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GRID INTEGRATION SERIES: IMPACT OF VARIABLE RENEWABLE ENERGY ON SYSTEM OPERATIONS

Scaling Up Renewable Energy

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GRID INTEGRATION SERIES: IMPACT OF VARIABLE RENEWABLE ENERGY ON SYSTEM OPERATIONS

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ACRONYMS, ABBREVIATIONS, AND GLOSSARY OF TERMS

AC	Alternating current
AGC	Automatic generation control, a technology used to control production levels of generators in response to imbalances
CAISO	California Independent System Operator
CEA	Central Electricity Authority
CENACE	Centro Nacional de Control de Energía, Mexico's system operator
CREG	Comisión de Regulación de Energía y Gas (Colombia)
CREZ	Competitive renewable energy zone
DOE	Department of Energy (United States)
DR	Demand response/load response
DSM	Deviation settlement mechanism
EEX	European Energy Exchange
EIM	Energy imbalance market
ERAV	Electricity Regulatory Authority of Vietnam
ERC	Energy Regulatory Commission
ERCOT	Electric Reliability Council of Texas
EVN	Electricity of Vietnam
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GW	Gigawatt
IEA	International Energy Agency
IEGC	Indian Electricity Grid Code
kV	Kilovolt
kWh	Kilowatt hour
LBNL	Lawrence Berkeley National Library (U.S. DOE)
LMP	Locational marginal price
MEM	Mexico's wholesale electricity market
MER	Central American Regional Energy Electricity Market
MISO	Midcontinent Independent System Operator
MW	Megawatt
NGCP	National Grid Corporation of the Philippines
NLDC	National Load Dispatch Center
NREL	National Renewable Energy Library (U.S. DOE)
NYISO	New York Independent System Operator

PJM	Pennsylvania–New Jersey–Maryland Independent System Operator
POSOCO	Power System Operation Corporation, a central-level entity in India for system operations
PPA	Power purchase agreement, an agreement between the seller and buyer of power
PV	Photovoltaic, a solar panel to convert solar radiation into electrical energy
RGMO	Restricted governor mode of operation
RLDC	Regional load dispatch center
RRAS	Reserves Regulation Ancillary Services
SIEPAC	Panama and Central America Regional Market
SLDC	State load dispatch center, an entity in each state of India to balance load and generation
SURE	Scaling Up Renewable Energy (USAID project)
UPME	Unidad de Planeación Minero Energética (Colombia)
USAID	United States Agency for International Development
VRE	Variable renewable energy
WESM	Wholesale Electricity Spot Market

EXECUTIVE SUMMARY

Power systems are highly dynamic and are affected by a range of quickly changing factors, as well as by season and year. Adding renewable energy, which is itself variable in nature, to an already dynamic power system can pose challenges. However, variable renewable energy (VRE) can be effectively integrated into the grid if the power system has sufficient operational flexibility or the ability to respond to changes in electricity demand and generation.

This paper looks at how improved operations can increase a power system's flexibility to integrate large amounts of VRE. Specifically, it focuses on the planned addition of large-scale solar and wind energy generation in five developing countries: Colombia, India, Mexico, the Philippines, and Vietnam. The experiences of advanced national power systems with high shares of VRE provide a set of global best practices, from which seven characteristics can be used to assess the maturity of a power system in its ability to respond to the challenges of VRE integration:

1. Market protocols to access system flexibility
2. Clear dispatch rules for VRE
3. Grid code requirements for VRE
4. Long-term agreements for regional interconnection
5. Sufficient transmission capacity/planned investment
6. Ancillary services market products to reward flexibility
7. VRE forecasting integrated into system operations

Most of the five focus countries are in the early stages of VRE integration. Therefore, at this point, they do not face any critical problems with respect to VRE integration.

INDIA is a leader among the countries assessed, with an installed VRE capacity of 84.39 gigawatts (GW) with 37.28 GW of wind, 32.52 GW of solar, and the rest in biogas and small hydro.[1] In January 2020, India announced a target of 450 GW of VRE by 2030. It has adopted enhanced grid codes for VRE to support grid operations and is implementing a comprehensive VRE forecasting framework, with penalties for large deviations and plans to reduce the forecast time block from 15 minutes to 5 minutes. Ancillary service markets were introduced in 2016, but these are very limited with participation of only slow tertiary services.[2] India has increased its balancing area by synchronously interconnecting its five regional grids to make a single large grid, with scheduling and dispatch remaining a state-level responsibility. The country is working to adopt several planning and regulatory measures to achieve a target of 175 GW of VRE installed capacity by 2022. India is also planning green corridors to expand transmission capacity to integrate VRE resources.

MEXICO's VRE share is currently at a little more than 6 percent, and the country is at the forefront of addressing VRE integration challenges to achieve a 35 percent target by 2024.[3] Its market protocol and dispatch rules are favorable for VRE integration. Mexico also has a comprehensive VRE forecasting framework but with some gaps due to the lack of penalties for large deviations between actual and forecast. The country operates an energy balance market to meet it reliability needs. Its wholesale energy market is based on a locational marginal price (LMP) framework and is being operated in both

[1] https://energy.economictimes.indiatimes.com/news/renewable/india-has-installed-84-gw-of-renewable-energy-capacity-so-far-mnre/73042867.
[2] https://bridgetoindia.com/ancillary-services-market-still-at-an-early-stage-of-development/.
[3] This is a clean energy target that also includes nuclear and efficient cogeneration along with VRE resources.

day-ahead and real time with 15-minute intervals. The wholesale market also includes various ancillary services. Mexico updated its grid codes in 2016 to include stricter technical requirements for VRE resources to support system operation. It has cross-border interconnections with Belize, Guatemala, and the United States, but interchange is limited due to legacy agreements. Mexico has undertaken transmission strengthening and is developing competitive renewable energy zones (CREZ).

THE PHILIPPINES has a seven percent VRE share, with targets to achieve 50 percent overall renewable energy penetration by 2030. The country operates a wholesale electricity spot market in both day-ahead and real time with 5-minute intervals. The dispatch rules in the market lack economic curtailment, provide preferential dispatch to VRE, and implement curtailment for reliability reasons only. The Philippines updated its grid code for VRE interconnection and adopted a comprehensive VRE forecasting framework. It has a strong enabling framework but faces some regional interconnection and transmission infrastructure limitations. Backbone transmission projects are planned to address line congestion problems in the Visayas, and the Philippines is undergoing a process to establish competitive renewable energy zones.

COLOMBIA's VRE share is very limited (less than one percent), but the northeastern state of La Guajira has over 9,000 megawatts (MW) of wind potential. Colombia carried out its first successful renewable energy auction which awarded contracts that will boost the country's renewable energy capacity by 1,374 MW with 1,077 MW of wind and 297 MW of solar power generation. Results from this auction in October 2019 and a separate reliability auction in February 2019 will bring VRE participation to 12 percent in the generation mix by 2022. Colombia has scarcity pricing and reliability charge mechanisms to ensure the reliability of its long-term supply. It currently has a day-ahead market but is considering an intraday market where solar and wind plants with long-term contracts are expected to enjoy priority in dispatch. In the current market framework, VRE generation is dispatched on priority when available. Colombia has cross-border connections with Ecuador and Venezuela, and its transmission company, ISA, is a partner in building Panama's underwater cable to connect to the Central American Regional Electricity Market (MER). It has identified transmission upgrades to evacuate 1,500 MW of VRE from La Guajira. However, the absence of VRE technical requirements in the grid code and the lack of an ancillary services market and VRE forecasting framework are challenges to advancement.

VIETNAM has about 327 MW of wind[4] and 4,500 MW of solar capacity[5] installed as of the end of 2019. The country is working on the design of a new wholesale market, which is in the pilot stage, but renewable energy resources have not yet been integrated into the pilot. All generating resources greater than 30 MW, including VRE, will be integrated in the wholesale market after its full implementation. In the current market framework, VRE is dispatched on priority and the new wholesale market will have similar dispatch rules. Vietnam is facing challenges with limited cross-border ties, the absence of VRE requirements in the grid code, lack of an ancillary services market, lack of system-wide planning to address transmission congestion caused by VRE project siting, and no VRE forecasting framework.

Each country has its own market designs and regulatory policies for operating systems reliably. The integration of significant VRE requires focus and interventions to enhance the seven benchmark characteristics/capabilities outlined above. Some of the focus countries have made progress and are at a

[4] https://www.eco-business.com/news/gusty-growth-vietnams-remarkable-wind-energy-story/.
[5] http://documents.worldbank.org/curated/en/949491579274083006/pdf/Vietnam-Solar-Competitive-Bidding-Strategy-and-Framework.pdf.

certain level of readiness to integrate solar and wind energy, thanks to enhanced grid codes, market protocols to access system flexibility, clear dispatch rules for VRE, and sufficient transmission capacity/planned investment. However, some face challenges with long-term agreements for regional interconnection, ancillary services, and products to reward flexibility and integrating VRE forecasting into system operations.

The key conclusions on the focus countries' adoption of system and market practices to integrate VRE are:

MARKET PROTOCOLS TO ACCESS SYSTEM FLEXIBILITY. All the countries assessed here score average on this metric and can manage adequate resources with their current market protocols. India should accelerate the development and implementation of a regulatory or market framework to support investment in supply- or demand-side resources in the long term; the framework must be capable of meeting the need for flexible resource capacity under a growing share of VRE. Vietnam is working on the design of a new wholesale market, and Colombia has a proposal to include a capacity market for long-term contracts.

CLEAR DISPATCH RULES FOR VRE. Mexico and the Philippines have an LMP market framework, but the Philippines' dispatch rules lack economic curtailment for VRE. India and Colombia are considering the introduction of intraday and real-time markets. VRE resources in Vietnam's new wholesale market will be dispatched on priority.

GRID CODE REQUIREMENTS FOR VRE. Colombia, India, Mexico, the Philippines, and Vietnam updated their grid codes for VRE.

LONG-TERM AGREEMENTS FOR REGIONAL INTERCONNECTION. Colombia and Mexico have plans to increase their cross-border interconnections. India interconnected all regional grids to make a single large grid, but scheduling and dispatch remain a state-level responsibility, with some coordination by regional load dispatch centers and the national dispatch center, Power System Operation Corporation (POSOCO). India can benefit from better coordination across state balancing areas by moving toward a regional/national economic dispatch model. The Philippines and Vietnam are facing challenges with regional interconnections.

SUFFICIENT TRANSMISSION CAPACITY/PLANNED INVESTMENT. India and Colombia have planned investment in transmission projects to integrate VRE. Mexico and the Philippines are considering establishing competitive renewable energy zones. Vietnam has not yet planned any investment to strengthen the grid for VRE integration.

ANCILLARY SERVICES MARKET PRODUCTS TO REWARD FLEXIBILITY. India, Mexico, and the Philippines have preliminary ancillary services markets. Colombia and Vietnam are behind in setting up such markets, but their policy makers are considering the subject.

VRE FORECASTING INTEGRATED INTO SYSTEM OPERATIONS. Mexico and the Philippines have comprehensive VRE forecasting frameworks in place but lack penalties for large deviations between actual and forecast. India has a comprehensive VRE forecasting framework with penalties for deviations; the plan is to reduce the forecast time block from 15 to five minutes. Colombia has developed a forecasting framework, while Vietnam is developing one.

INTRODUCTION

To operate optimally, power systems must constantly balance the demand and supply of electricity. Adding renewable energy to the supply mix can pose challenges for power systems because of the inherent variable and uncertain nature of this resource. As the presence of variable renewable energy (VRE) increases, namely solar and wind power, the current paradigms to operate power systems need to evolve. New operating procedures and control room tools need to be developed in view of the increased uptake of solar and wind generation.

Power sectors have untapped sources of flexibility that can reliably integrate larger shares of renewable energy into the mix, but this requires much planning.[6] For a system with a high penetration of VRE, operational flexibility is key. Such flexibility enables nearly real-time decision-making related to power plants and transmission interconnections. The degree of system flexibility depends on factors like electricity trades on short-term markets and the technical standards or grid codes under which the power system operates.[7]

This paper analyzes how improved system operations can contribute to the increased flexibility of a power system in view of integrating VRE, particularly large amounts of solar and wind energy. The analysis characterizes how five developing countries—Colombia, India, Mexico, the Philippines, and Vietnam—are managing, or planning to manage, their power systems in relation to global best practices. These five countries are evaluated in terms of the seven characteristics in Figure 1, which indicate their readiness to address the challenges associated with increasing shares of VRE:

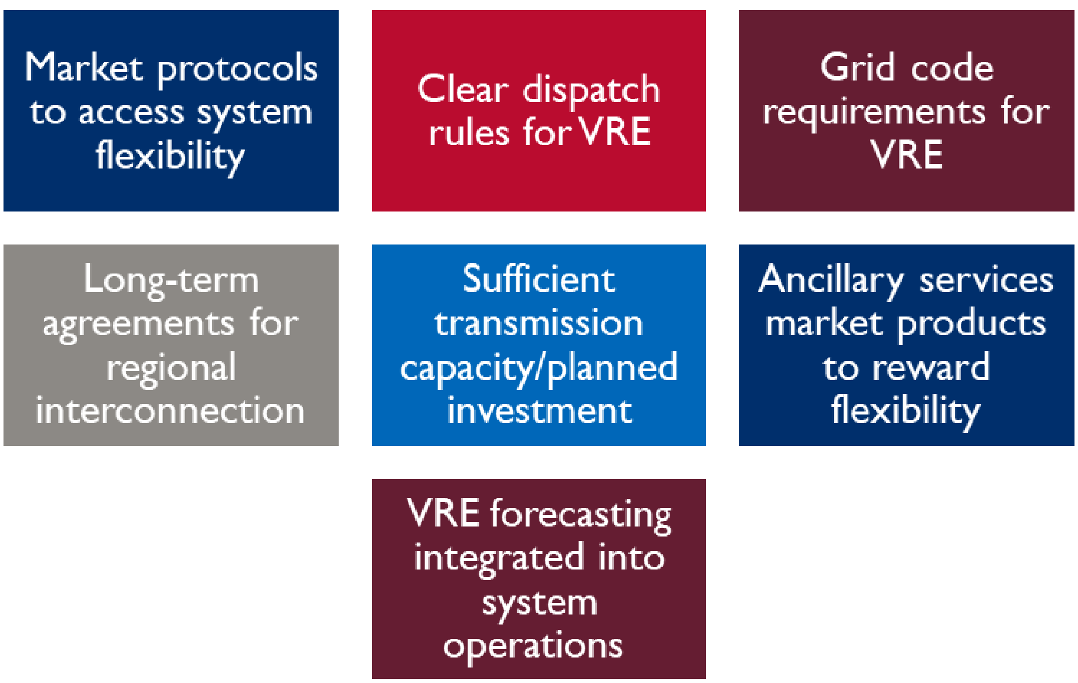

Figure 2. Seven Characteristics to Assess Readiness for Increasing Shares of VRE

[6] NREL. Fact sheet on system flexibility.
[7] IEA, 2017.

The paper also looks at each country's efforts to integrate VRE into its grid, focusing on the links between system operation and the effect of an increased share of VRE generation. Last, it points out specific areas in which the United States Agency for International Development (USAID) could implement technical assistance pilots to support countries in accelerating the integration of VRE in their systems. This research for this paper was conducted in three steps:

STEP 1: DESK RESEARCH. The team used country summary reports for Colombia, India, the Philippines, Mexico, and Vietnam as a starting point to summarize the key features of each country's power sector, experience with VRE management, challenges encountered, solutions implemented, and plans to operate the power system with a higher share of VRE (Annex B).[8] It supplemented this information with reports, presentations, official decrees, and other public information, to the extent available.[9]

STEP 2: INTERVIEWS. The team interviewed energy sector specialists and experts from the National Renewable Energy Laboratory (NREL), Electricity of Vietnam, and Scaling Up Renewable Energy's (SURE) implementing partner, Tetra Tech. The experts' knowledge of VRE-related system operations in the five countries helped fill information gaps regarding challenges and solutions planned or in implementation to operate a system with a higher share of VRE. Annex A contains a list of experts interviewed.

STEP 3: COUNTRY ANALYSIS. The team used the information from desk research and interviews to develop an assessment of country readiness to respond to the challenges associated with higher shares of VRE.

[8] USAID developed summary power sector reports for 12 countries under the SURE Program in 2018.
[9] It was challenging to capture the most updated operational characteristics of the grids and plans in Colombia and Vietnam, where power system regulations are still changing.

POWER SYSTEMS WITH VARIABLE RENEWABLE ENERGY

VARIABILITY AND UNCERTAINTY IN ELECTRICITY SYSTEMS

Power systems are highly dynamic and are affected by a range of quickly changing factors, as well as by season and year. Within each timescale (days, hours, minutes, or seconds), the balance between load and generation must be planned and maintained. In the timescale of seconds and minutes, a system's stability and reliability are primarily maintained by automatic control systems.

