	**Stakeholder Meetings**	**Stakeholder Meetings**

Important Considerations

- Significant data collection and preparation
- Scenario preparation defines potential pathways
- Significant iteration between phases
- Stakeholder engagement at each phase

Who are the typical stakeholders?

- Wind and solar data providers
- System operator(s)
- Utilities (if distinct from system operator)
- RE plant owners/operators/developers
- Conventional plant owners/operators/developers
- Transmission developers (if distinct from utilities)
- Regulators and Policymakers
- Public Advocates

Stakeholder Meetings	**Stakeholder Meetings**	**Stakeholder Meetings**	**Stakeholder Meetings**

Stakeholder engagement across various phases is important, but takes different forms depending on the phase of the study.

Technical Review Committee (TRC)

- Why use a TRC?
  - Ensure technical accuracy with high quality data, and contribute to a robust, credible, actionable study
  - Link studies to industry concerns; reduce risk of being an academic study
  - Ensure rigorous peer-review and input at all stages of study
  - Deepen understanding of high RE issues and solutions among stakeholders
- What does the TRC do?
  - Assist the sponsors in developing study parameters—objectives, scenarios, and sensitivities
  - Reviews modeling team's methods, data sources, assumptions, and other key issues
  - Helps interpret modeling results
  - Links model outcomes with policy and regulatory processes
  - Endorses technical rigor of the study

Example:
http://www.pacificorp.com/content/dam/pacificorp/doc/Energy_Sources/Integrated_Resource_Plan/2017_IRP/PacifiCorp_2017_FRS_TRC_TechnicalMemo_Final.pdf

Input Data for Grid Integration Studies

Task 1: Data Collection

Data element	Example parameters	Dimensions and resolution
Solar resource	Solar irradiation, temperature, wind speed, solar forecasts and associated error for multiple historic weather years	Temporal (e.g. hourly), spatial (e.g. 10 km, or site-specific), forecast/actual, forecast horizon (e.g. hour-ahead, day-ahead);
Wind resource	Wind speed, temperature, pressure, wind forecast and associated error for multiple historic weather years	Temporal (e.g. hourly), spatial (e.g. 4 km, or site-specific), height of measurement, forecast/actual, horizon
Wind turbine capabilities	Turbine power curve, fault ride through, active power frequency response, inertial response, reactive power, fixed and variable O&M costs for current and potential future systems	Individual facility data or average values, depending on study objectives
PV system capabilities	Conversion efficiencies, active power control (via smart inverters), storage, other system characteristics, fixed and variable O&M costs for current and potential future systems	Individual facility data or average values, depending on study objectives
Hydro resources	Hydrological constraints (e.g. seasonal water availability), pumping capabilities, reservoir sizes for multiple historic weather years	Individual facility data or average values, depending on study objectives
Thermal fleet characteristics	Fuel type, capacity, operational limitations (e.g. due to fuel or water availability), ramp rates, minimum turn downs, heat rate curves, start-up times, availability / outage rates, fuel prices, operational costs (e.g. cycling costs), fixed and variable O&M costs for current and potential future systems	Individual facility data or average values, depending on study objectives

Input Data for Grid Integration Studies (continued)

Task 1: Data Collection

Data element	Example parameters	Dimensions and resolution
Load Data	Historic electricity demand and forecasts	Temporal, spatial, forecast/actual, forecast horizon
Transmission Data	Location of lines, rated voltage, rated capacity, line impedance, reactive compensation units, transformers, dynamic line ratings interconnections to other systems, historical load flows for current and potential future systems	Spatial
Grid Operation Practices	Dispatch interval, market/interchange rules and rates, forecast scheduling practices, interconnections to other systems, RE curtailment practices, and other grid codes for current and potential future systems	N/A
Other Operational Constraints	Fuel availability, air/water temperature impacts on plant efficiency/availability, operational (spin, non-spin) and planning reserve margins for current and potential future systems	N/A
Demand Response and Storage availability	Availability, costs for current and potential future systems	Individual facility data

Data for Grid Integration Studies

Task 1:
Data Collection

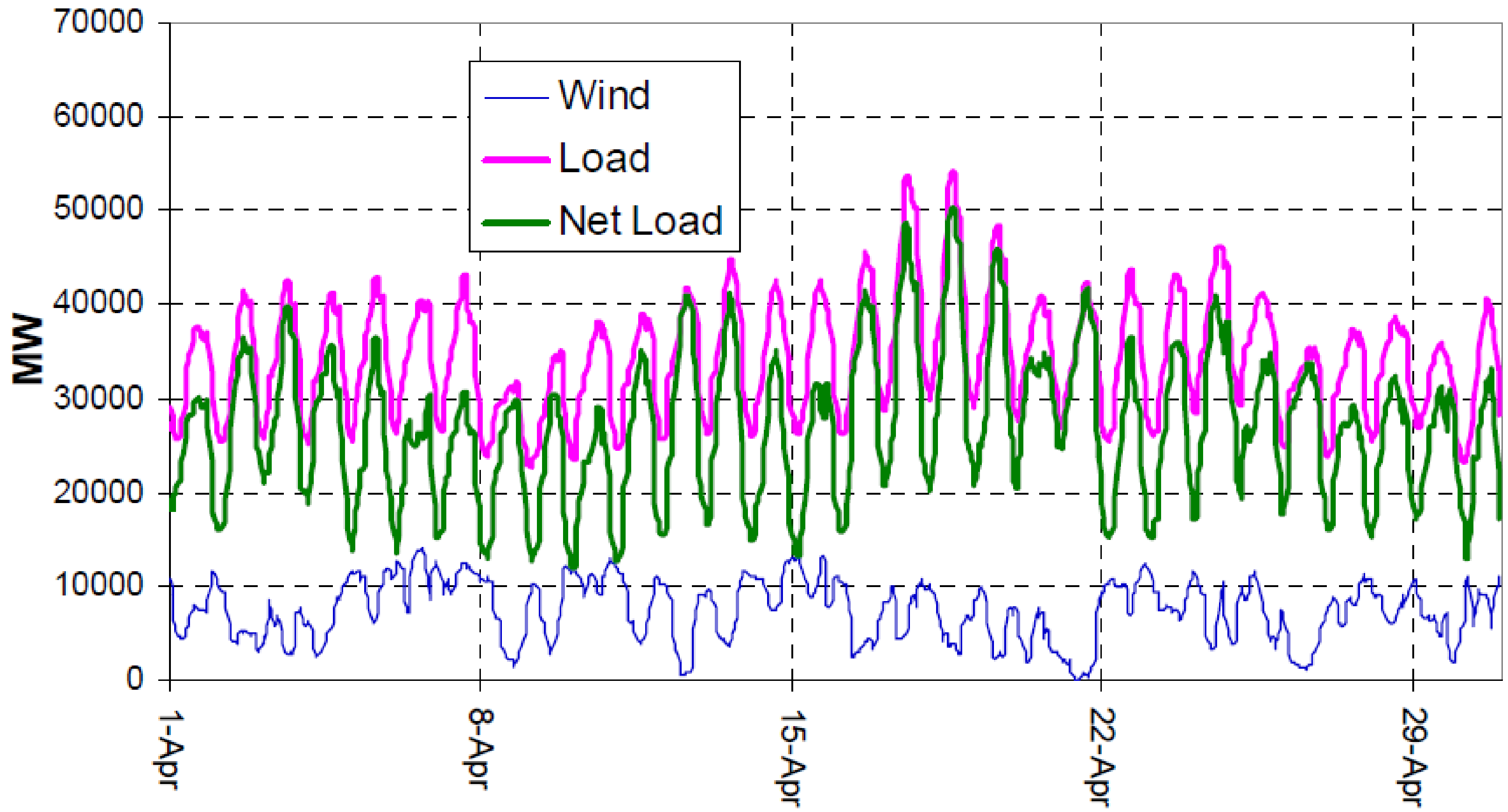


Figure 2- Load, 15 GW of wind generation, and net load for April of study year

Source: ERCOT 2008

Scenario Development: Important Definitions

Task 2:
Scenario Development

- **Scenario: A scenario is one possible future electric generation system.**
  - A typical analysis has 3-4 scenarios, which might vary by total renewable generation penetration, the ratio of solar to wind generation, mix of storage, rate of demand growth, etc.

- **Sensitivities: A sensitivity is generally an alternative operational practice or the availability of a mitigation option.**
  - For example, changing the flexibility of load or hydro resources; changing the size of a balancing area. A sensitivity is applied to all scenarios and the results are reported relative to the base case (scenarios without sensitivity options).

Different Types of Grid Integration Studies

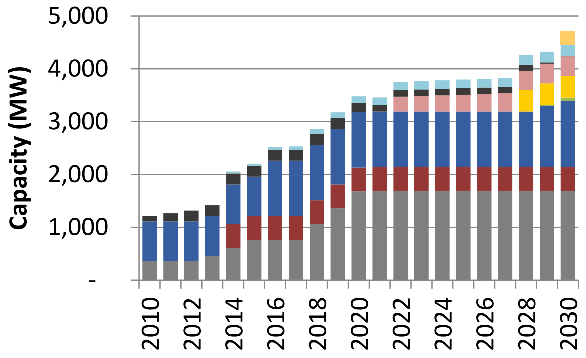
Task 3:
Analysis

1. Capacity Expansion Planning

Questions addressed:

- Where, when, how much, and what types of generation and/or transmission capacity do I need to achieve RE targets at least cost?

Key Stakeholders:
Ministry of Energy, Planning agency, Utility

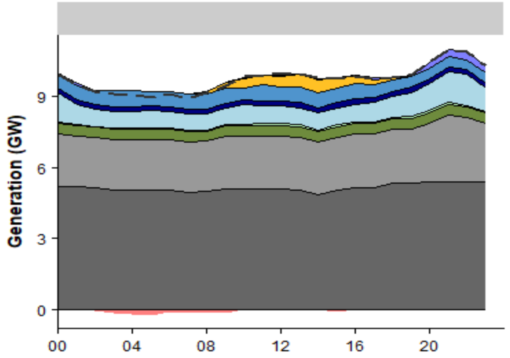


2. Production Cost Modeling

Questions addressed:

- What are the system-wide operating costs and impacts associated with RE development? What are impacts of different flexibility options?

Key Stakeholders:
Regulators, utilities, transmission operators, generators

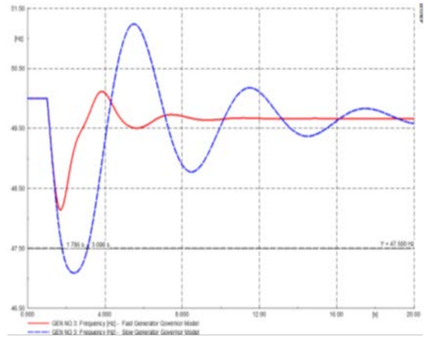


3. Power Flow Studies

Questions addressed:

- Does the system meet reliability criteria? How does the power system respond to a disturbance under various RE deployment scenarios?

Key Stakeholders:
Transmission and distribution system operators, utilities, regulators



1. Capacity expansion planning

Task 3:
Analysis

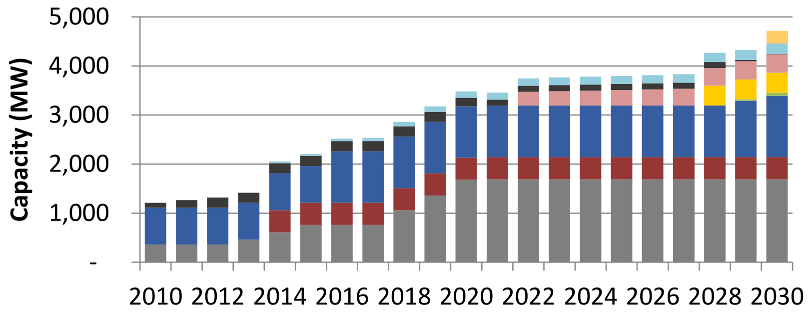
Objective:
Identify investment and retirement decisions to MINIMIZE

Net Present Value

Generation & Transmission Investments
\+ Fixed O&M Costs
\+ Fuel Costs
\+ Reserve Costs
\+ Environmental Costs

Subject to investment, operational, environmental constraints.

Year 1 | Year 2 • • • Year 30



Scenarios and Assumptions

Task 3:
Analysis

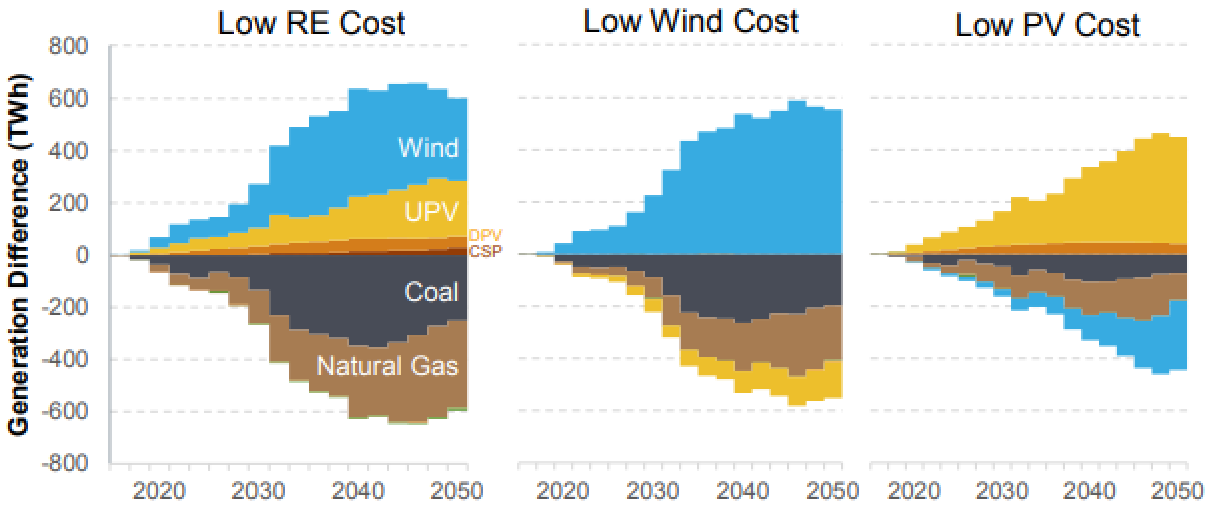
Policy scenarios:

- Nationally Determined Contribution (NDC)
- Renewable Portfolio Standard (RPS)
- Carbon Policy

Other assumptions:

- Fuel cost
- Load growth
- Technology costs
- Technology development

Example: Generation difference between medium-case scenario and different RE cost scenarios



Source: Wesley Cole et. al., *2017 Standard Scenarios Report: A U.S. Electricity Sector Outlook*, NREL, https://www.nrel.gov/docs/fy18osti/68548.pdf

Purpose of long-term planning in LAC: Basis for policy making, investment, and stakeholder engagement

Task 3: Analysis

Colombia:
Basis for policy making, establishing **signals for investment** and capacity expansion needs

Uruguay:
To design policies to support technologies and to promote **investment needs**

Brazil:
To be used as a **basis for formulating public policies**

Argentina:
To establish a framework of discussion for the **design of new policies** and for the **discussion with actors of the sector**.

