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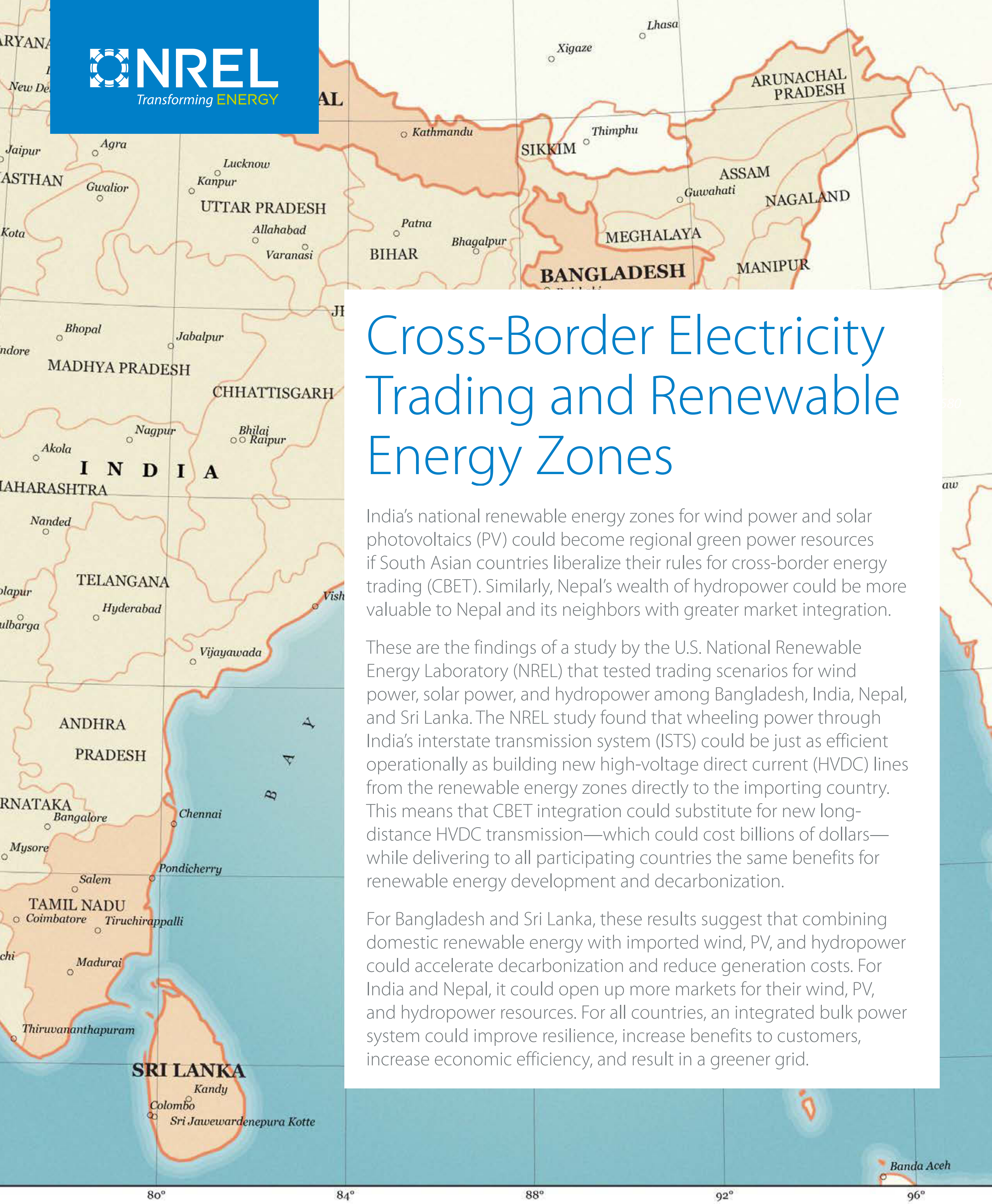

Cross-Border Electricity Trading and Renewable Energy Zones

India's national renewable energy zones for wind power and solar photovoltaics (PV) could become regional green power resources if South Asian countries liberalize their rules for cross-border energy trading (CBET). Similarly, Nepal's wealth of hydropower could be more valuable to Nepal and its neighbors with greater market integration.