Variability refers to the predictable changes in power demand and/or generation.[10] Variability exists within loads on an hourly, daily, and even seasonal basis. With the integration of more solar and wind power plants, which generate variable power output dependent on weather conditions, the system's variability increases.

Uncertainty is inherent to power systems and can take the form of load (demand) changes, generation outages, and transmission contingencies. Uncertainty refers to the inability to accurately predict the power demand and/or generator output (supply).[11] Since weather, and thus output from solar and wind generators, cannot be perfectly predicted, these technologies introduce additional uncertainty to the system.

These factors can create power imbalances and power flow changes at all levels of the grid and must be balanced by the system operator. As more VRE capacity is integrated into a grid network, operational challenges increase. Linkages between VRE and system operations can include:[12]

SYSTEM STABILITY. VRE generators are non-synchronous generators and are not inherently capable of contributing to system inertia, voltage, and frequency control. A high penetration of VRE affects system stability by reducing system inertia, reducing voltage and frequency control capabilities, and creating more volatile power flow patterns. However, modern technologies for VRE, enabled by power electronics devices, provide grid services such as system inertia, primary frequency regulation, active voltage control, controlled ramping, and fault ride-through capability.

OPERATING RESERVES. VRE generation can affect the required reserves as penetration increases—operating reserves such as regulation, load following, spinning and non-spinning reserves—due to unexpected changes and large ramps.

GENERATION FORECASTING. The uncertainty of variable resources has implications for scheduling thermal generation assets ahead of time, particularly when done one day ahead or longer. Higher VRE generation than expected in real time can create an over-generation situation and the need for curtailment when inflexible thermal generation cannot be backed down. Forecasting generation output from these variable resources greatly improves scheduling and reduces the need for reserves.

[10] https://greeningthegrid.org/resources/factsheets/sources-of-operational-flexibility.
[11] https://greeningthegrid.org/resources/factsheets/sources-of-operational-flexibility.
[12] https://emp.lbl.gov/sites/default/files/lbnl_anl_impacts_of_variable_renewable_energy_final.pdf.

POWER MARKET AND ELECTRICITY PRICES. A study from the U.S. Department of Energy's (DOE) Lawrence Berkeley National Laboratory (LBNL) shows that at higher penetration of VRE, the temporal and geographic patterns of wholesale electricity prices are altered and reduced. Ancillary service prices could potentially increase.[13]

TRANSMISSION CONGESTION. In a system that is not properly planned, transmission capability may become limited between the location of VRE generation and load centers. This can lead to more frequent transmission congestion and curtailment of VRE generation.

LONG-TERM RESOURCE ADEQUACY AND PLANNING RESERVE MARGINS. System planning ensures adequate capacity in the system to maintain reserve margin and reliably serve the expected peak demand. VRE resources can provide capacity value to the system by generating during peak demand periods. The capacity value of VRE resources is dependent on the extent to which VRE generation coincides with demand patterns. This capacity value of VRE can decline as penetration increases because of changes in net load pattern. A high level of VRE generators with lower availability may create the need to have a higher reserve margin requirement to satisfy applicable reliability standards.

VRE also has desirable characteristics that can aid power system operation, such as providing the reactive power support traditionally supplied by conventional resources. Power systems can purchase such services or make appropriate modifications to VRE power plants to supply them.

FLEXIBILITY OF POWER SYSTEMS

Power systems can effectively integrate VRE power into the grid if they have sufficient operational flexibility. Operational flexibility is the ability of a power system to respond to changes in electricity demand and generation. Flexibility in the system already exists but may need to be increased to incorporate greater penetration of VRE. System flexibility can be enhanced in several ways:

FLEXIBLE GENERATION. Dispatchable conventional thermal power plants can provide flexibility if they can ramp up and ramp down rapidly to follow net load;[14] quickly shut down and start up; and operate efficiently at a lower minimum level during high VRE output periods. Modifications to equipment and operational practices of conventional thermal plants can provide increased flexible generation.

MARKET DESIGN AND PROTOCOLS. Market design can unlock significant flexibility, often at lower economic costs than options that require changes to the physical power system. Adjusting day-ahead generation scheduling practices to allow changes closer to real time allows dispatch decisions to be made based on improved forecasts of both VRE output and demand. This decreases the need for expensive reserves and allows for more accurate and efficient market operation.

TRANSMISSION STRENGTHENING. A well-planned transmission grid enables the integration of higher levels of VRE by accommodating diverse VRE locations and locations far from loads, reducing transmission congestion, and providing access to flexible resources in other regions.

[13] https://emp.lbl.gov/sites/default/files/lbnl_anl_impacts_of_variable_renewable_energy_final.pdf.

[14] Net Load is the difference between forecasted load and expected electricity production from VRE, https://www.caiso.com/documents/flexibleresourceshelprenewables_fastfacts.pdf.

INTERCONNECTED AND EXTENDED BALANCING AREAS. Interconnection with neighboring networks and extended transmission lines gives the system greater access to various balancing resources. The aggregation of generation assets through interconnection improves flexibility and reduces net variability across the power system. Other sources of flexibility include smart network technologies and advanced network management practices that minimize bottlenecks and optimize transmission usage.[15]

FLEXIBLE DEMAND AND STORAGE. Demand/load response (DR) allows consumers to participate in load control based on price signals. DR provides flexibility by responding to supply-side variability and grid conditions. Storage technologies such as pumped hydro, thermal storage, and batteries provide system flexibility. Storage resources hold energy produced during periods of excess VRE generation and then discharge this energy when it is needed.

ADVANCED FORECASTING. Advanced VRE forecasting in day-ahead and real-time operation helps reduce the amount of system flexibility needed to integrate VRE resources. The incorporation of forecasting into system operation enables system operators to determine unit commitment and reserve requirements, which can, for example, minimize a thermal plant's ramping requirements and reserves. See USAID's Variable Renewable Energy Forecasting white paper.[16]

[15] https://greeningthegrid.org/resources/factsheets/sources-of-operational-flexibility.
[16] https://pdf.usaid.gov/pdf_docs/PA00WPK7.pdf

OPERATING A SYSTEM WITH A HIGH SHARE OF VARIABLE RENEWABLE ENERGY

The International Energy Agency (IEA) defines four phases of VRE integration, which are differentiated by the effects on power system operation resulting from increasing shares of annual VRE generation (Figure 3). As the effects of VRE become noticeable, operational practices can be upgraded and modified to integrate more VRE capacity and maintain smooth system operation. For example, a forecasting system to predict VRE output is needed so that flexible power plants can efficiently balance VRE (and demand) variability.

Phase 1 - VRE's share in annual electricity generation up to around 3 percent

- VRE capacity has no noticeable effect on the system

Phase 2 - VRE's share in annual electricity generation: 3 percent to almost 15 percent

- VRE has noticeable effect, but is manageable by upgrading some operational practices
- Example of upgrades: forecasting of VRE plant output to balance flexible resources along with that of electricity demand

Phase 3 - VRE's share in annual electricity generation rises to a share of 15 percent to almost 25 percent

- VRE poses significant integration challenges, e.g., variability affects the overall system's operation
- Flexibility in this context describes the ability of the power system to respond to uncertainty and variability in the supply-demand balance, in the timescale of minutes to hours

Phase 4 - VRE's share in annual electricity generation rises from 25 percent to almost 50 percent

- VRE poses highly technical challenges for the stability of power system's operation in very short timescales (a few seconds and less)
- VRE capacity covers nearly 100 percent of demand at certain times

Figure 4. Four Phases of VRE Integration

Three of the countries examined in this paper, the Philippines, Vietnam, and Colombia, were in phase one as of 2016, with less than three percent VRE, which has no noticeable effect on their systems. Two countries—India and Mexico—are in phase two. India is a leader with four percent of VRE share in its annual generation, followed by Mexico with 3.2 percent of VRE share. Neither country experiences any noticeable effect on its systems. However, it should be noted that many of these countries have large amounts of VRE projects planned or in pipeline and should be preparing their systems for higher levels of penetration. The readiness of power systems, from a system operations perspective, to integrate VRE is evaluated here based on seven factors (see Figure 5). These factors for each country's power sector are described in Annex B, based on publicly available information.

These seven characteristics are used to assess the general level of maturity of the power systems of the five countries to respond to the challenges associated with higher shares of VRE and advance through the phases outlined in Figure 6. The characteristics reflect best practices from the U.S. and Europe as identified in the power systems that are operating successfully with high VRE penetration. Each of the seven characteristics is described below. Within each characteristic's description, the stars indicate increasing level of complexity or enhancement (★ being lowest).

MARKET PROTOCOLS TO ACCESS SYSTEM FLEXIBILITY

DESCRIPTION	BEST PRACTICES
• No organized market for maintaining resource adequacy or sub-hourly dispatch ★ • Hybrid market approach to increase system flexibility ★★ • Combine centralized dispatching control with optimized high-resolution dispatching and reduced balancing intervals ★★ • Sub-hourly scheduling and dispatch (5-to10-minute intervals) ★★ • Capacity market to incentivize flexible resources that cannot recover costs in the energy market ★★★	• In the U.S., the Midcontinent Independent System Operator (MISO) runs a real-time market with 5-minute dispatch intervals, which allows fast-start resources and demand response to set the price when they are economic. The dispatch in 5-minute intervals reduces the movement of conventional thermal generators; the system becomes efficient and the reserve requirement is reduced. • In the performance-based capacity markets in MISO, the Pennsylvania-New Jersey-Maryland interconnection (PJM), and New York Independent System Operator (NYISO) regions, the peaking or flexible resources are dispatched only to meet peak load conditions, which cannot recover their cost from the energy market only. The capacity market incentivizes such resources to contribute to the system capacity when needed most. • There is no centralized wholesale market in the Western U.S., but the introduction of an energy imbalance market (EIM) provided a platform to access flexible resources (both demand and supply) to manage high solar generation in the California real-time market.

CLEAR DISPATCH RULES FOR VRE

DESCRIPTION	BEST PRACTICES
• No clear dispatch rules for VRE; treated as must-run or receives preferential dispatch when available ★ • Allows economic curtailment during over-generation (*i.e.*, provides economic signals using zonal/nodal prices) ★★ • Integrates VRE into the economic dispatch and commitment tools ★★★	• MISO's Dispatchable Intermittent Resource program allows it to send economic dispatch signals to wind generators in real time, similar to other conventional resources. This eliminated manual curtailment of wind generators during over-generation condition. • Several markets in the United States adopted an LMP nodal pricing framework, which allows negative pricing to occur during over-generation. The negative pricing means the generator pays for generating power which acts as an economic signal for backing down generation and shifting capacity into high pricing regions.

GRID CODE REQUIREMENTS FOR VRE

DESCRIPTION	BEST PRACTICES

• No specific technical and operational requirements for VRE in the grid code ★
• Technical standards for interconnection requirements of VRE generators: ★★
  – Voltage and reactive power control
  – Low voltage ride-through capability
  – Frequency/inertia response
  – Communication requirement
• VRE provides grid services ★★★
  – Frequency and voltage regulation
  – Dispatchability
	• The Electricity Reliability Council of Texas (ERCOT) requires wind plants to have automatic voltage regulators and maintain 0.95 lagging/leading reactive power at the interconnecting substation.
	• Hydro Quebec requires wind plants to provide inertial responses during system disturbances. The technological advancements in power electronics devices have enabled VRE plants to provide frequency control by extracting stored inertial energy from the wind turbines, which helps maintain system stability against sudden frequency changes.

LONG-TERM AGREEMENTS FOR REGIONAL INTERCONNECTIONS	
DESCRIPTION	BEST PRACTICES
• Limited or no interconnection with neighboring regions ★ • Interconnection with neighboring networks and extended transmission lines give the system greater access to various balancing resources ★★★	• Markets for regional energy exchange or hybrid market – such as EIM in the Western U.S. and the European Energy Exchange (EEX).[17] The EIM allows California to share balancing resource across neighboring jurisdictions, which leads to a reduction in reserve requirements and improves interchange efficiency over shorter time intervals. • PJM has a deep level of regional interconnection and is actively researching problems associated with integrating wind power. Lessons from a sophisticated market like this can feed into the decision-making of developing countries.[18] • Denmark expanded its balancing area by connecting to Nordic power markets. Linking with the cross-border market enabled power exchanges with neighboring countries and allowed VRE resources to access pumped hydro storage in the Nordic pool to store surplus power.

ANCILLARY SERVICES AND PRODUCTS TO AWARD FLEXIBILITY[19]	
DESCRIPTION	BEST PRACTICES
• No market framework for ancillary services ★ • Conversion of a baseload coal plant into a peaking plant by changing operational practices, monitoring and managing temperature ramp rates, creating a suite of inspections for all affected equipment ★★ • Ramping products[20]—ramp requirements can be calculated considering the short-term load forecast, resource plan deviation, VRE forecast, and system demand adjustment ★★★ • Compensation mechanisms for balancing ★★★ • Flexible ramping product to incentivize fast ramping capacity ★★★	• California ramping market: The California Independent System Operator (CAISO) implemented a flexi-ramp product in the real-time market, and MISO is looking at introducing a new product.[21] CAISO's ramping market compensates generators for remaining off but available during a subsequent 5-minute interval if ramping needs exceed forecasts. • ERCOT allows fast-response loads (i.e., DR) to participate in the ancillary services market. ERCOT derives 50 percent of the contingency reserve from DR in the form of fast-frequency response.

VRE FORECASTING INTEGRATED INTO SYSTEM OPERATIONS	
DESCRIPTION	BEST PRACTICES
• No framework for VRE forecasting ★ • New generation of probabilistic reliability standards, operating procedures, and control room tools ★	• CAISO's ramp uncertainty prediction tool from the U.S. DOE's Pacific Northwest National Laboratory dynamically and adaptively correlates to changes in system conditions[23]

[17] EEX is the leading energy exchange in Europe; it develops, operates, and connects secure, liquid, and transparent markets for energy and related products.
[18] openknowledge.worldbank.org/bitstream/handle/10986/17507/773070v10ESMAP0ISP0Lessons0BN004010.pdf?sequence=1&isAllowed=y.
[19] Demand and storage, new ramping products, capacity markets.
[20] Lawrence E. Jones, Renewable Energy Integration, Second Edition, Academic Press.
[21] Ibid.
[23] https://www.osti.gov/servlets/purl/1234682.

VRE FORECASTING INTEGRATED INTO SYSTEM OPERATIONS	
DESCRIPTION	BEST PRACTICES
• Optimal control for renewable energy generation. Primary control: As synchronous machines are being replaced by new assets, new control methods are being studied such as derivative feedback for wind turbines supplemented by a controllable amount of battery storage ★★★ • New optimization algorithms for system operation in a reliable and economical way. A robust and stochastics unit commitment for system operator is an example of how to set a competitive framework for VRE[22] ★★★	• ERCOT deployed probabilistic wind forecasts for the next two hours updated every five minutes, which improved the accuracy of wind power ramp forecasting.[24] ERCOT can now commit daytime resources with a better understanding of the likelihood of additional resource needs for large ramping events caused by changes in wind generation. • The grid operator in Denmark constantly compares actual wind output in real time against the wind forecast done the day before. The variation between actual output and forecasted value is then used to better forecast wind output over the next hours ahead of real time. This process virtually eliminates errors in the predictability of wind output.[25]

[22] Ibid., Chapter 8, page 109.
[24] http://newenergyupdate.com/wind-energy-update/texas-wind-set-real-time-forecast-boost-move-faster-dispatch.
[25] https://www.greentechmedia.com/articles/read/does-denmark-hold-the-key-to-integrating-large-amounts-of-intermittent-rene#gs.LOK9cJ8.

SELECTED COUNTRY EXPERIENCE

Five countries were assessed based on the seven characteristics summarized in Table 1. Countries were ranked on each characteristic, with ★★★ indicating the most favorable conditions to advance VRE integration and ★ being the least favorable.[26] The last row in the table provides an overall ranking for the characteristics or the country (each ★ = 1 point). A high-level summary of the country findings is provided in within this section, including the reasons for each characteristic's ranking. Annex A lists the stakeholders interviewed for this study, while Annex B summarizes the background information collected for each power system.