Slide curtesy of Daniel Russo, IRENA

2. Production Cost Modeling

Task 3: Analysis

Objective: Assess the impacts of different penetrations of VRE on power system operations

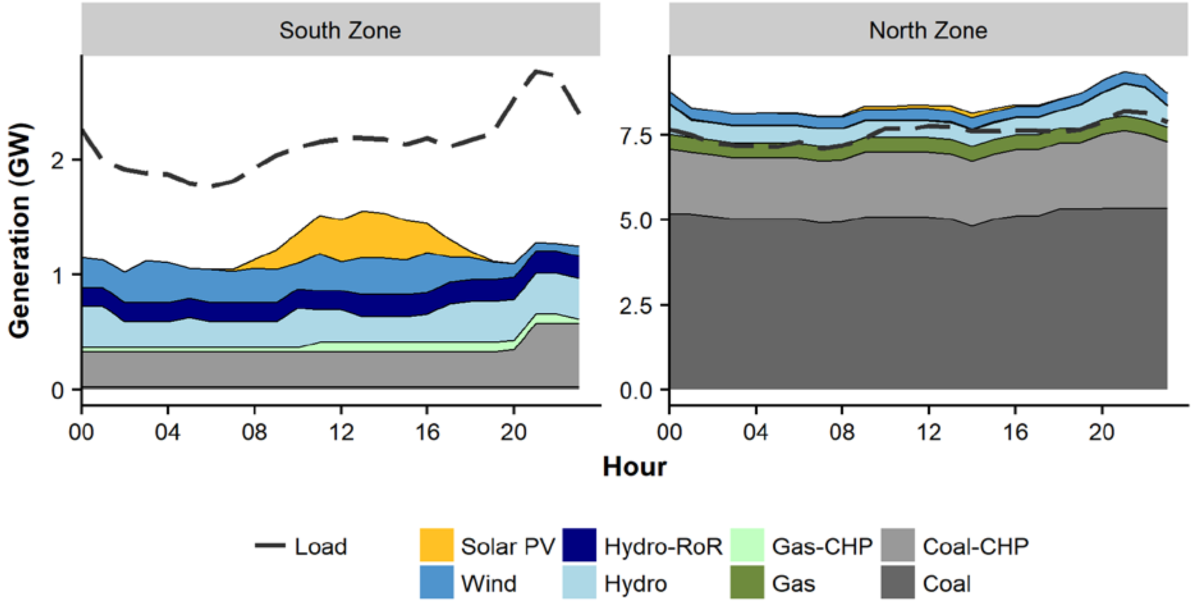
Key stakeholders

- Utility companies
- Transmission system operators
- Regulators
- Generation companies

Methodology

- Simulate the unit commitment and economic dispatch of a power system
- Approximate the daily operations of a transmission system operator
- Simulate an entire year of system operations
- Calculate the cost of production electricity

Example: Kazakhstan generation profile with 2,500 MW renewable energy



Dispatch Output from Production Cost Modeling

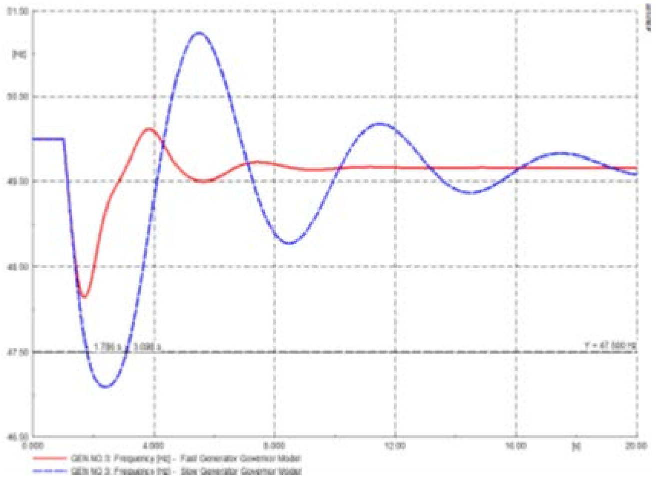
Task 3: Analysis

3. Technical stability studies

Task 3:
Analysis

- Operating a system with a high shares of non-synchronous generators (e.g., solar PV, and wind) is a challenge as a system currently requires synchronous generators to provide frequency and voltage response after a contingency event to ensure system **stability**

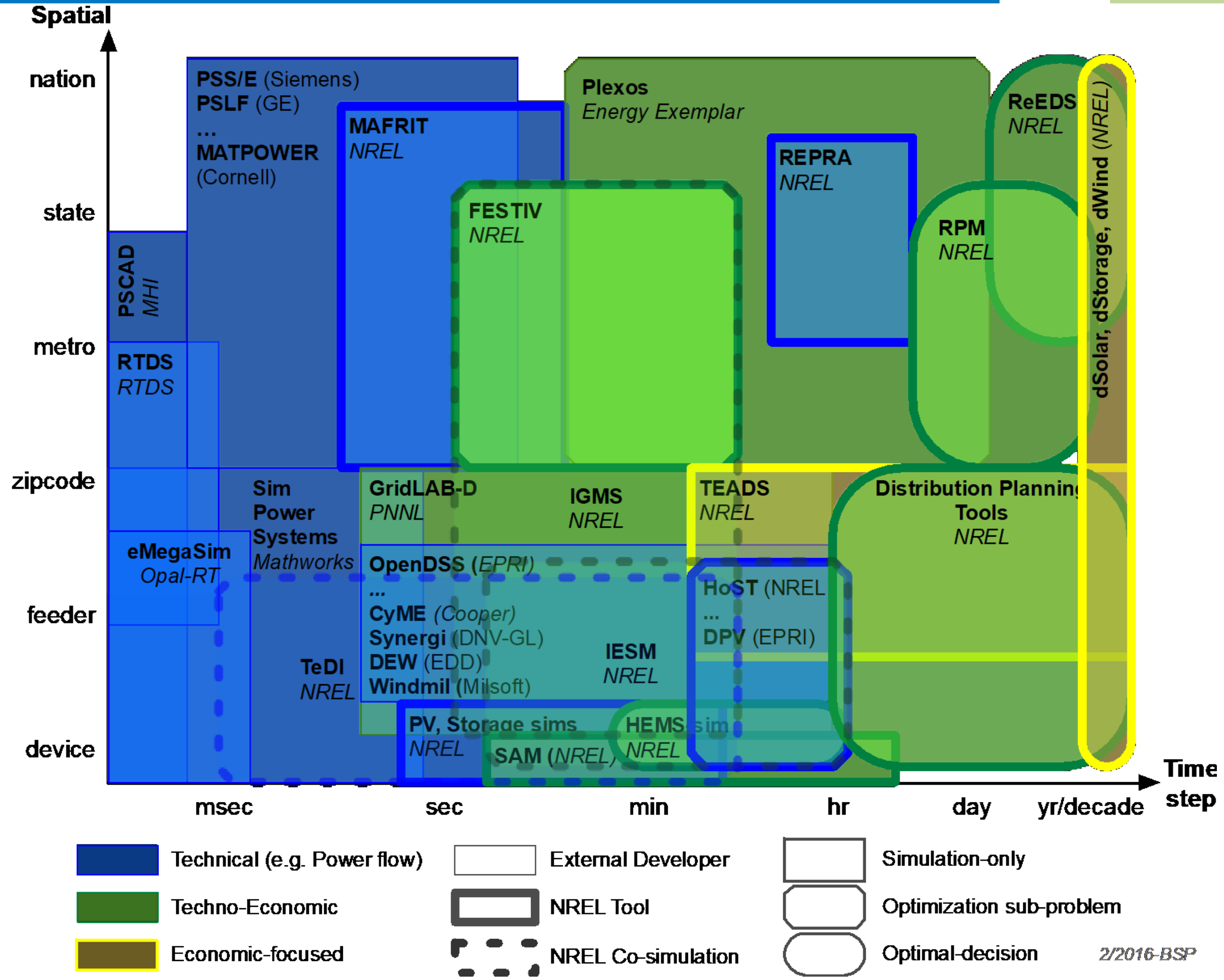
- **A good long-term plan addresses:**
  - **A hard constraint on instantaneous penetration limits under different operational setup - it can be rule of thumb or based on a full dynamic study**



Slide adapted from Daniel Russo, IRENA

Modeling tools

Task 3:
Analysis



Reporting results

Task 4:
Facilitation and Reporting

Study products may include:

- Technical reports
- Summary presentations
- Journal articles
- Underlying datasets (if cleared to be disseminated by the data providers)
- Visualizations (e.g., videos, data viewers, and infographics)
- Press releases

RE INTEGRATION STRATEGIES

100 GW SOLAR 60 GW WIND

NORMAL OPERATIONS	COORDINATED SCHEDULING AND DISPATCH		COAL PLANT FLEXIBILITY		
STATE-LEVEL DISPATCH, 55% MINIMUM GENERATION	REGIONAL	NATIONAL	LOWER MINIMUM PLANT GENERATION (40% of capacity)	HIGHER MINIMUM PLANT GENERATION (70% of capacity)	LOWER MINIMUM PLANT GENERATION (40% of capacity) WITH REGIONAL BALANCING AREA COORDINATION
230,000 INR Crore Annual Production Cost	2.8% Savings annually	3.5% Savings annually	Negligible Savings annually	0.90% Increased cost annually	3.3% Savings annually
1.4% Renewable energy curtailment	1.3% Renewable energy curtailment	0.89% Renewable energy curtailment	0.76% Renewable energy curtailment	3.5% Renewable energy curtailment	0.73% Renewable energy curtailment

Impact of RE integration strategies on production costs and RE curtailment (Palchak et al. 2017)

Additional types of analysis not covered in this webinar

- Demand projections
  - How does demand change in the future? Share of demand across industrial, commercial, and residential sectors
- Capacity adequacy assessment
  - How much additional load can be served reliably with the integration of new generation?
  - Test outputs of capacity expansion results to ensure capacity adequacy criteria are met
- Distribution system planning
  - What upgrades are needed at the distribution level to integrate increasing levels of rooftop PV?
- Hybrid and off-grid system planning
  - How should off-grid systems be designed to provide reliable and affordable energy access?

Tips for your own studies

- Clearly defined study questions
  - What is the goal? What do you want to learn?
- Best tools for the question
  - Are the correct models being applied to answer the study questions?
- Data
  - Is the data quality sufficient to trust the results?
- Transparency
  - Is the process for making assumptions transparent? Are the results publicly available?
- Peer reviewed
  - Do impartial external experts review the results?

Thank you

Ilya Chernyakhovskiy, NREL

Additional Resources

Visit the Grid Integration Studies topic page for more information:
http://greeningthegrid.org/Grid-Integration-Toolkit/Topics-And-Resources/grid-integration-studies

Visit www.greeningthegrid.org for additional references and helpful reading materials on grid integration topics.

greening the grid

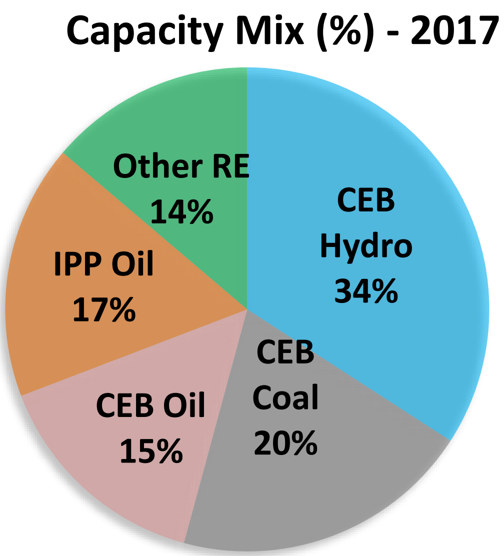
CEYLON ELECTRICITY BOARD

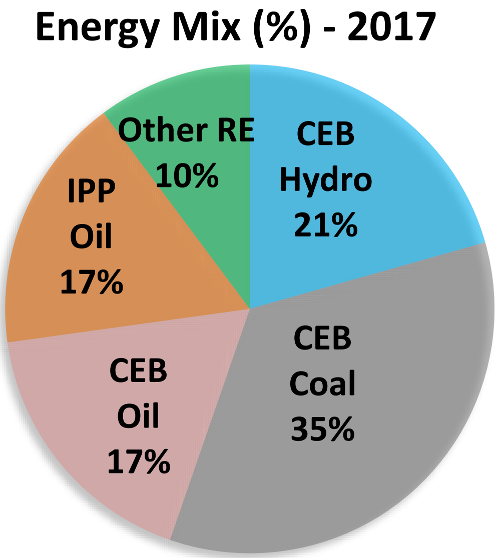
INTEGRATION OF RENEWABLE BASED GENERATION INTO SRI LANKAN GRID 2018-2028

Generation and Transmission Planning Branch
Ceylon Electricity Board

Randika Wijekoon
Electrical Engineer (Generation Planning)
Randika.Wijekoon@ceb.lk

