ECONOMIC ANALYSIS

A. Background, Approach, and Economic Rationale

1. India has set ambitious targets for increasing renewable energy. About 30 gigawatts (GW) of renewable energy capacity (mostly wind and solar power) are expected to be installed during India’s Twelfth Five-Year Plan period (ending 31 March 2017), bringing total installed renewable energy capacity to about 54.5 GW (18% of total installed generating capacity and about 11% of total electrical energy requirement). India’s National Action Plan on Climate Change (2008) targets renewable energy to be 15% of the country’s electricity generation by 2020. To achieve these targets, a renewable purchase obligation (RPO) scheme was introduced, with jurisdictional electricity regulators in each state responsible for setting annual RPO targets for electricity distributors and some large power consumers (including those with captive power plants). Introduced in parallel was a renewable energy certificate (REC) program to allow states with limited renewable energy resources to meet their RPO targets by buying RECs from renewable energy generators or traders in other states.

2. Most of the growth in installed renewable energy capacity will take place in six states—Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Rajasthan, and Tamil Nadu. The Power Grid Corporation of India Limited (POWERGRID) and state transmission utilities have jointly considered network reinforcement requirements to meet the challenges posed by intermittent renewable energy generation, and the Central Electricity Authority has subsequently approved a series of investments in intrastate and interstate transmission facilities (the “Green Energy Corridors”). In this context, one main objective of the Green Energy Corridor and Grid Strengthening Project is to increase electricity transmission capacity from renewable energy-rich states to load centers in the country’s north and beyond. The Asian Development Bank (ADB) has been requested to finance one part of an interstate transmission scheme (Part D) to transmit electricity generated from solar and wind resources in Rajasthan and Gujarat to the major load center and interregional grid connection point at Moga (Punjab). The other parts of the scheme (A, B and C) are financed by the German development cooperation, through KfW.

3. An unrelated subproject will increase electricity transmission capacity between the national grid’s western and southern regions to address looming electricity shortages in the south. In general, additional interregional grid capacity facilitates power transfer among states and regions. Because peak power demand does not occur at the same time in all places, one state or region may have surplus power when another has a deficit. The regional grid facilitates transfers from surplus to deficit areas, thereby optimizing the system, integrating the electricity market, encouraging power trading and competitive electricity pricing, and improving the generation mix. For the western and southern regions, this high voltage direct current (HVDC) subproject is a response to the indefinite delay of thermal generation projects planned for the southern region, mainly resulting from non-availability of gas supply to the region. This will expand western–southern interconnectivity from about 10 GW to 16 GW. Using HVDC technology improves efficiency and reduces transmission losses when compared to alternating current lines.

4. ADB’s proposed lending will support investment in (i) a Green Energy Corridor component consisting of (a) construction of a 765 kilovolt (kV) double circuit transmission line from Ajmer (Rajasthan) to Moga (Punjab) via Bikaner (Rajasthan), (b) establishment of a 785/400 kV substation at Bikaner and a 400 kV double circuit transmission line to connect to the existing

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3 The program allows for the cost of electricity generation from renewable energy sources to be split into two parts: the cost of electricity generation equivalent to conventional energy sources, and the cost for environmental attributes.
Bikaner substation, and (c) establishment of a real-time measuring and monitoring scheme; and (ii) a capacity expansion between the western and southern regions via (a) construction of two 800 kV HVDC terminal stations at Raigarh (Chhattisgarh) and Pugalur (Tamil Nadu) and (b) two 320 kV HVDC terminals at Pugalur (Tamil Nadu) and Trichur (Kerala).

5. The economic analysis was conducted following ADB’s guidelines for economic analysis and for cost–benefit analysis. The benefits of the proposed investment include resource cost savings (for the Green Energy Corridor component) and a reduction in demand not served (for the HVDC component). Some system-related benefits are also expected, including increased dynamic and transient stability allowing for greater renewable energy, and enhanced operational flexibility to cope with intermittency of renewable energy generation.