These are the findings of a study by the U.S. National Renewable Energy Laboratory (NREL) that tested trading scenarios for wind power, solar power, and hydropower among Bangladesh, India, Nepal, and Sri Lanka. The NREL study found that wheeling power through India's interstate transmission system (ISTS) could be just as efficient operationally as building new high-voltage direct current (HVDC) lines from the renewable energy zones directly to the importing country. This means that CBET integration could substitute for new long-distance HVDC transmission—which could cost billions of dollars—while delivering to all participating countries the same benefits for renewable energy development and decarbonization.

For Bangladesh and Sri Lanka, these results suggest that combining domestic renewable energy with imported wind, PV, and hydropower could accelerate decarbonization and reduce generation costs. For India and Nepal, it could open up more markets for their wind, PV, and hydropower resources. For all countries, an integrated bulk power system could improve resilience, increase benefits to customers, increase economic efficiency, and result in a greener grid.

Illustration by Billy Roberts, NREL

Study Design

The analysis tested representative scenarios for possible cross-border delivery of renewable energy. Each scenario paired Bangladesh or Sri Lanka with a renewable energy zone—wind power or PV in Tamil Nadu (India) or hydropower in Nepal. The study adapted an operational model developed by NREL for previous South Asia study projects.[1] It simulates operations of the power system for every hour of a future year designed to represent 2022.

Photo from iStock 1186364428

Apart from what is added manually as part of a test scenario, the model does not on its own add generation or transmission. The volume of total unit generation is matched exactly to total load for every hour of the year, such that operating cost (fuel consumed, the cost of starting and stopping a thermal unit, and variable maintenance costs) are minimized while respecting transmission limits and other equipment constraints.

The wind power and PV scenarios used hourly resource profiles that were based on previous NREL studies of commercially developable sites in Tamil Nadu. The representative wind site has an estimated capacity factor of 38%, while the PV site (assumed to be a fixed-tilt design) has a capacity factor of 15%. The production profile for the hydropower site was based on run-of-river plants in western Nepal's Karnali River basin, also examined in previous NREL studies. Hydropower output is constant throughout the day but varies seasonally with monsoon and dry-month cycles.

Scenarios tested include: energy from 1 GW of Tamil Nadu wind or PV capacity delivered to Bangladesh; energy from 1 GW of Tamil Nadu wind power or PV capacity delivered to Sri Lanka; and energy from 1 GW of Nepal hydropower capacity delivered to Bangladesh. Each scenario for delivery to Bangladesh was tested two ways: using a new HVDC transmission line to deliver energy directly, and wheeling the energy through India's ISTS to the border and increasing by 1 GW the capacity of the back-to-back HVDC tie between West Bengal (India) and Bangladesh. Practically speaking, additional flows from Tamil Nadu to Sri Lanka would require a new HVDC transmission line, thus the wheeling scenario was not modeled for Sri Lanka.

The wheeling scenarios assumed a liberalized CBET regulatory regime, such that moving power to or from Bangladesh, Nepal, or Sri Lanka was comparable to moving power between Indian states. Because the study looked at operational costs only, comparisons between scenarios do not account for capital costs such as new transmission lines or expanding the West Bengal-to-Bangladesh HVDC tie.

The two modes of delivery—wheeling versus a direct DC line—revealed no appreciable difference with respect to delivery to Bangladesh. Operational costs and domestic generation being offset were the same in both cases. Therefore, wheeling power through India's ISTS appeared to offer the same operational benefits as building a separate line to bypass the ISTS altogether, *as long as there is no institutional restraint on moving power between countries*.

1 For technical details, see Brendan McBennett et al. *Cross-Border Energy Trade between Nepal and India: Assessment of Trading Opportunities*; and Amy Rose et al. *Cross-Border Electricity Trade between India and Sri Lanka: Impact on Power System Operations*.