TABLE 1. VRE INTEGRATION RANKING

	COLOMBIA	INDIA	MEXICO	PHILIPPINES	VIETNAM
Level of VRE Penetration	IEA PHASE 1	IEA PHASE 2	IEA PHASE 3	IEA PHASE 4	IEA PHASE 5
Market Protocols to Access System Flexibility	★★	★	★★	★★	★ (toward ★★)
Clear Dispatch Rules for VRE	★	★	★★	★	★
Grid Code Requirements for VRE	★★	★★★	★★★	★★	★
Long-Term Agreements for Regional Interconnection	★	★★	★ (toward ★★)	★	★
Sufficient Transmission Capacity / Planned Investment	★★	★★★	★★ (toward ★★★)	★★	★
Ancillary Services and Products to Reward Flexibility[27]	★	★★ (toward ★★★)	★★ (toward ★★★)	★★	★ (toward ★★)
VRE Forecasting Integrated into System Operations	★★	★★ (toward ★★★)	★★	★★	★ (toward ★★)
Country Total	10	14	14	12	8

Note: ★ = 1 point, ★★ = 2 points, ★★★ = 3 points

[26] The stars used in here do not relate to the criteria used in the previous section.
[27] Demand and storage, new ramping products, capacity markets.

From the assessment of the five countries, the following observations can be made:

- **The countries are at an early stage of integrating variable renewable energy;** therefore, no critical problems were identified (in four out of five countries, the VRE share is less than 10 percent).
- **India and Mexico are at the forefront of integrating solar and wind;** Mexico is the highest ranked, followed by India and the Philippines. The Philippines has a strong enabling framework but faces some regional interconnection and transmission infrastructure limitations.
- **Vietnam and Colombia are setting up policies and incentives** to procure large-scale solar and wind. In 2019 both countries have seen a sharp jump in VRE installations. The areas where countries ranked the lowest are:
  - **Long-term agreements for regional interconnection:** Colombia and Mexico plan to increase their cross-border interconnections. India interconnected all of its regional grids to form a single large grid but scheduling and dispatch are state-level responsibilities. India can benefit from better coordination across state balancing areas by moving to regional/national dispatch. The Philippines and Vietnam have challenges with regional interconnections.
  - **Ancillary services and products to reward flexibility:** India, Mexico, and the Philippines have started ancillary services markets, but these are at an early stage. Colombia and Vietnam are behind in setting up ancillary services markets.
  - **VRE forecasting integrated into system operations:** Mexico and the Philippines have comprehensive VRE forecasting frameworks in place, but lack penalties for high deviations between actual and forecast. India has a comprehensive VRE forecasting framework that is currently under implementation, with plans to reduce the forecast time block to 5 minutes. Colombia and Vietnam are yet to develop a VRE forecasting framework.
- Areas where countries ranked the highest demonstrate:
  - **Grid code requirements for VRE:** Each of the five countries has updated its grid codes.
  - **Market protocols to access system flexibility:** All assessed countries scored average on this topic and can manage adequate resources with their existing market protocols. India needs to develop a regulatory or market framework to support investment in supply- or demand-side resources in the long term; the framework should meet the need for flexible resource capacity under a growing VRE scenario. Vietnam is working on the design of a new wholesale market and Colombia has a proposal to include forward capacity markets for long-term contracts.
  - **Clear dispatch rules for VRE:** Mexico and the Philippines have an LMP market framework, but the Philippines' dispatch rules lack economic curtailment for VRE. India and Colombia are considering the introduction of intraday or real-time markets. Vietnam's new wholesale market will not integrate VRE as a generating resource but needs to revise rules and protocols to include them in future.

– **Sufficient transmission capacity/planned investment:** India and Colombia have planned investment in transmission projects to integrate VRE. Mexico and the Philippines are considering establishing competitive renewable energy zones. Vietnam has not yet planned any investment to strengthen the grid for VRE integration.

COLOMBIA

Colombia aims to benefit from the complementary nature of wind power and its hydro-based system. Wind power offers a counter-cyclical feature for more reliable operation, which is especially crucial in view of the extended droughts the country has experienced in recent years.[28] The northeastern state of La Guajira has over 9,000 MW[29] of wind potential; the main challenge to realizing this potential is transmission capacity constraints. Investments are being undertaken in La Guajira for alternating current (AC) lines and substations to integrate 1,500 MW of wind power. Colombia carried out its first successful renewable energy auction, which awarded contracts that will boost the country's renewable energy capacity by 1,374 MW with 1,077 MW of wind and 297 MW of solar power generation at a historic low price. Colombia's power system is characterized in Table 2 based on desk research (to the extent information was publicly available) and interviews with the SURE team.

TABLE 2. COLOMBIA'S RANKING IN SELECTED CHARACTERISTICS

CHARACTERISTIC	RANKING	REASON	POTENTIAL NEXT STEPS
Market Protocols to Access System Flexibility	★★	• In 2006, Colombia introduced a scarcity price and reliability charge to ensure the reliability of the long-term supply. • Dispatch at one-hour intervals • The regulatory commission on energy and gas, Comisión de Regulación de Energia y Gas (CREG), has proposed to revise the scarcity price and reliability charge mechanism. The proposal also includes a forward capacity market for long-term contracts.[30]	• Short-term market based on LMP framework • Forward capacity market
Clear Dispatch Rules for VRE	★	• The country is considering an intraday market (the current market is day-ahead). Solar and wind plants with long-term contracts are expected to receive priority in dispatch. • Preferential dispatch—VREs are dispatched on priority when available. • Resolution 4-0791 provides a framework for long-term contracts favoring emission reduction and resource diversification.	• Integrate VRE into the economic dispatch and commitment tool
Grid Code Requirements for VRE	★★	• The grid code has been recently updated to include wind and solar technical specifications.	• VRE to provide grid support
Long-Term Agreements for Regional Interconnection	★	• Colombia is connected to Ecuador and Venezuela, but the Ecuador interconnection is inadequate, and Venezuela no longer trades with Colombia. Panama's interconnection	• Strengthen the regional interconnection

[28] Studies by Unidad de Planeación Minero Energética (UPME) have shown that wind patterns in several locations in Colombia are counter cyclical to rain patterns, particularly during droughts. This counter-cyclical feature of wind generation could contribute to maintain hydro reservoirs at higher levels during periods of low rain, increasing the system's resilience to cope with prolonged droughts.
[29] Interview with Jairo Gutierrez, SURE Project Lead, Colombia.
[30] CREG Expert Panel on Colombian Energy Market Reform, David Harbord, October 4, 2016.

TABLE 2. COLOMBIA'S RANKING IN SELECTED CHARACTERISTICS

CHARACTERISTIC	RANKING	REASON	POTENTIAL NEXT STEPS
		cable was planned to connect to the Central American Regional Electricity Market (MER), which can further contribute to flexibility since MER is not a hydro-based generation mix. But the project was suspended due to a lack of capital and technical and socioenvironmental problems.[31]	
Sufficient Transmission Capacity / Planned Investment	★★	• Transmission reinforcements that have been identified to evacuate 1,500 MW[32] of VRE in La Guajira include: a 500 kilovolt (kV) double-circuit AC line in Cuestecitas, several substations, and HVDC lines.	• Identify and build more transmission projects to tap VRE resources
Ancillary Services and Products to Reward Flexibility	★	• Incipient ancillary services rules, only secondary reserves are regulated. In theory, hydropower could be a source of flexibility, but the country has endured a prolonged and intense drought that has lowered hydro reservoir levels. • The ancillary services market is under discussion by the regulator.[33]	• Consider an ancillary market • Introduce ramping products
VRE Forecasting Integrated into Operational Practices	★★	• The system operator is setting up a forecasting team and conducting a pilot. • Comprehensive forecasting framework was introduced in 2019 Grid Code update which includes penalties for deviations	• Set up a comprehensive VRE forecasting framework • Introduce penalties for deviations from forecast

INDIA

India expects that by 2027, its installed capacity from renewable energy sources will be as high as 44 percent.[34] Its power system is characterized in Table 3, based on desk research and the study team's assessment.

TABLE 3. INDIA'S RANKING IN SELECTED CHARACTERISTICS

CHARACTERISTIC	RANKING	REASON	POTENTIAL NEXT STEPS
Market Protocols to Access System Flexibility	★	• Historically, there has been investment to ensure resource adequacy, especially in thermal and hydro capacity. But in the long term, India needs to develop a regulatory or market framework to support investment in supply- or demand-side resources that can meet the need for flexible resource capacity under a growing VRE scenario.	• Develop a capacity or scarcity mechanism to maintain flexibility and resource adequacy

[31] https://www.panamatoday.com/panama/panama-asks-indigenous-region-guarantee-electric-interconnection-colombia-8213.
[32] UPME Plan de Expansión de Referencia Generación – Transmisión 2017 – 2031. www1.upme.gov.co/Documents/Energia%20Electrica/Plan_GT_2017_2031_PREL.pdf.
[33] https://www.enelamericas.com/content/dam/enel.../en/.../Focus_Colombia.pdf.
[34] http://regridintegrationindia.org/wp-content/uploads/sites/3/2017/09/1_2_GIZ17_xxx_presentation_Pankaj_Batra.pdf.

TABLE 3. INDIA'S RANKING IN SELECTED CHARACTERISTICS			
CHARACTERISTIC	RANKING	REASON	POTENTIAL NEXT STEPS
		• In its Greening the Grid study, DOE's NREL suggested developing a new tariff structure that moves away from focusing on energy delivery. Agreements can specify various performance criteria, such as ramping, specified start-up or shut-down times, and minimum generation levels, along with notification times and performance objectives that achieve flexibility goals.[35] • Renewable energy generators are allowed to sell power to third-party and captive consumers.	
Clear Dispatch Rules for VRE	★	• India is considering the introduction of a real-time market with gate closure[36] of 1.5 hours prior to delivery. The gate closure will gradually be reduced as process automation improves.[37] • Treats solar and wind as a must-run station;[38] however, the country could employ alternative approaches to limit financial risks, such as annual caps on curtailed hours. • Deviation charges for under- or over-injection.[39] • Special dispensation for states with more than 1,000 MW combined solar and wind. • NREL recommended the implementation of base scheduling and dispatch of power based on production costs (merit order dispatch).[40]	• Form a centralized dispatch market based on the LMP framework • Integrate VRE into the economic dispatch and commitment tool
Grid Code Requirements for VRE	★★★	• Grid code requires VRE to provide fault ride-through capability, frequency control support and comply with power factor constraints. • In 2017, the grid code was amended and includes the integration of VRE such as scheduling renewable energy and forecasting solar energy.[41] • The system operator can curtail solar and wind for security and safety reasons.	• N/A
Long-Term Agreements for Regional Interconnection	★★	• Single large grid, synchronously interconnecting all the regional grids; 78 GW of inter-regional transmission capacity. • Scheduling and dispatch are a state-level responsibility, but India can benefit from better coordination across state balancing areas by moving to regional/national dispatch.	• Continue discussions on six cross-border energy interconnections between Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka.

35 https://www.nrel.gov/docs/fy17osti/68745.pdf.
36 Gate closure is the point before actual generation occurs, by which time a resource is committed and can't be changed. A shorter gate closure time allows VRE to be scheduled more accurately, reducing imbalances and the need for flexibility.
37 http://www.cercind.gov.in/2018/draft_reg/RTM.pdf.
38 http://regridintegrationindia.org/wp-content/uploads/sites/3/2017/09/1_2_GIZ17_xxx_presentation_Pankaj_Batra.pdf.
39 Ibid.
40 https://www.nrel.gov/docs/fy17osti/68745.pdf.
41 http://regridintegrationindia.org/wp-content/uploads/sites/3/2017/09/GIZ17_189_posterpaper_Monika_Yadav.pdf.

TABLE 3. INDIA'S RANKING IN SELECTED CHARACTERISTICS			
CHARACTERISTIC	RANKING	REASON	POTENTIAL NEXT STEPS
		• Limited cross-border interconnections: Bhutan (1,450 MW import), Bangladesh (500 MW export), and Nepal (300 MW export). • Initial discussions for six cross-border energy interconnections between Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka.[42]	
Sufficient Transmission Capacity / Planned Investment	★★★	• Green Energy Corridor I Project integrates about 43 GW of renewable energy capacity. • Green Energy Corridor II involves connectivity for 20 GW of solar parks in such states as Andhra Pradesh, Madhya Pradesh, Karnataka, Rajasthan, and Gujarat.[43]	• Green Energy Corridor project is in progress
Ancillary Services and Products to Reward Flexibility	★★ (toward ★★★)	• Ancillary services include frequency support and balancing services • Slow tertiary control (effect is felt only after 20-30 minutes) through the Reserves Regulation Ancillary Service (RRAS) has been implemented since April 2016.[44] • Hydro power stations have not been utilized for RRAS so far. • Directives for fast tertiary services through RRAS using hydro are to be introduced at the appropriate interstate level. • The Central Electricity Regulatory Commission (CERC) is considering redesigning the current framework of the ancillary service mechanism in India.[45]	• CERC to consider redesigning the current framework of the ancillary service mechanism in India.
VRE Forecasting Integrated into Operational Practices	★★ (toward ★★★)	• The VRE forecasting framework requires day-ahead forecasting with a time block of 15 minutes and allows for 16 updates to the forecast on an intraday basis. • The penalty for large deviations in actual versus forecast is included in the framework. • India's comprehensive VRE forecasting framework has been implemented in many states and is currently under implementation in others. Future plans are to reduce the forecast time block to 5 minutes.	• A comprehensive VRE forecasting framework is currently under implementation.

[42] www.adb.org/sites/default/files/publication/173198/south-asia-wp-038.pdf.

[43] https://www2.deloitte.com/content/dam/Deloitte/in/Documents/energy-resources/in-enr-the-evolving-energy-landscape-india-april-2018-noexp.pdf.

[44] www.nrel.gov/docs/fy17osti/68745.pdf and http://www.cercind.gov.in/2018/draft_reg/RTM.pdf.

[45] https://powerline.net.in/2018/09/10/cerc-notifies-discussion-paper-redesigning-ancillary-services-market/.

MEXICO

In Mexico, wind and solar photovoltaic (PV) alone will account for almost one-fourth of the total installed capacity additions from 2015 to 2029,[46] equivalent to approximately 13 GW. The country's power system was transformed in 2013, when the sector was reformed from a vertically integrated sector to a more competitive one. Part of the legacy is a huge overcapacity in generation. Mexico's power system is characterized in Table 4 based on desk research and interviews with the SURE team,

TABLE 4. MEXICO'S RANKING IN SELECTED CHARACTERISTICS

CHARACTERISTIC	RANKING	REASON	POTENTIAL NEXT STEPS
Market Protocols to Access System Flexibility	★★	• Focus on reliability. Mexico has a capacity balance market[47] for the 100 most critical hours of the previous year. • Currently installed capacity is easily sufficient to meet peak demand. Reserves are expected to peak in 2020.[48] • Long-term energy auction products: energy, capacity and clean energy certificate. Other renewable energy projects can be contracted as merchant plants or with bilateral agreements. • Mexico operates its wholesale electricity market in real time with 15-minute time intervals. • A scheduling system for VRE resources is absent.[49]	• Move forward with the capacity market for long-term resource adequacy
Clear Dispatch Rules for VRE	★★	• Mexico's wholesale market works on an LMP nodal pricing framework, which allows negative pricing to occur during over-generation. This sends economic signals to back down generation.	• Integrate VRE into the economic dispatch and commitment tools
Grid Code Requirements for VRE	★★★	• The grid code was updated in 2016.[50] It includes intermittent renewable energy power units and outlines the importance of increasing power system flexibility.	• N/A
Long-Term Agreements for Regional Interconnection	★ (toward ★★)	• Underutilized interconnections with Belize, Guatemala and USA. Limited trade flow due to legacy agreements. • Since 2016 Mexico has been in discussions on how to harmonize the regulatory frameworks and build infrastructure to connect Mexico to the SIEPAC[51] line (Panama and Central America Regional Market).[52]	• Interconnection of Mexico to the SIEPAC

[46] IEA 2016—Next-Generation Solar and Wind.
[47] In Spanish, "Mercado de balance de potencia," https://www.cenace.gob.mx/Paginas/Publicas/MercadoOperacion/AcreditacionReqPotencia.aspx
[48] Reserva de Planeación Eficiente (Margen de Reserva), page 85, https://www.gob.mx/cms/uploads/attachment/file/331770/PRODESEN-2018-2032-definitiva.pdf.
[49] http://www.cre.gob.mx/documento/3979.pdf.
[50] http://www.dof.gob.mx/nota_detalle.php?codigo=5432507&fecha=08/04/2016 or https://www.cenace.gob.mx/Docs/MarcoRegulatorio/AcuerdosCRE/Resoluci%C3%B3n%20151%202016%20C%C3%B3digo%20de%20Red%20DOF%202016%2004%2008.pdf.
[51] Sistema de Interconexión Eléctrica de los Países de América Central.
[52] https://www.gob.mx/sre/prensa/mexico-y-centroamerica-avanzan-en-la-integracion-electrica-64627.