6. Solar and wind power are still more expensive than conventional power in India, and impose an additional cost burden due to their intermittency. Government intervention via India’s Electricity Act, 2003, the National Action Plan on Climate Change (2008), and the Jawaharlal Nehru National Solar Mission (2010) has created the necessary legal and regulatory framework to capture the environmental benefits of solar and wind power, thereby attracting private sector investment. However, the enabling transmission infrastructure for increased penetration of renewable energy remains a public sector responsibility. This provides the rationale for ADB support.

B. Demand Analysis

7. POWERGRID adopts India’s official demand forecast—the 18th Electric Power Survey—as the basis for its analysis. This forecast covers the Twelfth Five Year Plan period. It was reviewed against actual peak and energy demand to the end of FY2015 (as reported by the Central Electricity Authority) for states relevant to this economic analysis (Gujarat, Himachal Pradesh, Rajasthan, and Tamil Nadu). Based on this review, downward adjustments were made to FY2017 forecasts for Gujarat (about 15% for peak demand and 7% for energy demand) and Tamil Nadu (about 17% for peak demand and energy demand). Forecasts were then extended to 2020, assuming gradual declines in demand growth rates, and were held constant thereafter.

C. Least Cost Analysis

8. This economic analysis does not consider the overall economic case for India’s renewable energy generation targets and states’ RPO trajectories. The analysis’s starting point is an assumption that renewable energy generation is an economically rational choice for India at the penetration levels targeted, and that tariff-based bidding and a functioning REC market will ensure renewable energy resources are developed on a least-cost basis from a national perspective. This assumption implies that the least-cost analysis for the Green Energy Corridor subproject only requires a comparison between transmission options rather than comparing generation with transmission options. In this context, it is noted that all subproject components have been vetted and approved by the Central Electricity Authority and been subject to detailed power systems analysis by POWERGRID. Given the relatively short lead times for renewable energy generation when compared to transmission infrastructure and the short timeframes within which renewable energy targets are to be achieved, the decision to adopt 765 kV appears economically rational.

4 The transmission lines connecting these terminals are not funded by ADB but are included in this economic analysis.
9. For the HVDC subproject, the alternative to building transmission capacity to import power from the western to southern regions is to construct a new coal-fired generating plant in the southern region. Ignoring the practical issues relating to this option (availability of coal and rail capacity for it), the transmission option’s levelized cost was calculated as Rs0.8 per kilowatt-hour (kWh) compared to the estimated levelized incremental cost of coal imported by rail from Chhattisgarh (as compared to electricity generation in Chhattisgarh itself) of Rs1.4 per kWh. POWERGRID also demonstrated that the selected HVDC solution (part 800 kV and part 320 kV) is a lower-cost and technically superior option to using only 800 kV.

D. Cost-Benefit Analysis

10. Investment costs. Investment costs were taken from POWERGRID’s detailed project reports. For the Green Energy Corridor subproject, costs for parts A–C (funded by KfW) were included in the analysis to ensure proper matching of cost and benefits, as were POWERGRID’s indicative costs for transmission connections to the national grid, energy storage, and a renewable energy management center. Costs were expressed in second quarter 2015 terms, and the domestic price numeraire was used. Cost components were categorized as: equipment, civil works and construction, land, preparatory work, external project management, and environmental and social mitigation. Traded inputs and fuel were valued at their border price equivalent values, then adjusted to the domestic price numeraire by multiplying by a shadow exchange rate factor (SERF) of 1.03. Non-traded inputs were valued at domestic prices. It was assumed that there are no significant distortions in the wage rates for skilled labor. For unskilled labor, as underemployment exists in the economy, a shadow wage rate of 0.75 was adopted (footnote 7). Land was valued at its opportunity cost. Taxes, financing charges, and price contingencies were excluded. An average operating and maintenance cost of 1.5% of total capitalized project cost was adopted, reflecting international experience and the Central Electricity Regulatory Commission’s typical benchmarks.

11. Cost–benefit analysis of the green energy corridor assumes renewable energy generation development is the same in “with project” and “without project” scenarios, and therefore the cost of new renewable energy capacity does not need to be considered. This assumption allows for analyzing the economic impact of transmission augmentation independently from the merits of renewable energy. The assumption is considered reasonable for this analysis because renewable energy-rich states are planning renewable energy capacity development independently of subproject planning. (The states’ plans for renewable energy capacity development were an input into green energy corridor planning.)