Results for Bangladesh

Each type of imported power demonstrated value to Bangladesh, but the benefits differed among the scenarios. The differences were due in part to how the production profiles of the renewable resources match Bangladesh load. Tamil Nadu wind power and Nepal hydropower match more closely with load than does Tamil Nadu PV. For Nepal hydropower, the correlation is more seasonal than hourly, while the correlation for wind is more hourly.

Imported wind power would likely offset large amounts of peaking power from fuel oil, one of Bangladesh's most expensive generation resources. Importing 1 GW of Tamil Nadu wind power replaces 3.4 TWh of domestic generation at a savings of $175 per MWh replaced.

Nepal hydropower also correlates with Bangladesh load, but tends to be constant throughout the day. Compared to the same amount of Tamil Nadu wind capacity, 1 GW of Nepal hydropower offset more domestic generation in Bangladesh—5.5 TWh, at a savings of $168/MWh for the energy replaced.

One GW of solar capacity in Tamil Nadu generates less energy than 1 GW of Nepal hydropower or 1 GW of Tamil Nadu wind power. Also, because solar's sunrise-to-sunset profile is less correlated with Bangladesh load, the savings per unit of energy was also less—$158 per MWh replaced.

In addition to the cost savings, carbon dioxide emissions from power generation in Bangladesh fell by nearly 10% in the Nepal hydropower scenario. Importing wind power from Tamil Nadu reduced emissions by 5.5%, while importing PV reduced emissions by 2.5%.

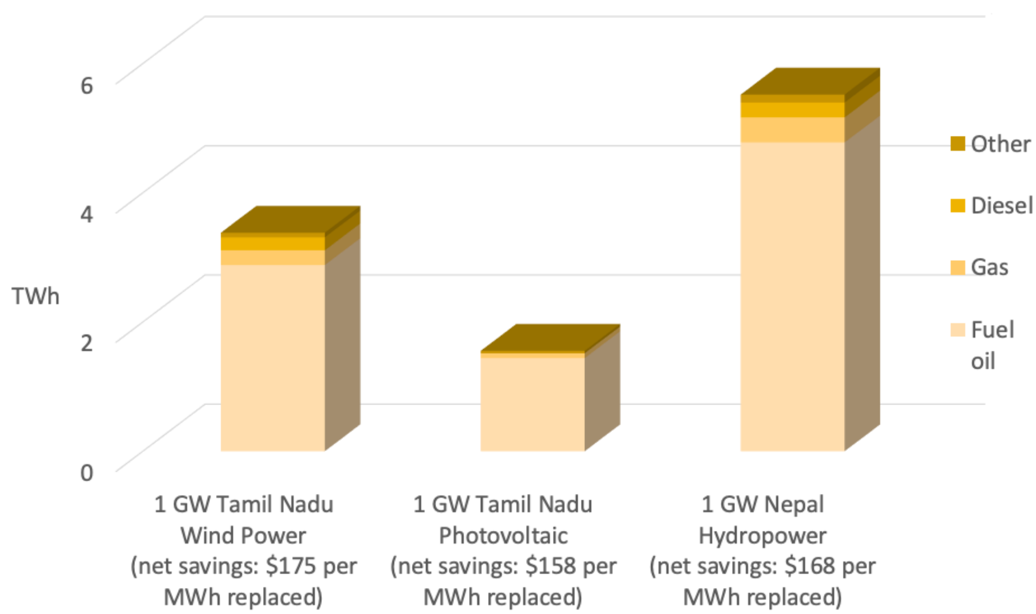

Figure 1. Domestic Generation in Bangladesh Replaced by Power from Renewable Energy Zones
"Other" includes coal and domestic hydropower

Results for Sri Lanka

PV imported from Tamil Nadu tends to be highly correlated with load in Sri Lanka. The correlation is fairly consistent across all months, which suggests that regardless of the season, PV will be offsetting the day's most expensive domestic power.

Per megawatt of capacity, wind power from Tamil Nadu offsets a larger amount of generation than PV because it produces more energy during the year. It is less correlated with load, however, so the value per unit of energy displaced is less. This is because most of the energy that Tamil Nadu PV would replace comes from peak-period natural gas generators. Overall, PV saves Sri Lanka $80 per MWh replaced, while wind saves $62 per MWh.