Sri Lanka- Country Information

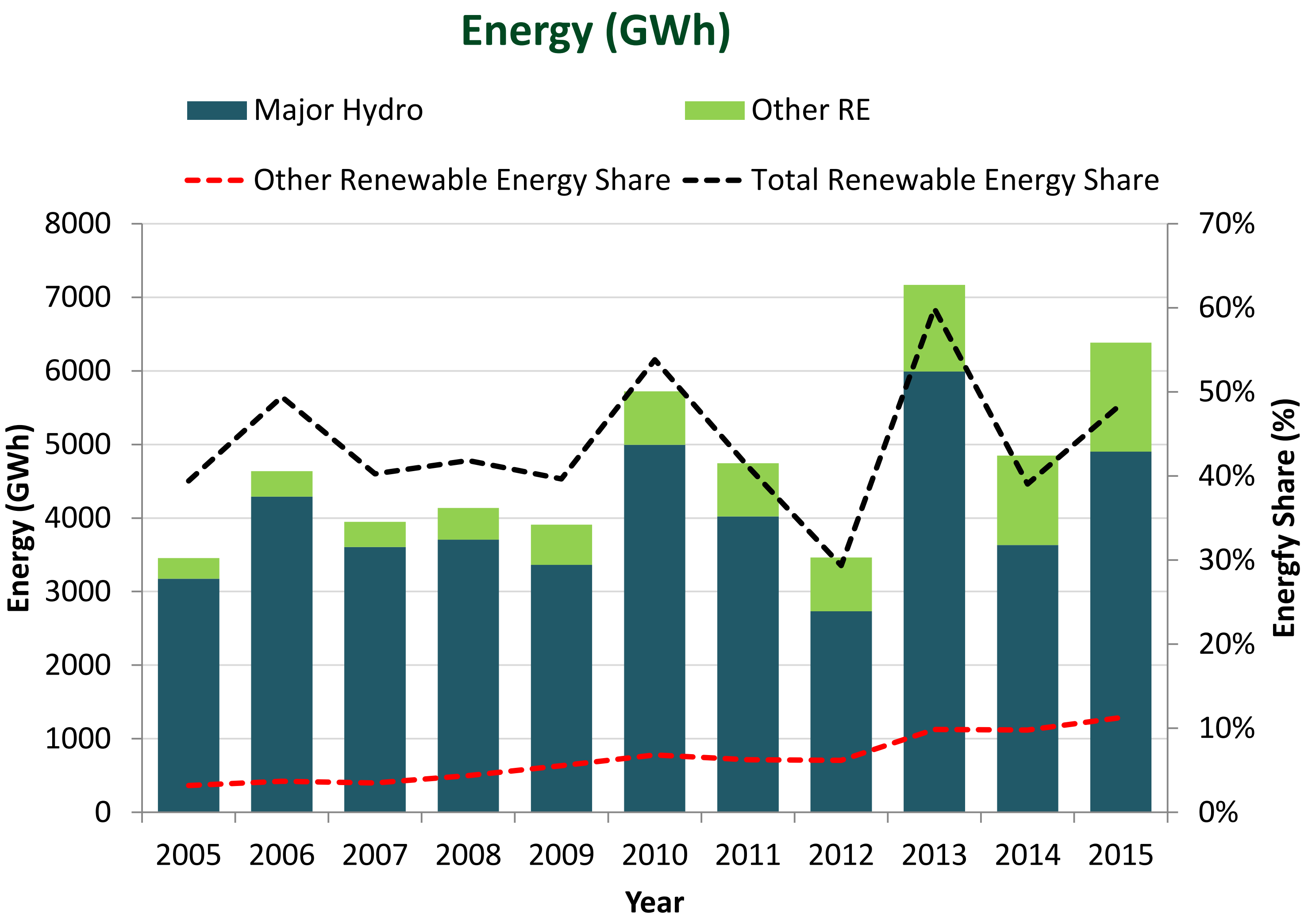


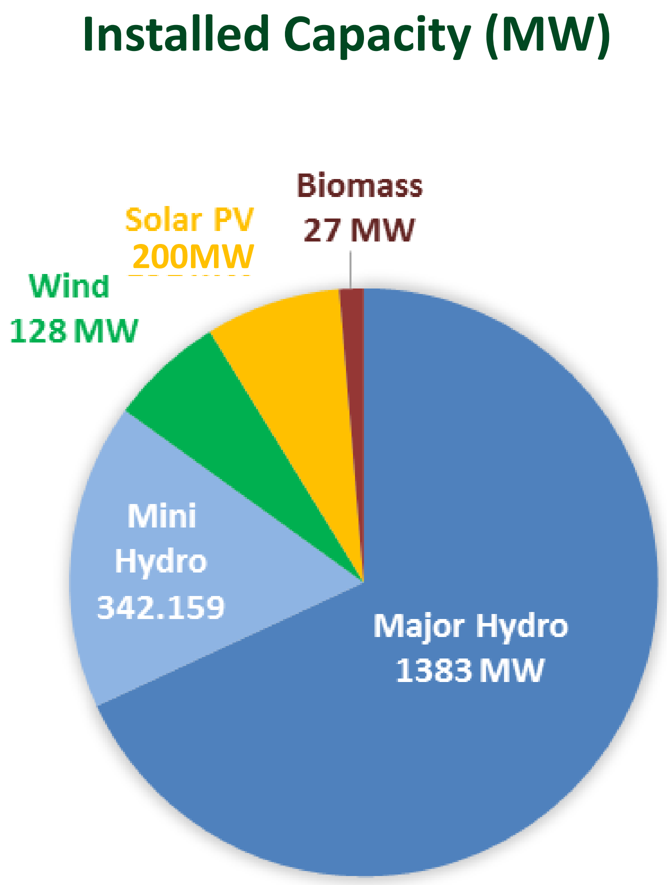


Population	21.2 million
GDP per capita	3,835 USD (2016)
Area	65610 km^2
Peak Demand	2,523 MW
Annual Electricity Demand	14,620 GWh
Electrification Level	99%
Per Capita Electricity Consumption	603 kWh per yr
CO2 emissions	0.886 (tons per capita)

	Capacity (MW)	Energy (GWh)
CEB Hydro	1,377	3,014
CEB Thermal - Coal	810	5,071
CEB Thermal - Oil	604	2,560
IPP Thermal - Oil	687	2,485
Other RE	558	1,489
Total	**4,036**	**14,620**

Past RE Development





Variable Renewables

Wind	- 128MW
Solar Rooftop	- 150MW
Solar Grid Scale	- 50MW
Total VRE	- 328MW

Primary Concerns for initiating the study

- ✓ Ambitious RE Targets
- ✓ Availability of Quality RE Resources

! **But how much can we integrate Reliably and Economically in to the power system ?**

- ! **Impact on system operation**
- ! **Impact in system stability**
- ! **Performance of RE resources**
- ! **Future capacity planning**
- ! **Economic Optimization**
- ! **Variability and Uncertainty**
- ! **High Seasonality**
- ! **Lack of visibility and controllability**

Main Components of the study

Capacity Expansion Study

- Long Term Electricity demand
- Timing and sizing investment decision of Power Sector infrastructure
- Economic Analysis
- RE policy targets and compliance
- Technology advancements

System Operation Study

- Impact of VRE on Power System Operation
- Impact on system operation cost
- Identification of operational constrains and bottlenecks
- Identification of required enhancements

Power System Stability and Power flow Study

- Steady State Behaviour of the power system
- Dynamic Behaviour of the power system
- Identification if system enhancements

Outline of the 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

Short Term - Medium term operational study

Medium term Hydro Thermal Optimization,

Economic Dispatch in 30min time steps

Operational Constraints, curtailments

Results and Analysis

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

Data Requirement

- Future Electricity Demand forecast
- Time series historical demand data
- Projected time series electricity demand profiles
- Projected system losses and generation requirement

- RE resource Locations
- High resolution wind speed measurement data for wind resources
- High resolution solar radiation data for Solar resources
- High resolution power output data from existing wind and solar plants
- Wind and Solar PV plant modelling technical parameters

- Technical and cost parameters of existing power plants
- Technical and cost parameters of future candidate existing power plants
  (Max and Min Output, FOM, VOM, Startup costs, Efficiency Ramp rates, reactive power capability, Capital Costs, etc.)
- Hydrological inflow data and Hydro system operational constraints
- Plant maintenance program for future years
- Plant operational constraints
- System operation policies and constraints
- Transmission Network data and study models (Steady state and dynamic)

Performance Assessment of Renewable Energy Resources

(Wind, Solar PV, Major Hydro, Mini-hydro)

01. Wind

Five wind regimes were identified and wind plants were modelled based on actual site measurements for wind Production estimation

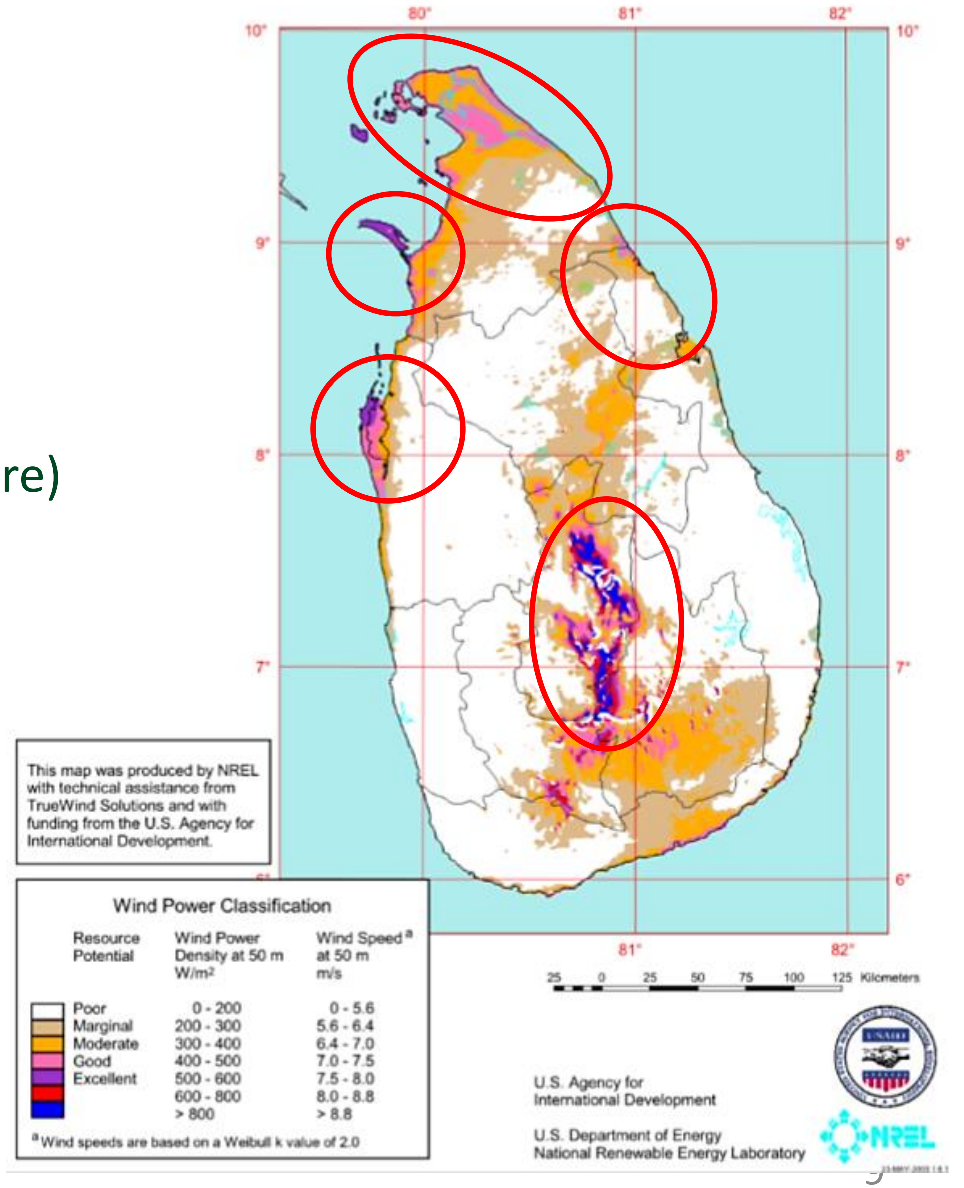
- **Wind Regimes for Modelling**

- **Available Resource Data**

  (Wind speeds, Wind direction, Pressure and Temperature)
- **Wind turbine and farm models**

  (Turbine Characteristics, Farm Layout)

Sri Lanka Wind Resource Map



01. Wind

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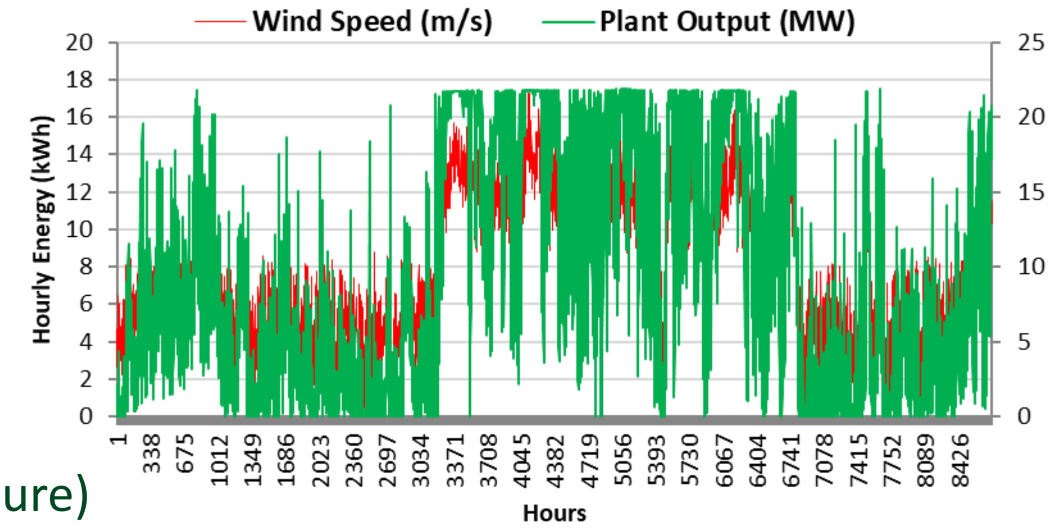
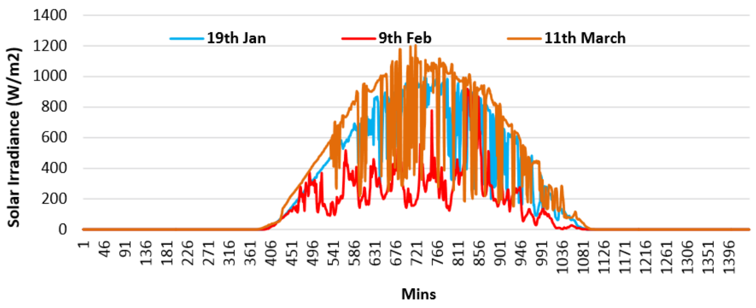
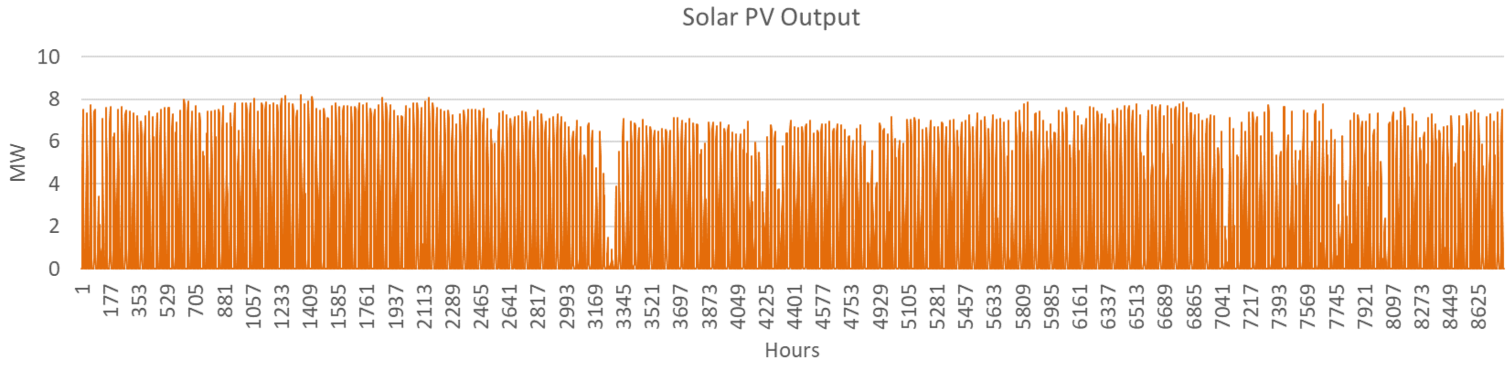


Wind Regime	Annual Plant Factor
Mannar	36.71%
Puttalam	31.37%
Hill country	19.06%
Northern	34.07%
Eastern	37.32%

