Executive Summary

By the end of 2018, the estimated share of renewable energy (RE) in global electricity generation was at 26%, an all-time high.[1] Electricity sourced from renewable capacity including wind, solar, and biomass reached a record 12.1% of total global electricity capacity in 2018.[2] In 2019, total global renewable energy generation capacity reached 2,351 GW – around a third of total installed electricity capacity. Hydropower accounts for the largest share with an installed capacity of 1,172 GW – around half of the total.[3]

Most surprisingly, however, the projected share of renewable electricity generation is projected to almost double from currently 26% to 44% by 2040, which would surpass coal by as early as 2026. Combined, solar PV and wind's global share of electricity generation could collectively surge from 7% to 26%. Technological innovation in solar and wind have driven renewable production to all-time highs, powering the move towards "all-electric energy systems" and independence from fossil fuel sources.

Despite this progress, the sector experiences growing pains. On the other side of the equation, electricity demand is set to increase 62% resulting in global generating capacity almost tripling between 2018 and 2050, or by 1.5% per year. "High-level" penetration, or proportion, of renewables in the grid is inevitably met with variability caused by weather and meteorological impacts on supply, and electricity intermittency occurs as supply-demand fall out of balance. The determination of "high" or "low-level" penetration can be quantitatively thought of as a breadth metric examining to what extent renewables are integrated into grid and account for a significant portion of its final energy consumption. High renewable penetration requires more flexible mechanisms to bolster resilience.

Developments in grid-scale battery storage, though ongoing, are currently technically inadequate and commercially unfeasible to overcome the intermittency problem. Without a breakthrough in long-duration battery technology to counteract the problem of controlling the load with fluctuating sources of variable renewable energy (VRE) like wind and solar, policymakers, utilities, and producers alike are faced with difficult considerations in determining sensible energy policy. This report summarizes the successful approaches taken by contributor countries and offers five viable solutions to intermittency, based on an assessment of the responses to the following questions:

- How is electricity distributed and stored, upon generation?
- What technologies must be improved to offset challenges in intermittency?
- Can targets be met, and by what year?
- Must existing fossil energies be phased out alongside this transition, or can they coexist?
- What policies best support systems with least resistance in intermittency?

This report compiled the contributions of 21 member organizations that serve on the CAETS Energy Committee: Argentina, Australia, Canada, China, Croatia, Czech Republic, France, Germany, Hungary, India, Japan, South Korea, Mexico, New Zealand, Nigeria, Pakistan, South Africa, Sweden, Switzerland, the United States, and Uruguay.

In order to gain some understanding of the respective country's solutions of the member representatives, similarly situated countries were analyzed as peer groups, and were then categorized based on their relative positions in

[1] REN21. Renewables 2019 Global Status Report; REN21 Secretariat: Paris, France, 2019; ISBN 978-3-9818911-7-1. http://www.ren21.net/gsr-2019/

[2] "International Energy Agency; International Renewable Energy Agency; United Nations Statistics Division; World Bank; World Health Organization. 2020. Tracking SDG 7 : The Energy Progress Report 2020. World Bank, Washington, DC. World Bank. https://openknowledge.worldbank.org/handle/10986/33822

[3] IRENA (2019), Renewable Capacity Statistics 2019, International Renewable Energy Agency, available at: www.irena.org/publications

the transition process. Peer-group analysis showed that implementation challenges and solutions for combatting intermittency are different across country archetypes.

This report assessed the performances of countries in several categories as follows as the basis for grouping for comparative review: energy mix portfolio, renewable electricity generation, climate policy and future milestones, and the presence of interconnected systems. The solutions proposed by contributing CAETS countries, given the wide breadth of their approaches, have been grouped into the following three categories:

Group A: Cross-Border Transmission Systems: Group A countries are characterized by their expansive distribution networks that transcends borders. Most countries have already accomplished high RE generation capacity, and now shift their focus to not only continue increasing generation efficiency, but also solving the intermittency issue by mass-scale energy trading via intercontinental distribution networks. While some countries have inherited infrastructural powerhouses from past investments, others have made deliberate modern investments to install high-capacity and long-distance transmission lines, with the goal of being resilient to intermittency. The result is a 'super grid', i.e. a single continental-scale, interlinked power market. This approach makes available benefits like congestion management, curbing of supply and demand imbalances, short-term storage as load-following reserve, and diversification of energy portfolios. Through integration, participating countries can dynamically align demand in the face of fluctuating supply. This flexibility reduces the need for costly individualized baseload generation.

Group B: Interregional Transmission & Distribution (TND) Systems: Group B countries are those with systems with varying degrees of renewable penetration that have dealt domestically with intermittency issues by installing nonintermittent power reserve systems that can quickly be dispatched to load-follow the fluctuations of VRE sources. Dispatchable power technologies such as pumped storage hydropower generation, gas-fired combined heat and power generation, biomass, geothermal, or to some extent, microgrid systems, can provide scalable amounts of electricity to cover demand immediately and independently of interruptions like adverse meteorological conditions. Due to individualized needs mostly in geographically isolated areas such as island chains have confronted and resolved supply-demand imbalance by developing innovative demand-response technologies.

Group C: Variable Renewable Energy (VRE) Growth Systems: Group C countries are those with low VRE penetration and/or high fossil-to-renewable ratio, and therefore experience few intermittency problems relating to VRE. These countries have focused on increasing renewable penetration as well as integration of solar PV and wind plants through investments in power transmission and distribution infrastructure. To realize these priorities, large investments in grid connection, generation capacity, and reinforcement of transmission lines between producing and consuming regions, are needed throughout the entire electrical grid. One challenge while expanding VRE production is the linking of variable renewables to the grid, which requires large up-front investments in AC/DC or HVDC transmission lines to connect new power plants located far from the load centers that they serve. Another concern is the transitioning out of fossil fuel reliance, which will slow the transition to green energy on account of its use as a ramping crutch.

The complex energy transition, which includes the interaction between different systems, has diverse challenges. A strategy to systemically shift to clean energy is not restricted to shifts in merely increasing renewable generation in a given nation's energy portfolio. Regardless of the level of mitigating technology, every country that confronts the issue of accelerating its nation's energy transition will require coordinated policy action to effect supply-side technological and demand-side solutions.