Wind power would also offset more baseload coal generation. Replacing off-peak power from coal has less economic impact than replacing peak-period generation, but it has a greater impact on carbon dioxide emissions. One GW of Tamil Nadu wind power reduces Sri Lanka's generation-related emissions by 29% for the year, while 1 GW of Tamil Nadu PV reduces emissions by 18%.

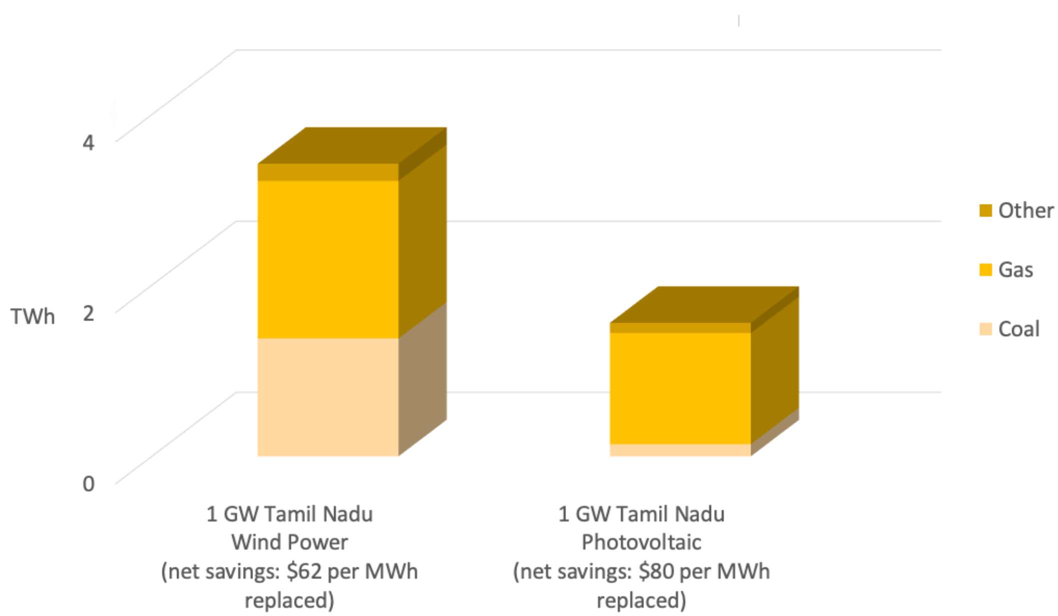

Figure 2. Domestic generation in Sri Lanka replaced by power from renewable energy zones "Other" includes fuel oil and domestic hydropower, wind, and solar.

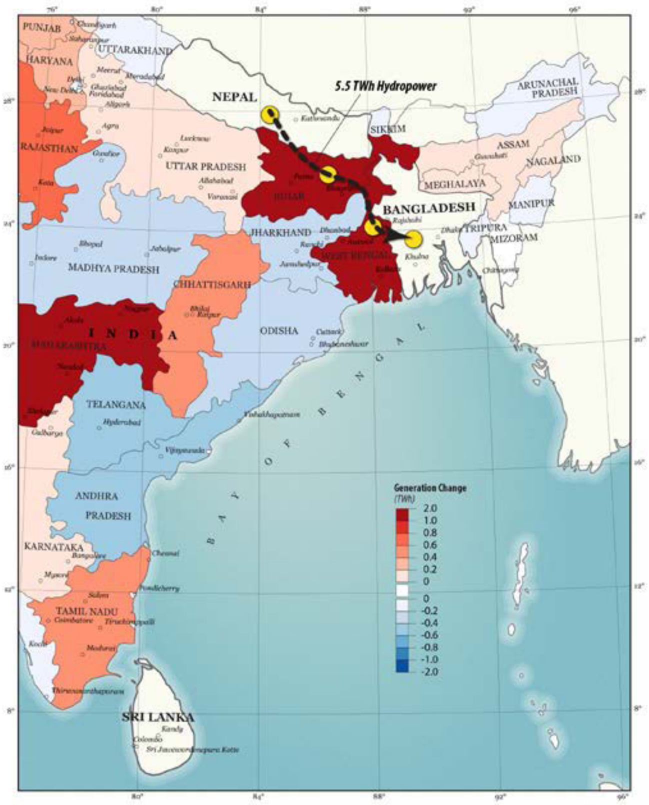

Figure 3. Nepal Hydropower to Bangladesh: Changes in Annual State Generation. *Illustration by Billy Roberts, NREL*