02. Solar

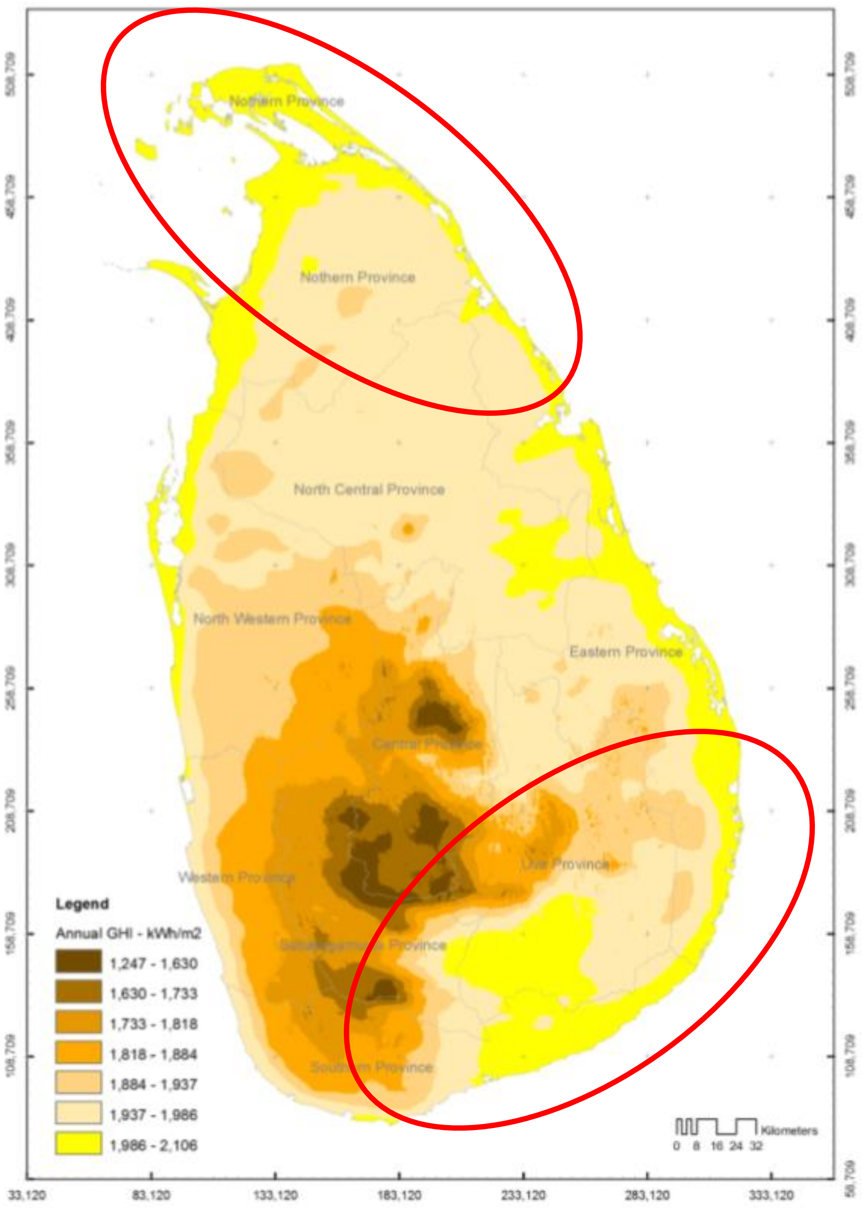
Two Solar regimes are modelled based on data for production estimati





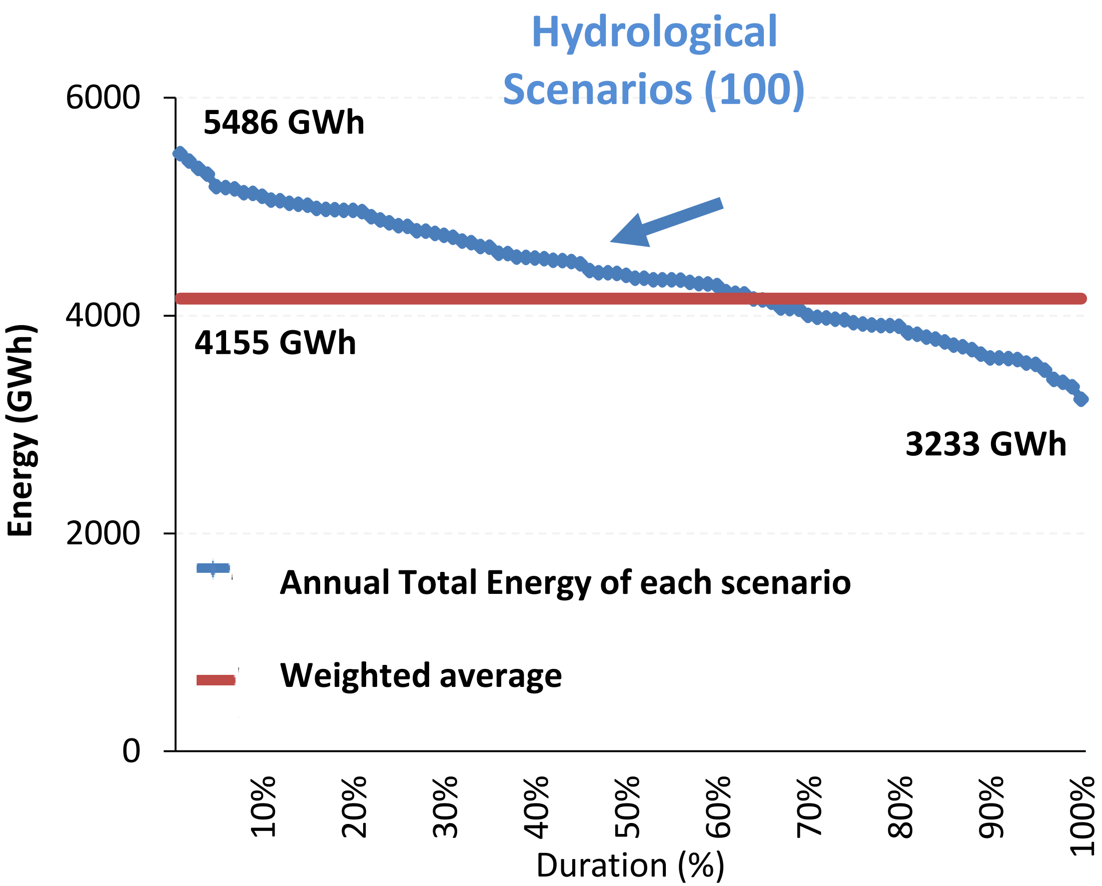
Solar Regime	Annual Plant Factor
Hambanthota	16.3%
Kilinochchi	15.6%

Spatial Distribution of GHI in Sri Lanka

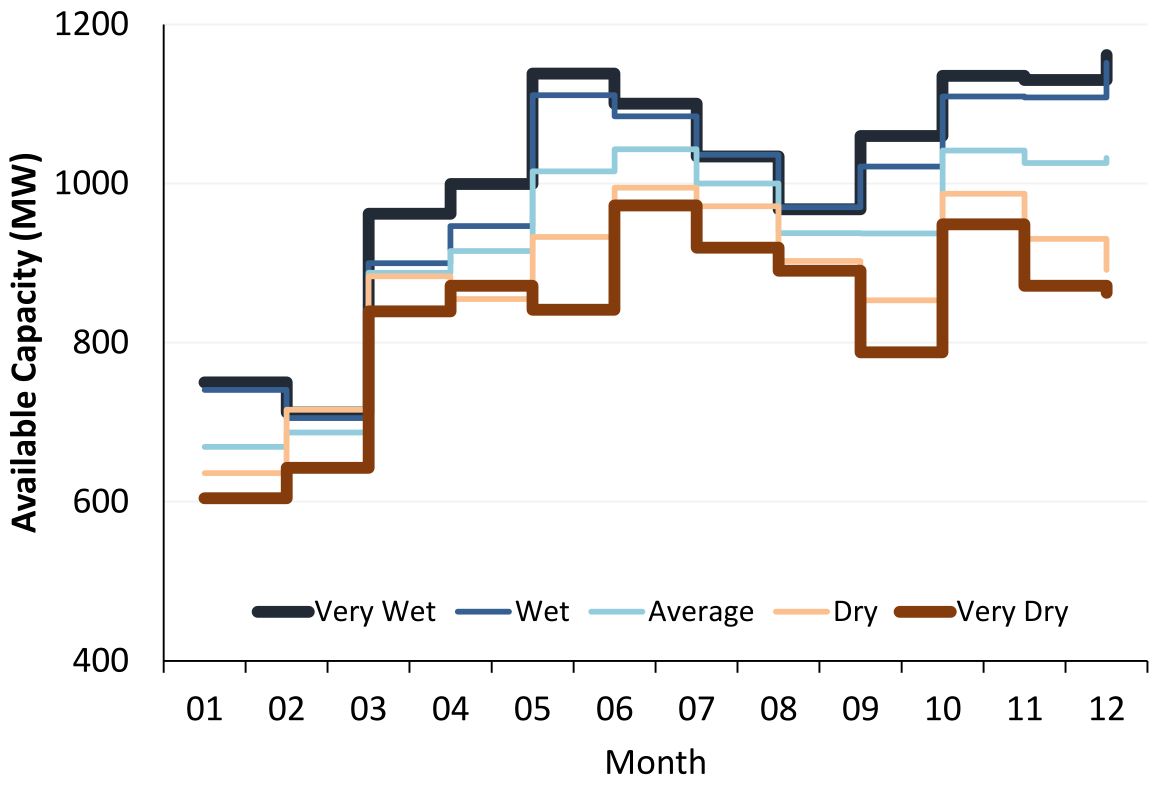


03. Major Hydro

Energy Contribution



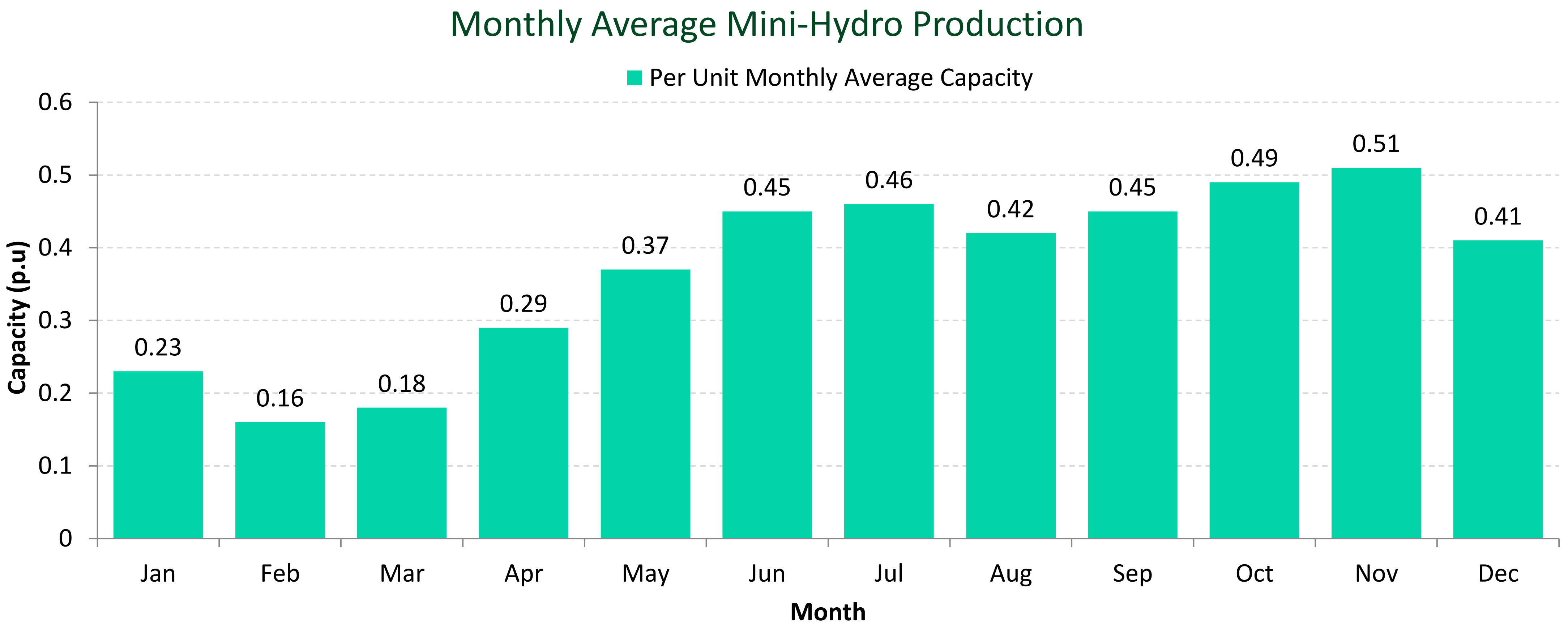
Capacity Contribution (Monthy Avg)



New Projects in the Pipeline

35 MW Broadlands	20 MW Seethawaka
120 MW Uma Oya	15 MW Thalpitigala
31 MW Moragolla	20 MW Gin Ganga

04. Mini Hydro



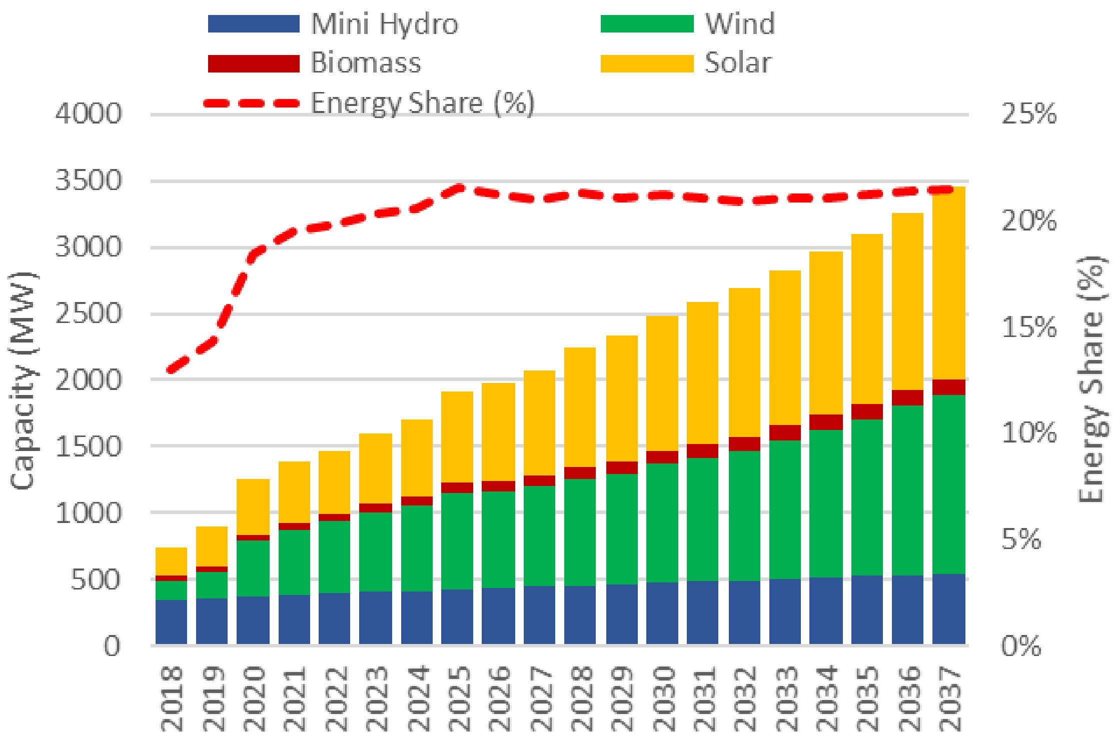
- The annual plant factor of each model is 36.3 % in the average Hydro Condition
- Seasonal variation is derived based on Historical Data