TABLE 4. MEXICO'S RANKING IN SELECTED CHARACTERISTICS

CHARACTERISTIC	RANKING	REASON	POTENTIAL NEXT STEPS
Sufficient Transmission Capacity / Planned Investment	★★ (toward ★★★)	• Mexico is developing its competitive renewable energy zones.[53] • Transmission bids including two 500 kV lines: one in Oaxaca (expected to evacuate 3,000 MW of RE power)[54] and one in Baja California.[55]	• CREZ is under development
Ancillary Services and Products to Reward Flexibility	★★ (toward ★★★)	• Ancillary services include voltage and frequency control, non-reserve system services, and black-start capabilities. • Renewable energy plants can offer capacity in long-term energy auctions and be remunerated. • Centro Nacional de Control de Energía (CENACE)[56] is evaluating whether to set ancillary services requirements per node.[57]	• Add more ancillary products (such as ramping) in the market
VRE Forecasting Integrated into Operational Practices	★★	• Mexico has a comprehensive VRE forecasting framework in place (day-ahead forecast plant and the system operator). • The Danish Energy Agency and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) are helping the system operator CENACE.[58] • There is a lack of penalties for large deviations between actual and forecast.	• Introduce penalties for deviations from forecast

THE PHILIPPINES

VRE resources account for seven percent of the total installed capacity in the Philippines, with a target to achieve a 50 percent share by 2030. The Philippines introduced a wholesale electricity spot market in 2006, updated its grid code for the interconnection of VRE, and adopted a comprehensive VRE forecasting framework. Its power system is characterized in Table 5, based on desk research and the study team's assessment.

TABLE 5. THE PHILIPPINES' RANKING IN SELECTED CHARACTERISTICS

CHARACTERISTIC	RANKING	REASON	POTENTIAL NEXT STEPS
Market Protocols to Access System Flexibility	★★	• The Philippines runs the wholesale electricity spot market (WESM) with 5-minute dispatch intervals. • The competitive market is facing some reserve shortages.	• Implement forward capacity market

[53] In Spanish: Atlas Nacional de Zonas con Alto Potencial de Energías Limpias (AZEL) https://www.gob.mx/sener/articulos/atlas-nacional-de-zonas-con-alto-potencial-de-energias-limpias?idiom=es.
[54] http://saladeprensa.cfe.gob.mx/boletines/show/8487/.
[55] https://www.gob.mx/sener/articulos/subasta-electricidad?idiom=es.
[56] Centro Nacional de Control de Energía.
[57] IEA 2016.
[58] CENACE-Energinet Partnership.

TABLE 5. THE PHILIPPINES' RANKING IN SELECTED CHARACTERISTICS

CHARACTERISTIC	RANKING	REASON	POTENTIAL NEXT STEPS
Clear Dispatch Rules for VRE	★	• The WESM in the Philippines is based on the LMP nodal pricing framework, which sends economic signals to back down generation. • VRE is curtailed only for reliability reasons; it receives preferential dispatch and therefore there is no economic curtailment.[59] • "Strategic, economic curtailments of solar and wind energy can enhance system flexibility." "Enabling strategic, economic curtailment may involve reviewing and, if necessary, revising laws, rules, and operational practices that mandate preferential renewable energy dispatch."[60]	• Integrate VRE into the economic dispatch and commitment tools
Grid Code Requirements for VRE	★★	• The grid code requires VRE to provide fault ride-through capability, and comply with voltage, frequency and power factor support/constraints.[61] • Automatic variable renewable energy curtailment is currently allowed by the Philippines grid code for reliability reasons.	• Revised the Grid Code for VREs to provide grid support services
Long-Term Agreements for Regional Interconnection	★	• Initial consideration but nothing implemented.[62]	• N/A
Sufficient Transmission Capacity / Planned Investment	★★	• The Cebu-Negros-Panay 230 kV backbone transmission project will add 800 MW between Negros and Cebu, which will address line congestion problems in the Visayas.[63] • The Philippines is considering establishing competitive renewable energy zones.[64]	• Establish CREZ or expand transmission network to integrate more VRE resources
Ancillary Services and Products to Reward Flexibility	★★	• Stringent requirements to provide reserves. Generating units, qualified reserve-providing facilities, can provide ancillary services if they met the requirements set forth in the Energy Regulatory Commission's (ERC) Ancillary Services Procurement Plan (ERC 2011).[65] • Circular to include energy storage in the operations and trading of the WESM.[66]	• Add more ancillary products (such as ramping) in the market
VRE Forecasting Integrated into Operational Practices	★★	• The Philippines has a comprehensive VRE forecasting framework. The grid code requires forecasting at both the system and plant levels. • Lack of penalties for large deviations between actual and forecast.	• Introduce penalties for deviations from forecast

[59] NREL, Greening the Grid: Solar and Wind Grid Integration Study for the Luzon-Visayas System of the Philippines.
[60] Ibid.
[61] Philippine Grid Code, 2016 Edition.
[62] https://www.doe.gov.ph/energists/index.php/2-uncategorised/12747-power-grid-interconnections-gaining-headway-within-asean-region.
[63] https://www.sunstar.com.ph/article/153011.
[64] https://www.doe.gov.ph/announcements/request-comments-draft-department-circular-establishing-and-development-competitive.
[65] NREL, Greening the Grid: Solar and Wind Grid Integration Study for the Luzon-Visayas System of the Philippines.
[66] www.doe.gov.ph/sites/default/files/pdf/announcements/draft_dc_doe_adoption_of_ess_in_the_electric_power_industry.pdf.

VIETNAM

Vietnam is working on the design of a new wholesale market, which is currently in the pilot stage. Renewable energy is not integrated as a generating resource in the pilot stage. All generating resources over 30 MW will be integrated into the wholesale market after full implementation.[67] Institutional changes are also underway, and the country envisions strengthening the capacities in the power sector for VRE integration planning. Vietnam's power system is characterized in Table 6 based on desk research, to the extent information was publicly available, and interviews with NREL.

TABLE 6. VIETNAM'S RANKING IN SELECTED CHARACTERISTICS

CHARACTERISTIC	RANKING	REASON	POTENTIAL NEXT STEPS
Market Protocols to Access System Flexibility	★ (toward ★★)	• Existing resources are adequate, and the country maintains a high reserve margin (up to 35 percent). • Vietnam established a pilot wholesale electricity market; a competitive retail market will be operational by 2021.[68]	• Create a framework for the forward capacity market
Clear Dispatch Rules for VRE	★	• In the current market framework, VRE is dispatched on priority when available and the new wholesale market will have similar dispatch rules. • The national utility, Electricity of Vietnam (EVN) might put some renewable energy power purchase agreements (PPAs) on hold until more studies on grid integration are undertaken.	• Integrate VRE into the economic dispatch and commitment tools
Grid Code Requirements for VRE	★	• Grid codes/contracts do not specify best practices capabilities for renewables to be controllable.	• Revise the grid code to include technical and operational requirements for VRE
Long-Term Agreements for Regional Interconnection	★	• Fundamental question for the market: consider expanding to a regional market or continue to be only domestic.	• Strengthen the regional interconnection
Sufficient Transmission Capacity / Planned Investment	★	• The Global Wind Energy Council recommended: "planning and investment will be needed to ensure the successful integration of variable renewable energy such as wind and solar." [69]	• Study transmission expansion and identify transmission projects to integrate VRE resources
Ancillary Services and Products to Reward Flexibility[70]	★	• No market framework for ancillary services is currently in place • Hydro plants mainly provide ancillary services. • EVN and national load dispatch center (NLDC) are considering ancillary service markets for frequency regulation services.	• Create a framework for the ancillary market

[67] http://www.aseanenergy.org/blog/the-history-and-roadmap-of-power-sector-reform-in-vietnam/.
[68] https://en.evn.com.vn/d6/news/Vietnam-Competitive-Wholesale-Electricity-Market-in-2017-ready-for-official-pilot-operation-66-163-476.aspx.
[69] http://gwec.net/wp-content/uploads/2018/06/Industry-statement-Vietnam_VWP18_7June_FINAL.pdf.
[70] Demand and storage, new ramping products, capacity markets.

TABLE 6. VIETNAM'S RANKING IN SELECTED CHARACTERISTICS

CHARACTERISTIC	RANKING	REASON	POTENTIAL NEXT STEPS
VRE Forecasting Integrated into Operational Practices	★ (toward ★★)	• There is no existing framework for VRE forecasting. • NLDC recommended to EVN to develop its own forecasting system but funding is an issue.	• Create a comprehensive framework for VRE forecasting

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Power system flexibility is important for supporting VRE integration; this flexibility can be unlocked through improved system operation. The sources of operational flexibility include fully controllable conventional power units, renewable energy curtailment, energy storage plants with fully dispatchable storage, electric vehicle fleets, demand-side participation, and regional power import/export between zones. Other sources include smart network technologies and advanced network management practices that minimize bottlenecks and optimize transmission usage. The value of operational flexibility can be compensated via ancillary services, enabling the cost-efficient procurement of control reserve products.

Some best practices for system and market operation to enable power system flexibility include:

MARKET PROTOCOLS TO ACCESS SYSTEM FLEXIBILITY. Centralized dispatching control with sub-hourly (5- to 10-minute) scheduling and dispatch intervals reduce the movement of conventional thermal generators, making the system become efficient and reducing reserve requirements. The capacity or resource adequacy market incentivizes flexible resources to contribute to system capacity when needed most.

CLEAR DISPATCH RULES FOR VRE. The integration of VRE into the economic dispatch and commitment tools eliminates manual curtailment during over-generation conditions. The locational marginal price (LMP) nodal pricing framework allows negative pricing to occur during over-generation and acts as an economic signal for backing down generation and shifting capacity into the high pricing region.

GRID CODE REQUIREMENTS FOR VRE. Enhanced technical and operational requirements for VRE in the grid code help support the system's operation under higher VRE generation.

LONG-TERM AGREEMENTS FOR REGIONAL INTERCONNECTION. Shared reserves, a larger balancing area, and more diverse generation help increase system flexibility and integrate high VRE generation.

SUFFICIENT TRANSMISSION CAPACITY/PLANNED INVESTMENT. Transmission reinforcement is a key to increasing flexibility and reliability since it allows the sharing of various capacity resources across regions.

ANCILLARY SERVICES MARKET PRODUCTS TO REWARD FLEXIBILITY. Ancillary markets incentivize various flexible resources such as peaking plants, demand response, and storage to provide ancillary services.

VRE FORECASTING INTEGRATED INTO SYSTEM OPERATIONS. The deployment of sophisticated forecasting techniques into day-ahead and real-time operation allows efficient system management and the minimization of large ramping events.

The assessed countries are recognizing the changes needed to operate a power system in the presence of an increased share of VRE generation and, as such, have updated their grid codes, interconnection processes, and dispatch rules for VRE. They are also investing in expanding their transmission capacity nationally as well as internationally. However, the countries have been grappling with long-term agreements for regional interconnection, ancillary services and products to reward flexibility, and forecasting and integrating VRE into system operations.

RECOMMENDATIONS: SUGGESTED STUDIES FOR POWER SYSTEM OPERATIONS WITH HIGH SHARES OF VARIABLE RENEWABLE ENERGY

The following pilots are recommended for three of the five countries—Mexico, Vietnam, and Colombia—in view of their aspirations to integrate larger shares of variable renewable energy in their power systems. These pilots target changes in institutional frameworks that can unleash low-cost flexibility in power systems and help them move smoothly from phase 1 to phase 2 to phase 3, etc. The pilots are suggestions to be validated and further fine-tuned with respective local stakeholders. A capacity-needs assessment of the knowledge and tools of the system operators could further refine gaps.

Potential pilots have not been considered for India and the Philippines in view of the extensive and advanced studies already performed in those countries. NREL, for example, performed a "Greening the Grid" study for the Indian power system, which is a very comprehensive study of the Indian power grid to quantify the potential effects of high levels of VRE. The study serves as the basis for decision-making by policy makers and system operators. A similar NREL study conducted for the Philippines led to the establishment of a five-minute market. Table 7 outlines suggested studies relevant for each of the focus countries.

TABLE 7. SUGGESTED STUDIES

PROPOSED SOLUTION	RATIONALE AND SUGGESTED STUDIES
• Benefit of Increasing Coal Generators' Flexibility • Countries: Vietnam[71]	• Coal plants generally operate as baseload. High VRE penetration poses a challenge to the operation of coal fleets, especially where coal's share is high in the generation mix. The coal generators with flexible characteristics (*e.g.*, ability to cycle on and off and run at lower output) increase system flexibility to integrate high levels of VRE. The lower minimum output allows the plant to turn down when the system's need for generation is low, such as during high VRE generation, and yet still be available to ramp up for the evening net load peaks. The reduction in up and down time allows coal plants to cycle off/on more frequently. The conversion of coal plants to increase flexibility requires modifications to hardware and operations. • **Suggested study:** Pilot study to determine the system-wide benefit(s) of coal plant flexibility under high VRE penetration. The findings will support regulators or policy makers in comparing the costs and benefits of coal flexibility with other measures.
• Assess the Flexibility Needs and Cost of Flexibility • Countries: Colombia, Mexico, and Vietnam[72]	• Increasing VRE levels in the system creates a need for additional flexible resources, which must respond in real time to changes in VRE output to keep the system balanced. This is typically provided by reserves. The sudden change in VRE output over a short period creates a need for resources with fast ramping capability. The flexibility needed can be accomplished by utilizing the flexibility of existing resources (coal, gas, hydro), demand response, storage, or distributed energy resources. • **Suggested study:** Pilot study to identify the need for additional flexible resources and reserves under high VRE penetration.

[71] NREL has already performed studies for India and the Philippines. Coal has a low share in capacity mix for Columbia and Mexico.
[72] The Greening the Grid study covers this for India and the Philippines.

TABLE 7. SUGGESTED STUDIES

PROPOSED SOLUTION	RATIONALE AND SUGGESTED STUDIES
• Study to Assess the Benefits of Moving to Sub-Hourly Scheduling and Dispatch and Provide Recommendations for Transition • Countries: Colombia and Vietnam[73]	• Markets relying on bilateral contracts and fixed hourly schedules and dispatch are expected to face operational challenges due to the uncertainty in VRE forecasting under high VRE penetration. The sub-hourly scheduling and dispatch involves increasing the frequency of dispatch intervals and allows the system to operate close to real time. It reduces the movement of conventional generators and minimizes reserve requirements and VRE curtailment. It encourages flexible resources to support system operation under such uncertainties. • **Suggested study:** Pilot study on how moving to sub-hourly scheduling could affect the overall system cost, reserve requirements, and VRE curtailment.
• Transmission Expansion Studies to Integrate VRE • Countries: Colombia and Vietnam[74]	• Transmission expansion is one of the key measures to integrate large amounts of VRE in the system. It allows access to high-quality VRE resources, which are often concentrated in regions far from load, and reduces transmission congestion. New transmission enlarges the balancing area, which provides more load diversity and generation reserves, thereby reducing the need for flexible resources overall in the system as well as in the local region. Transmission lines are generally developed in 5-8 years and most of the effort is related to cost allocation and siting issues. On the other hand, VRE plants are generally developed in shorter timeframes, and the lag between new transmission and VRE poses system operation and curtailment risks. • **Suggested study:** Conduct a pilot to identify regions of high renewable resources and level of transmission expansion to interconnect them with the grid and expand the balancing areas. The findings of this pilot will help policy makers develop a framework to resolve cost-allocation and siting issues, such as Texas's CREZ regulatory process, which is being considered in Mexico and the Philippines.

[73] The Greening the Grid study covers this for India. Mexico conducts scheduling and dispatch every 15 minutes. The Philippines' market operation functions are being transferred to a new entity—the Electricity Market Operator of the Philippines.

[74] CREZs are being considered in Mexico and the Philippines; this pilot will study the potential of CREZ in Colombia and Vietnam.

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ANNEX A. LIST OF INTERVIEWS

TABLE 8. LIST OF INTERVIEWS

COUNTRY	NAME AND ORGANIZATION
Colombia	Jairo Gutierrez, Tetra Tech SURE Project Lead Colombia, Completed on July 23, 2018
India	Jaquelin Cochran, NREL via email; SURE, Team Research
Mexico	Ignacio Rodríguez and Adrian Paz, Tetra Tech, Completed on August 24, 2018
The Philippines	Jessica Katz, NREL, Completed on August 23, 2018
Vietnam	Jessica Katz, NREL, Completed on August 23, 2018 Dinh Xuan Duc and Nguyen Duc Ninh, EVN NLDC, Completed on October 16, 2018

ANNEX B. COUNTRY SUMMARIES

This annex summarizes the information collected during the desk research and interviews that inform the country rankings on VRE integration characteristics.