12. POWERGRID estimated parts A–C of the interstate Green Energy Corridor initiative (funded by KfW) will cost Rs75.47 billion (in 2014 terms and including interest during construction). For inclusion in this economic analysis, POWERGRID’s cost estimate was adjusted by backing out interest during construction and inflating to 2015. It was then converted to shadow pricing. Based on guidance from POWERGRID, it was assumed that completion of parts A–C will coincide with the ADB-funded part D, such that benefits for the entire Green Energy Corridor investment begin accruing in 2020.

13. Investment benefits. The Green Energy Corridor subproject is a means to export excess renewable energy from states that will either have a surplus of generation beyond RPO requirements or will not be able to absorb capacity outside of peak demand periods. This will not

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7 SERF and the shadow wage rate are based on values used in other recently approved projects in India.

8 A piecemeal transmission investment approach (multiple sequenced 400 kV lines) risks causing stranded or delayed renewable energy-generation investments. The Green Energy Corridor’s integrated, interstate solution somewhat mitigates this risk. However, the extent of this mitigation is hard to quantify and is thus excluded in the analysis.
only support renewable energy capacity expansion but will also form part of the integrated interstate and interregional grid, and thus provide for the flow of real and reactive power derived from conventional generation as well as renewable energy, optimizing generation dispatch at a regional level, enhancing transient and dynamic stability, and improving overall grid security. The only benefit that can reasonably be quantified on a stand-alone basis is the ability to export renewable energy generation from renewable energy-rich states (Gujarat, Rajasthan, and Himachal Pradesh). However, because renewable energy generators can either sell their renewable energy at a preferential tariff or sell electricity generation and environmental attributes associated with renewable energy generation separately (as allowed under the REC scheme), it does not necessarily follow that Gujarat and Rajasthan will export all renewable energy in excess of their RPOs. Exports will depend on the overall supply–demand balance in renewable energy-rich states when the project is commissioned, the development of renewable energy in other states, and the extent to which penalties are imposed on entities not meeting their RPOs. As these factors are unknown, this analysis assumes that only one third of the forecast renewable energy surpluses (above RPOs) will be exported through the Green Energy Corridor. This exported electricity would displace coal-fired generation from existing plants (a resource cost saving) in states with renewable energy shortfalls. The World Bank’s projections of international coal prices, shadow priced using SERF, were used to estimate a levelized economic cost of electricity generation from existing coal plants of Rs3.6 per kWh. On this basis, the annual cost of avoided coal generation is estimated to be about Rs59.1 million.

14. Without the HVDC subproject, un-served demand in the southern region would increase to an estimated 10 GW and 5,300 gigawatt-hour (GWh) by FY2021, the expected year of subproject commissioning. It is assumed that without the subproject, a small proportion of this demand would be served by alternative energy sources (kerosene lamps for domestic consumers and diesel generators in other sectors), resulting in a non-incremental benefit (resource cost saving). The rest of the demand would remain un-served, meaning the subproject accrues an incremental benefit. The non-incremental benefit was quantified assuming only 1% of un-served domestic demand (16 GWh in 2021, increasing to 46 GWh by 2024) and 10% of demand in other sectors (369 GWh in 2021, increasing to 1,047 GWh by 2024) would be met from alternative sources. This was valued using the World Bank’s projections for international crude oil prices, converted to border price-equivalent values for kerosene and diesel fuels. These prices were then shadow-priced using SERF and levelized, giving an economic alternative fuel cost of Rs41.2 per kWh for domestic consumers and Rs21.3 per kWh for other consumers. Because no new customer connections are assumed, the incremental benefit (4,908 GWh in 2021, increasing to 13,944 GWh by 2024) was valued using the 2014 weighted average cost in the southern region of about Rs5.0 per kWh. This ignores the small consumer surplus likely to accrue to consumers as a consequence of the HVDC subproject. In this analysis, coal-fired power is both a direct cost (for the HVDC subproject) and a benefit (as an avoided cost for the Green Energy Corridor subproject). Sensitivity analysis shows that on an aggregate basis, the analysis is neutral for assumptions regarding the environmental cost of electricity generation from coal, and for this reason no value has been ascribed to this cost. In addition, benefits from the more efficient transmission line and substations are already embedded in the model.