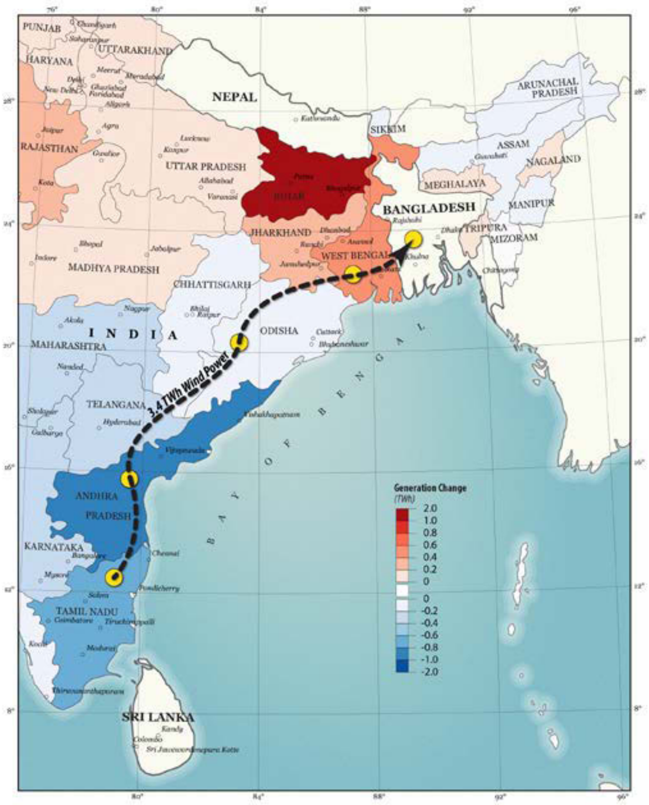

Figure 4. Tamil Nadu Wind to Bangladesh: Changes in Annual State Generation. *Illustration by Billy Roberts, NREL*

Wheeling Power through India to Bangladesh

For India, the primary consequence of cross-border trading in renewable power was to rearrange power flows between state networks when the power was wheeled through its network rather than delivered directly through an HVDC. The net economic impact to India was small, however.

Contractually, wheeling is simply moving energy through several interconnected networks from a point of injection to a distant point of delivery, accounting for the constraints of affected generators and transmission availability. But what happens on the grid physically is less direct, resembling a bazaar full of traders all standing in place with each one striking deals with those standing next to them. In the simulation, wind power in Tamil Nadu—which has low marginal cost—had an economic tendency to reduce generation from the most expensive thermal units. It also tended to reduce the net flow of power from neighboring Andhra Pradesh to the north, leading to a reduction in generation there as well. These reductions in turn changed the flows between other states in the region on the path to Bangladesh—some increasing, some decreasing, but all due to new underlying opportunities for cost savings. In terms of total volume, the net result of these state-to-state changes was an additional GW of power injected in Tamil Nadu, and an additional GW of power delivered to Bangladesh.[2]

Wheeling Tamil Nadu wind power or Nepal hydropower to Bangladesh tended to increase generation from thermal units in India's Eastern Region.[3] This suggests that getting power to Bangladesh might need the support of additional generation in the Eastern Region (within generator capabilities and available transmission). Due to production decreases elsewhere, however, the all-India impact on total generation cost was negligible.

2 In practice, power flows between states today are mostly governed by contracts and transmission availability. Actual interstate flows might be largely unchanged regardless of potential savings.