COLOMBIA

COUNTRY SUMMARY		
VRE Share		19.5 MW operational (wind), less than 1 percent[75]
Renewable Energy Target		6.5 percent generation from non-large hydro renewables for all those with access to the grid by 2020[76]
KEY FEATURES OF THE COLOMBIAN POWER SECTOR		
Power Sector Structure	•	Generators and retailers sell and buy energy through a day-ahead electricity market, bilateral contracts, and a reliability charge mechanism.[77]
Key Stakeholders	• • •	Independent system operator (XM) with the National Dispatch Center (Centro Nacional de Despacho)[78] and the market administrator (Administrador del Sistema). Energy planning: Unit of Energy Mining Planning (Unidad de Planeación Minero Energética or UPME). Regulator: Energy and Gas Regulatory Commission (CREG).
Generation & Transmission	• • • •	Supply mix: hydro-dependent. Hydro 71 percent, gas 17 percent, fuel oil 9 percent, other renewable energy 3 percent. Transmission: bottlenecks in the north of the country. A 500 kV AC line to la Guajira in 2022 is planned. Dispatch: Hourly. Cross-border interconnections: Venezuela (215 MW import capacity and 285 MW export capacity) and Ecuador (205 MW import capacity and 336 MW export capacity).[79]
Operations	• •	Dispatch protocols: Supply offers are submitted the day ahead of dispatch. The solution is calculated at a central point. Plants can offer secondary reserve services as well.[80] [81] Operating reserves:[82] Minimum operation levels are calculated on May 1, considering reservoir levels.[83]
VRE Forecasting	•	Responsibility of the generator.[84]

[75] https://colombiareports.com/the-promises-and-challenges-of-renewable-energy-in-colombia/.
http://www.nortonrosefulbright.com/knowledge/publications/134774/renewable-energy-in-latin-america-colombia
http://large.stanford.edu/courses/2017/ph240/pinilla2/.

[76] A policy objective to integrate non-hydro renewables is to take advantage of the complementarity of VRE, especially wind energy, with the hydrological patterns for the large hydro plants. https://publications.iadb.org/handle/11319/8146.

[77] Reliability charge and firm energy obligation. This is the product designed to guarantee the reliability of the energy supply in the long run at efficient prices. The reliability charge is the regulatory mechanism governing capacity expansion. It allows generators to have a fixed income for delivering specific levels of firm energy, regardless of their daily participation in the wholesale market, allocated for periods of up to 20 years, thus reducing investment risks. In return, generators must be available and meet their firm energy obligations when shortage conditions arise in the system. For the allocation and determination of the price of the firm energy obligations, a competitive market mechanism is used to ensure the most efficient price determination through auctions of firm energy obligations.

[78] Colombia also has the National Operation Council (Consejo Nacional de Operación), a private organization, to agree on technical aspects to guarantee the reliable, safe, and economic operation of the energy system.

[79] www.xm.com.co/boletinxm/publishingimages/boletin265/presentacion_nohemi_venezuela.pdf.

[80] http://www.xm.com.co/Paginas/Generacion/despacho.aspx.

[81] Control Automático de Generación (AGC) o Regulación Secundaria de Frecuencia, www.sciencedirect.com/science/article/pii/S0301421512009226.

[82] From the grid code – operation (CREG) http://apolo.creg.gov.co/Publicac.nsf/Indice01/Codigos-1995-RES.025-1995.COD..REDES.-.COD..OPERACION?OpenDocument.

[83] Colombia has 23 reservoirs for power generation and others; http://www.xm.com.co/Paginas/Hidrologia/Embalses.aspx.

[84] Interview with Jairo Gutierrez, SURE Project Lead Colombia.

EXPERIENCE WITH VRE

With regard to interconnection permits and transmission rights of solar and wind power plants, UPME has received payments of transmission rights for seven utility-scale wind plants.[85] In view of the interconnection of wind power plants and other VRE plants, the system operator XM is piloting different wind, solar, and small-hydro forecasting methodologies with international vendors.[86] Furthermore, Fraunhofer Institute, with support from the Danish transmission system operator (Energinet), has provided support for building local staff capacities by facilitating training in power factory simulations and VRE integration studies.[87]

CHALLENGES FOR VRE INTEGRATION

The team identified the following challenges for integrating the necessary wind and solar capacity to meet the country's renewable energy aspirations:

LIMITED TRANSMISSION CAPACITY. Wind and solar potential is concentrated in the north of the country (the La Guajira region). UPME has received interconnection requests for over 4,000 MW of VRE plants.

LIMITED CROSS-BORDER TRADE. Colombia has considered the possibility of interconnecting with Panama and the Central America regional market (SIEPAC line). Challenges for interconnection include that the line will need to be built across protected areas.

LIMITED ANCILLARY SERVICE MARKET.[88] Only the commercial responsibility for reserves is regulated.[89]

DATED GRID CODE. The grid code needs to better reflect recent technology advances.

INADEQUATE METHODOLOGY TO CALCULATE OPERATING RESERVES WITH VRE. XM requested SURE's technical assistance to update the methodology for calculating reserves in view of the thousands of MW of wind and solar expected with the approaching energy auctions.[90]

LIMITED REMUNERATION OPTIONS FOR VRE PLANTS. The reliability charge, "Cargo por confiabilidad," limits the ability of VRE plants to compete with other generation sources.

LIMITED LOCAL TECHNICAL CAPACITIES. XM has requested assistance to build capacities in their VRE forecasting team.[91]

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[85] Montos de interconección - Interview with Jairo Gutierrez, SURE Project Lead Colombia.
[86] Interview with Jairo Gutierrez, SURE Project Lead Colombia.
[87] www.xm.com.co/EnMovimiento/Documents/Boletin335/ResumenEenrgiaRenovable.pdf.
[88] Servicios complementarios in Colombia.
[89] "Mercados de servicios complementarios en el MEM es incipiente" www.dnp.gov.co/Crecimiento-Verde/Documents/ejes-tematicos/Energia/MCV%20-%20Energy%20Supply%20Situation%20vf.pdf.
[90] Interview with Jairo Gutierrez, SURE Project Lead Colombia.
[91] Ibid.

SOLUTIONS BEING IMPLEMENTED OR PLANNED

The team identified the following solutions that Colombia is implementing:

EXTEND TRANSMISSION CAPACITY TO THE NORTH. A 500 kV AC transmission line connecting La Guajira is expected to come online in 2022, allowing 1,250 MW of wind power to be integrated into the national grid.

CROSS-BORDER INTERCONNECTION WITH PANAMA. Technical and economic pre-feasibility studies have been completed for an underwater cable with the goal of being part of the Central America regional market (MER) in which some of the VRE could be exported as an alternative to curtailment.[92]

IMPLEMENT AN INTRADAY MARKET. CREG is evaluating the prospect of implementing an intraday market.[93]

UPDATE THE GRID CODE TO INCLUDE VRE TECHNICAL REQUIREMENTS. The code should encompass frequency, voltage, harmonics, etc.[94]

INTRODUCE LOCATIONAL MARGINAL PRICES. By having a more transparent and efficient mechanism of valuing electricity, the competitiveness of renewable energy plants could increase.[95]

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[92] www.etesa.com.pa/etesa_avanza.php?id=490.

[93] www.upme.gov.co/Estudios/2015/Integracion_Energias_Renovables/INTEGRACION_ENERGIAS_RENOVANLES_WEB.pdf and letter form 2018 www.cno.org.co/sites/default/files/archivosAdjuntos/carta_a_creg.pdf.

[94] www1.upme.gov.co/Documents/PHC-066-15-11_Informe%20Final_v1.pdf from 2015 and www.dnp.gov.co/Crecimiento-Verde/Documents/ejes-tematicos/Energia/MCV%20-%20Energy%20Supply%20Situation%20vf.pdf from 2017.

[95] www.dnp.gov.co/Crecimiento-Verde/Documents/ejes-tematicos/Energia/MCV%20-%20Energy%20Supply%20Situation%20vf.pdf.

Figure 7. Transmission Grid in Colombia[96]

[96] See original: http://sig.simec.gov.co/GeoPortal/Mapas/Mapas.

AGENDA REGULATORIA 2020									
Sector	Macrotemas	#	Proyectos	Prioridad	Primer semestre		Segundo semestre		2021
Energía Eléctrica	Mercado de energía de largo plazo	1	Mecanismo MAE propuesta por Derivex	1	Consulta	Dec Def			
		2	Sistema de contratación de energía propuesto por la BMC	1	Consulta			Dec Def	
	Mercado de energía de corto plazo	3	Despacho vinculante y mercado intradiario	1	Consulta			Dec Def	
		4	Servicios complementarios	1		Consulta		Dec Def	
	Cargo por confiabilidad	5	Revisión de la regulación del proceso de subastas del cargo por confiabilidad	1	Consulta	Dec Def			
		6	Revisión de las métricas de confiabilidad en el SIN	2		Consulta		Dec Def	
		7	Reglamento para la medición de variables hídricas para el cargo por confiabilidad y operación	1	Documento		Consulta	Dec Def	
	Mercado minorista	8	Respuesta de la demanda	2	Documento		Consulta	Dec Def	
		9	Metodología tarifaria del G	1	Consulta		Dec Def		
		10	Metodología tarifaria del CU	1		Consulta	Socialización	Dec Def	
		11	Metodología tarifaria de C	2			Consulta		
		12	Revisión de las reglas de autogeneración y generación distribuida en SIN	1	Consulta	Dec Def			
		13	Implementación de la medición inteligente	1		Dec Def			
	Transporte de energía	14	Metodología tarifaria de remuneración de transmisión	1	Consulta		Dec Def		
		15	Metodología para las Convocatorias en el STN y STR.	1	Documento	Consulta		Dec Def	
		16	Convocatorias en el STN y STR	1	X	X	X	X	
		17	Asignaciones de capacidades de transporte	1	Consulta			Dec Def	
		18	Actualizaciones de ingresos de transmisores	1	X	X	X	X	
		19	Aprobación de ingresos de distribución	1	X	X	X	X	
		20	Ajuste Código de Redes	1		Consulta		Dec Def	
		21	Ajuste reglamento de distribución	1		Consulta (Global)		Dec Def	
		22	Restricciones en el SIN	1					
		23	Reglas para auditorías de calidad del servicio	1	Consulta	Dec Def			
	Zonas No Interconectadas	24	Metodología fórmula tarifaria en ZNI	1	Consulta		Dec. Def		
		25	Reglas para la prestación de servicio en la ZNI	1	Consulta		Dec. Def		
	Intercambios internacionales	26	Intercambios internacionales	2	X	X	X	X	

Figure 8. CREG 2020 Regulatory Agenda

INDIA

COUNTRY SUMMARY	
VRE Share	As of July 2018: wind 9.9 percent and solar 6.7 percent share of total installed capacity. [97]
Renewable Energy Target	175 GW of installed renewable energy capacity by 2022, including 60 GW of wind and 100 GW of solar.

KEY FEATURES OF INDIA'S POWER SECTOR	
Power Sector Structure	• Generators and retailers can sell and buy energy through both the day-ahead and real-time electricity market at power exchanges, but volume is limited because of bilateral contracts.
Key Stakeholders	• System operator: Power System Operation Corporation (POSOCO) operating the National Load Dispatch Centre (NLDC): scheduling and dispatch over inter-regional links. • Regional load dispatch centers (RLDCs): scheduling and dispatch over interstate links. • State load dispatch centers (SLDCs): scheduling and dispatch within a state. • Central Electricity Regulatory Commission (CERC): energy regulator. • Central Electricity Authority (CEA): short-term and prospective planning, technical standards, data collection, National Electricity Plan. • The Ministry of Power: policies, R&D, electrification, thermal and hydropower matters, CEA-CERC matters. • Power Grid Corporation of India Ltd./Central Transmission Utility: transmission planning and operation over the interstate network. • State Transmission Utility: state-level transmission planning and operation.
Supply Mix	• Coal based. Installed capacity in 2018: 57 percent coal, 7 percent natural gas, 0.2 percent oil, 13.2 percent hydro, 2 percent nuclear, and 17 percent VRE.
Generation & Transmission	• Generation capacity of 343 GW as of June 30, 2018. [98] Long-term contracts are entered through PPAs for durations up to 25 years (90 percent of power procurements are made by distribution companies. • Single large grid, synchronously interconnecting all regional grids. Seventy-eight GW of inter-regional transmission capacity as of November 30, 2017.[99] Lack of state-of-the-art infrastructure with state transmission and distribution utilities. Aggregate technical and commercial losses at around 25 percent.[100]
Ancillary Services	• In 2015/2016, the CERC introduced the ancillary services mechanism. The purpose was to provide a centralized instrument to manage grid frequency. • Real-time ancillary service markets: generators that are called upon to provide such ancillary support are paid their fixed and variable charges plus a markup of INR 0.50/kilowatt hour (kWh). The payment to the generators is made from the deviation settlement mechanism (DSM) surplus pool. POSOCO has reported some challenges in implementation (excessive reliance on ancillary services for longer durations) and the CERC is already working on the next-generation reforms in the ancillary services mechanism.[101] • Slow tertiary control through ancillary services has been implemented since April 2016. Hydropower stations have not been utilized for RRAS so far. Directives for fast tertiary services through RRAS using hydro are to be introduced at the interstate level. • Payment to the generators under RRAS is done on the basis of the scheduled quantum and any deviation is handled through DSM regulations. Sustained failure to provide the regulation reserves by any generator (barring unit tripping) leads to stringent penalties.[102]

[97] http://www.cea.nic.in/reports/monthly/executivesummary/2018/exe_summary-07.pdf.
[98] https://powermin.nic.in/en/content/power-sector-glance-all-india.
[99] https://powermin.nic.in/sites/default/files/uploads/IRCTC_ENG.pdf.
[100] www2.deloitte.com/content/dam/Deloitte/in/Documents/energy-resources/in-enr-the-evolving-energy-landscape-india-april-2018-noexp.pdf.
[101] www.cercind.gov.in/2018/draft_reg/RTM.pdf.
[102] http://www.cercind.gov.in/2015/draft_reg/Ancillary_Services.pdf.

KEY FEATURES OF INDIA'S POWER SECTOR	
	• No commitment charges are payable to the RRAS providers for making themselves available in the RRAS market. • The energy dispatched under RRAS is deemed to be delivered at the regional periphery. Under- and over-injection by the RRAS provider is treated as per the CERC Unscheduled Interchange/DSM Regulations.
Scheduling & Dispatch	• Scheduling occurs on a day-ahead basis. • Dispatch occurs on a 15-minute basis.[103]
Operating Reserves[104]	• Minimum primary reserves of 4000 MW on an all-India basis considering 4000 MW generation outage as a credible contingency.[105] • Secondary and tertiary reserves corresponding to the largest unit size in the region are mandated in a decentralized fashion (total approx. 3600 MW on an all-India basis). • Primary control from generating units is mandated as per the Indian Electricity Grid Code (IEGC). However, the IEGC has an historical variant of primary control in the form of the restricted governor mode of operation (RGMO). Directives for RGMO are to be phased out by April 1, 2018, and replaced with "speed control with droop." • Currently no secondary control (automatic generation control or AGC) is available. POSOCO has already submitted a detailed procedure for implementing secondary control throughout the country through AGC. A pilot project on AGC with the National Thermal Power Corporation, Dadri Stage-II, has been implemented, which will be put into operation after approval of the Commission. • Slow tertiary control (effect is felt only after 20-30 minutes) through RRAS.
Cross-Border Interconnections	• Existing cross-border interconnections: Bhutan (1450 MW import), Bangladesh (500 MW export), and Nepal (300 MW export). • Initial discussions for six cross-border energy interconnections between Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka.[106]
Grid Code for VRE[107]	• VREs are required to have fault ride-through capability. • VREs are required to maintain power factors between 0.95 lagging and 0.95 leading at the connection point. • VREs are required to provide frequency support by ramping up and ramping down the active power output as per the system operator's request.
VRE Forecasting	• Decentralized VRE forecasting is in place, in which each VRE generator provides day-ahead and intraday generation forecasts. Deviation penalties are levied for block-wise absolute percentage error greater than 15 percent; penalties increase as deviation increases above 25 and 35 percent. • Regional forecasting is done by the concerned RLDC to facilitate secure grid operation. The concerned RLDC may engage a forecasting agency to undertake forecasting for renewable energy generators, which are regional entities. These generators are also required to provide the forecast to the concerned RLDC; they may be based on their own forecast or RLDC's forecast.[108] • For state-level sales, forecasting is by the VRE generator or qualified coordinating agency acting on behalf of VRE generators; a forecast by the SLDC is also acceptable.

[103] http://niti.gov.in/writereaddata/files/document_publication/RE_Roadmap_ExecutiveSummary.pdf.
[104] http://www.cercind.gov.in/2018/Reports/50%20Hz_Committee1.pdf.
[105] http://www.cercind.gov.in/2015/orders/SO_11.pdf.
[106] www.adb.org/sites/default/files/publication/173198/south-asia-wp-038.pdf.
[107] http://www.cercind.gov.in/Current_reg.html.
[108] https://posoco.in/wp-content/uploads/2017/03/pro.pdf.

