Ready for Renewables

Grid Planning and Competitive Renewable Energy Zones (CREZ) in the Philippines

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Department of Energy Philippines

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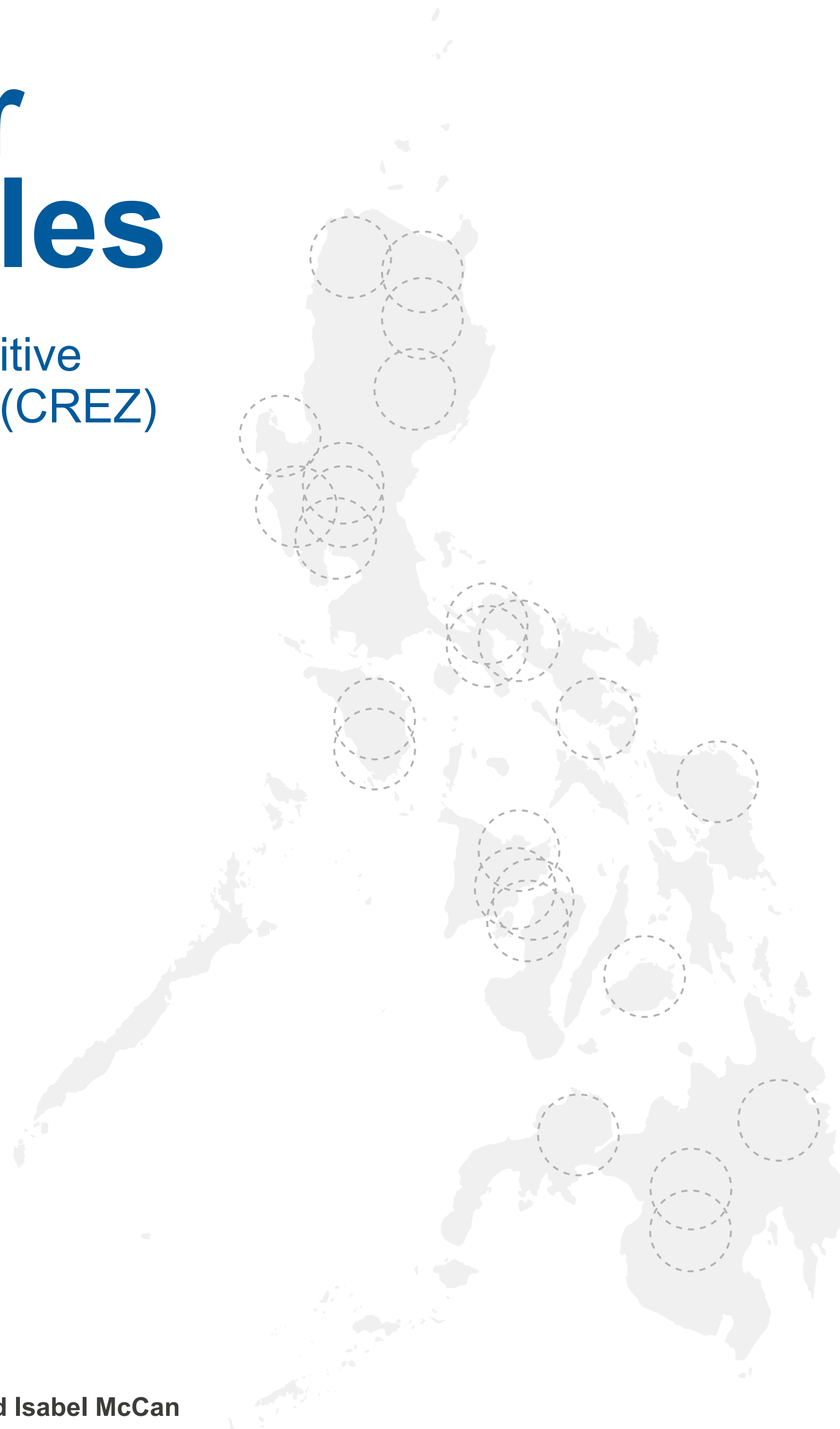

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NOTICE

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Message from the Secretary of Energy

Indigenous renewable energy (RE) resources and private sector investment are central in achieving the Philippines' vision of ensuring sustainable, secure, accessible, and affordable energy supply and services. With our country having been gifted with an abundance of RE resources, we have sought to make significant strides in maximizing their development and utilization. Through the years, the Department of Energy of the Philippines (DOE) has been working hard to establish and implement various RE policy mechanisms under the Renewable Energy Act of 2008, which are necessary to support market development for new RE projects.

This primer serves as a testament to the collective efforts of the DOE, Energy Regulatory Commission, National Renewable Energy Board, National Transmission Corporation, National Grid Corporation of the Philippines (NGCP), and all our other partner government agencies and stakeholders in improving our national RE landscape. To this end, I am pleased to present the outcomes of the Competitive Renewable Energy Zones (CREZ) process, performed in accordance with DOE Circular No. DC2018-09-0027, entitled "Establishment and Development of Competitive Renewable Energy Zones in the Country", issued on 13 September 2018.

The CREZ process uses the availability of new and upgraded bulk transmission to direct RE development to the most economical project locations. Attracting new projects in these zones will produce more energy per megawatt, given that these zones were selected based on both the quality of available resources and the ease of their development. Clustering projects in CREZ areas will enable the use of higher voltage lines with lower losses per kilometer and lower costs per kilowatt-hour in transmitting the energy services to be delivered to customers. The resulting improvement in transmission access will benefit our variable wind and solar, as well as our geothermal, biomass, hydropower and conventional energy resources.

The high-volume, cost-effective RE development enabled by CREZ transmission will support multiple national goals, including:

- increased energy independence with the greater use of our indigenous energy resources;
- the facilitation of open and non-discriminatory access to the national transmission grid;
- improved power sector resilience;
- accelerated greenhouse gas emissions reduction;
- catalyzed economic growth from lower electricity bills, greater local investment, and new green jobs; and
- supporting the achievement of the RE Sector Roadmap by attaining 20 GW of new RE capacity by 2040.

Lastly, I would like to take this opportunity to express the DOE's sincere appreciation to the United States Agency for International Development (USAID) and the U.S. Department of Energy's National Renewable Energy Laboratory for their technical assistance, which has strengthened the DOE and NGCP's ability to plan and manage greater amounts of indigenous renewable resources on the national grid.

Maraming salamat at mabuhay!

ALFONSO G. CUSI
Department of Energy

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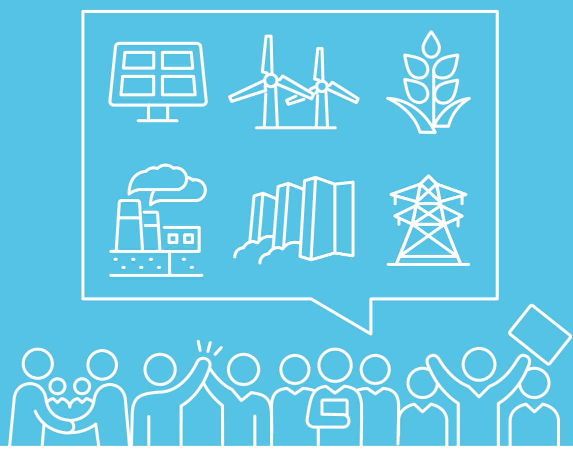
CREZ Vision



Use transmission to direct RE development to places that optimize use of the indigenous resources and maximize benefits to the people of the Philippines.

The DOE launched the CREZ process to help achieve the country's goals of scaling up RE generation on the power system and to ensure sustainable, secure, reliable, accessible, and affordable energy. The CREZ process identifies the most economic RE resource areas so transmission planning and expansion can accelerate their development (**Box 1**). By proactively focusing transmission expansion to these resource areas, RE generation development obstacles such as transmission access, energy curtailment, land permitting (such as protected or high-slope areas), and regulatory barriers are easier to overcome thus, reducing risk for private sector RE investment. New transmission stemming from the CREZ process will help all RE resources in the Philippines, including wind, solar, geothermal, biomass, and hydropower.

The CREZ process in the Philippines is informed by successful RE zone projects in the United States and other countries, which demonstrate that successful proactive transmission planning for renewables:

- Helps integrate significant RE capacity
- Eliminates regulatory bottlenecks
- Avoids land permitting obstacles
- Drives competition
- Reduces costs
- Supports efficient, reliable, and resilient power system operation.

The CREZ process also complements other policies supporting small-scale and distributed indigenous RE resource development and the overall energy diversification policy. It is one tool in the government's suite of policies to cost-effectively accelerate deployment of large-scale RE in the Philippines.

BOX 1

What Is a CREZ?

A **CREZ** is a geographic area with high concentrations of cost-effective RE and strong developer interest. CREZ data informs the selection of new and enhanced transmission lines, encouraging new development toward the best RE resource areas. While there is no requirement to site new RE projects in a CREZ, access to transmission is an advantage. A CREZ itself does not have specific borders. Instead, it is defined by proximity to transmission.

The CREZ process is a proactive transmission planning approach that supports investment in transmission expansion and/or upgrades for large-scale RE development. Undertaking the CREZ process can increase the share of all RE while maintaining system reliability and economics. It also leverages economies-of-scale development for wind and solar while creating new opportunities for other types of RE due to increased transmission access.

