USAID IS SUPPORTING the Creation of a Regional Electricity Market in Central Asia

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"Central Asia is rich in renewable energy (RE) resources like solar and wind energy. For instance, Kazakhstan currently has about 1,200 megawatt (MW) of installed RE capacity and it is expected to double the figure by 2025. While Uzbekistan has no RE plants yet, the government has prioritized constructing 1,000 MW of RE plants by 2023, about 5,000 MW and some 8,000 MW by 2025 and 2030. The country's sources of RE can be increased to reduce the greenhouse gas (GHG) emissions from the power sector. The cost of solar and wind power is also dropping rapidly as demonstrated in recent RE auctions in Uzbekistan where the offered cost of solar was about 1.8 US cents per kilowatt hour (kWh), which is lower than the cost of new fossil-fuel based generation."

In addition, the RE subsector is prime for investment and development; currently, there is increased foreign and domestic interest as well as available capital for RE development while governments are raising targets for RE generation and integration. However, there are impediments to the integration and generation of high levels of RE due to the costs of grid integration and the need to prepare grids to absorb RE. Fortunately, over the past two decades a strong body of international knowledge, experience and solutions has developed to resolve these impediments. Although the solutions are country-specific,

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the methodology for modeling and analysis are common and the mitigation measures can be synopsized and applied from past experiences. The purpose of this article is to propose global best practice methodologies and measures to mitigate the impacts of integrating and generating high levels of RE at the national and regional levels in Central Asia.

This article will also address how a regional electricity market in Central Asia provides a sustainable long-term solution to developing large amounts of variable renewable energy at national and regional levels. In addition to lowering the costs of electricity, a regional market will help to mitigate the impacts of developing RE by facilitating the regional trade of flexible generation capacities. The available flexible generation capacities will support the initiatives of individual Central Asian countries to safely and securely generate large amounts of RE and transition to low-emission, climate resilient and clean energy economies.

HOW WILL RE DEVELOPMENT PLANS IMPACT REGIONAL SYSTEM OPERATION? LIVE EXAMPLES

As mentioned, RE power plants operation have impacts upon national and regional grids–some positive and some negative. For the purposes of this article, it is convenient to separate into two categories the impacts of connected utility-scale RE plants on the transmission system:

IMPACT ON TRANSMISSION SYSTEM

- *Reduce static and dynamic stability of the grid*
- *Cause congestion, and modify power transfer capacity on inter-regional transmission lines*
- *Change voltages and short-circuit profiles*
- *Introduce harmonics*
- *Require upgrades to the transmission network to mitigate the above impacts*

IMPACT ON SYSTEM OPERATIONS

- *Increase variability and uncertainty in generation, hence require more frequent re-dispatching*
- *Require higher amount of flexibility from existing generation fleet*
- *Require higher amount of dispatchable load following capacity*
- *Require higher amount of operating reserves*
- *Require higher amount of sharing of reserves among neighbors*

The technical and infrastructure costs to mitigate these impacts are paid for by a national power system and are called the costs of RE integration. The impacts of developing RE can be illustrated by examining a case where high amounts of RE generation are developed in the south region of Kazakhstan. Since the southern region has a power deficit and large quantities of power flows into this zone from the northern region, RE development in the south would result in the following impacts:

1. Impact on the regional transmission system:

1. Transfer capacity is an important operational parameter of a transmission network and is determined by the static stability limit of a power system. A System Operator uses transfer capacity for short-term planning, from day-ahead to real time. In the case of Kazakhstan, higher amounts of RE in the south will reduce both the transfer capacity requirement and limit. A detailed power systems modeling should be performed for different scenarios that correspond to time slices that represent extreme conditions in the south like high RE generation and load. This power system modeling would investigate if the reductions in transfer capacity limits are more than the RE generation in the south, which would impact the regional flow of power. To mitigate the impacts in such a case, investments would be required for instance in installation of synchronous condensers or series reactors.

2.1. Transient and small signal stability are important considerations during time periods when the RE penetration is close to 50 percent of average load. As RE generators have no inertia, this penetration can lead to lower grid inertia resulting in larger oscillations and poorer damping of oscillations. A detailed power systems modeling could be performed to quantify the impacts on the southern Kazakhstan region and the Central Asia Power System (CAPS). If there is significant impact, then appropriately sized synchronous condensers or power system stabilizers can mitigate the impact.