RE SCENARIOS &
CAPACITY EXPANSION PLANNING

RE Development Scenarios

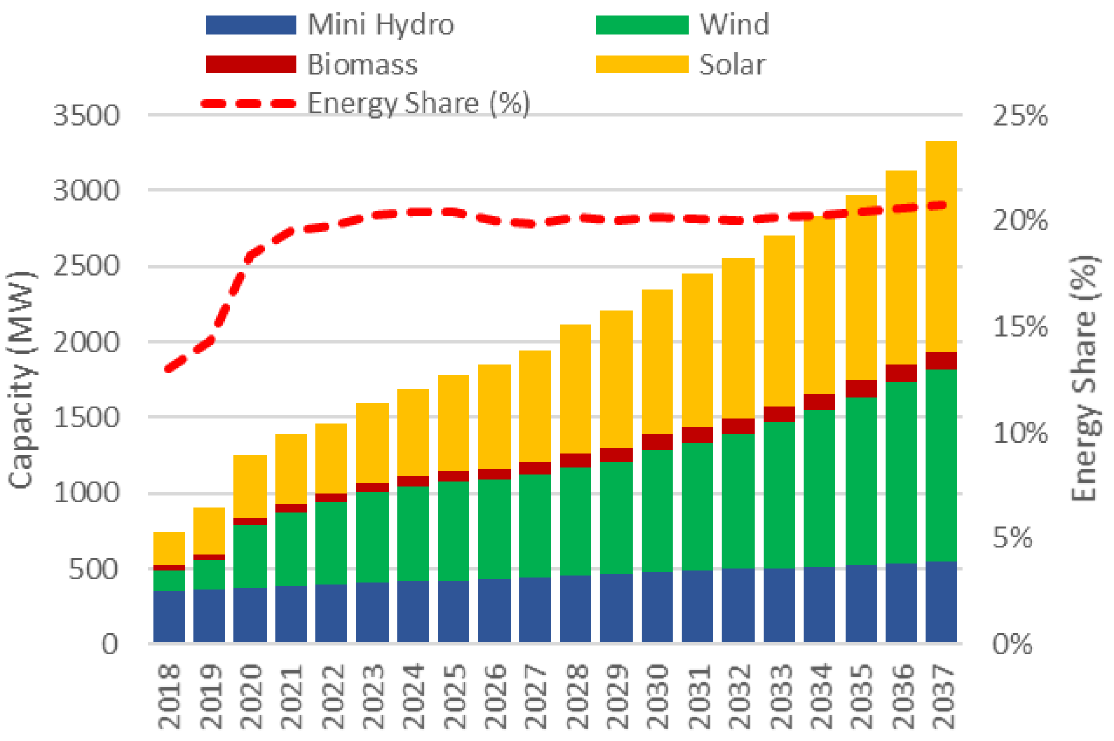
Projection 1

2717 MW addition in 20 years



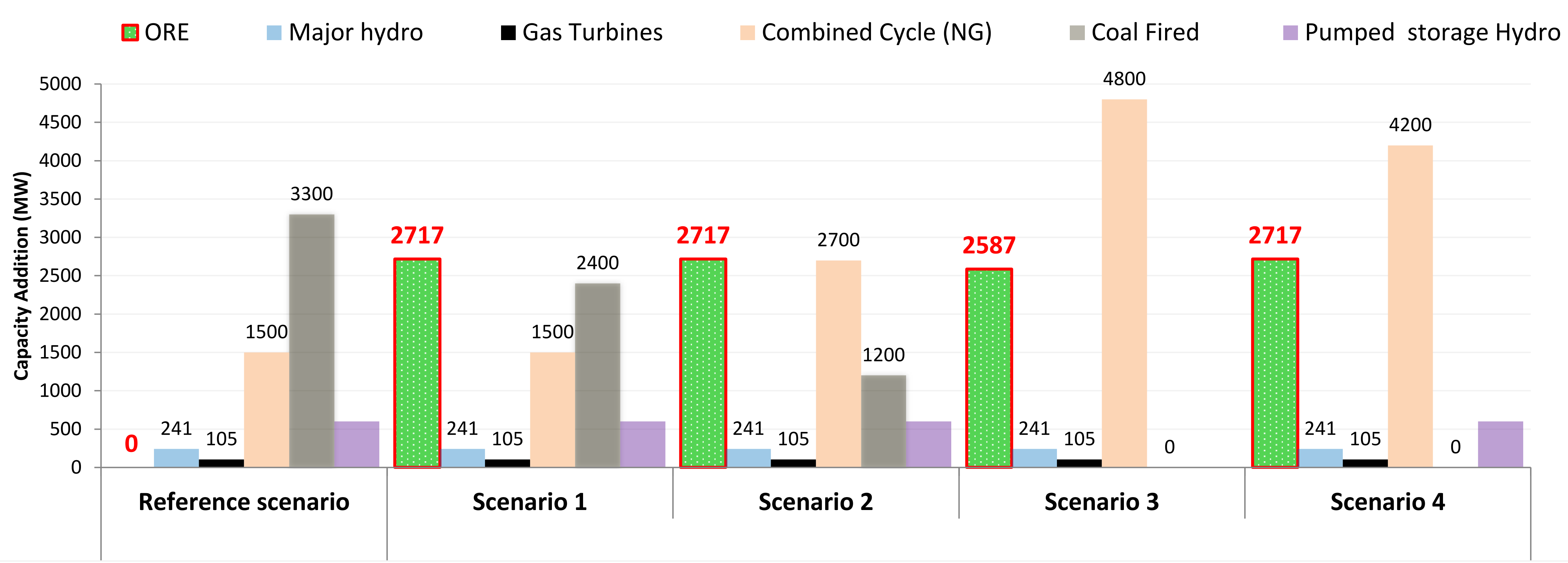
Projection 2

2587 MW addition in 20 years



Optimized Long Term Planning Scenarios

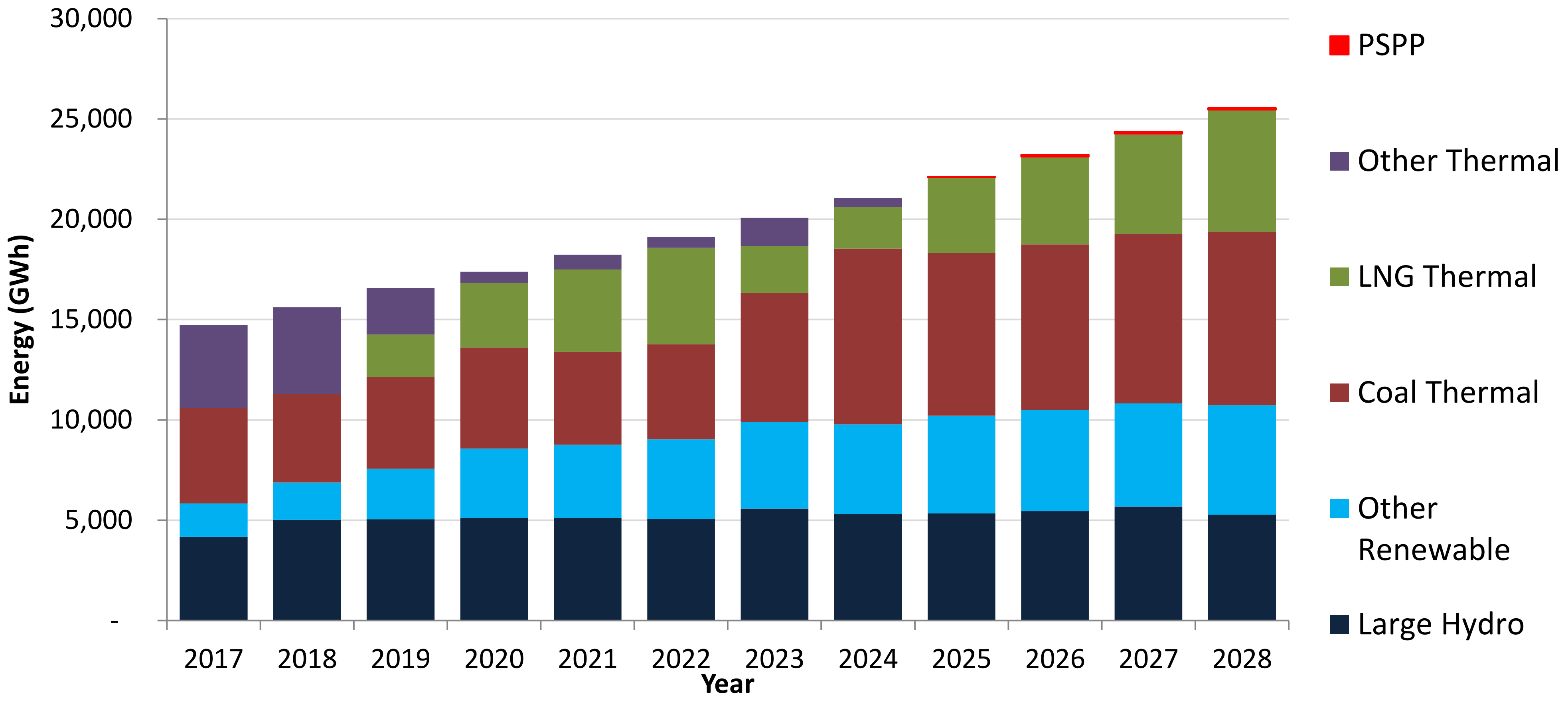
Scenario	Description
Reference	Only the existing “other renewable energy” by 2016 is included and No future ORE development is assumed
Scenario 1	New Combined cycle power plants are restricted in western region. Coal and Pumped hydro plants included
Scenario 2	Development Coal units are limited with pumped hydro and more Combined cycle units are permitted in other locations
Scenario 3	Development coal units and pumped hydro units are restricted. All new additions are combined cycle units.
Scenario 4	All new additions are combined cycle power plants with pumped hydro development



SYSTEM OPERATIONAL STUDY

System Operation Study

Medium Term Hydro Thermal Optimization



- Medium Term Hydro thermal optimization software
- Short term dispatch optimization software

System Operation Study

Short term operation optimization

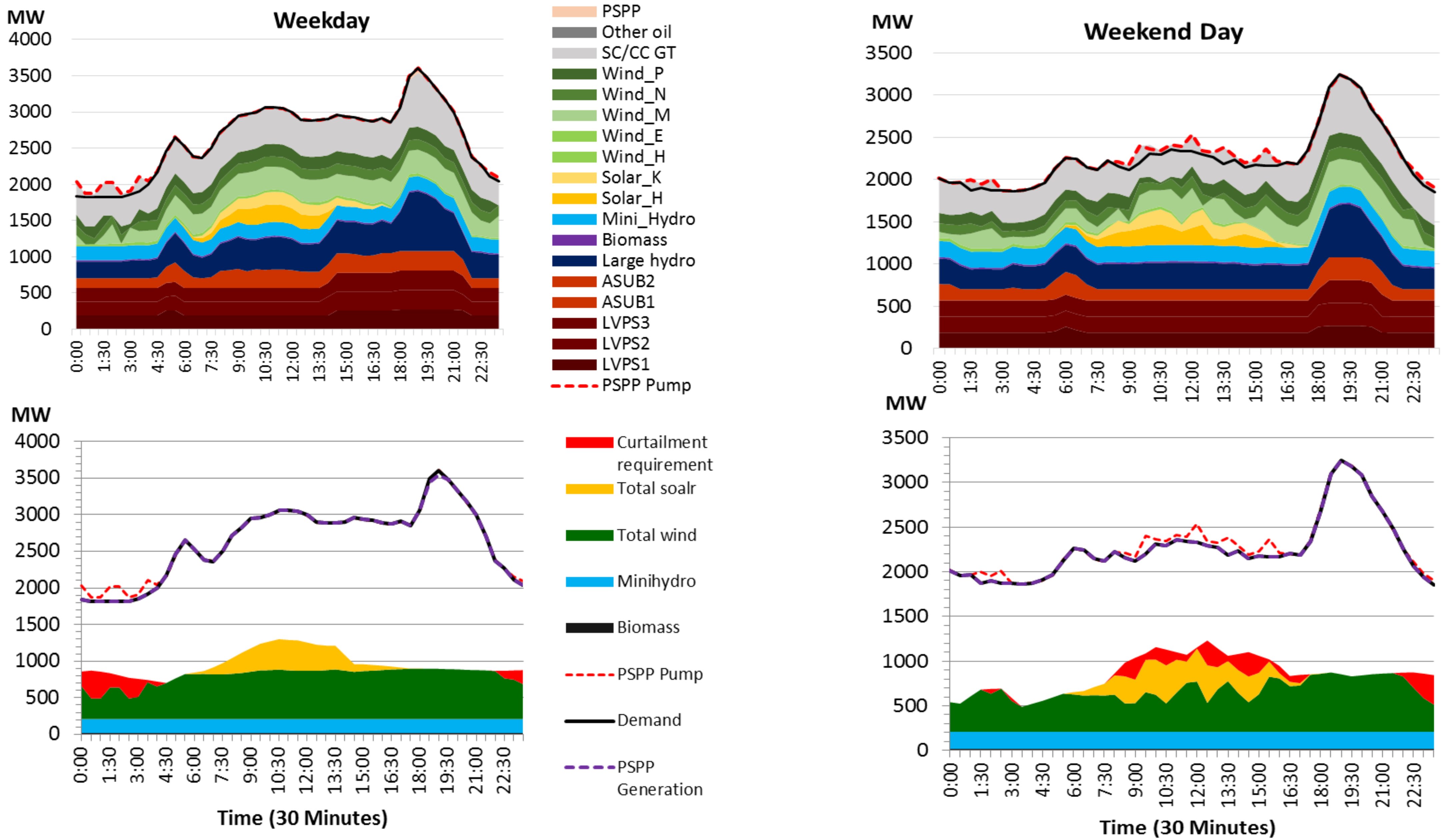
- Hydro plant operational characteristics
- Thermal plant operational characteristics
- System operation constraints