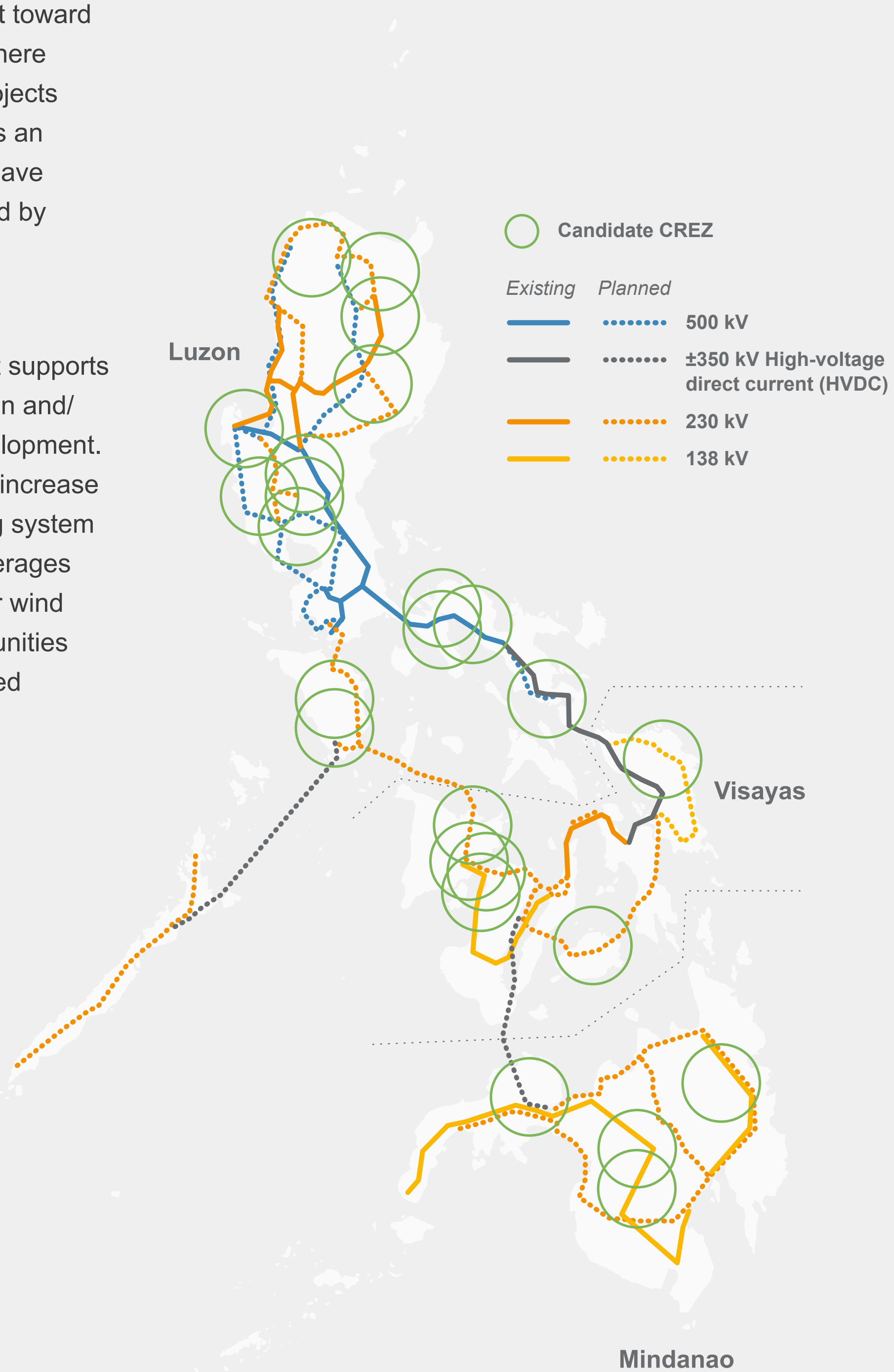


Figure adapted from NGCP

CREZ Process Outputs

The CREZ process advances the energy sector goals of the Philippines.

Identified Abundant, High-Quality, Economic RE Resources

- Stakeholders identified 25 individual CREZ across the Philippines with high-quality RE resources, limited development constraints, and strong private developer interest.
- The resource capacity in these zones exceeds the Philippines' Renewable Energy Roadmap goal of at least 20 GW of renewable power on the grid by 2040, offering plenty of flexibility in finding the most cost-effective transmission build-out scenarios (DOE 2020).
- These resources, along with additional committed generation capacity, will meet load growth, ensure power quality, and support system reliability.

Reduced RE Deployment Barriers

- The CREZ process solves the timescale misalignment and circular financing dilemmas RE projects often face with traditional planning approaches (**Box 2**) (Lee, Flores-Espino, and Hurlbut 2017).
- The CREZ process offers opportunities for reducing costs and amplifying benefits by evaluating the transmission needs of the system as a whole, as opposed to upgrading the system incrementally based on the needs of specific projects.
- Effectively planned transmission systems will mitigate transmission congestion in the long term as RE penetration and demand increase.

Improved National Coordination for Power System Planning

- Undertaking the CREZ process spurred an unprecedented level of coordination between DOE, the Energy Regulatory Commission, NGCP, the National Transmission Corporation (TransCo), and other stakeholders on transmission modeling and proactive development planning.
- The process established the Technical Advisory Committee (TAC) and working groups for transmission and generation modeling, which together will drive future innovative transmission development planning for the country.
- Improved generation planning and transmission planning will reduce curtailment of variable RE, particularly wind and solar generation.

Enhanced Opportunities for RE Investment

- There is less uncertainty about where RE developers can find the highest quality RE resources and transmission access.
- Investors and lenders can assess a larger number of more competitive opportunities, making RE investments more bankable.
- The process induces competition for RE development and lower energy prices by connecting transmission to areas with abundant, high-quality RE resources.
- Resources are available for all energy sector stakeholders to learn about competitive RE resource availability.[1]

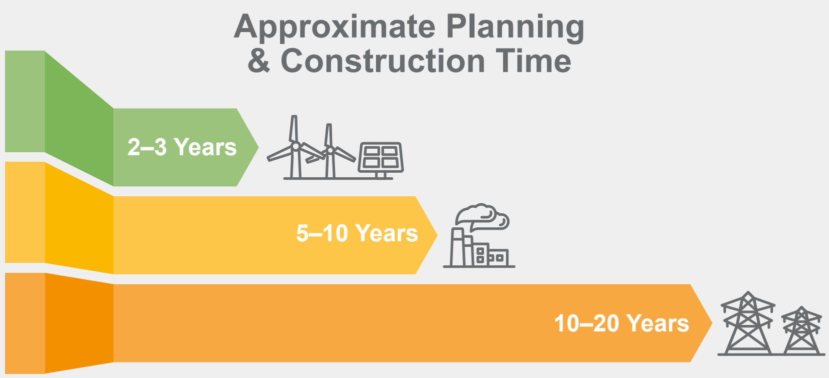
[1]You can find additional information on the CREZ on DOE's webpage: https://www.doe.gov.ph. Data on the CREZ are also available on RE Data Explorer: https://www.re-explorer.org.

BOX 2

RE Deployment Barriers: Timescale Misalignment and Circular Dilemma

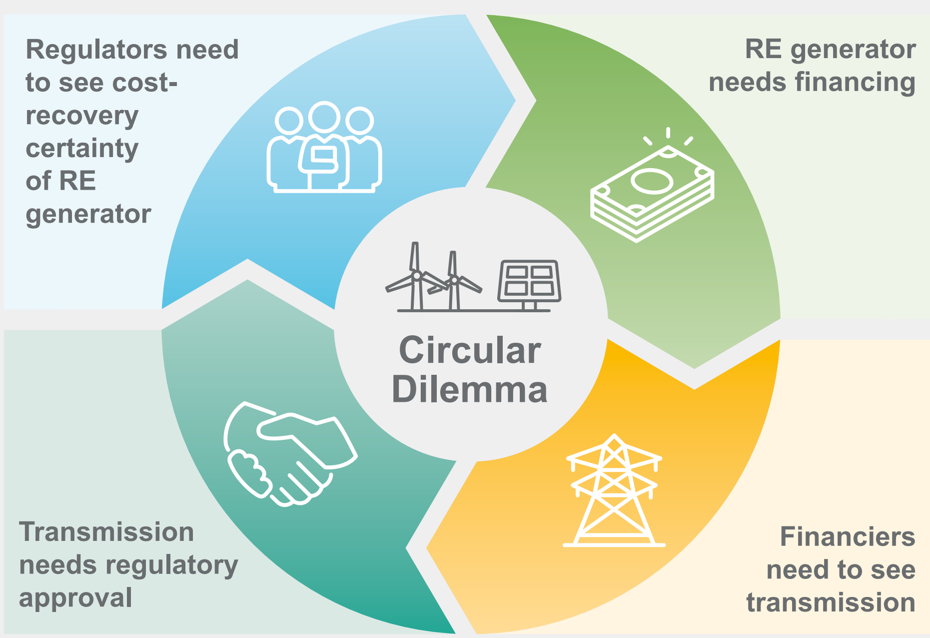
Timescale Misalignment

Traditional transmission planning approaches are often misaligned with RE scale up. Deployment of large-scale wind and solar generation may only require a year or less, while transmission planning and development may take 10 or more years.



Circular Dilemma

RE generator development requires financing, but remote wind or solar resources cannot be financed until transmission access is available; however, transmission lines cannot be built without cost recovery certainty or demonstrated need from wind or solar generation.



Stakeholders and Coordination Efforts

The stakeholder-driven CREZ process strengthens energy sector coordination.