EXPERIENCE IN OPERATING A SYSTEM WITH VRE

GRID INTEGRATION. In 2017, NREL published a study[109] to evaluate the operation of India's power grid with 175 GW of renewable energy to identify potential grid reliability concerns and actions needed to cost-effectively integrate this level of wind and solar generation. It was concluded that power system balancing with 100 GW of solar and 60 GW of wind is achievable at 15-minute operational timescales with minimal renewable energy curtailment. Figure 13 summarizes the RE integration strategies analyzed in the report.

ENERGY STORAGE. Beyond India's experience with pumped storage, CERC issued a draft white paper on the potential of energy storage solutions to address the challenges of integrating VRE generation while improving the operating capabilities of the grid, lowering power purchase cost and ensuring high reliability by maintaining unscheduled interchanges, as well as deferring and reducing infrastructure investments in new projects.

CHALLENGES

RE-DESIGNING REAL-TIME ELECTRICITY MARKETS IN INDIA. CERC published a discussion paper on the re-design of real-time electricity markets aimed, among other things, at implementing changes to discourage the market participants from using the DSM as a trading platform, discourage the use of ancillary services or DSM/UI as a substitute for energy trades at intraday time horizons, and respond to POSOCO's request for intraday portfolio optimization.[110]

SOLUTIONS BEING IMPLEMENTED OR PLANNED

GREEN ENERGY CORRIDOR is being considered for interstate transfer, but intrastate transmission is still a challenge. Investment in transmission capacity to integrate about 32 GW of renewable energy capacity is estimated at $5 billion.[111]

LOWERING MINIMUM OPERATING LEVELS of coal plants (from 70 percent to 40 percent) is the biggest driver to reduce renewable energy curtailment, from 3.5 percent down to 0.76 percent.

ELECTRICITY MARKET REDESIGN. USAID/India has contracted with the National Association of Regulatory Utility Commissioners to work with CERC on market designs.[112] CERC has proposed to re-design the intraday market mechanisms as follows:

- The markets shall be based on double-sided closed auctions with uniform market clearing prices.
- The real-time market shall be conducted once every hour for delivery in four 15-minute blocks in each hour. Such faster transaction/settlement requires automation, and the Commission has already initiated action on this (through amendments in regulations to implement the National Open Access Registry).
- Timelines for real-time markets are shown in Figure 11 in this annex.

[109] https://www.nrel.gov/docs/fy17osti/68745.pdf.
[110] http://www.cercind.gov.in/2018/draft_reg/RTM.pdf.
[111] http://regridintegrationindia.org/wp-content/uploads/sites/3/2017/09/1_2_GIZ17_xxx_presentation_Pankaj_Batra.pdf.
[112] Communication with Jaquelin Cochran, NREL.

SOLAR/WIND + STORAGE AUCTION. The Solar Energy Corporation of India Limited (SECI) issued in August 2018 a request for proposal for the design, engineering, supply, construction, erection, testing, and commissioning of a 160 MW solar-wind hybrid power plant with battery energy storage in Andhra Pradesh.[113] The World Bank is supporting the project.[114]

REDESIGNING ANCILLARY SERVICES MARKET. CERC is considering redesigning the current framework of the ancillary service mechanism in India.[115]

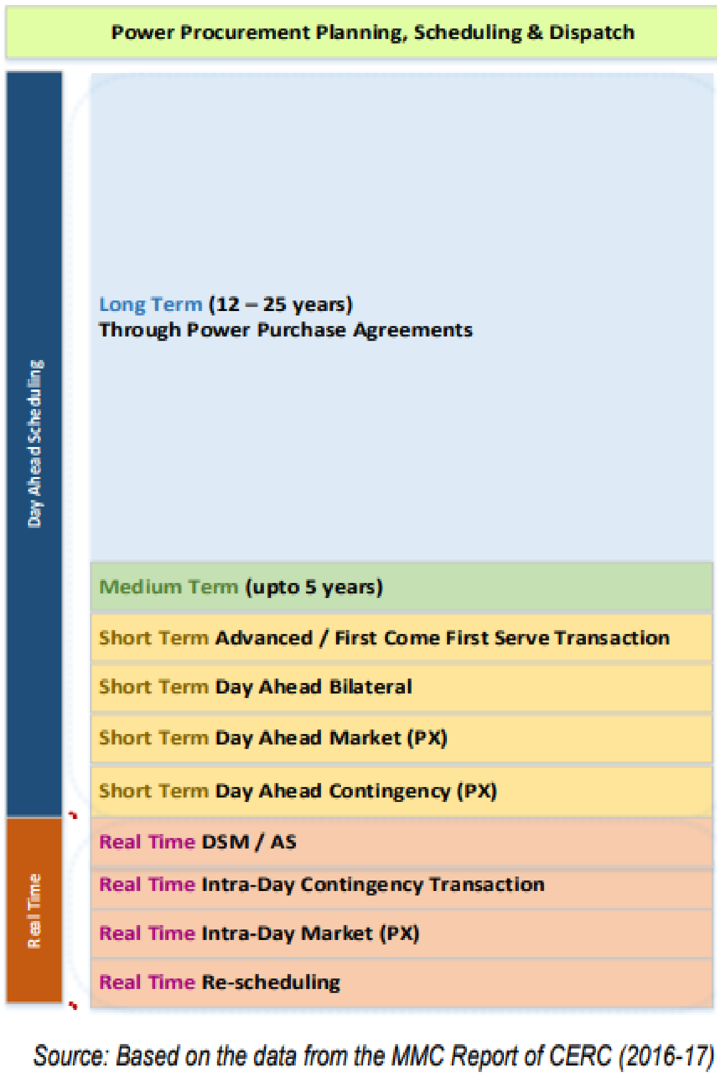

Figure 9. Power Procurement Planning in India[116]

[113] http://seci.co.in/show_tender.php?id=310 .
[114] SURE mission June 2018.
[115] https://powerline.net.in/2018/09/10/cerc-notifies-discussion-paper-redesigning-ancillary-services-market/.
[116] www.cercind.gov.in/2018/draft_reg/RTM.pdf.

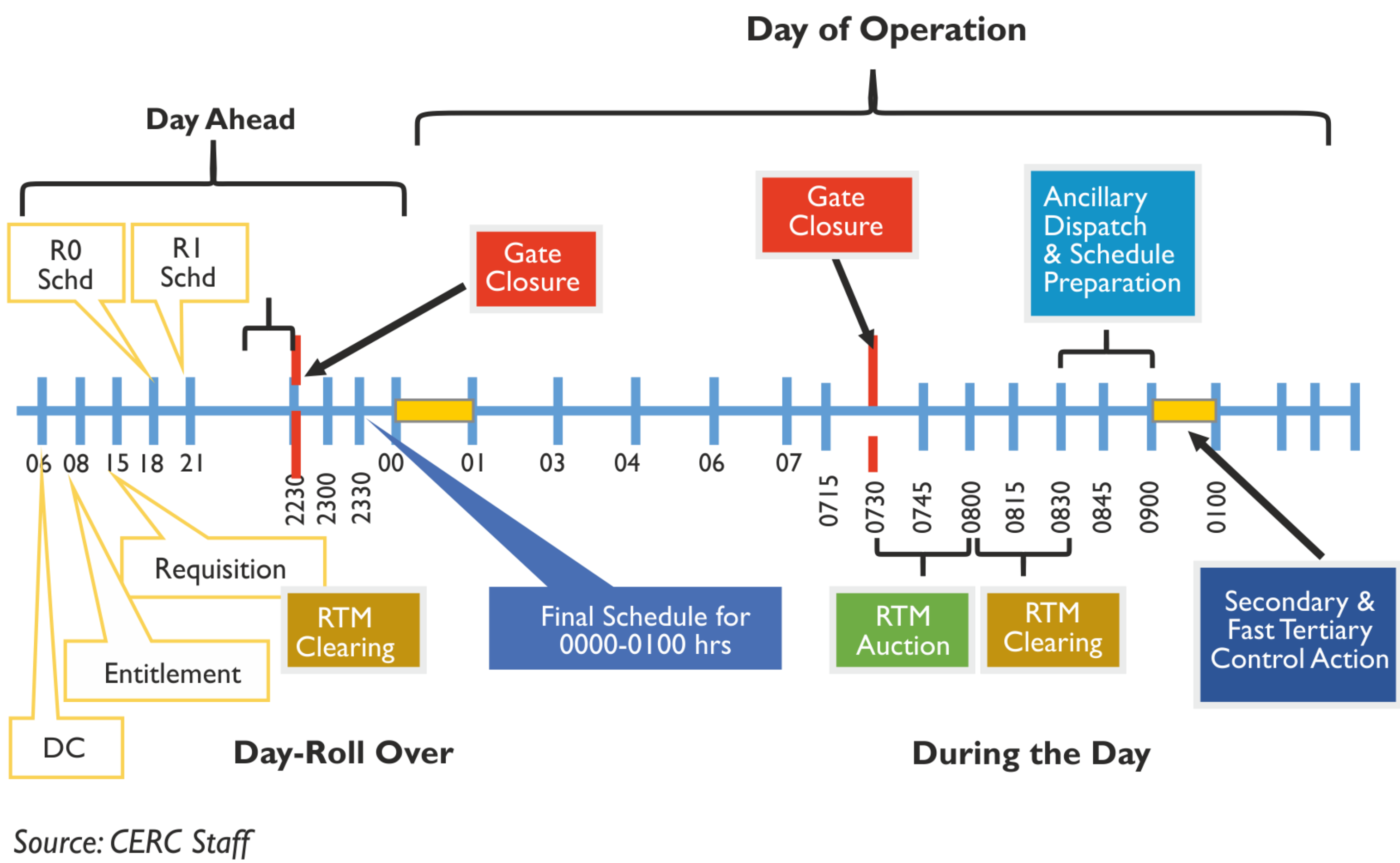

Figure 11. Proposed Real-Time Market in India[117]

[117] Source: CERC staff.

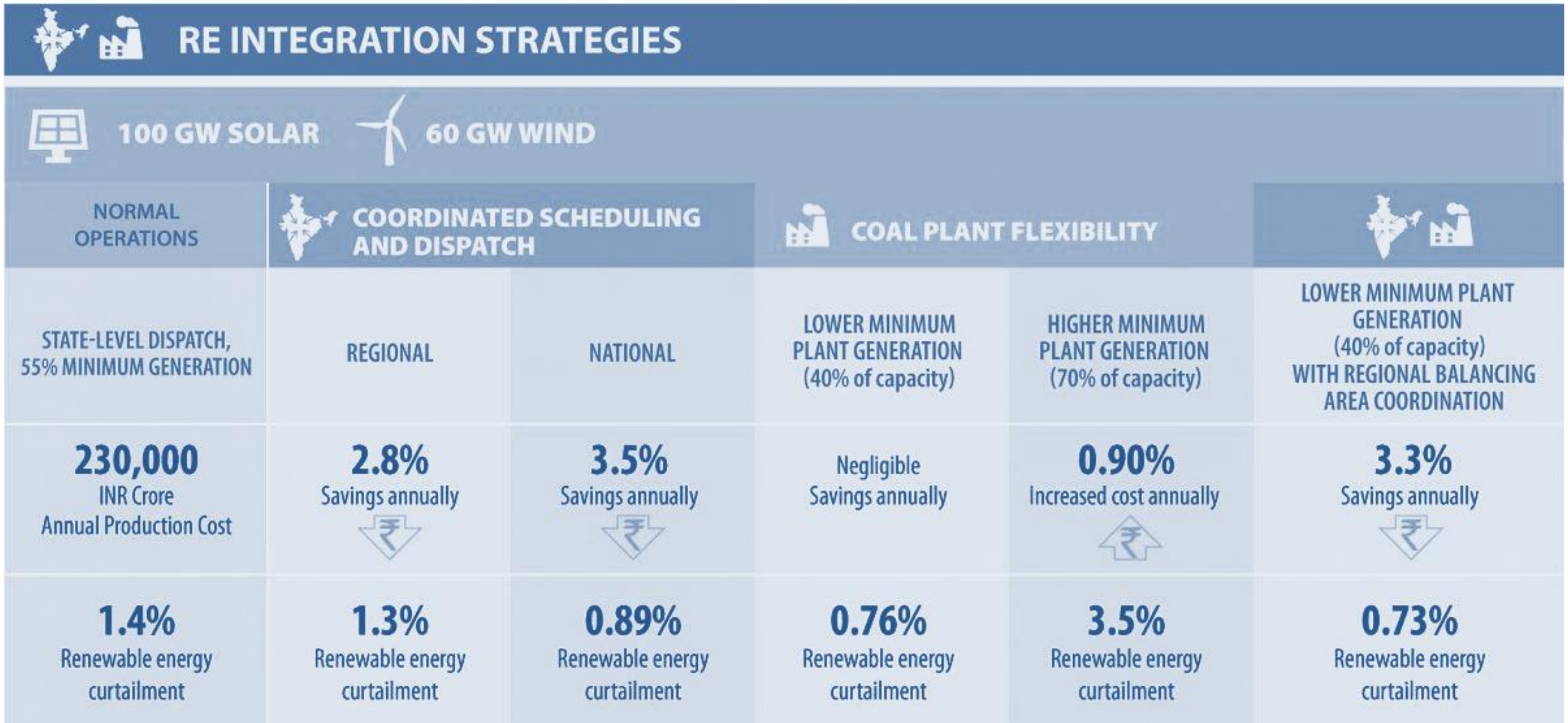

Figure 13. India's Renewable Energy Integration Strategies[118]

[118] Greening the Grid: Pathways to Integrate 175 Gigawatts of Renewable Energy into India's Electric Grid.

MEXICO

COUNTRY SUMMARY	
VRE Share	Wind has 5.9 percent and solar has 0.1 percent share of total installed capacity.[119]
Renewable Energy Target	35 percent clean energy generation by 2024.[120]

KEY FEATURES OF MEXICO'S POWER SECTOR	
Power Sector Structure	• The wholesale electricity market (MEM) began operations in 2016. Prices are set on a nodal basis. • MEM has a day-ahead market and a real-time market. It includes bilateral schedules.
Key Stakeholders	• Independent system and market operator: Centro Nacional de Control de Energía (CENACE).
Generation & Transmission	• Diversified: Combined cycle, 50 percent; thermal, 12 percent; coal, 10 percent; gas, 6 percent; nuclear and cogeneration, 5 percent; hydro, 10 percent; and renewables, 6 percent.
Ancillary Services[121]	• Installed capacity can easily meet peak demand. Mexico's electricity system enjoys a comfortable generation reserve margin. • Reserves: Regulation, spinning and non-spinning reserves (10 min), secondary or supplementary reserves.[122]
Dispatch	• Day-ahead market and real-time market.[123] • The real-time market is a four-cycle process: • 30 minutes before each hour for the operation conditions divided in 15 minutes for the hour. • 15 minutes before each dispatch interval to set the LMP. • 5 minutes before each 5-minute interval defines the economic dispatch in regard to the current generation and demand conditions. • Control signals every 4 seconds for generation plants.
Cross-Border Interconnections	• Limited trade flow. Lines with United States, Belize, and Guatemala. • United States transfer capacity: export (1,236 MW) and import (983 MW). However, trade flow is limited due to legacy arrangements.[124]

[119] https://www.iea.org/publications/freepublications/publication/EnergyPoliciesBeyondIEACountriesMexico2017.pdf.
[120] http://www.rechargenews.com/wind/1444141/clear-path-to-tripling-of-mexican-wind-by-2024-energy-secretary.
[121] Ley de la Industria Eléctrica (LIE), en su artículo 3, fracción XLIII, los Servicios Conexos se definen como el "Los servicios vinculados a la operación del Sistema Eléctrico Nacional y que son necesarios para garantizar su Calidad, Confiabilidad, Continuidad y Seguridad, entre los que se podrán incluir: las reservas operativas, las reservas rodantes, la regulación de frecuencia, la regulación de voltaje y el arranque de emergencia, entre otros, que se definan en las Reglas del Mercado." http://www.cenace.gob.mx/SIM/VISTA/REPORTES/ServConexosSisMEM.aspx.
[122] http://www.cenace.gob.mx/SIM/VISTA/REPORTES/ServConexosSisMEM.aspx.
[123] https://www.ineel.mx/boletin042016/divulgacion.pdf.
[124] IEA 2016.