One year

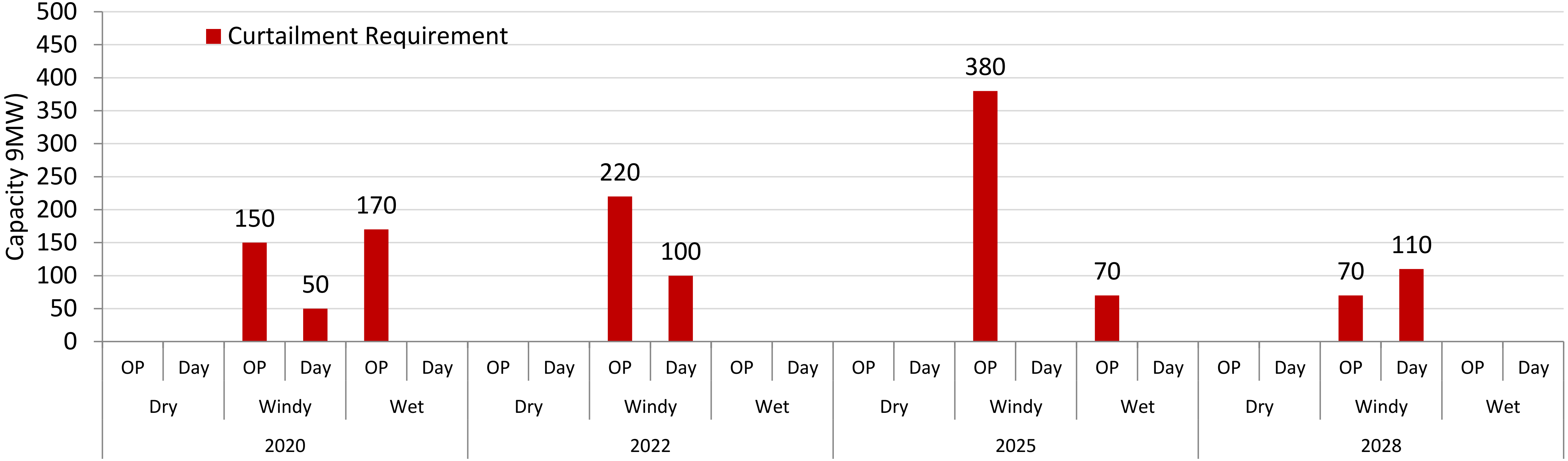
<table>
<tr><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td colspan="4">Dry Period</td><td colspan="4">High Wind Period</td><td colspan="4">Wet Period</td></tr>
<tr><td colspan="4">Weekday & Weekend</td><td colspan="4">Weekday & Weekend</td><td colspan="4">Weekday & Weekend</td></tr>
</table>

- A weekday and a weekend per period
- Selected years 2018,2020, 2022,2024,2025,2028
- Total of 36 simulation

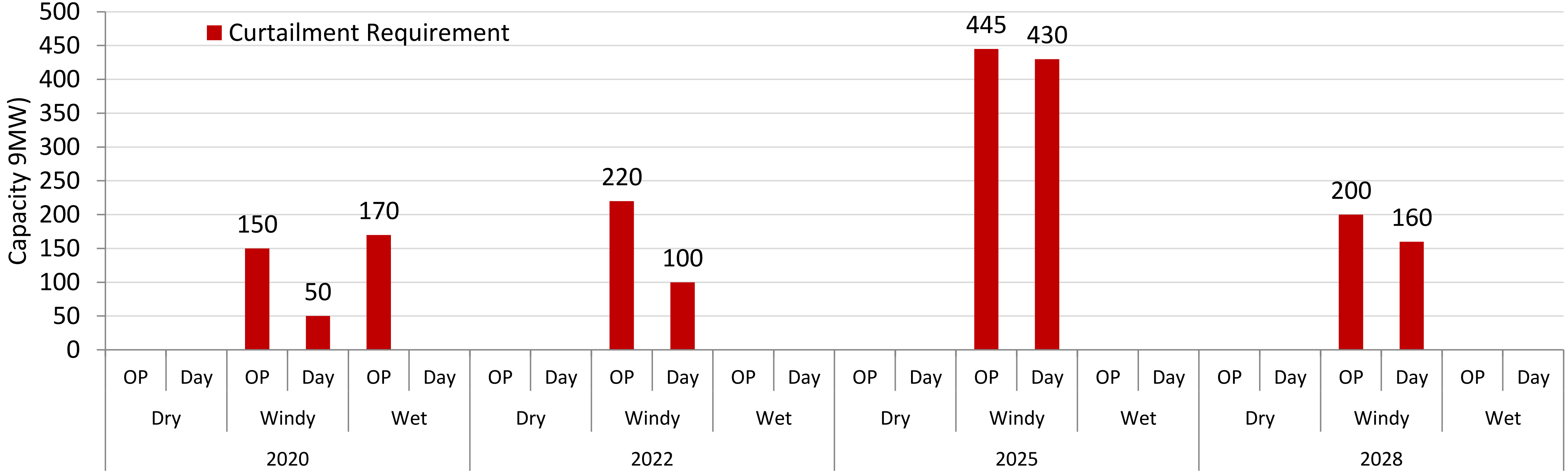
OPERATIONAL STUDY (Dispatch Results 2025- High wind season)



Scenario 1: Coal Fired, Combined cycle and Pump Storage units development



Scenario 3: Development of Combined cycle units only



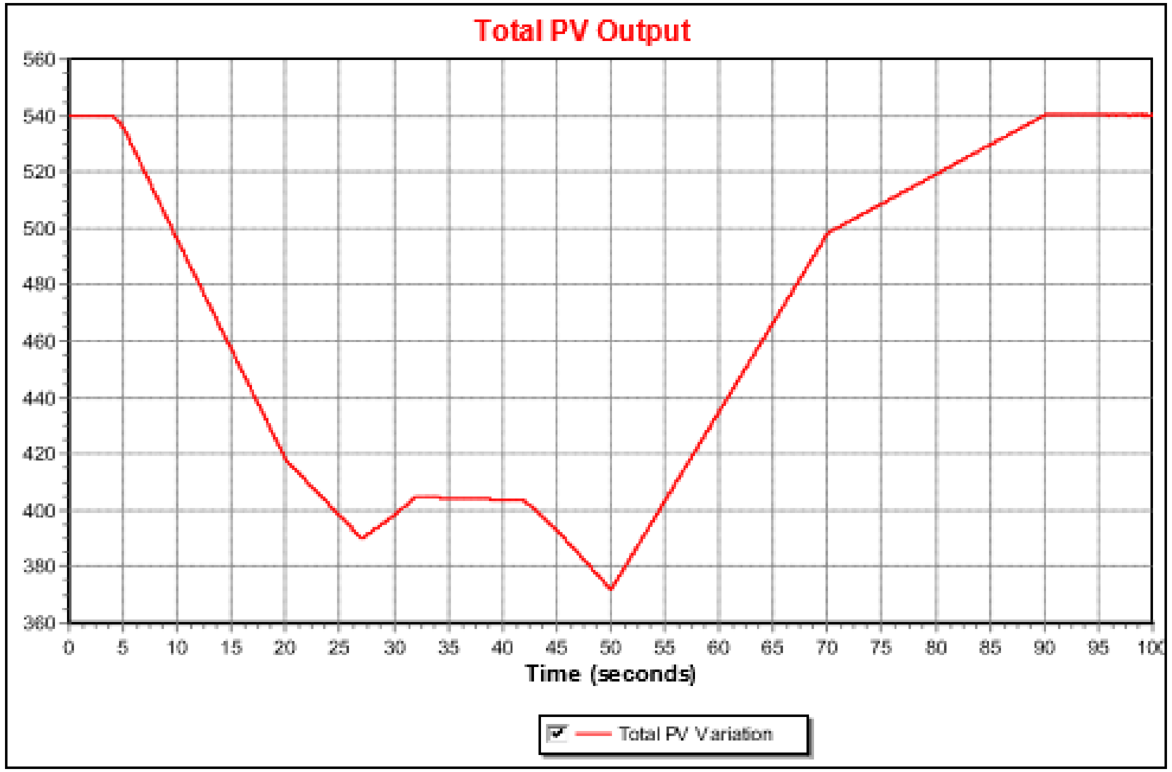
Variable Renewable Energy Curtailment

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	-	-

POWER SYSTEM STABILITY STUDY

Short term frequency stability analysis

100 seconds duration



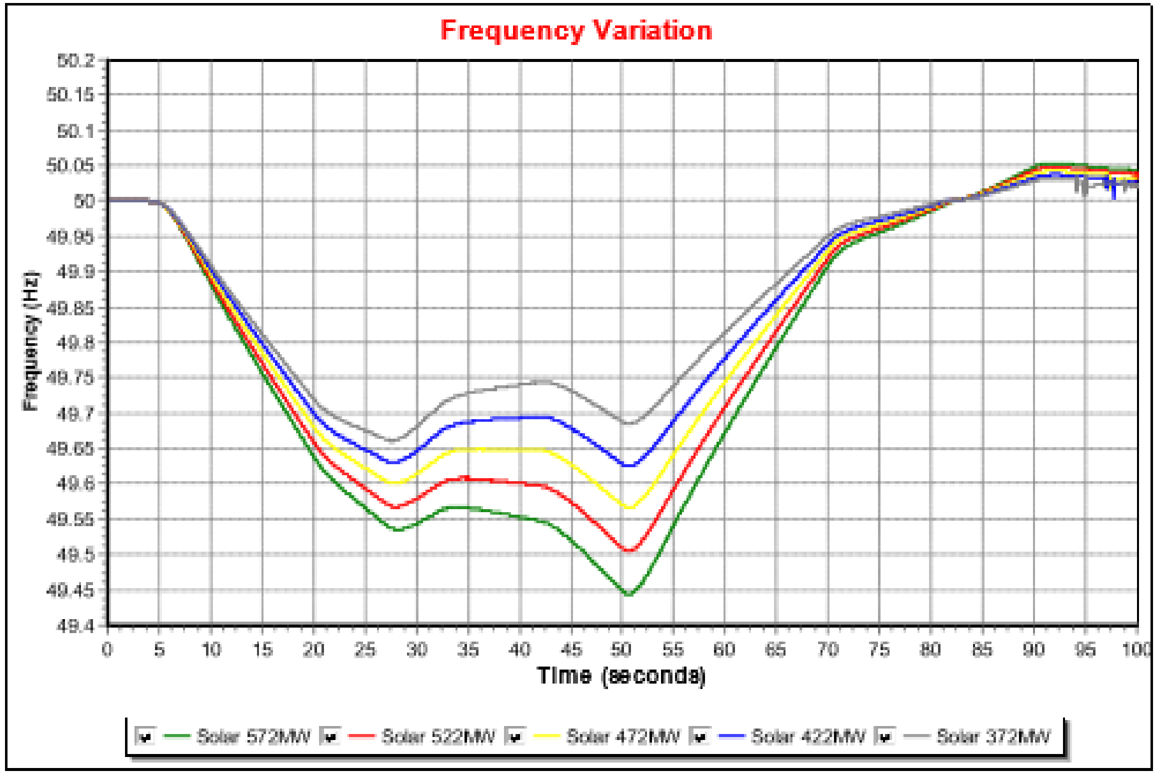
Solar ramp rate for 540 MW solar capacity in 2022.

Scenarios used for study

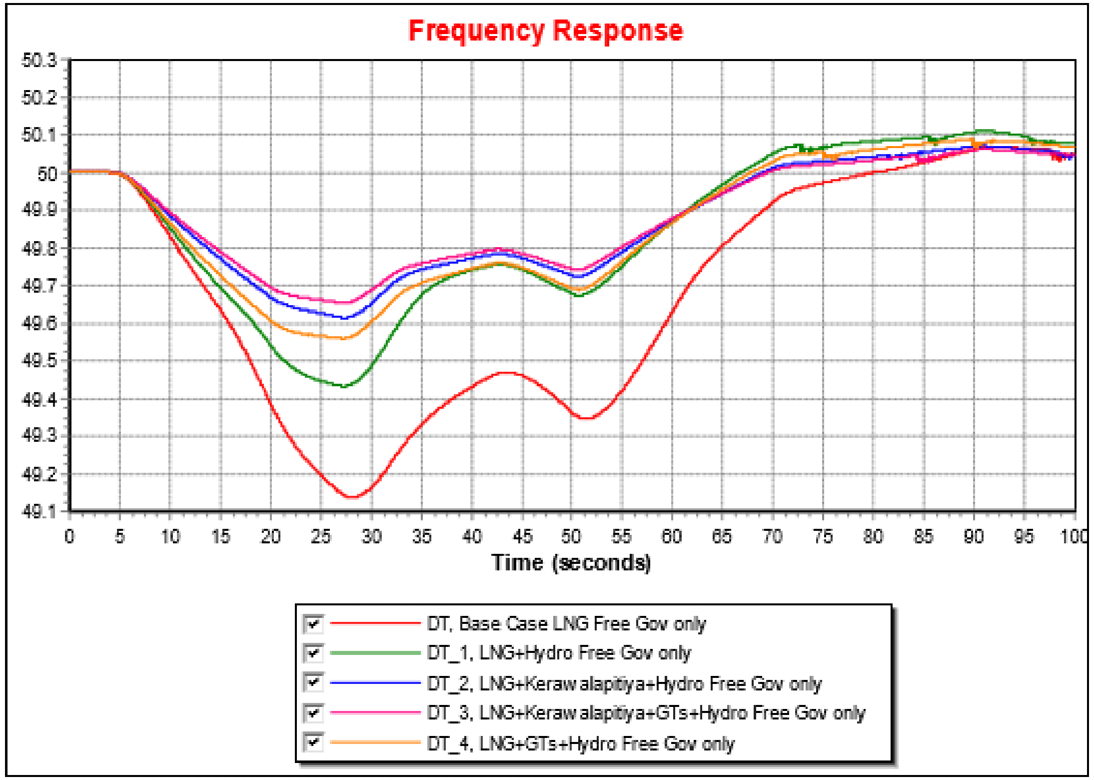
Year	
2018	▪ Case 1: Only swing machine is used for free governor ▪ Case 2: Swing machine + GT7 used for free governor ▪ Case 3: Swing machine + KCCP used for free governor ▪ Case 4: With All Hydro Governor (Victoria, Kotmale, Upper Kotmale, N'Lax) ▪ Case 5: Swing machine + KCCP + GT7 + 2x35MW GTs used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