The CREZ process was a stakeholder-driven planning process chaired by the Philippines DOE with support from USAID and NREL (**Figure 1**). The TAC, chaired by the DOE undersecretary, with the participation of nine core energy sector institutions and additional ad-hoc institutions, provided direction on the development, review, and validation of the CREZ process. **Figure 2** shows the institutional structure and stakeholders.

The Zone Identification and Technical Analysis Working Group (Zone WG) identified the candidate CREZ locations in terms of RE resource quality and strong developer interest, while the Transmission and Generation Modeling Working Group (Transmission WG) analyzed transmission expansion options to connect these zones to the grid. The grid modeling responsibilities of DOE (capacity expansion modeling) and NGCP (production cost modeling) were harmonized through the Transmission WG, where they developed a first-of-its-kind coordinated system modeling approach for the country. Transmission WG representatives also participated in a month-long technical exchange at NREL to advance the CREZ process as described in **Box 3**.

Zone Identification and Technical Analysis Working Group Meeting, June 1, 2018

Philippines CREZ Public Consultation, July 31, 2018

TAC Meeting, November 5, 2019

Photos from the DOE

FIGURE 1 *Participation of CREZ stakeholders from across the Philippines' energy sector*

Chair
Department of Energy (DOE)

Initiate and lead the planning activity

Convene relevant parties and ensure the process will culminate in meeting the project vision, i.e., that transmission enhancements occur

USAID

Technical Advisory Committee (TAC)
Chairperson: DOE Undersecretary

Guides and reviews the outputs of the working groups

Ensures the technical validity and relevance of the integrated clean energy transmission and generation planning analysis efforts

Working Groups (WG)

Zone Identification and Technical Analysis WG (Led by DOE)

Responsible for the identification of study areas and candidate zones

Identifies and validates candidate renewable energy zones

Generation and Transmission Modeling WG (Led by DOE)

Responsible for defining and analyzing new generation and transmission enhancement scenarios

Conducts transmission system scenario development and modeling

Stakeholders

Department of Energy (DOE)
National Renewable Energy Board (NREB)
National Transmission Corporation (TransCo)
National Electrification Administration (NEA)
National Grid Corporation of the Philippines (NGCP)
Philippine Electricity Market Corporation (PEMC)
Energy Regulatory Commission (ERC)
Independent Electricity Market Operators (IEMOP)
National Power Corporation (NPC)*
PNOC Renewables Corporation (PNOC-RC)*
Power Sector Assets and Liabilities Management Corporation (PSALM)*
Renewable Energy developer associations*
Electric Power Industry Participants and associations*
Academe*
Grid Experts*

**Indicates ad-hoc members whose participation is determined by the TAC as necessary.*

International Expert

National Renewable Energy Laboratory (NREL)

FIGURE 2 *CREZ institutional structure and stakeholders*

BOX 3

CREZ Technical Exchange at the National Renewable Energy Laboratory

Participants of the July 2019 CREZ technical exchange, pictured left to right: Ana Dyreson, Edward V. Neri, Laura Beshilas, Bryan Paul Q. Agustin, Nathan Lee, Jervie Bagsik, Clayton Barrows, Nori Christopher R. Reyes, David Hurlbut, Hanzel M. Cubangbang, Carlo Brancucci, and Jennifer Leisch. Photo by Werner Slocum, NREL 58528

A team of two representatives from the DOE and three representatives from NGCP participated in a month-long technical exchange at NREL in the United States in July 2019. The goal of this exchange was to create a set of transmission expansion options that incorporate the identified CREZ.

While at NREL, this team met regularly with an advisory committee consisting of senior NREL researchers who provided technical guidance throughout the process. Participants also attended a workshop series designed around the Philippines' interests in RE integration.

At the end of the exchange, the team presented the results of their work and showcased the coordination between the DOE's capacity expansion model (CEM) and NGCP's production cost model (PCM). The team also showed how the modeled transmission expansion scenarios capture integration of more than 30 GW of new wind and solar in the CREZ by 2040. Participants returned to the Philippines with a CREZ analysis framework and modeling tools to support continued scenario development and planning for integrated transmission and generation development.

Learn more about the 2019 CREZ technical exchange in the full length article: Research Exchange at NREL Accelerates Philippines' Clean Energy Transition.

CREZ Process Timeline and Phases

The CREZ process timeline and modeling framework support transparent transmission development planning.

The Philippines DOE Department Circular No. 2018-09-0027 established the vision and design of the CREZ process. USAID and NREL supported the development and implementation of this process by drawing on experiences and lessons learned in the United States and other countries. **Figure 3** describes the steps, key activities, and milestones of the Philippines CREZ process.

The Zone WG identified areas with the highest concentration of wind and solar resources. The group also examined methods for assessing geothermal, hydropower, and biomass resources distributed throughout the zones. They agreed on technology cost assumptions and developed levelized cost of energy (LCOE) estimates accounting for resource quality by location where appropriate. After identifying potential land-use constraints and the highest quality resources, the study areas were defined. From the study areas, the team identified 25 candidate zones with the highest commercial interest for inclusion in transmission scenario development.

During the transmission development phase, the Transmission WG used a capacity expansion model to study how wind and solar resources in the CREZ, along with the distributed geothermal, hydropower, biomass, and conventional power plants, contributed to the least-cost grid build-out to meet future demand. The group used a spreadsheet optimization tool to refine the amount of wind and solar selected within each CREZ based on the lowest LCOE in the region. Critically, for capturing potential congestion on the transmission system, the Transmission WG also analyzed the expected timing of RE generation. These CREZ build-out scenarios, along with additional committed power plant investments, were translated to a production cost model to study the hourly operations and transmission infrastructure needs on the future grid. The modeling framework analyzes the CREZ build-out scenarios under different transmission expansion scenarios. This framework, along with additional power flow modeling, will be used to select transmission plans. Finally, the Energy Regulatory Commission may consider investments that are designated as outputs of the CREZ process as a supporting factor in the regulatory review of Transmission Development Plan CREZ enhancements.

Significant improvements to the capacity expansion and production cost models were made through this process. The linkage of the capacity expansion, spreadsheet optimization, and production cost models will continue to support planning and scenario analysis for a variety of potential load growth, technology cost, and fossil fuel scarcity scenarios. **Figure 4** provides an illustration of the CREZ grid modeling collaboration approach. The Transmission Development Plan utilizes the CREZ process methods to document specific scenarios, modeling inputs and outputs, and results from the planning process. These models allow continued study of CREZ as the grid evolves.

Step	Activities	Milestone
1 Process design and vision statement	▶ Establish the vision and design	▶ Department Circular, September 13, 2018 ▶ 3-day workshop, October 2018
2 RE resource assessment and study area identification	▶ Select areas with highest resource potential ▶ Create study areas map and supply curves	▶ Zone WG bi-weekly meetings, Oct. 2018 – February 2019 ▶ Study areas identified and accepted by the TAC, February 2019
3 Candidate zones selection	▶ Identify zones with highest probability of development ▶ Create candidate zone map and supply curves	▶ Candidate zones identified and accepted by the TAC, February 2019
4 Transmission development	▶ Bundle candidate zones and conduct analyses of the options ▶ Create modeling framework for assessing transmission alternatives	▶ Transmission WG bi-weekly meetings, November 2018 – June 2020 ▶ Technical exchange at NREL, July 2019 ▶ TAC meeting review, November 2019
5 Final transmission plan designation	▶ Select transmission options	▶ Continued Transmission WG collaboration to explore transmission expansion options for the Transmission Development Plan
6 Transmission system upgrade	▶ Obtain approval and implement	▶ Part of the Philippines regulatory process

FIGURE 3 *CREZ process steps*

FIGURE 4 *CREZ grid modeling framework developed in a new DOE-NGCP collaboration within the Transmission WG*

Private Sector Development Opportunities

RE generation deployment is less expensive per MWh produced, more bankable, and more cost-effective.

The CREZ process opens opportunities for private sector development and reduces investment barriers by directing transmission development and RE developers to the Philippines' most promising RE opportunities. Additionally, this process supports cost-effective RE development because the CREZ are prescreened for high-quality resources, suitable topography, potential land-use constraints, and demonstrated private developer interest, thereby reducing overall feasibility assessment costs.

Vetted RE Capacity

- The 25 individual CREZ across the Philippines have an estimated gross capacity of 152 GW of new wind and solar photovoltaics (PV). The zones also include an estimated 365 MW of geothermal, 375 MW of biomass, and over 650 GW of hydropower capacity distributed across the Luzon, Visayas, and Mindanao systems (**Table 1**).
- The gross RE resources represent an upper-bound assessment for each zone; planning for generation at a lower threshold will allow competition to drive the highest quality resources to be developed first.
- These zones provide opportunities for RE projects with high capacity factors and a lower cost (Philippine peso) per megawatt hour (PHP/MWh) than other opportunities and are expected to result in:
  - Maximum MWh for the invested capital, for RE generation and transmission
  - Reduced curtailment of RE generation
  - High capacity factors resulting in high utilization of transmission assets.

Lower Investment Risks

- High spatial and temporal resolution wind and solar resource data for the meteorological year 2017 are now publicly available to support transparent, data-driven decision-making.
- Directing transmission to areas with the best RE resources reduces uncertainty around transmission access.
- CREZ designation is a supporting factor that the Energy Regulatory Commission may consider in the regulatory review of CREZ enhancements included in the Transmission Development Plan.