3 Changes due to wheeling Tamil Nadu PV were much smaller.

Nepal

A previous NREL study found that a multilateral regime for CBET could enable the use of hydropower in Nepal that would otherwise be curtailed.[4] The results of this study add a further insight: that achieving the most benefit does not require building a dedicated transmission line from Nepal across India and into Bangladesh. Wheeling Nepal hydropower across India's ISTS preserves almost all of the benefits to Bangladesh, provided that multilateral participation in the Indian wholesale power market is unobstructed by other national policies.

Nearly all of Nepal's domestic generation is hydropower, and most of that is run-of-river plants with limited operational flexibility. The previous NREL study found that while Nepal is building enough hydropower to reduce or eliminate domestic load shedding during the dry season, the lack of flexibility on its grid risks having an oversupply of capacity during the monsoon season. Participation in an integrated regional power market could help Nepal achieve an economically optimal balance balance: it could import power during the dry season and export surplus hydropower during the monsoon season.

Madi River, Nepal. *Photo from iStock 1139460362*

4 See David J. Hurlbut. 2019. *Cross-Border Energy Trade between Nepal and India: Trends in Supply and Demand*. NREL/TP-6A20-72345. https://www.nrel.gov/docs/fy19osti/72345.pdf; and Brendan McBennett, Amy Rose, David Hurlbut, David Palchak, Jaquelin Cochran. 2019. *Cross-Border Energy Trade between Nepal and India: Assessment of Trading Opportunities*. NREL/TP-6A20-72066. https://www.nrel.gov/docs/fy19osti/72066.pdf.

Additional Research

The results of this initial analysis suggest that cross-border electricity trades using South Asia's renewable energy zones holds potential benefits for all participating countries. Further analysis would expand the general understanding of these potential benefits.

Detailed Analysis of Impact Within Bangladesh and Sri Lanka

This study has treated Bangladesh, Sri Lanka, and Nepal each as single nodes of generation and demand; however, imported renewable energy would cause changes within the network that could affect the distribution of benefits within the country. A more detailed study could examine the impact of renewable imports on internal power flows, plant-level dispatch, plant load factors, and other unit-specific costs such as start-up and minimum run requirements. Including details within each country's network would also shed light on how renewable energy imports might affect dispatch during the peak load day, maximum renewable penetration day, and other times that are operationally critical.

Impact of Various Levels of Solar, Wind, or Hydropower Import on the System of Bangladesh and Sri Lanka

This study showed that Bangladesh and Sri Lanka could balance their power system with a 1-GW renewable energy import contract. Further study could examine the effect of higher import levels, especially when taking future load growth into account. One particularly important question: Is there a level of imports that would reduce or delay the need for a major domestic infrastructure investment, or would significantly reduce the risk of future load shedding?

Impact With Renewable Contracts from Different Renewable Zones

Imports from Tamil Nadu showed particular benefits to Bangladesh and Sri Lanka, as well as distinct influences on power flows between Indian states. Energy exported from Gujarat or another renewable energy zone might have different characteristics. Future analysis could explore which zones tend to have the greatest value for the importing country.

Best-Suited Import Portfolio for Bangladesh and Sri Lanka

Future study could also examine more contract options. One example could be a contract that combine renewables and conventional generation into a "shaped" product that matches load in the importing country. Another example would be renewables from Gujarat, and how wheeling power from that renewable energy zone might affect between-state flows in India differently than power from Tamil Nadu. A related question for analysis is whether it would be more cost-effective to bundle ancillary services with the contracted renewable energy, or to use domestic resources for the required ancillary services.

This brief was developed by Mohit Chandra Joshi, David J. Hurlbut, and David Palchak of the National Renewable Energy Laboratory for the U.S. Department of State's Bureau of South and Central Asian Affairs Regional Connectivity Program. A technical presentation of the study results is at www.nrel.gov/docs/fy20osti/77029.pdf. It is part of a project providing technical assistance to support increased cross-border electricity trade and cooperation in the South Asian region (including India, Nepal, Bhutan, Bangladesh, and Sri Lanka). The project aims to identify opportunities for, and the associated value of, increased power trade through peer-to-peer collaborations, power system modeling, regulatory roadmaps, and improved data.

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NREL/TP-6A20-76919 • July 2020