1.2.1. The regional power system is connected through 500 kilovolt (kV) lines that form a loop from eastern Kazakhstan to the Kyrgyz Republic to Tajikistan to Uzbekistan to southern Kazakhstan. In addition, Turkmenistan and Afghanistan are connected through Uzbekistan's grid. Higher penetration of RE, for instance in the Turkistan and Zhambyl provinces in southern Kazakhstan, and central zone of Uzbekistan, would alter the power flow in the loop and hence impact the regional power flow. In this case as well, a detailed power systems modeling could be used to assess the impact

on power flows and protection systems and develop appropriate mitigation measures.

2. Localized impacts on the southern Kazakhstan transmission and distribution network:

2.1. RE plants are usually located far away from load centers, or in weaker parts of the grid. The construction of RE plants in these weak grids necessitates that the network be strengthened near of the RE plants by building new transmission and distribution lines and upgrading substations. Additional interventions include reactive power compensation, more short-circuit current, and the redesign of protection system among other.

3. Impacts on regional system operations:

Large amounts of solar generation in a grid can cause sharp ramp cycles due to dropping solar generation from late afternoon to early evening, combined with a simultaneous increase in load. This is called the "duck curve" phenomenon. This scenarios would require larger amount of flexible dispatchable load following capacity (LFC) from thermal and hydro generators to counter the sharp ramp and ensure balance of supply and demand every moment. Given the Kazakh and Uzbek Governments' targets for solar power, the day-ahead schedule would require larger planned power exports during peak solar generation and imports during sharp ramps. In addition, thermal and hydro generators would need to operate at lower capacity factors, be required to ramp up and down and be subject to more frequent starts and stops.

3.1. The large-scale development of RE would require larger amounts of primary frequency response (PFR, or frequency containment reserves, FCR). The higher penetration of RE will result in high fluctuations in generation in the second to minute timeframe (higher unpredictable changes and higher ramping), which would require higher PFR. As present, PFR is provided by the Russian interconnection. Given the expected increase in PFR, the regional system operators may need to pool resources that can provide PFR.

3.2. Requirements for larger amount of regulation reserve (RR), and of frequency restoration reserves (FRR). The higher penetration of VRE will result in larger fluctuations in the minute by minute generation time-frame (higher unpredictable changes, higher ramping and forecast error), which would require higher RR. At present, RR is provided by local generators and the Russian interconnection. Given the expected need for the higher RR, the regional system operators may need to pool resources for RR.

All the above issues contribute to the cost of integration of RE. In most grids, experience shows that this cost of integration is very modest and there is no reason to believe that it would be different in Central Asia.

REGIONAL POWER SYSTEM OPERATION TO FACILITATE RE INTEGRATION

During the Soviet time, the five national power transmission system of Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, and Turkmenistan, were interconnected and operated synchronously and as one united system. The centralized coordination of operation and planning of all national systems was entrusted to a regional dispatch center based in Tashkent, Uzbekistan, which was assigned the function of managing the region's generation dispatch.

After the dissolution of the Soviet Union, the countries of Central Asia started pursuing a policy of self-sufficiency and energy independence, causing the disruption of power exchanges across national borders and a drastic reduction of trade volumes seen during Soviet time. In 2003, Turkmenistan unilaterally decided to disconnect its network from the CAPS and operate in parallel with Iran in island mode. Later in December 2009, due to disagreements with Tajikistan, Uzbekistan announced its withdrawal from the regional power grid.

Today, CAPS continues to operate in synchronous mode with only three national interconnected power networks, which trade power on a seasonal basis: Kyrgyzstan, Uzbekistan, and Kazakhstan, and through the latter with the Unified Power System of Russia. However, there are now expectations that all countries may return to operate their grids in a parallel and coordinated manner. Tajikistan and Uzbekistan have already reconnected their systems on islanded mode (asynchronous operation) as a first step to Tajikistan's full re-integration to CAPS, which is expected by 2022.

A synchronized, coordinated operation of all national power systems will enhance the required flexibility needed and will be critical to effectively integrate variable renewable generation projects across the region.

USAID SUPPORT FOR A CENTRAL ASIA REGIONAL ELECTRICITY MARKET (CAREM)

In 2018, the United States Agency for International Development (USAID) launched the Central Asia Regional Electricity Market (CAREM) Activity to provide technical assistance and capacity building to the countries of Central Asia in their efforts to establish an economically viable and sustainable regional electricity market. It is anticipated that the regional market will enhance the security of supply in Central Asia, bring substantial economic benefits to each country and promote their economic growth by attracting private investment into national power sectors. A competitive CAREM will ultimately serve as a platform for an expanded Central Asia - South Asia power market, facilitating commercial power exchange with Afghanistan and Pakistan via CASA-1000 transmission infrastructure. To achieve this objective, the CAREM Activity is promoting the efficient use of the region's resources to generate electricity, thus making it possible to increase the volume of power that can be traded by countries across national borders.