TABLE 1 *Cumulative CREZ Renewable Energy Capacity Across the Philippines' Systems*

Estimated CREZ Opportunity Capacity (MW)					
System	**Solar PV**	**Wind**	**Geothermal**	**Hydropower**	**Biomass**
Luzon	35,031	54,115	285	270,603	210
Visayas	11,876	25,429	40	1,917	71
Mindanao	11,203	14,443	40	382,514	93

Table 1 presents the screened opportunities for development within the CREZ across the Philippines' three grid systems. The CEM (part of the framework illustrated in **Figure 4**) considered the best of these opportunities to identify an initial least-cost generation build-out to meet future demand (see load projections in **Appendix B Step 4**). The spreadsheet optimization tool (also shown in **Figure 4**) then provided a distribution of optimized RE development within each of the zones. **Figures 5 and 6** present the resulting distribution of optimized CREZ solar PV and wind development, respectively, for a high demand future. These distributions, together with committed generators, are considered within the PCM CREZ build-out scenarios. The initial distribution of optimized CREZ RE development in **Figures 5 and 6** may change in future planning and Transmission Development Plan updates.

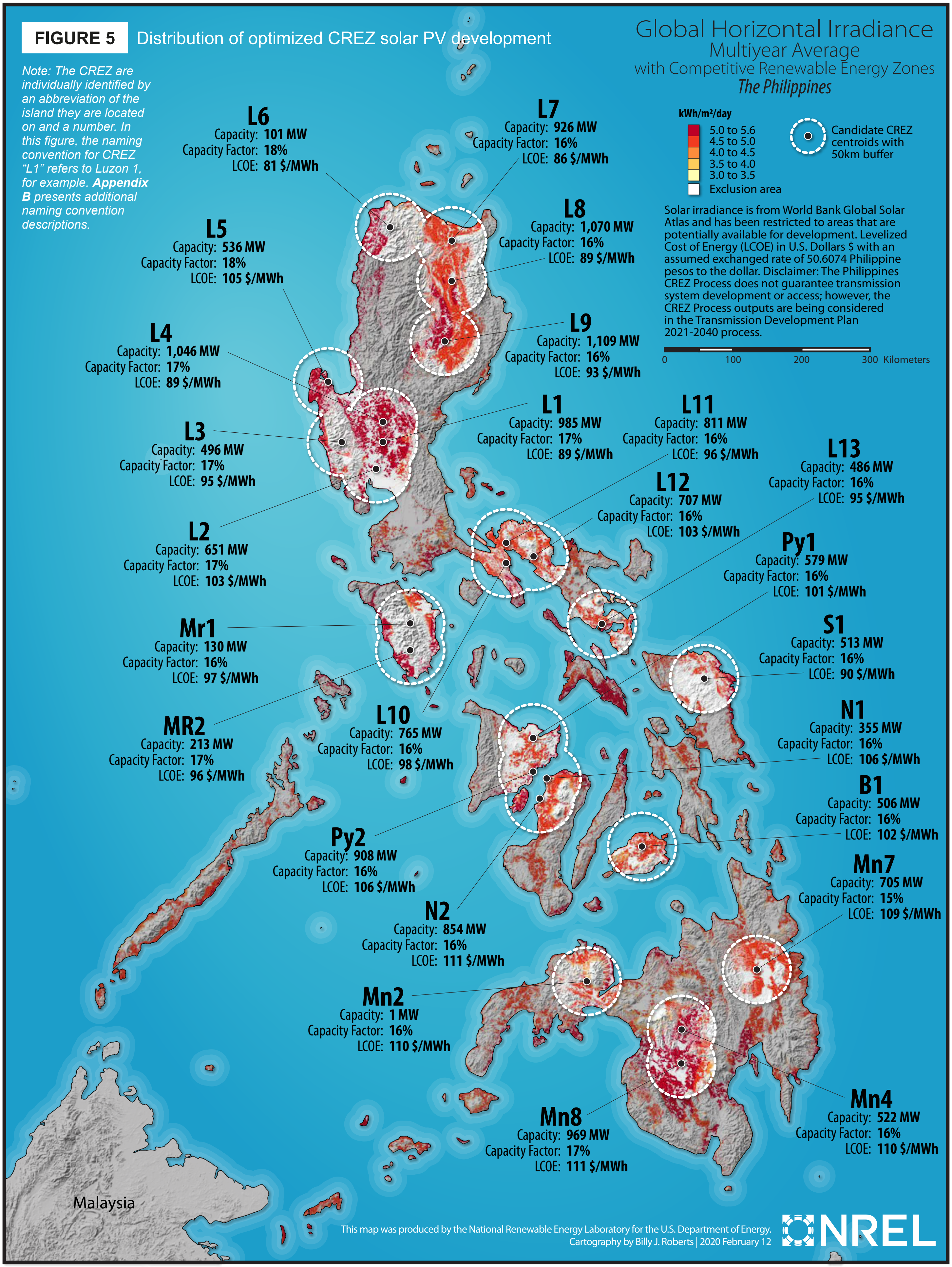


FIGURE 5 Distribution of optimized CREZ solar PV development

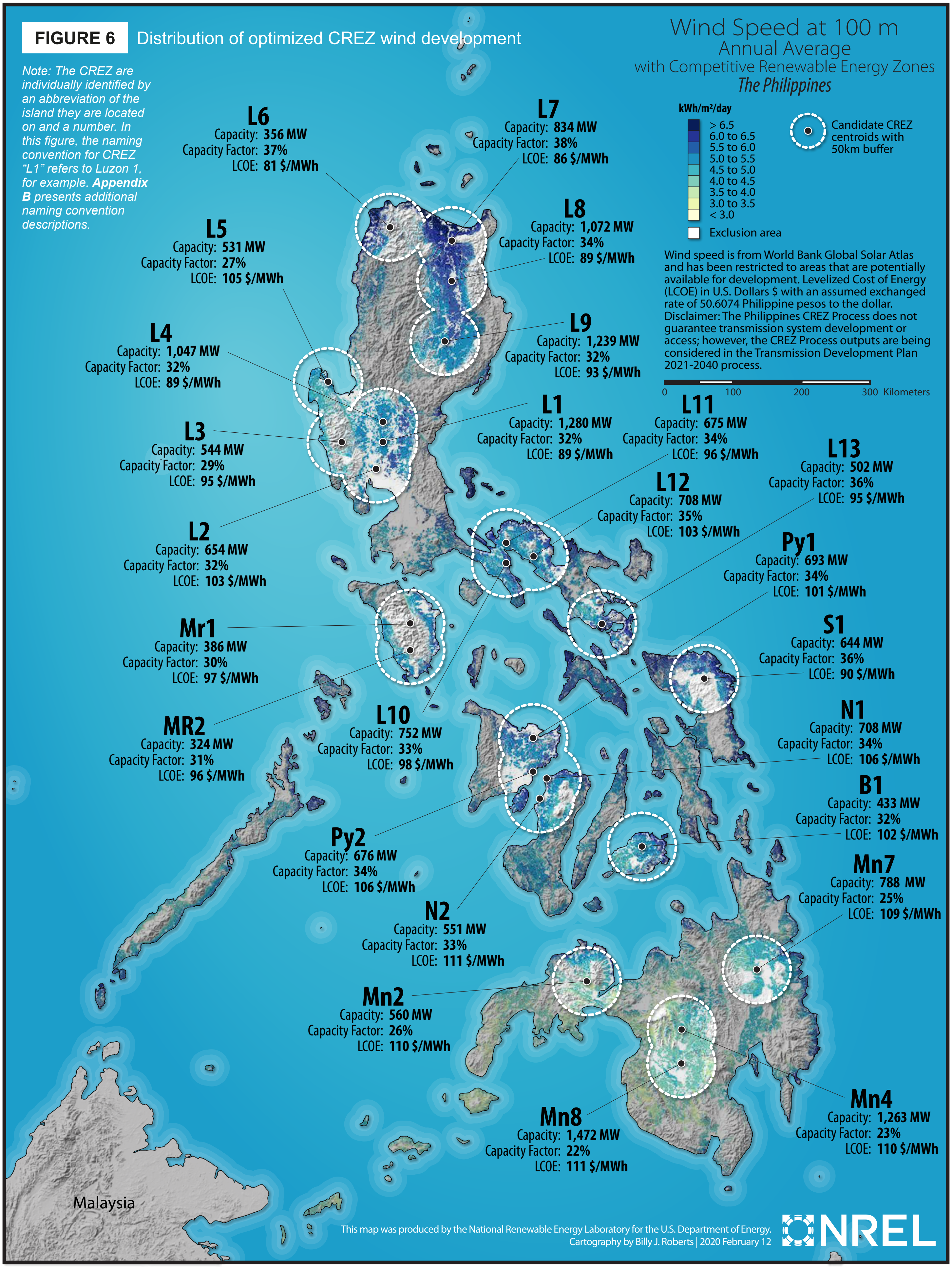


FIGURE 6 Distribution of optimized CREZ wind development

Achieving the Philippines' RE Goals

The CREZ process identified clusters of high-quality RE resources and points of transmission access. This information is now available for all stakeholders from the DOE and on RE Data Explorer (**Box 4**).

- RE developers possess great clarity on:
  - Where the highest-quality, utility-scale RE resources exist
  - Where and when transmission access will be available.
- Investors and lenders can:
  - Take advantage of lower risk on potential RE investments
  - Ensure developers are exploring these competitive opportunities.
- All energy sector stakeholders have access to more information online or by contacting the DOE.