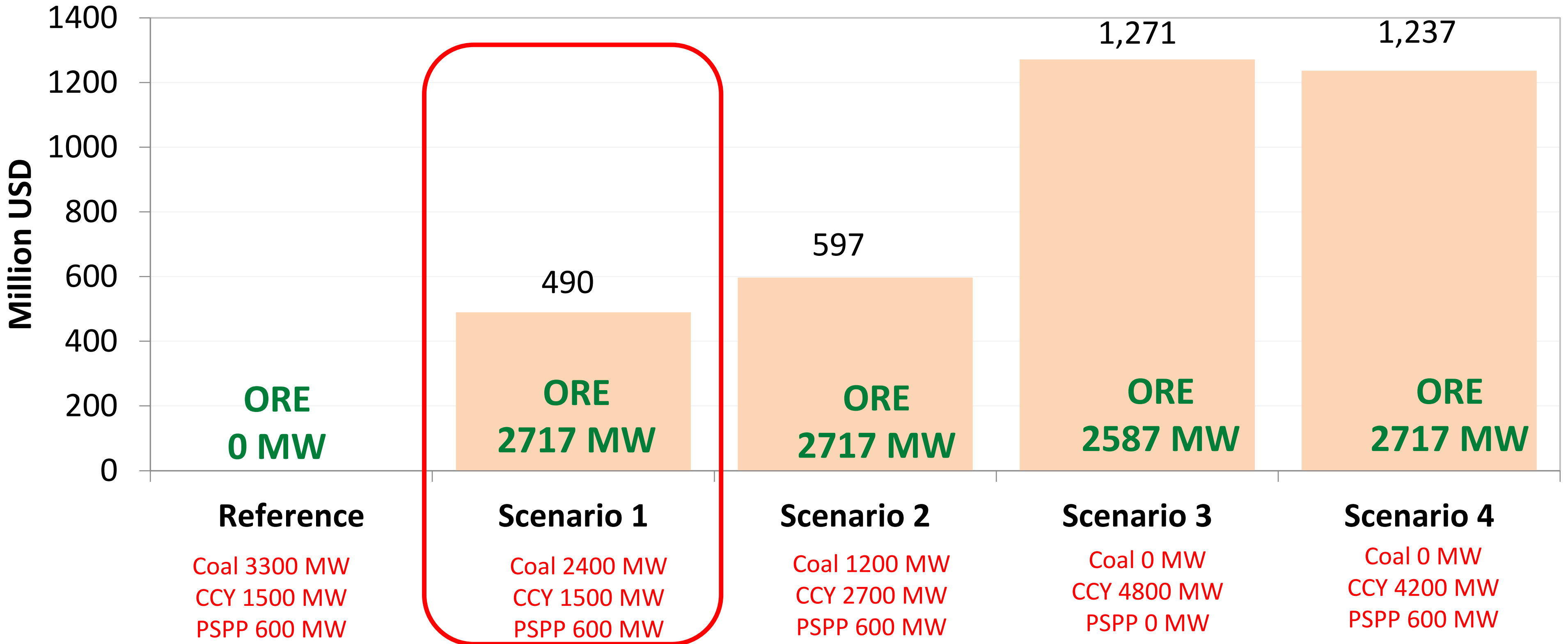
Scenario	State
Hydro Maximum Day Peak – DH	System Stable with Load Shedding
Thermal Maximum Day Peak - DT	System Stable with Load Shedding
Minimum ORE Day Peak – ORE_DP	System Stable
Hydro Maximum Night Peak - NH	System Stable with Load Shedding
Thermal Maximum Night Peak - NT	System Stable
Minimum ORE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

ECONOMIC COST ANALYSIS

Economic Cost Analysis

Scenario	Total PV Cost up to 2036 (USD million)	Difference with Reference Scenario (USD million)
Reference (Coal 3.3GW, CCY 1.5GW, PSPP 0.6GW)	12382.0	-
Scenario 1 (Coal 2.4GW, CCY 1.5GW, PSPP 0.6GW)	12872.0	490.0
Scenario 2 (Coal 1.2GW, CCY 2.7GW, PSPP 0.6GW)	12979.3	597.3
Scenario 3 (Coal 0 GW, CCY 4.8 GW, PSPP 0 GW)	13653.3	1271.3
Scenario 4 (Coal 0 GW, CCY 4.2 GW, PSPP 0.6GW)	13618.6	1236.6

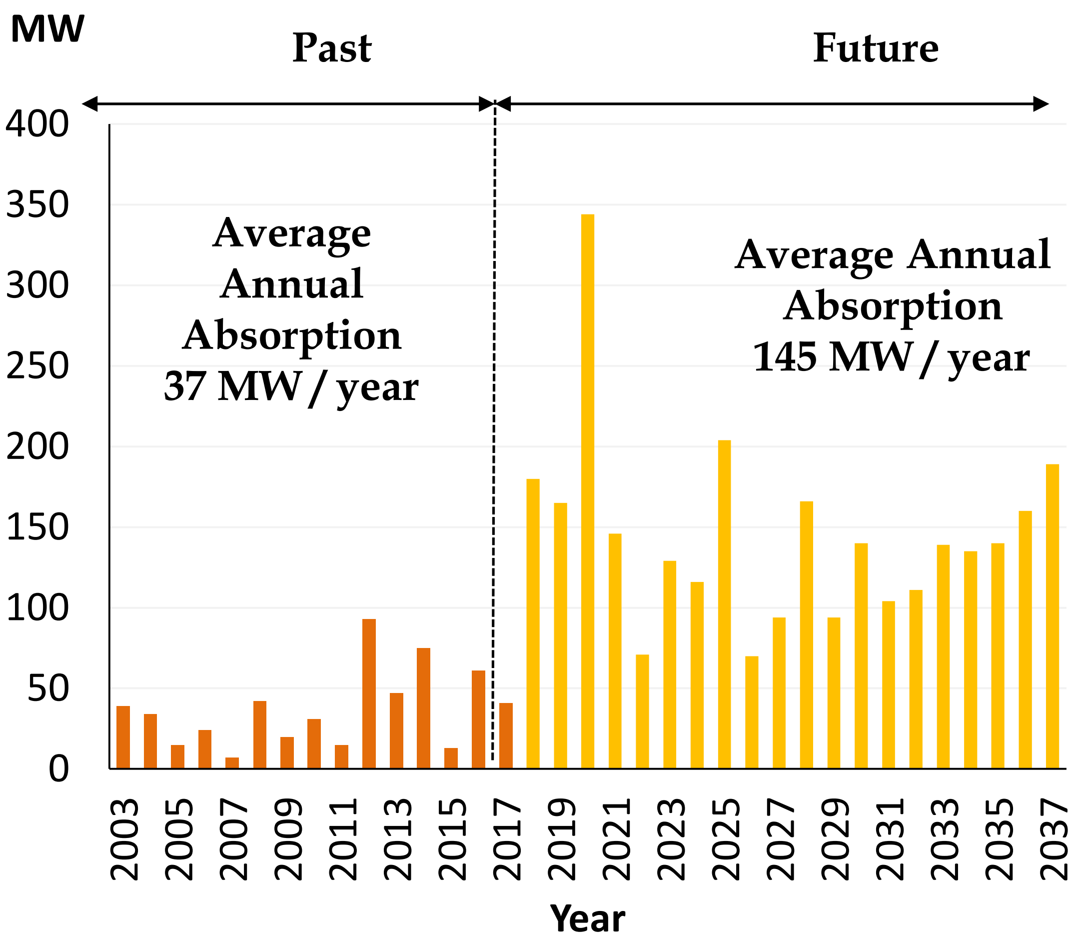
Cost Difference compared to the Reference Scenario



Key findings and recommendations

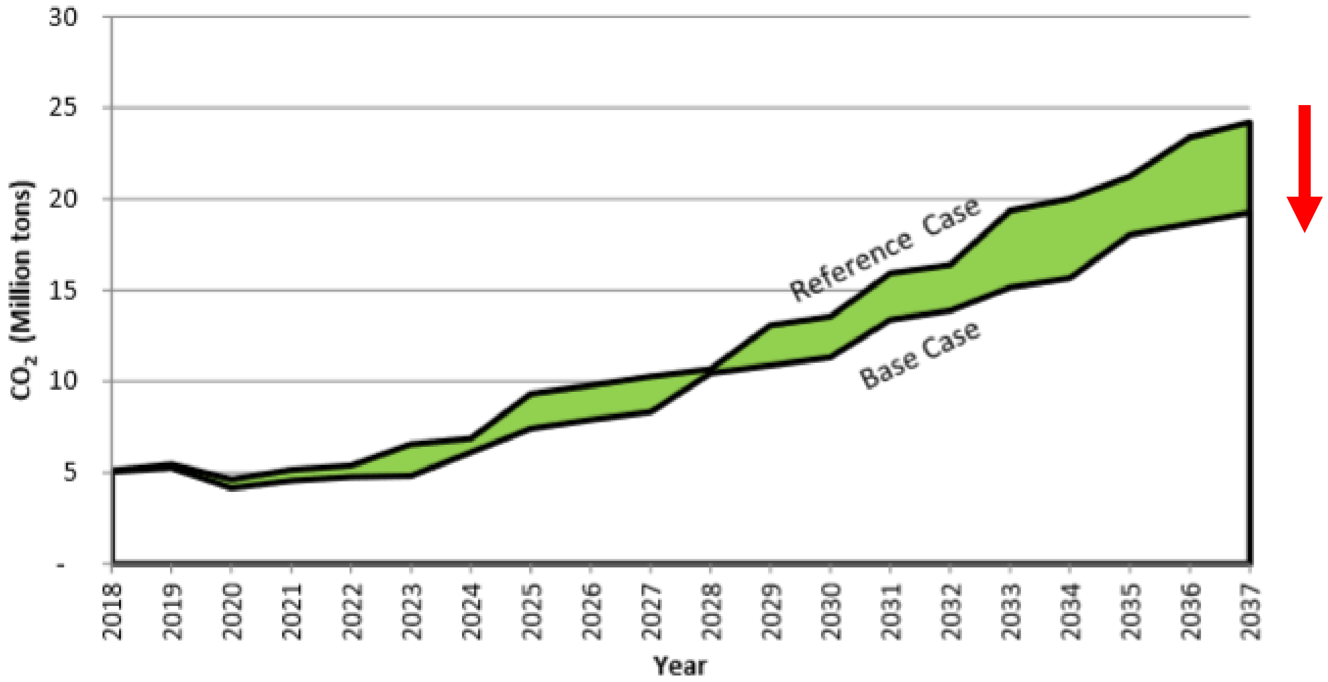
- Penetration levels **20-22% requires notable VRE curtailment**.
- Combination of low cost base load, combined cycle and grid scale storage (Pumped hydro) units is economically optimum for ORE integration.
- Establishing **wind and solar forecasting systems** to the national dispatch center.
- Providing Variable Renewable Energy (VRE) **curtailment rights to system operator**
- Base load power plants with **increased flexibility**
- Prioritizing the development of ORE locations
- Competitive bidding process for RE projects
- Minimizing the ‘Take or Pay’ risks of future LNG contracts

Key Outcome



Nationally Determined Contributions to UNFCCC

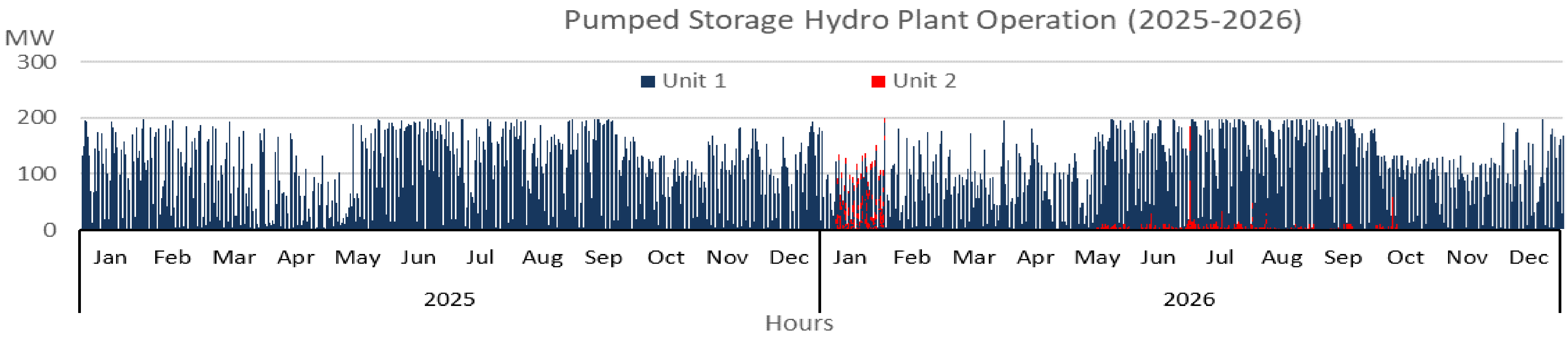
CO2 Emission Reduction
of the Base Case Compared to Reference Case



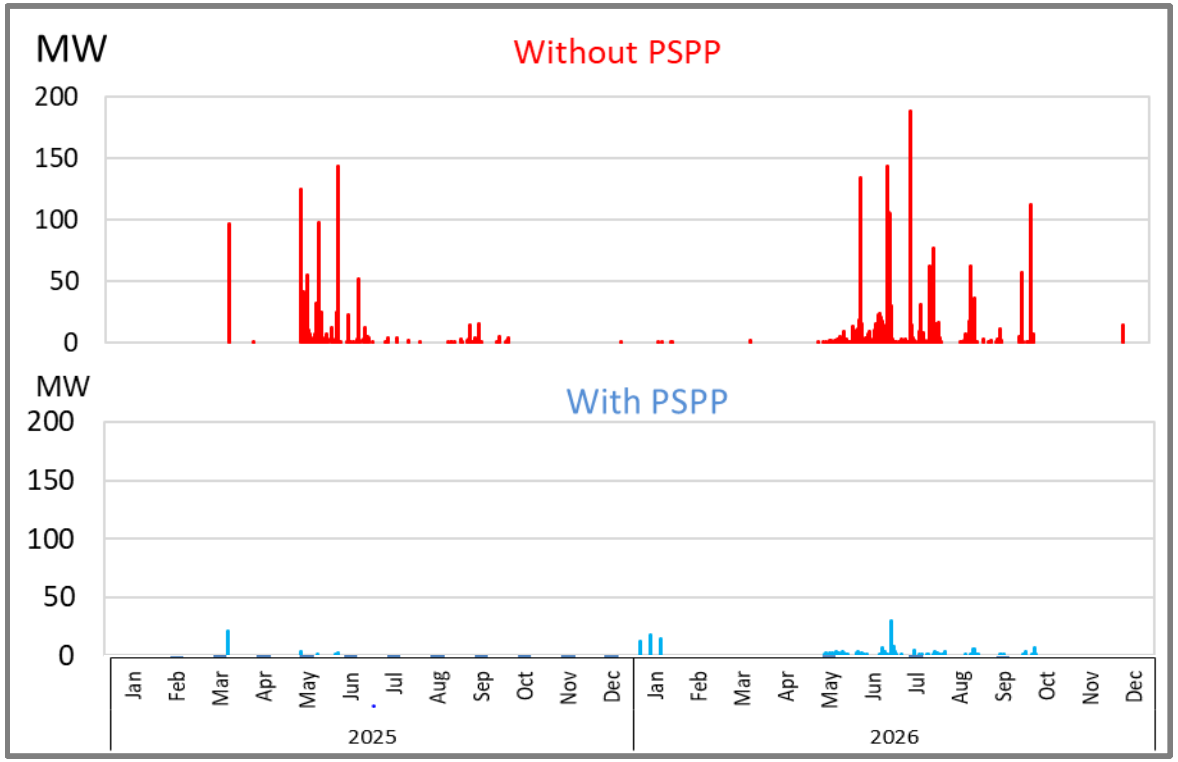
The study enabled the Average Annual Capacity Addition of Other Renewables to be nearly four times higher than the past.