Through USAID's assistance, the CAREM Activity is partnering with the countries in Central Asia to carry out multiple activities that are intended to create the rules, procedures and institutions necessary to building a regional market. For example, the CAREM Activity is assessing the present electrical conditions and capabilities of the regional transmission grid and all interconnections and their potential to support larger volumes of cross-border power exchanges. The intent of the study is to determine the existing physical and operational limitations and propose measures for the countries to address them. The regional market is expected to be supported by robust high-voltage interconnections between the countries and upgraded national transmission infrastructures. Once all national power systems are integrated again, their operation will be synchronized and centrally coordinated by CDC-Energy. This will create larger volumes of cross-border power flows and allow power systems to share operating reserves and effectively support each other during system emergencies. At the same time, integrated operation will facilitate and encourage large-scale power generation, and the deployment of solar and wind power plants throughout the region.

USAID'S CAREM ROADMAP AND ACTION PLAN

USAID and the CAREM Activity worked closely with Central Asian partners to develop a CAREM Roadmap and Action Plan that envisions a phased approach to create a regional electricity market. To facilitate the implementation of CAREM, the Central Asian countries established three expert-level (WGs) groups: technical, market development, and legal/regulatory. In coordination with the CAREM Activity team, the working groups reviewed the Roadmap and Action Plan, a detailed guide to implement the regional electricity market. On October 20, 2020 USAID conducted a meeting where the deputy ministers of energy of Kazakhstan, the Kyrgyz Republic, Tajikistan and Uzbekistan approved the Roadmap and Action Plan. The CAREM model and concept envisions that the market will be implemented in four phases and most of the benefits are to be achieved in the two initial phases. The initial phases require just a few regional agreements in order to be implemented.

THE REGIONAL ELECTRICITY MARKET - IMPLEMENTATION STRATEGY

Since USAID launched the CAREM Activity, the team has worked to create the market by following four parallel workstreams. This strategy is intended to maximize the effectiveness and impact of individual activities by focusing on the current challenges to expanded electricity trade in Central Asia: technical, legal/regulatory, commercial and staff training.

Through studies and assessments, the CAREM Activity is working to address the obstacles preventing the trade of electricity in larger volumes, including technical gaps in legal frameworks to establish commercial relationships, regulatory barriers, commercial issues (pricing), lack of clear procedures to trade, and absence of a coordinated transmission system operation.

The CAREM Activity team is also reviewing national policies, laws, regulations, and operating rules in an effort to harmonize them. In review, the team recommends the necessary amendments and adding provisions that would enable multilateral cross-border exchanges through a regional trading platform. Through work with counterparts, the team is also developing commercial rules and regulations to ensure bilateral contracts are honored and payments are provided.

Finally, the CAREM Activity is working closely with partner countries at the regional level to help overcome defined barriers and weaknesses, and create the necessary conditions for an intra-regional, multilateral electricity trading platform to become operational.

CAREM'S CAPABILITY TO FACILITATE RE INTEGRATION AND GREEN HOUSE GAS EMISSION REDUCTIONS

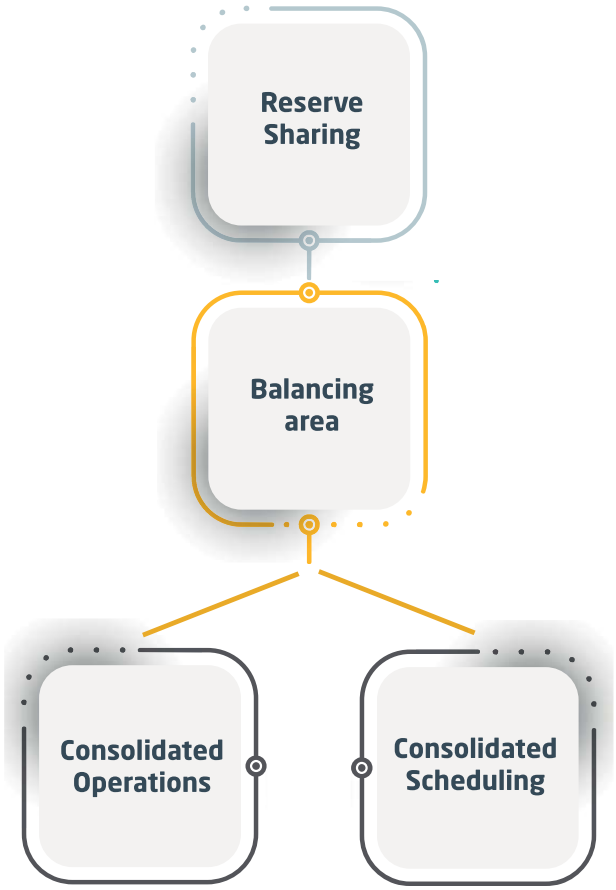
Around the world, national grids that have seen large penetration of RE, such as in Denmark, Ireland,

California, Texas, India, and China among others, have had to undergo significant transformations to integrate RE in effective and cost-efficient manners.