Next Steps for CREZ Implementation in the Philippines

- NGCP and DOE will include additional details about the CREZ process in the next Transmission Development Plan.
- NGCP is exploring additional transmission build-out scenarios that may increase variable RE shares and opportunities for private developers; and
- The CREZ process will be integrated into future transmission development planning in the Philippines.
- The DOE will lead the CREZ process forward and leverage the TAC and Transmission WG experience to:
  - Implement transmission expansion and development of CREZ by the private sector
  - Improve understanding of future energy demand developments across the system to inform policies and planning
  - Increase capacity to model and understand energy demand storage and advanced energy systems for effective energy sector planning and policymaking.

BOX 4

Explore the CREZ on RE Explorer

RE Data Explorer is a no-cost, user-friendly geospatial analysis tool for analyzing RE potential and informing decisions, developed by the NREL and supported by USAID: https://www.re-explorer.org.

REexplorer
MAPPING OUR ENERGY FUTURE

Explore additional CREZ data for the Philippines:

Solar

Wind

An Adaptable Process for Other Countries

The CREZ process may open similar opportunities for other countries seeking to scale up RE.

The Philippines is now a global leader in strategic RE development with the experience gained through the CREZ process. With stakeholder involvement and institutional buy-in, this process is reproducible in other locations.

The Philippines CREZ process is an excellent example for other countries exploring stakeholder-driven and proactive transmission planning to overcome similar barriers. The DOE, together with other leading institutions from the Philippines, is now in the position to share their knowledge and experience with other regional neighbors interested in adapting the CREZ process to their country.

The CREZ process is especially beneficial in locations where existing transmission infrastructure and regulatory barriers may limit RE expansion. The process is also a valuable tool to address transmission congestion in the long term as penetration of renewable generation on the grid and demand increase. Finally, the CREZ process encourages private sector investment in RE by demonstrating commitment to the construction of efficient transmission.

Through the USAID-NREL Partnership, USAID and NREL can also help countries explore the CREZ process and learn from the experience of the Philippines. For more information, visit the Renewable Energy Zone (REZ) Toolkit, which provides practitioners with the information needed to successfully apply the process: Greening the Grid - REZ Toolkit.

Appendices

Appendix A. Caveats and Considerations for the Philippines CREZ Process

- The CREZ process informs regulatory decision-making but does not supersede any law governing how transmission is built or financed. While much of the CREZ analysis work is technical, its aim is a regulatory order authorizing construction of new transmission included in the Transmission Development Plan (TDP). Therefore, all the technical work done in the CREZ process must be conducted in a way that allows it to be introduced as evidence that can withstand challenge in a regulatory proceeding.
- Regulators might not be able to participate directly in the CREZ process due to ex parte considerations (i.e., they cannot be involved in something they are likely to judge later in a legal proceeding). They can, however, provide general guidance on the criteria used to judge transmission cases.
- A successful CREZ process depends on real future demand for new RE capacity. Merely building transmission is no guarantee that RE will come. Demand can take the form of a government mandate. It can also be a reasonable, objective assessment of future market-based demand. In any case, demand must be substantial enough for a regulator to justify an order to build new transmission as part of a CREZ plan. This means translating demand into a number that transmission planners can use to right-size a plan for new transmission. The CREZ process does not create demand for RE; it merely redirects demand that is likely to be in the market to the most economic RE areas through transmission enhancement.
- The CREZ process does not guarantee transmission for any individual project. While the total capacity may be guaranteed at completion of a CREZ transmission proceeding, a developer will not receive any capacity portion unless they compete for it.
- Transparency of decisions in the CREZ stakeholder process is critical because it lends weight to CREZ results when they are later introduced as evidence in a regulatory proceeding.
- The CREZ process informs the Philippines' transmission planning process, and this report is a summary of this work. This work does not replace official planning processes in the Philippines. Readers should refer to the Philippines Energy Plan, Power Development Plan, TDP, or other official publications from the DOE for plans and updates on the CREZ process.
- The results of this work are not meant to be definitive or used for specific project siting. Appropriate due diligence, long-term data measurement, and validation activities are essential to confirm actual resource availability or project performance for any RE project development.
- The economic and financial assumptions presented for RE generation in this report are an estimate. Actual cost of generation at any location will vary due to unique factors related to the developer and specific project (such as capital costs, rates of return on equity, interest rates, discount rates, debt fractions, and appropriate taxes, among others).
- The estimated technical potential and costs presented in this report are highly sensitive to input data and assumptions. The results of this analysis may differ from results in other work with different input data and assumptions. The estimates provided were based on the best available data and information collected by NREL, the working groups, and the TAC at the time of publication. The cost of generation for renewables, including wind and solar technologies, changes constantly. Updated data and assumptions would change the resulting generation cost estimates.

Appendix B. Additional CREZ Process Technical Details

This appendix provides additional details on the activities, assumptions, and inputs related to the CREZ process. The appendix follows the steps of the CREZ process (see **Figure 3**).

Step 1: Process design and vision statement

The DOE led the development of the process design and vision statement, beginning on June 1, 2017 with a workshop focused on completing preliminary drafts. The TAC reviewed these drafts on May 31, 2018. The TAC agreed the scope would include the Luzon, Visayas, and Mindanao systems. The DOE conducted a public consultation of the draft circular entitled "Establishment and Development of Competitive Renewable Energy Zones in the Country" on July 31, 2018. The CREZ process design and vision statement were formalized in the DOE Circular No. DC2018-09-0027 issued on September 13, 2018 (DOE 2018). The TAC, Zone WG, and Transmission WG approved the process design and vision statement in a 3-day workshop on October 9–11, 2018.

Step 2: RE resource assessment and study area identification

Table B-1 presents the RE resource data collected and used for the Philippines CREZ process.

Table B-2 details potential constraints considered for wind and solar development when assessing the technical potential of wind and solar for the CREZ process. Spatial data were requested for all constraints considered to enable the technical potential assessment. The technical potential assessment identified the potential capacity (MW) and generation (GWh) available within each zone given potential development constraints, resource quality, and generation system assumptions following established methods (Lopez, Roberts, Heimiller, Blair et al 2012; Lee, Grue, and Rosenlieb 2018).

In practice, only a portion of the technically feasible sites within a zone may be developed, even if transmission access were available. The technical potential assessment applies broad potential development constraints to estimate generation capacity that may be technically feasible in an area; however, it does not capture the finer project-siting constraints that developers may eventually face. Developers in the Philippines will likely prioritize sites where cost is minimized, returns are maximized, and constraints to development are minimal, as they have limited capital for investment. The Zone WG applied an adjustment factor to each of the zones to account for these finer siting constraints. This was applied as a fraction of developable generation capacity in each zone. This approach does not assume what specific siting constraints may affect development or where specifically within the zone. Rather, it is a broad assumption that reduces the bulk capacity number for each zone as the specific future siting constraints are not yet known. The Zone WG agreed upon development adjustment factors of 1/36 of solar technical potential and 1/3 of onshore and offshore wind technical potential. This assumption informs later transmission modeling steps and can be revised by the TAC in future planning activities.

TABLE B-1 *Renewable Energy Resource Data for the Philippines: CREZ Process*

Resource Data	Description	Source	CREZ Process Application			
			Step 2	Step 3	Step 4	Step 5
Wind	Long-term annual average resource data with 1-km spatial resolution	Global Wind Atlas (DTU and World Bank 2020)	✓	✓		
Solar	Long-term annual average resource data with 1-km spatial resolution	Global Solar Atlas (World Bank and SolarGIS 2020)	✓	✓		
Wind	Hourly resource data for the year 2017 with 3-km spatial resolution. Data is available on RE Data Explorer.	NREL-developed data set			✓	✓
Solar	Hourly resource data for the year 2017 with 3-km spatial resolution. Data is available on RE Data Explorer.	Procured data from Vaisala, Inc.			✓	✓
Hydropower	Spatial data with estimated capacity and annual generation of potential hydropower sites greater than 5 MW	Philippines DOE	✓	✓	✓	
Biomass	Estimated capacity and annual generation available within each CREZ study area from rice hull, corn cobs, sugarcane bagasse, and coconut (shell and husk)	Philippines DOE	✓	✓	✓	
Geothermal	Spatial geothermal service contract data set with potential capacity	Philippines DOE	✓	✓	✓	