FUTURE IMPROVEMENTS

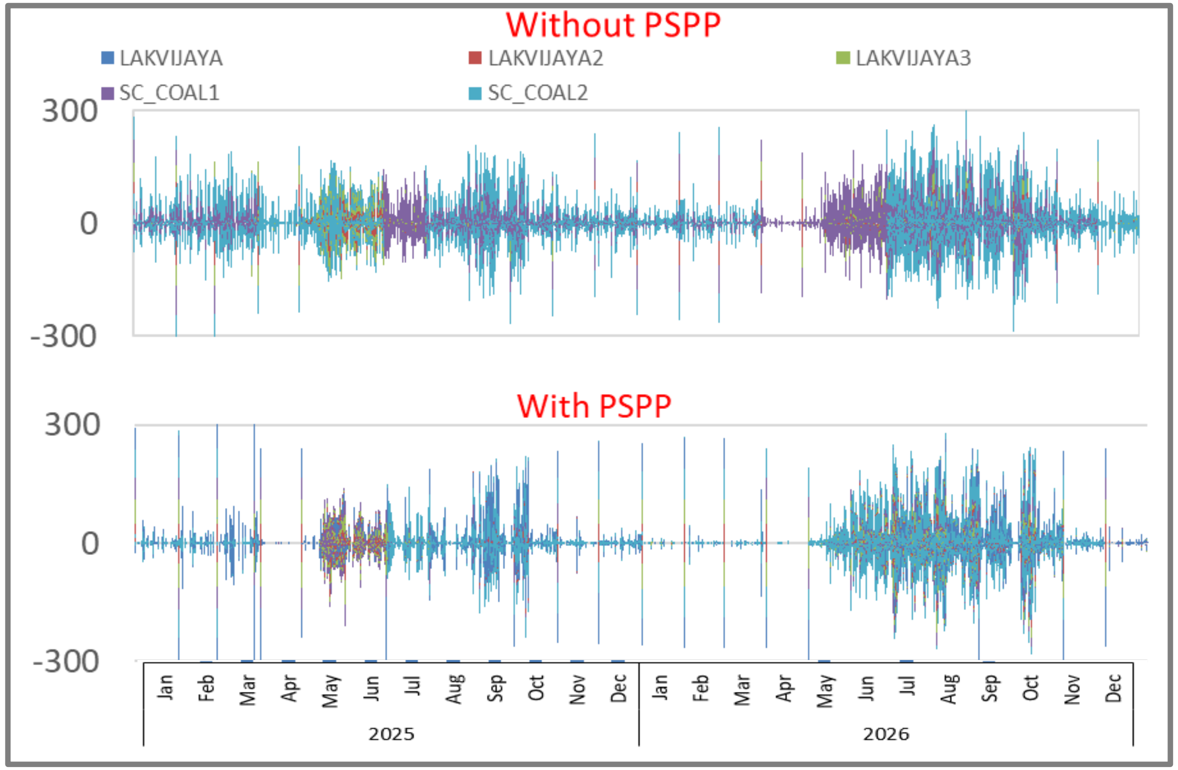
Impact of Pumped Storage Hydro Power Plant



VRE Curtailment

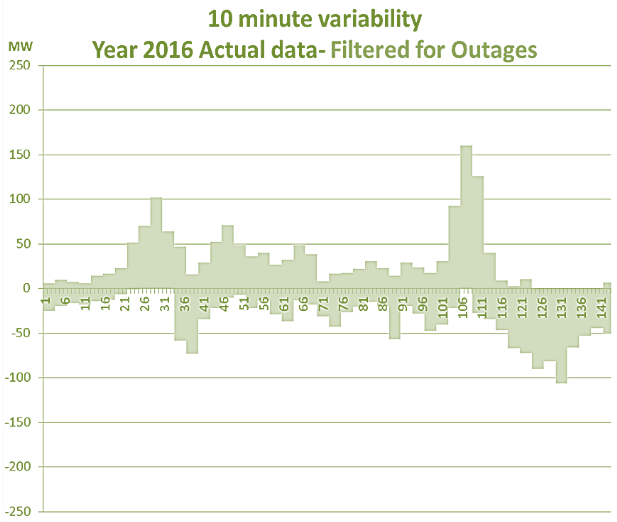


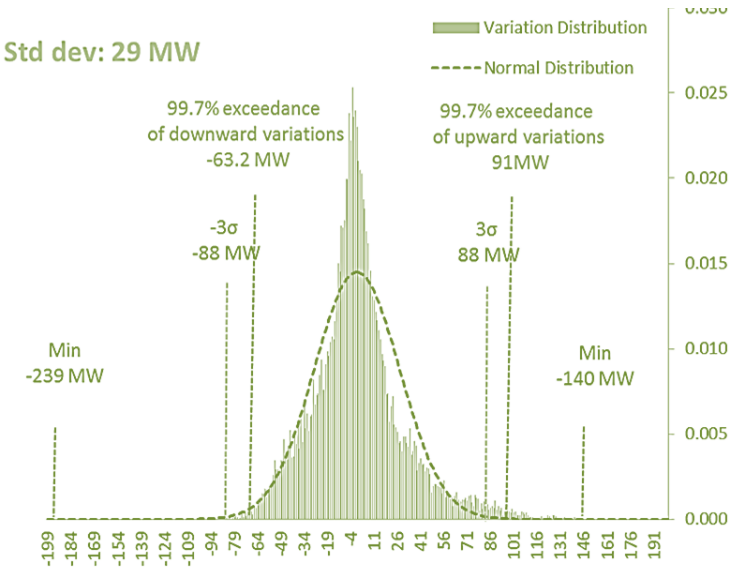
Baseload Plant Cycling

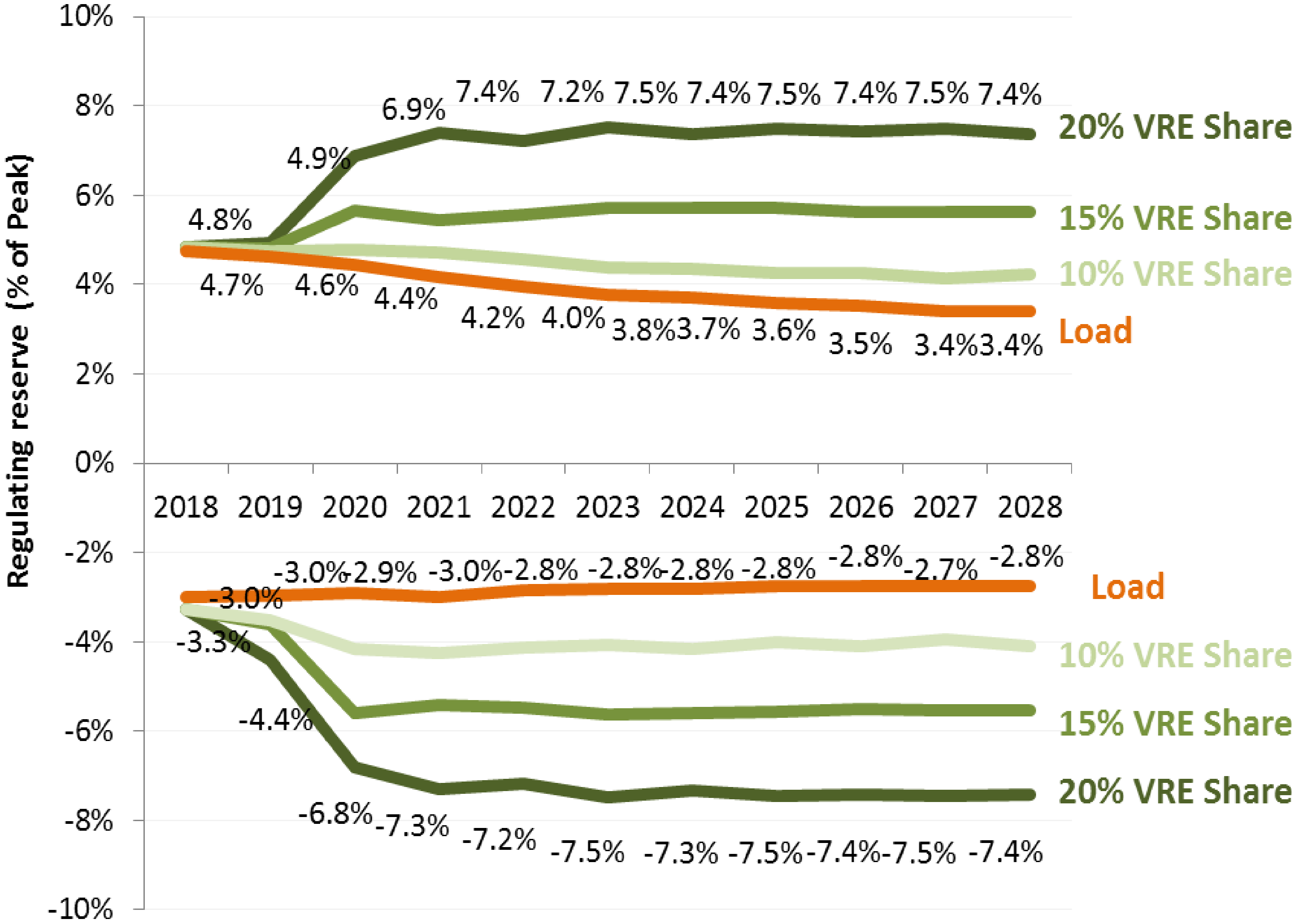


Operating Reserve Estimation

Regulating Reserve Estimation for VRE development scenario

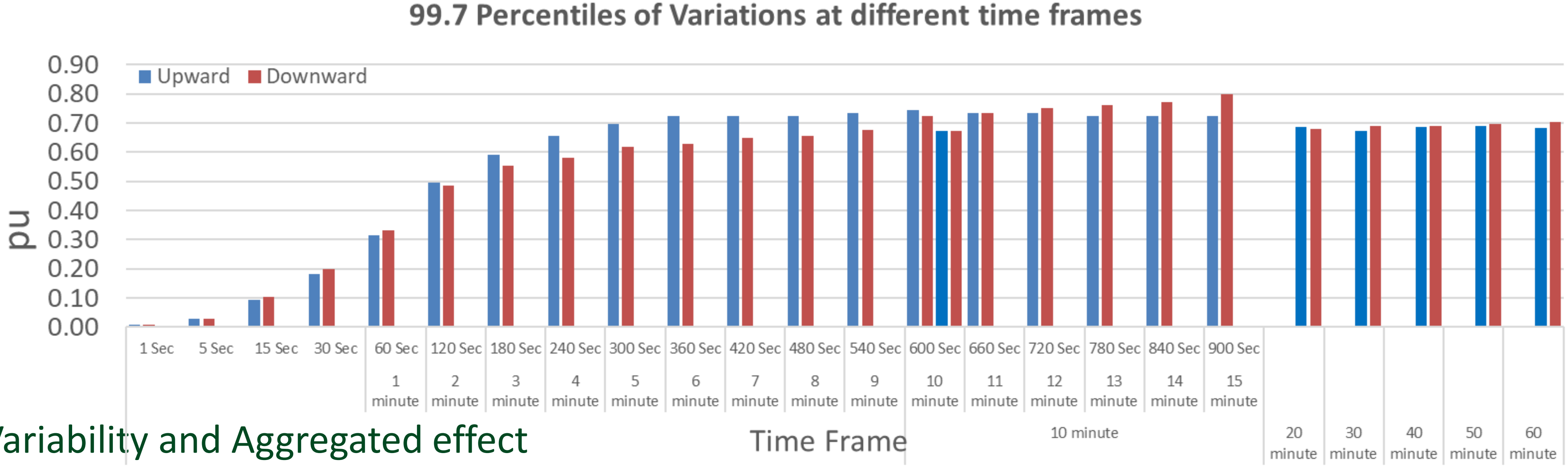




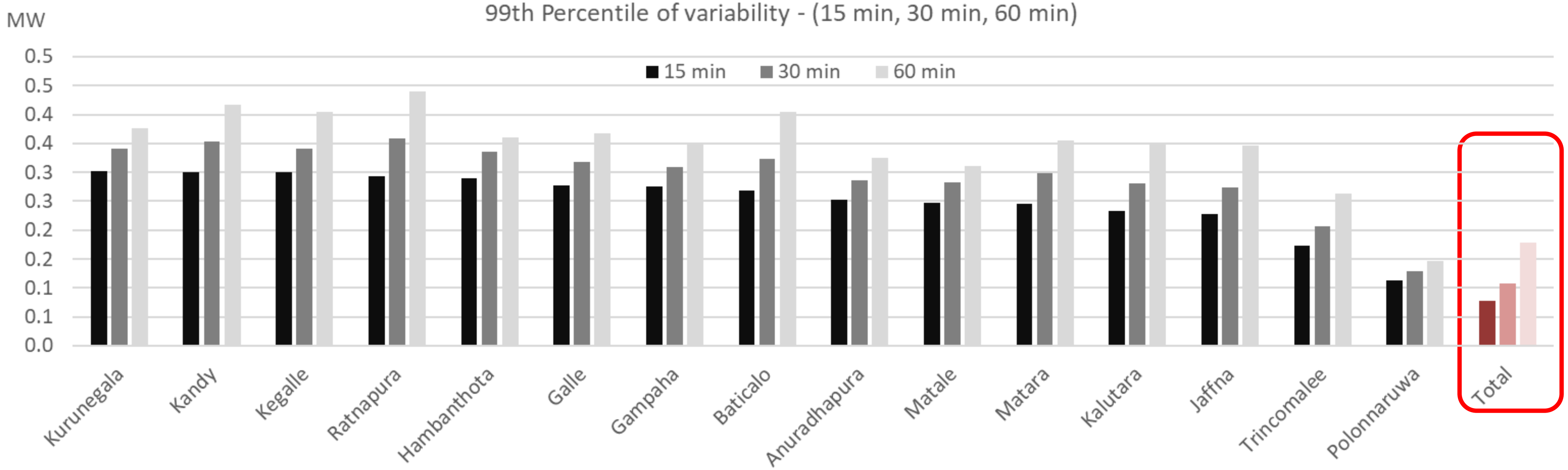


Assessing the Variability of Distributed Solar PV

Temporal Variability



Spatial Variability and Aggregated effect



Additional Studies

Capacity Expansion Study	• Long Term Electricity demand • Timing and sizing investment decision of Power Sector infrastructure • Economic Optimization and implications • RE policy targets and compliance • Technology advancements
System Operation Study	• Impact of VRE on Power System Operation • Impact on system operation cost • Identification of operational constrains and bottlenecks • Identification of required enhancements
Power System Stability and Power flow Study	• Steady State Behaviour of the power system • Dynamic Behaviour of the power system • Identification if system enhancements
Distribution System Integration Study	• Assessing the Impact on Distribution System • Power Quality, Reverse Power Flow, Islanding, Ground Fault and Transient Overvoltage, Short Circuit Strength

Thank You

Next Steps

- Access to tools and resources and continued engagement through facilitated online sessions
  - Online session 5 on RE Auctions with USAID Clean Power Asia: end-Oct/early Nov 2018
  - Webinar on Grid codes being developed along with USAID Greening the Grid
  - Online session 6 on Grid codes
- Learning resources development – case study, good practice
- Country-to-country peer learning opportunities
- Access to no-cost technical assistance

Thank you!

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