EXPANSION OF THE BALANCING AREA

One of the key transformations is increasing the balancing area (BA). BAs are geographic boundaries within which supply and demand are balanced by the system operator (balancing authority). Therefore, increasing the BA means increasing the coordination between neighboring balancing authorities to promote more efficient flows of energy. This is extremely important in BAs with high RE penetration as when generation is high in one BA, it may be lower in another. Cooperation between BAs gives system operators more operational flexibility and, thereby, reduces the impact of variability and uncertainty of RE generation.

Three types of approaches have been deployed around the world to increase BA cooperation and are relevant to Central Asia[1]:



1. Reserve Sharing. A higher penetration of RE requires higher amounts of reserves and hence the cost for balancing is higher. These costs can be mitigated by pooling of reserves across BAs—a simple way for each BA to increase reserves without physically adding new reserves to its own balancing area is to access a pool the reserves in the bigger balancing area. Given the abundance of hydropower in Tajikistan and the Kyrgyz Republic, these countries could pool the reserves and serve as key suppliers of PFR, RR and LFC. Supplying reserves to the regional balancing area can earn a premium for these countries that is much higher than providing baseload generation on a bilateral basis to a neighbor.

2. Coordinated Scheduling. The BAs can coordinate generation scheduling across different time frames (day-ahead, hour-ahead and intra-hour) to fill periods of under- and over-supply. In a regional power market, higher prices can be reduced at nodes during periods of under-supply through the use of locational marginal pricing and unit commitment and economic dispatch for the coordinated regional market.

3. Consolidated Operation. A higher penetration of RE is forcing the grid to be more dynamic and hence requiring the system operator to perform very fast and highly coordinated actions with generators (intra-hour dispatches and real time ancillary services). This cannot be managed through static bi-lateral or multi-lateral agreements. It will require consolidated operations akin to the European Network of Transmission System Operators for Electricity (ENTSO-E), which represents 42 electricity transmission system operators from 35 countries in Europe.

SYSTEM IMPACT STUDIES TO INTEGRATE RE INTO THE REGIONAL GRID

To assess and mitigate the impacts of RE on the regional power system, a variety of system impact studies should be performed to develop sustainable long-term solutions. Based on global best practice experiences, there are three primary types of system impact studies:

1. Power system study to assess the impacts of RE on static and dynamic stability. The outcome of this study is transmission network upgrades, including transmission lines, substations, reactive power compensation, protection systems, and active and reactive power controls.

2. Unit commitment and economic dispatch study to assess the impacts of RE on the dispatchability of conventional generation and

RE. It also determines the impact of RE on the production cost of electricity. The outcome of the study is upgrades to system operations, including faster dispatching, power markets, RE generation forecasting, automatic generation control, automated dispatch systems and others.

3. Flexibility and reserves requirement study to assess impacts of RE. The outcome of the study is an estimation of the flexible capacity requirement (LFC, PFR, RR and others), and recommendations for upgrade of existing generators and installation of new generators to meet the new flexibility and reserve requirements.

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Summary. As this article discusses, individual countries in Central Asia, such as Kazakhstan and Uzbekistan, have set ambitious targets to increase the share of renewable generation. To meet these targets, these governments will need to develop diverse technical solutions to minimize the cost of integration of variable generation. This article presents various solutions, based on accepted practice, to assess and mitigate the impacts of variable renewable generation at the regional level. The technical solutions focus mitigating the impacts of RE on the grid through upgrades to the transmission system and system operations, and adoption of regional electricity market and balancing area. One of the lowest cost solutions is to increase the balancing area to encompass the entire Central Asian region, thereby sharing reserves and coordinate scheduling and operation. As discussed, these solutions can be effectively implemented in a functional and coordinated regional power market. At present, the USAID-funded CAREM Activity is supporting the Central Asian governments to develop the rules, procedures and institutional arrangements to create this market and increase the deployment and development of renewable generation throughout Central Asia.