TABLE B-2 *Constraints Considered for Wind and Solar Resource Development*

Constraint Category	Constraint	Wind Constraint*	Solar Constraint	Data Source**
Resource quality threshold	Wind capacity factor ≥ 20%	✓		The Global Wind Atlas (DTU and World Bank 2020)
Resource quality threshold	Solar capacity factor ≥ 15%		✓	Global Solar Atlas (World Bank and SolarGIS 2020)
Administrative	Urban areas	✓	✓	Settlement Model (European Commission)
Infrastructure	Airports + 1 km buffer	✓		Department of Transportation
Infrastructure	Roads	✓	✓	Department of Public Works and Highways
Slope	Areas with > 20% grade	✓		Shuttle Radar Topography Mission – Digital Elevation Model version 4 (Jarvis 2018).
Slope	Areas witwh > 10% grade		✓	Shuttle Radar Topography Mission – Digital Elevation Model version 4 (Jarvis 2018).
Waterbodies	Lakes (and inland waters)	✓	✓	NAMRIA
Waterbodies	Rivers	✓	✓	NAMRIA
Land cover	Closed forest	✓	✓	NAMRIA
Land cover	Perennial crops		✓	NAMRIA
Land cover	Annual crops		✓	NAMRIA
Land cover	Marshlands and swamps	✓	✓	NAMRIA
Land cover	Mangroves	✓	✓	NAMRIA
Land cover	Fishponds	✓	✓	NAMRIA
Philippines NIPAS	Fish sanctuary	✓		World Database on Protected Areas (WDPA) from UNEP-WCMC and IUCN
Philippines NIPAS	Fish sanctuary and fish reserve	✓		WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Fishery refuge and sanctuary	✓		WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Fishery reserve	✓		WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Mangrove swamp forest reserve	✓	✓	WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Marine fishery reserve	✓		WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Marine and fish sanctuary	✓		WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	National park	✓	✓	WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Natural park	✓	✓	WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Natural biotic area	✓	✓	WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Natural monument	✓	✓	WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Protected area	✓	✓	WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Protected landscape	✓	✓	WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Protected seascape	✓	✓	WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Resource reserve	✓	✓	WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Seagrass protected area	✓		WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Seagrass sanctuary	✓		WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Seagrass and fish sanctuary	✓		WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Tourist zone and marine reserve	✓	✓	WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	Wildlife sanctuary	✓	✓	WDPA from UNEP-WCMC and IUCN
Philippines NIPAS	World Heritage Site (natural or mixed)	✓	✓	WDPA from UNEP-WCMC and IUCN

**Onshore and/or offshore wind **Spatial data from Institutions in the Philippines was aggregated and shared with the Zone WG for the CREZ Process by the National Mapping and Resource Information Authority (NAMRIA).*

TABLE B-3 *Renewable Energy Generation Technology Assumptions for the Philippines CREZ Process*

Technology Type	System Description	Capital Cost (Philippine Peso - PHP/MW)*	Fixed Operations and Maintenance Cost (PHP/MW/year)	Grid Connection Cost (substation tie-in, 69 kV, steel tower, single circuit line) (PHP/km/MW)
Onshore Wind	- Hub height: 100 m - Rotor diameter: 89–114 m (based on best technology for site with multiyear mean wind speed) - Machine rating 2 MW - Power Density: 3 MW/km^2	126,518,487	1,265,185	77,834
Offshore Wind	(See onshore wind)	316,296,217 (2.5 x onshore cost)	3,542,518 (2.8 x onshore cost)	108,958 (1.4 x onshore cost)
Solar PV	- Fixed-tilt system - Installed power: 1 kWp - Central inverters with Euro efficiency of 97.5% - DC losses of 7.5% - AC losses of 0.5% - Land-based - Power density: 36 MW/km^2	75,911,092	759,111	77,834
Hydropower	Small hydropower with capacity less than 50 MW	143,218,927	4,299,048	77,834
Geothermal	Generic technology based on Philippines Service Area Contracts data	303,644,368	1,012,148	77,834
Biomass	Generic technology assumptions from Philippines DOE	95,647,976	89,069,015	77,834

**Assumed exchange rate 50.6074 PHP/USD (average, Sept. 2019 to Aug. 2020). Bangko Sentral ng Pilipinas (2020).*

Table B-3 presents the technical and financial assumptions used to estimate technical potential and the LCOE for renewable energy generation technologies. The variable operation and maintenance costs and fuel costs are assumed to be zero for RE generation.

The LCOE was calculated following the approaches established in NREL's Annual Technology Database and previously applied in SE Asia, shown in **Equation B-1** (Lee, Flores-Espino, Oliveira, Roberts et al. 2019). The LCOE does not include regional cost multipliers (to adjust costs between different locations in the Philippines) or any access road costs. The financial and economic assumptions for the Philippines are shown in **Table B-4**.

Supply curves were produced for each of the CREZ study areas based on the calculated LCOE, RE resource data, and technology assumptions. Supply curves allow planners to quantify the energy resources that could be developed at or below a certain LCOE, estimate the annual generation with a zone, and compare these data across the study areas. The example supply curve for study area L7 shown in **Figure B-1** depicts the LCOE on the vertical axis for RE generators and the annual generation on the horizontal axis (in order of increasing LCOE).

The CREZ are individually identified by an abbreviation of the island they are located on and a number. In this figure, the naming convention for CREZ "L1" refers to Luzon 1, for example. Additionally, "N" refers to Negros, "Py" to Panay, "B" to Bohol, "Mn" to Mindanao, "S" to Samar, "Ms" to Masbate, "Mr" to Mindoro, "C" to Cebu, and "Pw" to Palawan.

Step 3: Candidate zones selection

Step 3 consists of screening the study areas identified to ensure they are commercially attractive for development in the Philippines. Certain zones with excellent RE resources may not

EQUATION B-1

$$LCOE = \frac{\text{Fixed Charge Rate} \times (\text{Capital Cost} + \text{Grid Connection Cost}) + \text{Fixed O\&M Cost}}{\text{Capacity Factor} \times 8{,}760 \text{ hours/year}} + \text{Variable O\&M Cost} + \text{Fuel Cost}$$

TABLE B-4 *Philippines Financial and Economic Assumptions for the LCOE*

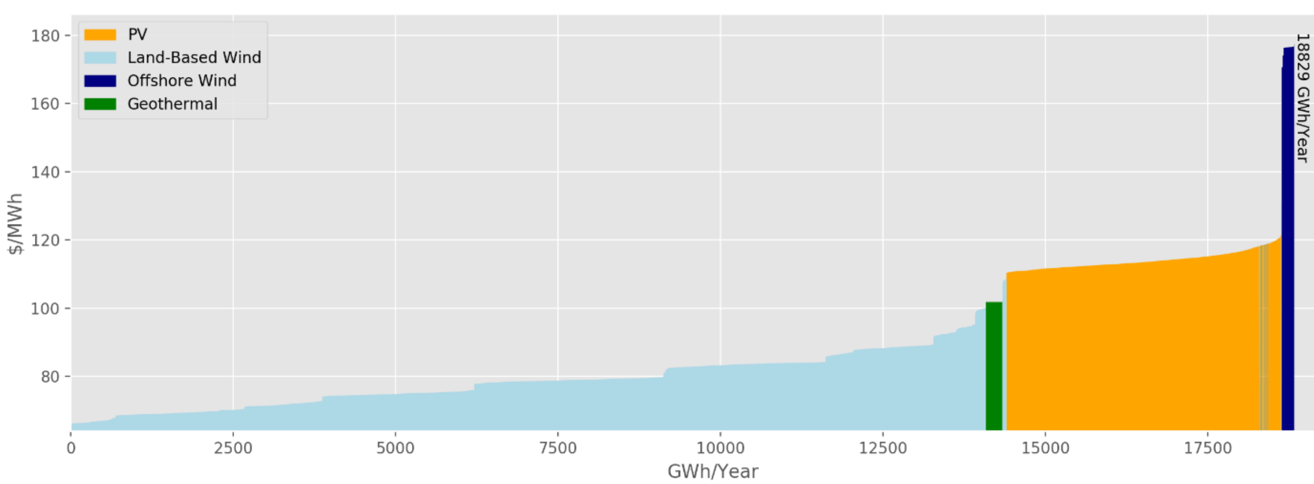
Assumption		Reference
Inflation rate, 2018 (%)	4.00	2018 Asian Development Outlook (ADB 2018)
Interest rate, real (%)	3.23	World Bank (World Bank 2020)
Debt fraction (%)	69.00	Nathan Lee et al. 2019 (Lee, Flores-Espino, Oliveira, Roberts et al. 2019)
Tax rate (%)	20.00	Philippines Bureau of Internal Revenue (Philippines Bureau of Internal Revenue)
Rate of return on equity, real (%)	9.22	International Monetary Fund (IMF 2020)
Project economic lifetime (years)	20	Nathan Lee et al. 2019 (Lee, Flores-Espino, Oliveira, Roberts et al. 2019)
Discount rate, nominal (%)	8.28	Calculated (NREL)
Fixed charge rate (unitless)	0.0920	Calculated (NREL)

be attractive to private developers for reasons not captured in **Step 2**.

RE service contracts in the Philippines are awarded to applicants that pass legal, technical, and financial evaluations on proposed commercial renewable energy projects. These contracts demonstrate credible threshold of financial and commercial interest in RE development from the private sector. The service contract process consists of two stages: (1) the predevelopment stage, and (2) the development or commercial stage (DOE). The Zone WG considered both stages when screening for candidate zones.

The Zone WG screened the study areas to assess the coverage of wind and solar development service contracts to identify the regions with high-quality RE resources and private sector interest. The selection criteria consisted of the wind and solar generation potential within the zone and the level of commercial interest (service contract coverage within 50 km of study area centroids). From the available study areas, the Zone WG selected 23 candidate zones with the highest generation potential and most service area coverage to consider in the next steps of transmission option development.

The Transmission WG reviewed the proposed set of candidate zones to assess the transfer capacity of existing and planned transmission enhancements near these zones. Transfer capacity was limited near three of the study areas, and both WGs agreed to screen out two of these zones (Ms1 and S2). The Transmission WG also suggested adding two additional zones (Mr1 and Mr2) initially screened by the Zone WG, as these zones could provide additional grid benefits given their location and existing



Hydropower: *Study area may contain resources with annual generation of 9.17 GWh/year with LCOE of 49.80 USD/MWh*
Biomass: *Study area may contain resources with annual generation of 157.14 GWh/year with LCOE of 381.29 USD/MWh*

FIGURE B-1 *Supply curve for Study Area L7* transmission capacity. **Table B-5** presents the results of the candidate zones screening: 25 candidate zones selected.