EXPERIENCE WITH VRE

- Mexico's experience with wind energy power plants goes back to the early 2000s. Recent clean energy auctions are providing a substantial boost to solar and wind energy projects.[125]
- Following the Texas experience, Mexico is developing a map of clean energy zones with the aim to enable the development of targeted strategic generation and transmission projects.[126]
- In 2015, NREL provided key messages for a first round of renewable energy integration studies and recommendations on how Mexico might best approach them, including a proposed process for conducting comprehensive integration studies in parallel with gradually increasing renewable energy targets.[127]

CHALLENGES FOR VRE INTEGRATION

STRONG LOCAL CAPACITIES FOR TRANSMISSION SIMULATION. NREL identified that Comisión Federal de Electricidad (CFE), Institute of International Education (IIE), and CENACE engineers are in the best position to undertake transmission grid simulations of load flow and dynamics. They can evaluate if existing system conditions would be strongly affected by near-term anticipated wind and solar deployments. Additional assessment may be in order.

PLANNING TRANSMISSION AND GENERATION CAPACITY NOT INTEGRATED. Integrated transmission and generation planning can contribute to an optimal expansion of the system overall.

SOLUTIONS BEING IMPLEMENTED OR PLANNED

CAPACITY MARKET. In the clean energy auctions, wind and solar projects can be remunerated for the energy provided as well as for their capacity. CENACE will operate a capacity market and calculate capacity prices once a year for the capacity that was available during the 100 critical hours of the system.[128]

GENERATION ADEQUACY *(from deterministic to probabilistic methods)***.** Mexico has plans to replace the reliability standard based on reserve margins to a target of loss-of-load probability, which will be used to calculate the level of capacity required in the system.[129]

[125] https://www.iea.org/publications/freepublications/publication/EnergyPoliciesBeyondIEACountriesMexico2017.pdf.
[126] Access to the AZEL in Spanish only https://www.gob.mx/sener/es/articulos/atlas-nacional-de-zonas-con-alto-potencial-de-energias-limpias?idiom=es and NREL report https://www.nrel.gov/docs/fy16osti/66656.pdf.
[127] Renewable Electricity Grid Integration Roadmap for Mexico: Supplement to the IEA Expert Group Report on Recommended Practices for Wind Integration Studies; www.nrel.gov/docs/fy15osti/63136.pdf.
[128] https://www.iea.org/publications/freepublications/publication/EnergyPoliciesBeyondIEACountriesMexico2017.pdf.
[129] Ibid.

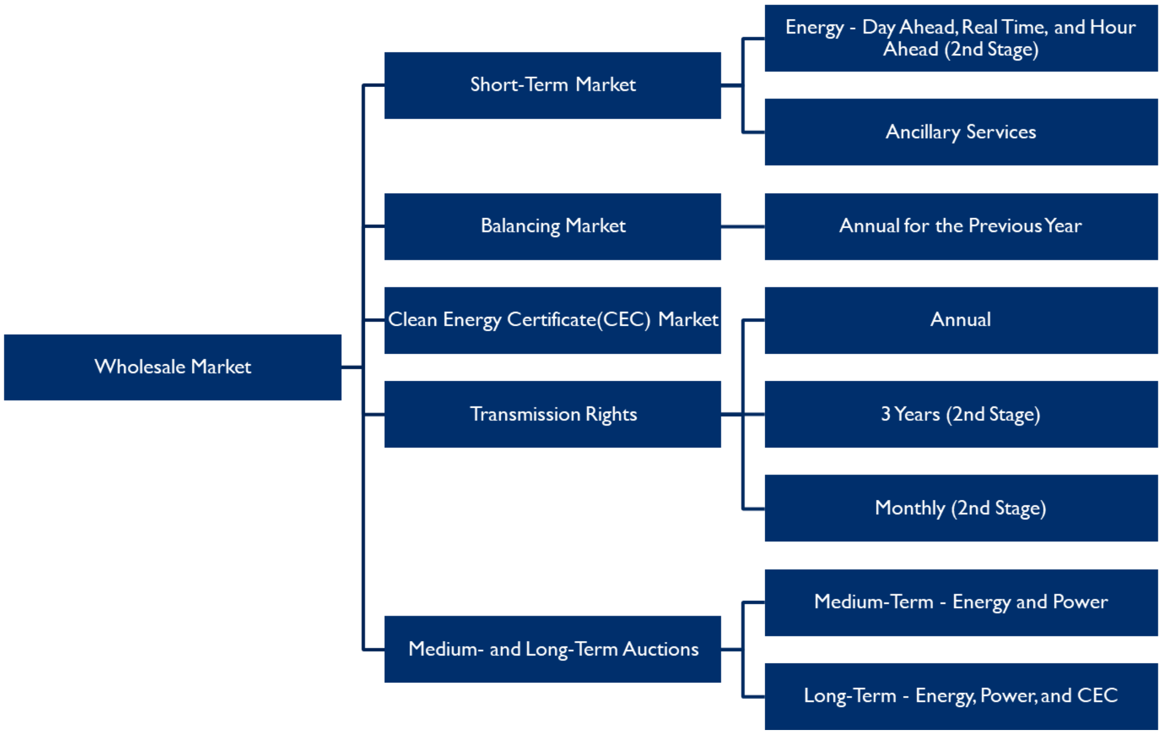

Figure 12. Structure of Mexican Wholesale Market[130]

[130] http://www.cenace.gob.mx/MercadoOperacion.aspx.

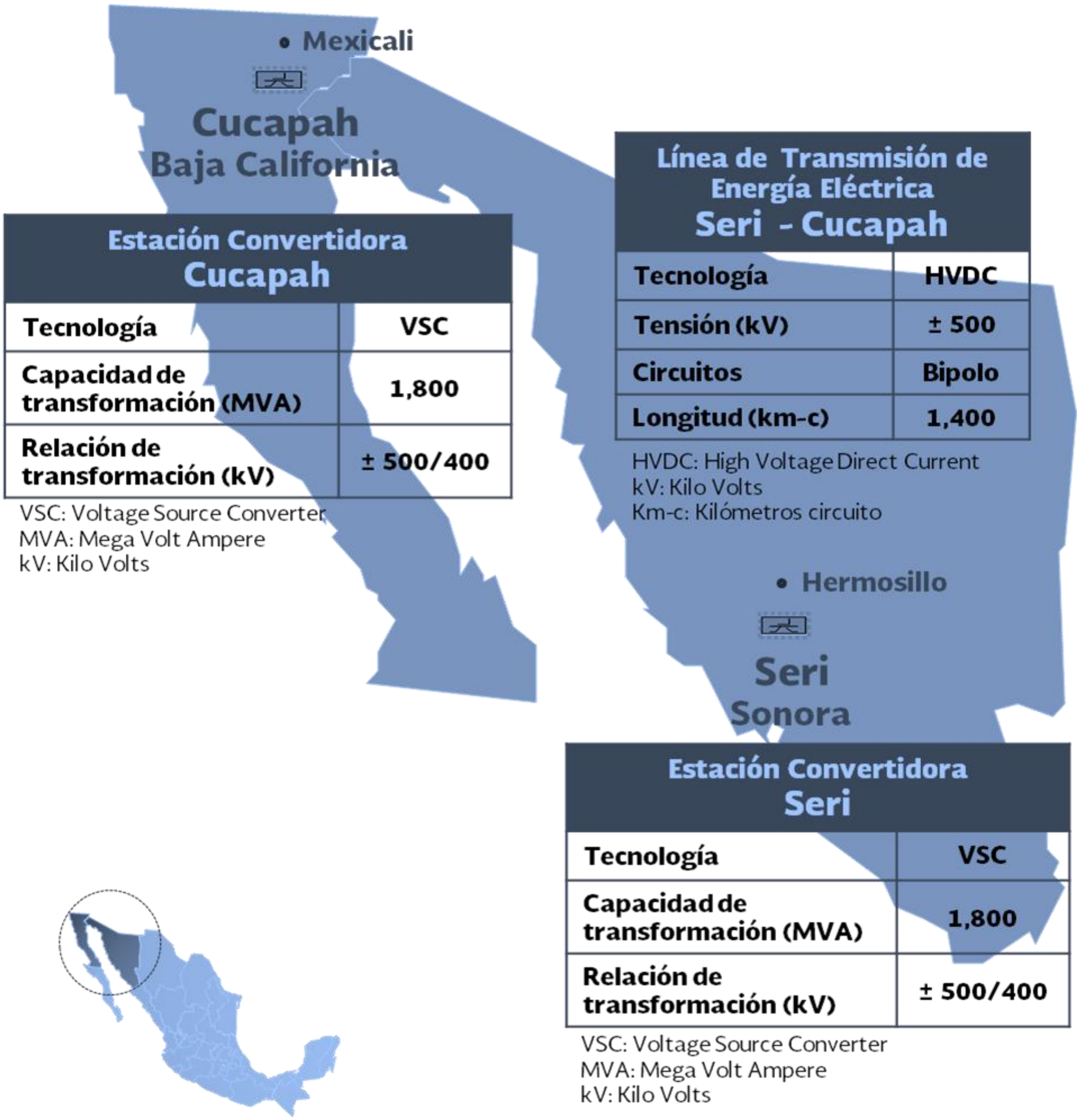

Figure 13. New Transmission Line Bids in Mexico[131]

[131] http://licitaciontransmision.energia.gob.mx/LicitacionTransmision/Proyecto.

THE PHILIPPINES

COUNTRY SUMMARY	
VRE Share	4 percent solar and 2 percent wind.[132]
Renewable Energy Target	30 percent for solar and 50 percent for wind are achievable in the power system as planned for 2030.

KEY FEATURES OF THE PHILIPPINES' POWER SECTOR	
Power Sector Structure	• The WESM was established in 2001 and began operations in 2006.
Key Stakeholders[133]	• System operator: National Grid Corporation of the Philippines (NGCP), operates, maintains, and develops the country's power grid. • The Philippine Electricity Market Corporation (PEMC) governs the WESM. • The Power Sector Assets and Liabilities Management Corporation (PSALM) is tasked to undertake the privatization and sale of the assets of the National Power Corporation (NPC) and the National Transmission Corporation (Transco).[134]
Generation & Transmission	• Fossil fuels dependent. Supply mix from 2016: coal 35 percent, oil and gas 32 percent, hydro 17 percent, geothermal 9 percent, and other renewable energy 7 percent.
Ancillary Services	• This market is currently being implemented.
Scheduling & Dispatch	• The market operator schedules dispatch using hourly demand bids and generation offers submitted by trading participants.[135] It uses a market dispatch optimization model considering transmission constraints and losses. The scheduling process starts with the week-ahead projection, the day-ahead projection, the ex-ante (real-time dispatch), and the real-time ex-post.[136]
Reserves	• Managed by the system operator, who takes reserves capacities out of the generation offers.[137]
VRE Forecasting	• VRE forecasting is required for all generators connected to the high-voltage backbone system in Luzon, Visayas, and Mindanao.[138]

EXPERIENCE IN OPERATING A SYSTEM WITH VRE

NREL, in the Greening the Grid study, modeled the Philippines' power system; its results indicate that it is possible to reach 50 percent renewable energy by 2030, per the country's target. The study considered currently planned generation and transmission investments.

[132] https://www.doe.gov.ph/sites/default/files/pdf/energy_statistics/02_2017_power_statistics_as_of_30_april_2018_capacity_per_plant_type2.pdf.
[133] IRENA, 2017 – RRA Philippines.
[134] https://www.businessinfo.cz/app/content/files/dokumenty/ENERGY_SECTOR_PHILIPPINES.docx.
[135] https://www.doe.gov.ph/sites/default/files/pdf/issuances/dispatch_protocol_manual_issue.pdf and Figure 10.
[136] http://www.wesm.ph/inner.php/the_market/wholesale.
[137] Ibid.
[138] Grid Management Committee, "The Philippines Grid Code, 2016 Edition," Energy Regulatory Commission, Pasig City, 2016.

CHALLENGES

RESERVE PROVISION WILL LIKELY NEED ADDITIONAL GENERATORS TO PROVIDE ANCILLARY SERVICES. NREL noted that, regardless of the renewable energy penetration, it will be crucial to procure and access flexible capabilities from generators (conventional and VRE) and to enhance the sharing of ancillary services between interconnections.[139] This is an opportunity to introduce an ancillary services market.

TO INTEGRATE MORE VRE, THE VISAYAS GRID WOULD BENEFIT FROM ENERGY STORAGE SYSTEMS. The Department of Energy recognizes that energy storage systems can manage the intermittent operations of the VRE generating plants' output, thereby ensuring system stability.[140]

GRID STABILITY ANALYSIS IN VIEW OF NEW VRE PLANTS. The International Renewable Energy Agency recommended a comprehensive grid evaluation with a focus on grid stability for the islands of Luzon, Visayas, and Mindanao.[141] The analysis will cover the present state of the infrastructure, quality of service and power flow, and stability assessments corresponding to solar or wind generation inputs at various points and different penetration levels. Similarly, NREL recommended power flow, contingency, and system dynamic analyses to verify system balancing capabilities under large renewable energy penetrations.[142]

SOLUTIONS BEING IMPLEMENTED OR PLANNED

To enhance power sector flexibility, the Philippines is implementing or planning in the near term to introduce faster market scheduling intervals, solar and wind forecasting, and an ancillary services market.

ANCILLARY SERVICES MARKET. The Department of Energy published draft Circular No. DC2018 for the adoption of energy storage systems in the electric power industry. It proposed that the system operator develop the accreditation process and a testing standard and procedure, for the approval of energy storage systems as an ancillary service provider. Additionally, the market operator is to develop and/or amend the WESM rules, manuals and procedures to allow energy storage systems to participate in the WESM.

The Department of Energy also published a draft circular for the development of a candidate spatial format CREZ map of potential high-quality clean energy zones that enjoy high levels of developer interest.[143]

With regard to the transmission development plan, the country plans to harmonize it with its renewable energy targets.[144]

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139 https://www.nrel.gov/docs/fy18osti/68594.pdf.
140 www.doe.gov.ph/sites/default/files/pdf/announcements/draft_dc_doe_adoption_of_ess_in_the_electric_power_industry.pdf.
141 IRENA RRA Philippines 2017.
142 https://www.nrel.gov/docs/fy18osti/68594.pdf.
143 www.doe.gov.ph/announcements/request-comments-draft-department-circular-establishing-and-development-competitive.
144 RENEWABLE ENERGY ROADMAP 2017–2040 https://www.doe.gov.ph/pep/renewable-energy-roadmap-2017-204.

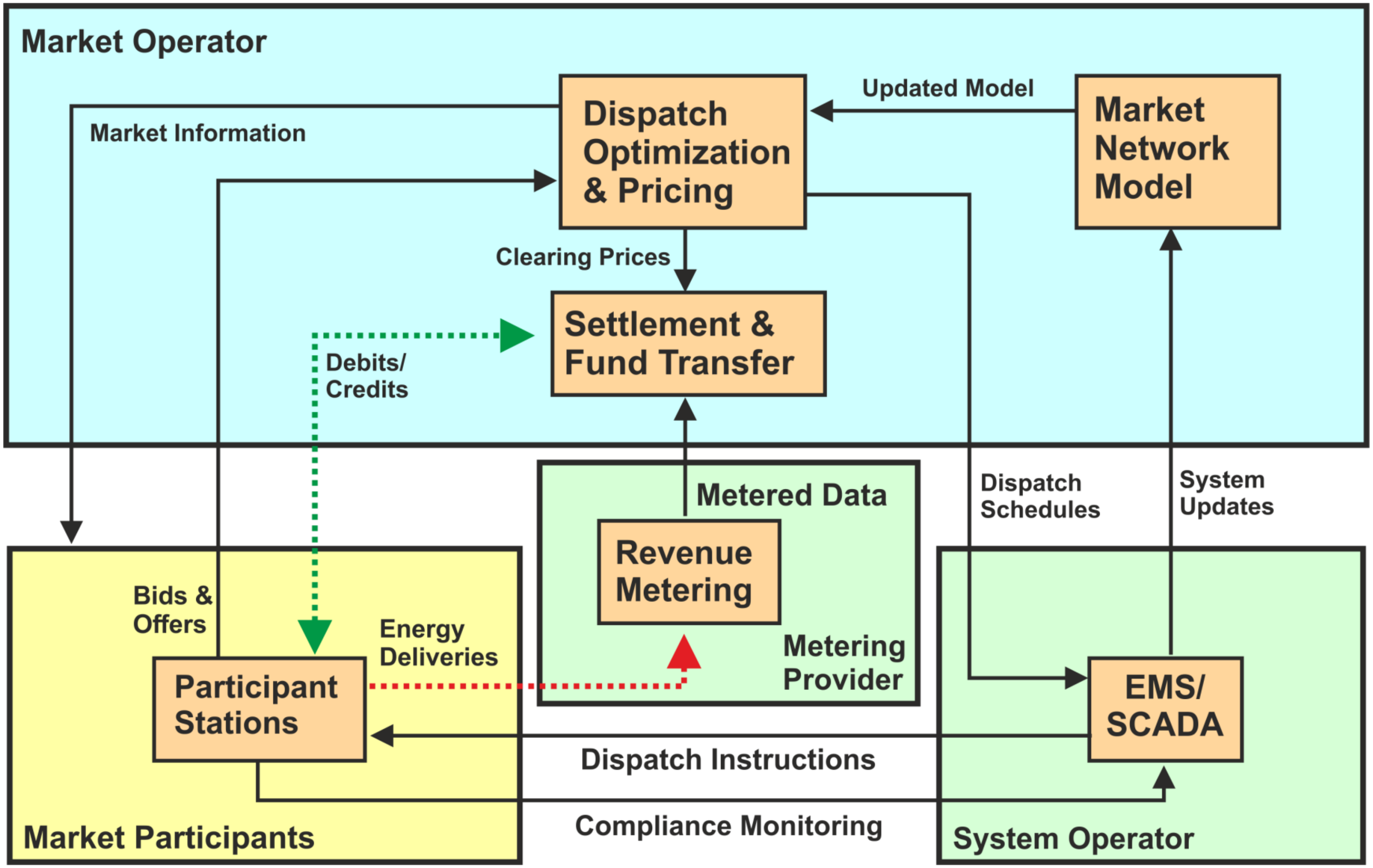

Figure 14. Philippines Electricity Market Operations Overview[145]

[145] https://www.doe.gov.ph/sites/default/files/pdf/issuances/dispatch_protocol_manual_issue.pdf.