15. **Estimated economic internal rate of return.** The economic evaluation used a period of 25 years. Separate cost–benefit calculations for the subprojects show economic internal rates of return (EIRRs) of 18.2% for the Green Energy Corridor and 14.4% for HVDC, thus showing stand-alone economic viability. The overall aggregated EIRR is about 16.6% (Table 1). This is a

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9 The REC scheme enables states falling short of RPOs to purchase RECs in lieu of contracting for renewable energy capacity from surplus states—a purely financial transaction with no implications for power flow.

10 Annual exports: Gujarat: 8,700 gigawatt-hours (GWh); Rajasthan: 6,200 GWh; and Himachal Pradesh: 1,600 GWh.
minimum estimate, as some expected benefits have not been quantified. In particular, only the renewable energy export benefits of the Green Energy Corridor subproject have been included, ignoring other system-related benefits expected to occur (but difficult to quantify with any certainty).

Table 1: Economic Internal Rate of Return Calculation for Aggregate Project (Rs million)

<table>
<thead>
<tr>
<th>Year</th>
<th>Benefits</th>
<th>Costs</th>
<th>Net Economic Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Incremental Output</td>
<td>Non-Incremental Output</td>
<td>Capital</td>
</tr>
<tr>
<td>2016</td>
<td>0</td>
<td>0</td>
<td>30,754</td>
</tr>
<tr>
<td>2017</td>
<td>0</td>
<td>0</td>
<td>69,939</td>
</tr>
<tr>
<td>2018</td>
<td>0</td>
<td>0</td>
<td>129,810</td>
</tr>
<tr>
<td>2019</td>
<td>0</td>
<td>0</td>
<td>161,558</td>
</tr>
<tr>
<td>2020</td>
<td>0</td>
<td>59,056</td>
<td>25,266</td>
</tr>
<tr>
<td>2021</td>
<td>24,540</td>
<td>67,571</td>
<td>28</td>
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<tr>
<td>2022</td>
<td>38,524</td>
<td>73,583</td>
<td>0</td>
</tr>
<tr>
<td>2030</td>
<td>69,718</td>
<td>89,070</td>
<td>0</td>
</tr>
<tr>
<td>2040</td>
<td>69,718</td>
<td>89,070</td>
<td>0</td>
</tr>
</tbody>
</table>

EIRR: 16.6%

( ) = negative, EIRR = economic internal rate of return, O&M = operation and maintenance.

Only selected years shown for brevity.

Source: Asian Development Bank staff estimates.

16. The risk that the proposed investment does not achieve satisfactory economic returns was identified from both the cost and benefit side (capital cost overruns, operating cost increases, reduced benefits, less demand growth, and combined downside scenario). For each identified risk, the aggregate EIRR’s sensitivity was tested and switching values were calculated. EIRR exceeded 12% in all cases (Table 2). The switching values are adequately separated from the base-case values, indicating that a change in any single key parameter beyond the value used in the sensitivity studies is unlikely to render the project non-viable. Based on these results, the investment appears to be economically viable.

Table 2: Sensitivity Analysis for Aggregate Project

<table>
<thead>
<tr>
<th>Sensitivity Parameter</th>
<th>Variation (%)</th>
<th>EIRR (%)</th>
<th>Switching Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>16.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Overall capital costs increased</td>
<td>15</td>
<td>14.6</td>
<td>34.1</td>
</tr>
<tr>
<td>2. Lower cost of conventional generation</td>
<td>(15)</td>
<td>15.5</td>
<td>(63.5)</td>
</tr>
<tr>
<td>3. O&amp;M increased</td>
<td>15</td>
<td>16.4</td>
<td>429.9</td>
</tr>
<tr>
<td>4. Combined – all</td>
<td>13.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

( ) = negative, EIRR = economic internal rate of return, O&M = operation and maintenance.

Source: Asian Development Bank staff estimates.

17. Conclusion. The economic analysis confirms that the proposed project is at the least cost and is economically viable. Sensitivity and risk analysis demonstrates that the expected economic performance is robust. From an economic perspective, the investment should proceed.