Step 4: Transmission development

Modeling activities in this step created the analysis tools and methods to characterize a set of implementable transmission development plans that could provide transfer capability to deliver power from candidate CREZ to load throughout the Philippines. The modeling framework established by the Transmission WG is summarized in **Figure B-2**.

A CEM determines the optimal future electricity infrastructure based on least cost of generating electricity as well as capital costs. The DOE used PLEXOS (Energy Exemplar) software to run a CEM that considered generation build out (not transmission) in a simplified three-node model where each of Luzon, Visayas, and Mindanao were represented by a single node. The CEM was configured to simulate 12 sample days per year to capture variability within the year.

The input data for the CEM was sourced as follows:

- Initial capital cost assumptions including wind, solar, hydropower, biomass, and geothermal capital costs were agreed upon during the CREZ process (**Table B-3**) with forward-looking cost decreases based on these starting points. Capital cost assumption are one of several modeling assumptions that continue to change based on best available information and model improvements.
- Fuel cost assumptions
- Annual average wind and solar capacity factor for each CREZ based on the hourly 2017 wind and solar data (**Table B-1**)
- Existing and committed power plants
- DOE load projections for medium and high demand (55- and 65-GW peak demand in 2040, respectively).

A limit on the CREZ development was assumed, representing the fact that the amount of transmission available at each CREZ's connection to the bulk transmission system would likely be less than the CREZ potential, encouraging competition to develop only the best resources in each zone. The total of wind and solar CREZ potential in each zone built by the CEM was limited by this value, which is varied from 25% to 100% in various iterations of the analysis. Reserve margin required was set at 25%.

The output of the CEM was a list of power plants built in each system each year. The conventional, hydropower, biomass, and geothermal power plant capacities are provided directly to the PCM while the wind and solar capacities are post-processed because the CEM did not have adequate complexity to capture the within-CREZ resource variability nor between-CREZ cost variability. A spreadsheet optimization tool was created by NGCP for this step. The tool used the LCOE supply curves for wind and solar described in this appendix to select a mix of wind and solar in the CREZ while respecting the total of the wind and solar capacity built in each system from the CEM. The output of

TABLE B-5 *Candidate Zone Selection*

		Potential Annual Generation (MWh shown in quartiles)			
		High (top 25%)	Middle	Low (bottom 25%)	
Service Contract Coverage (% of total area)	>10%	L1, L4, N1, N2, Py2	L2, L3, L6, Py1		▲ Most commercial interest
	1% to 10%	L7, L8, L12	B1, L5, L10, L11, L13, Mn7, S1	Mr2, C1, Mn5	
	<1%	L9	Mn2, Mn4, Mn8, Ms1, S2	Mr1, Mn1, Mn3, Mn6, Pw1, Pw2	Least commercial interest ▼
		◄ Most productive		Least productive ►	

Note: Candidate Zones selected by the Zone WG are listed in ***green****, and those added by the Transmission WG in* ***blue****. The Candidate Zones were considered in transmission expansion options. The screened study areas, shown in* ***orange****, were removed from consideration at for this phase of the CREZ process.*

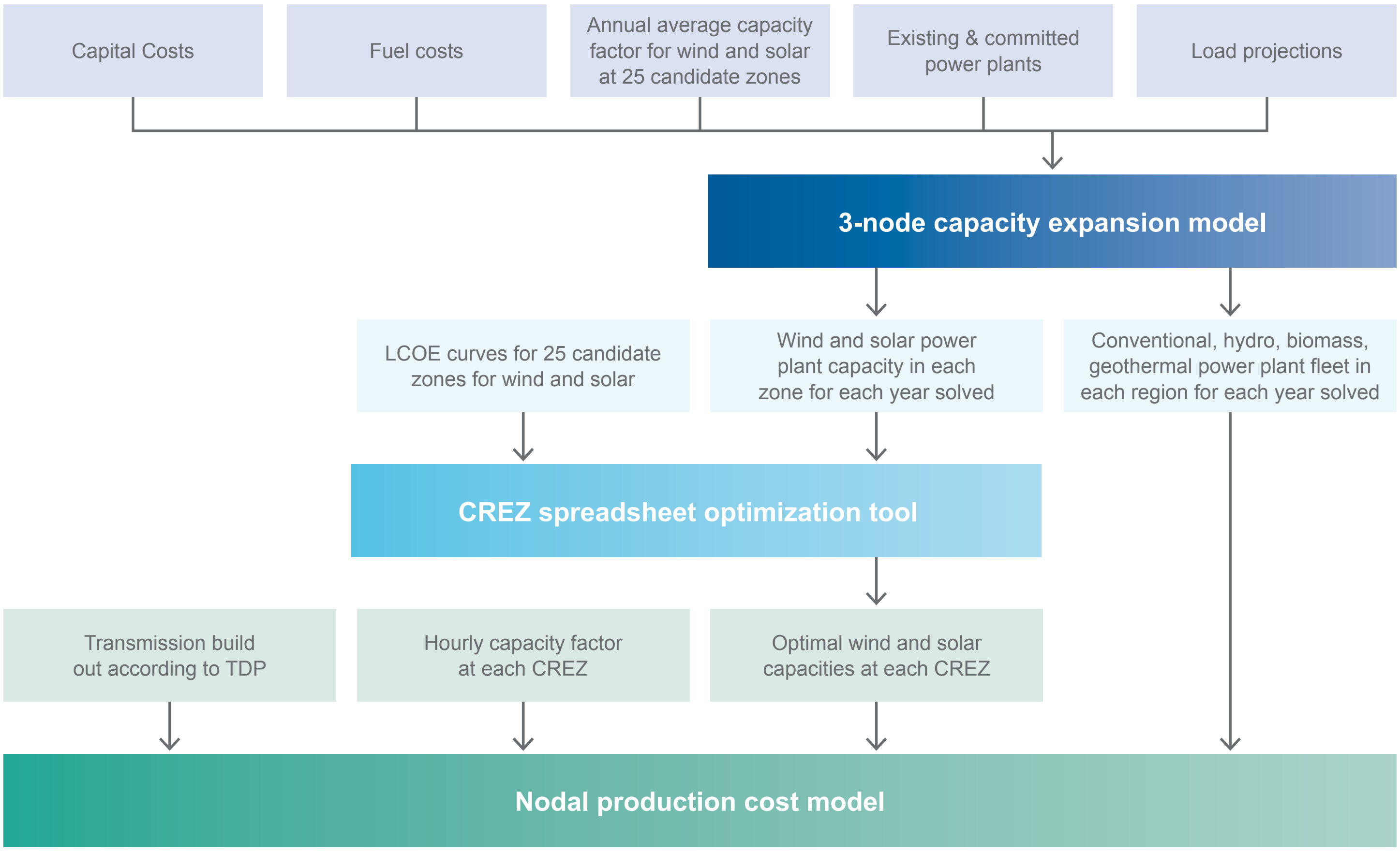


FIGURE B-2 *Framework and data flows for analysis of transmission plans, including CREZ*

the optimization tool is the solar capacity and wind capacity in each CREZ for each CEM solve year.

Production cost modeling is chronological electricity grid simulation used to study hourly to subhourly operation of a given transmission and generation infrastructure. A PCM considers generation costs to determine the least cost way to operate a grid within operational constraints. A PCM accounts for inter-hour constraints such as ramp limitations of individual generators. NGCP used PLEXOS production cost modeling to model hourly operation using a nodal representation of the bulk transmission system. The power plant capacities determined from the CEM and spreadsheet optimization for a given year of interest (typically 2040 in the analysis supporting the CREZ process) were used in the PCM. The underlying transmission network was from the TDP, and each generator is assigned to a node in the bulk transmission system (NGCP 2015). For power plants that do not yet exist, their location was determined based on NGCP's knowledge of the system and most likely location for new plants of each type. Since it is a chronological simulation, the PCM required hourly capacity factors for each wind and solar power plant, which were obtained from hourly capacity factor profiles representing a mean site in each CREZ zone (one for each of wind and solar in each zone). The hourly profiles are from the hourly 2017 wind and solar data described in **Table B-1**.

The initial scenario analysis that the DOE-NGCP team used is presented in **Table B-6**. Scenario analysis is ongoing; the following scenarios convey the type of scenarios considered and model linkages. DOE's medium load growth case was assumed for the CEM and the CREZ capacity allowed was varied. Two CEM scenarios were considered for system interconnections: (1) completely disconnected systems operating independently in Case 1, and (2) connection by existing high voltage in Case 2. These four CEM scenarios were then studied in the PCM. Generally, the team uses the TDP as the baseline for transmission expansion scenarios in the PCM. The operation of the system, as determined by the CEM and spreadsheet optimization tool for each scenario, is then studied in the PCM first assuming the current TDP. The model will violate individual limitations where needed to serve load and ancillary services requirements, and such violations provide information about needed transmission expansions. A "general" expansion from the TDP is analyzed by iterating on the PCM results to increase the capacity of individual lines whose thermal capacity is violated in the PCM. A "selective" expansion of the TDP is considered by only increasing the capacity of lines whose violation is above a certain threshold, making a less costly transmission expansion that resolves most of the line flow violation issues. PCM results of interest are system generation cost, unmet energy and reserves, transmission flows, and utilization of generators.