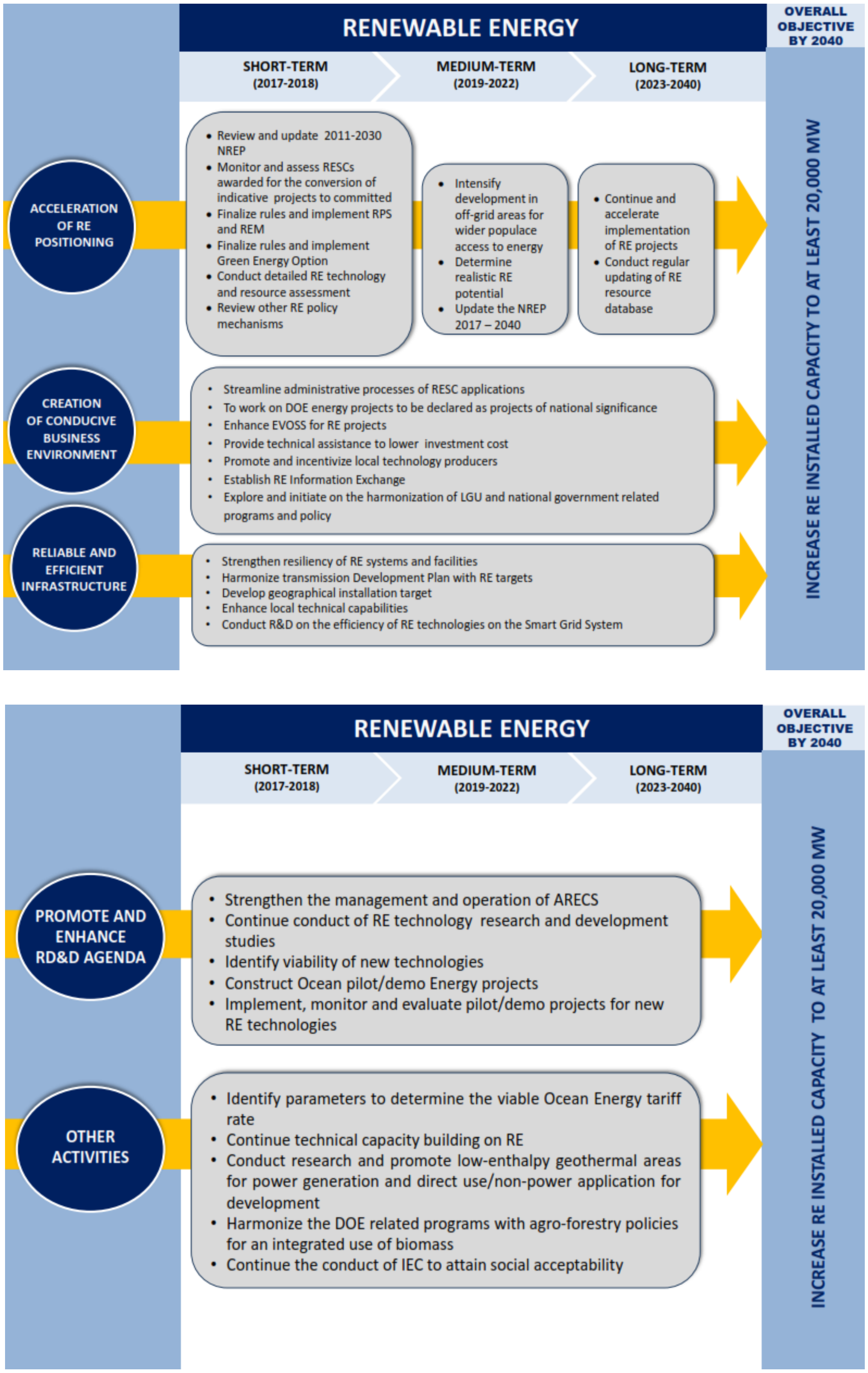

Figure 15. Philippines Renewable Energy Roadmap 2017–2040[146]

[146] https://www.doe.gov.ph/pep/renewable-energy-roadmap-2017-2040.

VIETNAM

COUNTRY SUMMARY	
VRE Share	Virtually nothing; however, there are more than 30 projects at some stage of development ranging from 20-300 MW.[147]
Renewable Energy Target	7 percent by 2020 and 10 percent in 2030.

KEY FEATURES OF INDIA'S POWER SECTOR	
Power Sector Structure	• Pilot wholesale electricity market with the goal to move to a competitive wholesale market in 2021.
Key Stakeholders	• System and market operator: National Load Dispatch Center (NLDC). • Electricity Regulatory Authority of Vietnam (ERAV). • Electricity of Vietnam (EVN) is the distributor of electric power and owns the majority of generating and transmission facilities.
Generation & Transmission	• Diversified mix: coal 36 percent, hydro 36 percent, gas 25 percent, oil and diesel 1 percent.
Reserves	• Frequency regulation reserve, spinning reserve, fast start, cold start, black start, reliability must-run, and voltage regulation are included in the grid code. Spinning reserve/frequency control reserve has been about 2-3 percent of total available generating capacity.[148] • Reserve margin: 34 percent countrywide; in the north it is as high as 40 percent.[149]
VRE Forecasting	• No clear requirements.
Cross-Border Interconnections	• Laos, China (power import,[150] and Cambodia (power export). Imports: 2 percent of the total electricity demand.[151]

EXPERIENCE IN OPERATING A SYSTEM WITH VRE

In April 2017, the country announced a feed-in-tariff of $0.0935/kWh for solar energy projects, and USAID organized a workshop on the development and financing of solar projects.[152] However, in the same year, the World Bank and Vietnam's Ministry of Industry and Trade began discussions for a pilot auction program for solar projects.[153]

CHALLENGES

SOLAR AND WIND ENERGY CONSIDERATIONS ARE EXCLUDED IN THE GRID CODE. The technical requirements to interconnect VRE with the transmission and distribution grid are lacking.[154]

[147] https://www.rvo.nl/sites/default/files/2017/11/factsheet-renewable-energy-vietnam.pdf.
[148] http://documents.worldbank.org/curated/en/312121471034470547/pdf/ICR-Main-Document-P115874-2016-07-25-22-10-08092016.pdf.
[149] http://documents.worldbank.org/curated/en/565671508913149200/pdf/120674-BRI-PUBLIC-24-10-2017-14-23-31-LWLJOKR.pdf.
[150] Interconnection with China is not connected with the national Vietnamese grid.
[151] http://gizenergy.org.vn/media/app/media/PDF-Docs/Publications/GIZ_Vietnam%20Power%20Market%20Overview_2015-10-26_small.pdf.
[152] https://www.usaid.gov/vietnam/program-updates/sep-2017-usaid-helps-spur-solar-energy-investments-vietnam.
[153] https://cleantechnica.com/2017/09/25/vietnam-launch-solar-power-auctions/.
[154] www.esmap.org/sites/esmap.org/files/DocumentLibrary/Session%203%20-%20Pham%20Quang%20Huy.pdf and http://gizenergy.org.vn/media/app/media/PDF-Docs/Publications/Capacity_Needs_Assessment_Wind_DKTI_project.pdf.

LIMITED LOCAL EXPERTISE ON THE MANAGEMENT OF VRE. ERAV and EVN do not have a clear picture on how to deal with increasing amounts of variable renewable energy.[155]

SOLUTIONS BEING IMPLEMENTED OR PLANNED

FACILITATING THE DEVELOPMENT AND FINANCING OF SOLAR ENERGY PROJECTS. USAID's Vietnam Low Emission Energy Program is working with Vietnam's private sector to accelerate clean energy development. USAID is helping T&T Group, a Vietnamese private firm, develop its first solar power project in Ninh Thuan province.

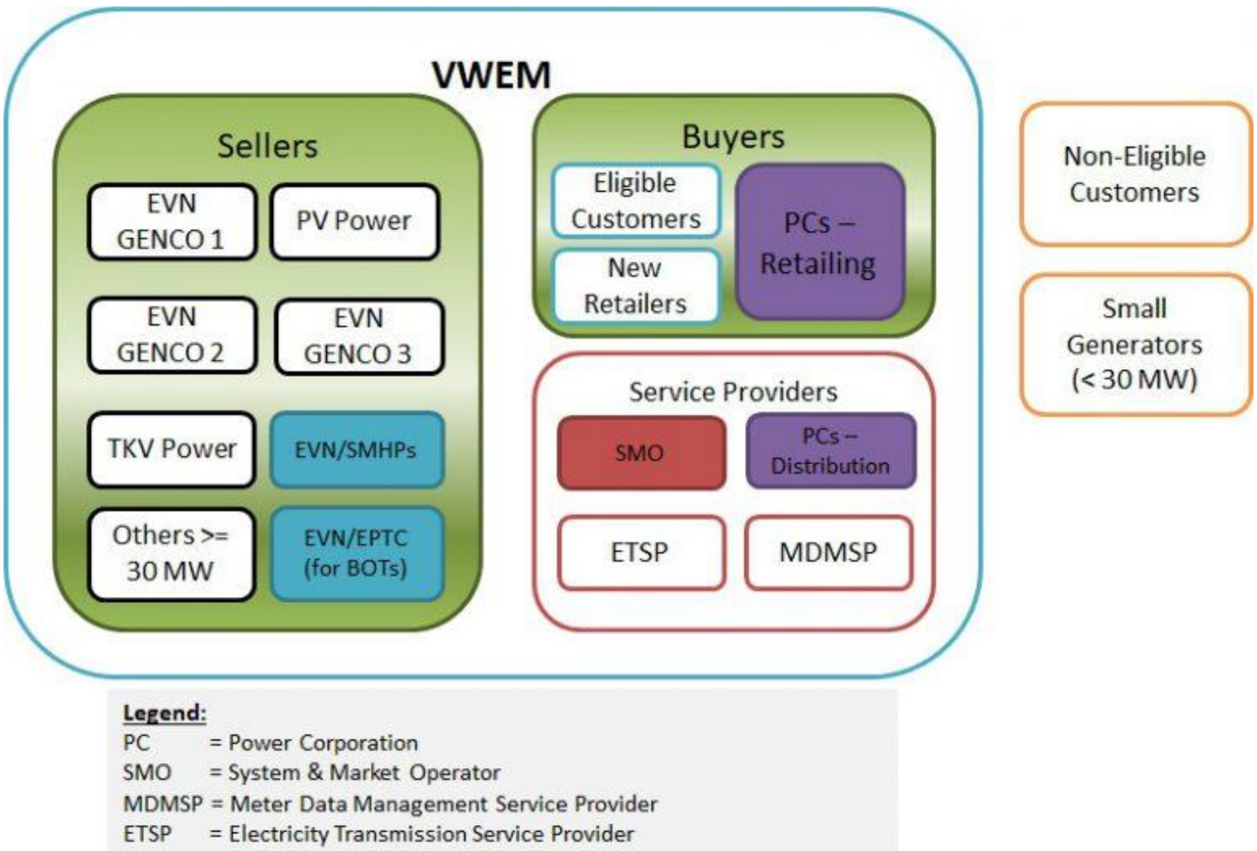

Figure 16. Model for Power Market Participants in Vietnam's Wholesale Electricity Market[156]

[155] http://gizenergy.org.vn/media/app/media/PDF-Docs/Publications/Capacity_Needs_Assessment_Wind_DKTI_project.pdf.
[156] http://www.aseanenergy.org/blog/the-history-and-roadmap-of-power-sector-reform-in-vietnam/.

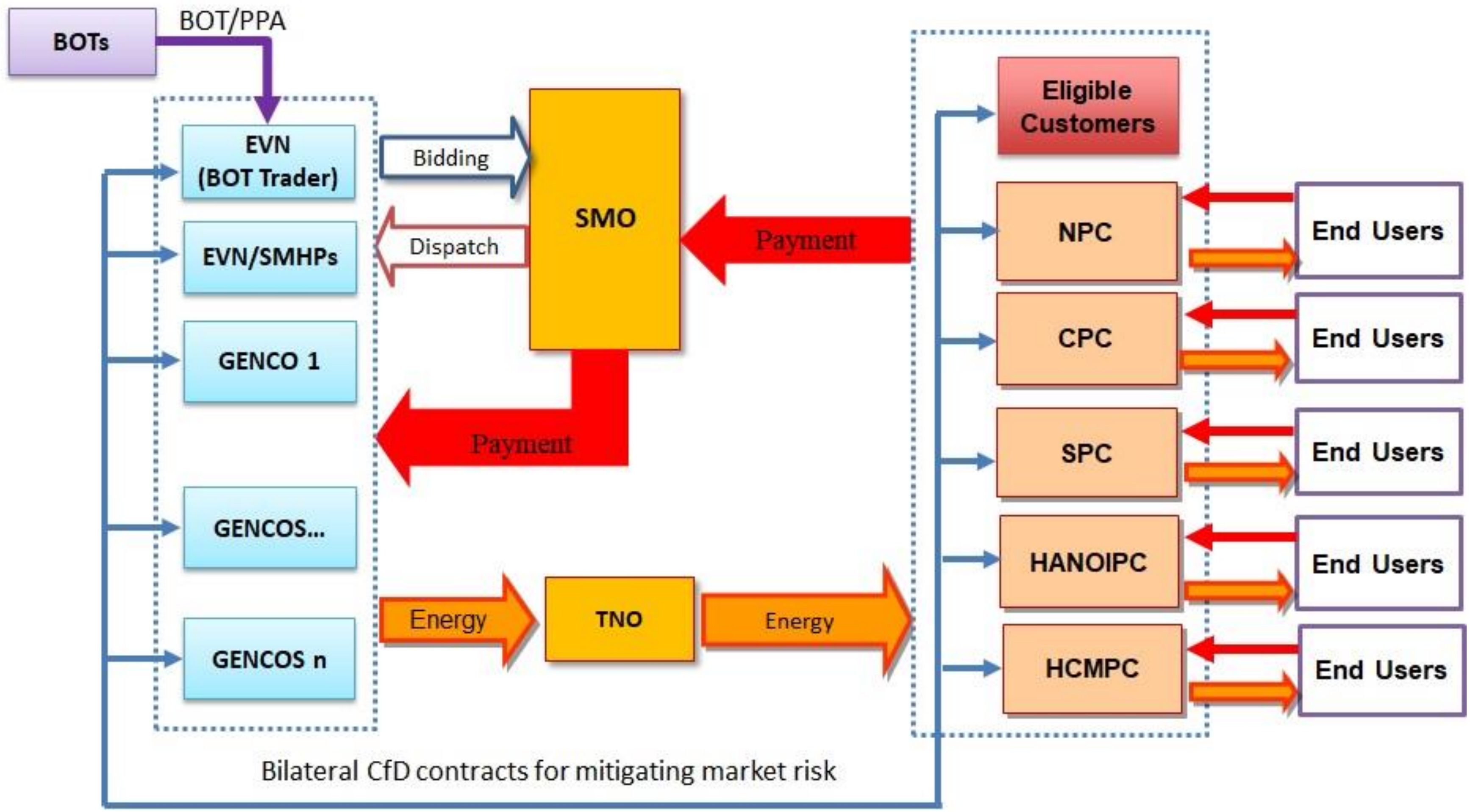

Figure 17. Structure of Vietnam's Wholesale Electricity Market