Model validation

Model validation demonstrates PCM capability by providing NGCP's validation of the PCM based on 2017 grid operations. For results from PCM modeling incorporating CREZ, see upcoming publications from the Philippines' planning processes. NGCP compared the actual 2017 energy generation to that simulated by the PCM, given the actual generator capacities that existed in 2017.

NGCP adjusted the PLEXOS model to closely match the actual 2017 generation and the usage of the high-voltage DC interconnection between Luzon and Visayas systems. Model calibration included adjusting the operation of must-run units, high-voltage DC outages, natural gas prices, and using wheeling charges between systems. Wheeling charges represent some level of friction between systems (i.e., a preference for in-system generation). **Figure B-3** and **Table B-7** show the results of the model calibration exercise. While there will always be differences between actual power system operation and power system simulation, this model validation provided confidence in the model.

Step 5: Final transmission plan designation and **Step 6:** Transmission system upgrade

Steps 5 and 6 consist of incorporating the selected transmission expansion scenarios (from **Step 4**) into the Philippines Transmission Plan, approval through the regulatory process, and implementation of transmission expansion and upgrades. As the Transmission WG continues to explore scenarios and inform the TDP, details on these steps will be made available by the Philippines DOE and NGCP through future TDPs and other relevant planning documents.

TABLE B-6 *Examples of Scenarios Considered in Transmission WG's Modeling Framework*

CREZ Growth	Case 1: Isolated Systems	Case 2: Interconnected Systems with Constraints
25% of CREZ capacity eligible	Current TDP	Current TDP
	TDP + Generation Expansion	TDP + Generation Expansion
	TDP + Selective Expansion	TDP + Selective Expansion
100% of CREZ capacity eligible	Current TDP	Current TDP
	TDP + Generation Expansion	TDP + Generation Expansion
	TDP + Selective Expansion	TDP + Selective Expansion

TABLE B-7 *Annual Generation Share (%) by Type From Modified Production Cost Model and Actual System Operations*

Philippines	Coal	Oil-based	Natural Gas	Geothermal	Hydro	Wind	Biomass	Solar	Total
Modified	53.8%	1.5%	21.3%	10.6%	9.0%	2.7%	0.4%	0.8%	**100.0%**
Actual	49.2%	2.8%	22.8%	11.4%	10.5%	1.1%	0.8%	1.4%	**100.0%**

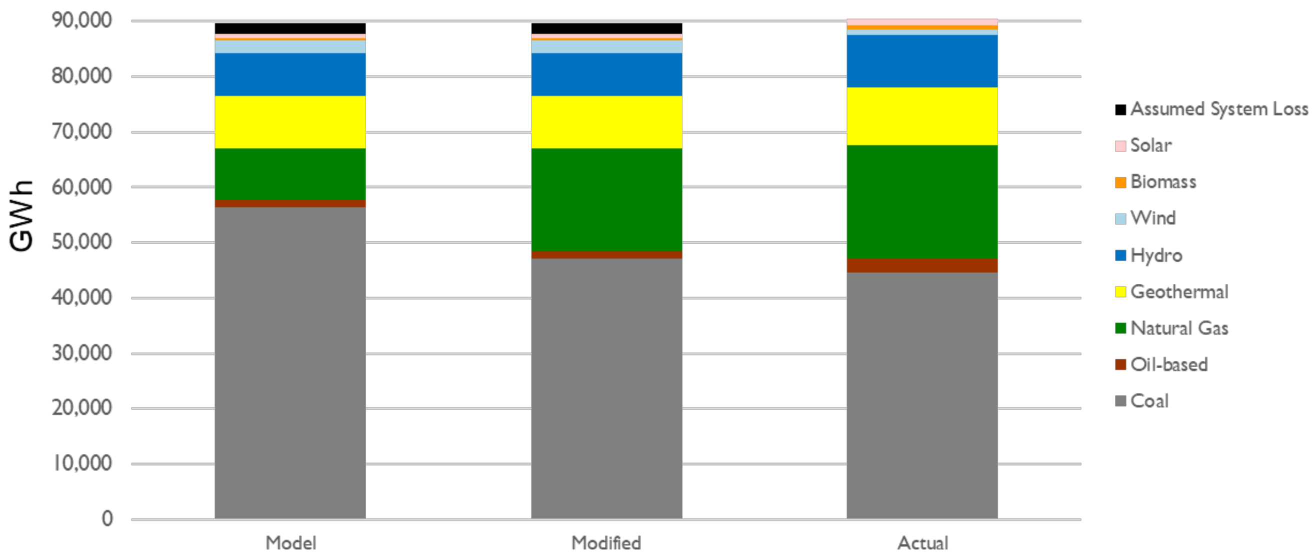


FIGURE B-3 *Annual generation by type from modified production cost model and actual system operations*

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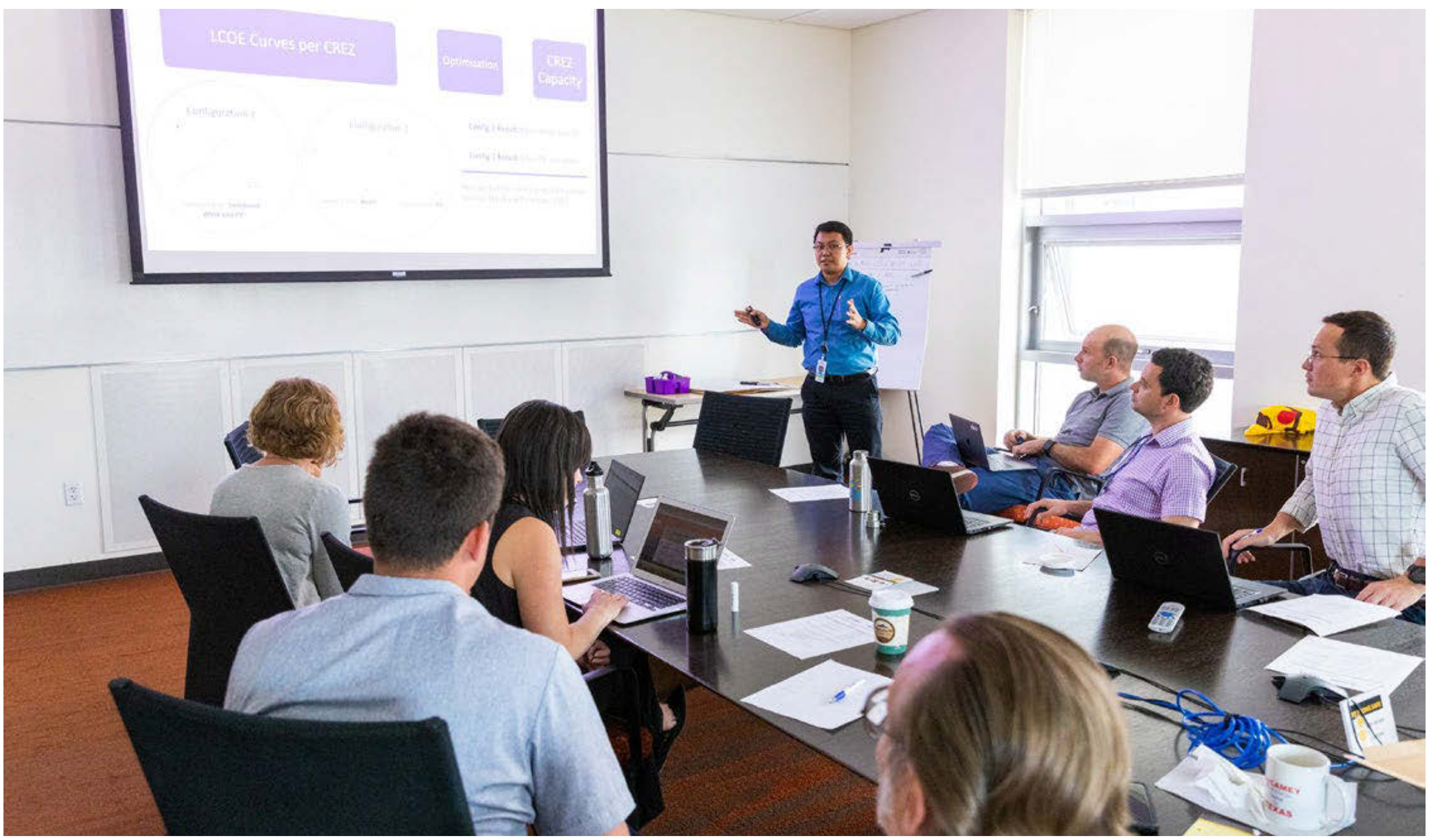
Acronyms and Abbreviations

CEM	*capacity expansion model*
CREZ	*Competitive Renewable Energy Zone(s)*
DOE	*Department of Energy of the Philippines*
HVDC	*high-voltage direct current*
LCOE	*levelized cost of energy*
NAMRIA	*National Mapping and Resource Information Authority*
NGCP	*National Grid Corporation of the Philippines*
NREL	*National Renewable Energy Laboratory*
PCM	*production cost model*
PHP	*Philippine peso*
PV	*photovoltaics*
RE	*renewable energy*
TAC	*Technical Advisory Committee*
TDP	*Transmission Development Plan*
TransCo	*National Transmission Corporation of the Philippines*
Transmission WG	*Transmission and Generation Modeling Working Group*
USAID	*United States Agency for International Development*
Zone WG	*Zone Identification and Technical Analysis Working Group*



Attendees of the Philippines CREZ Technical Exchange final NREL advisory meeting discuss the final presentations on CREZ capacity expansion planning approach and results. Photos by Werner Slocum, NREL 58531, 58552

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