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Advanced Energy Partnership for Asia

Modeling the Least-Cost Operation of Bangladesh's Electricity Grid with Higher Levels of Renewable Energy

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National Renewable Energy Laboratory (NREL)

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Image: iStock 1041657418

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Renewable Energy Zones Input Data

Solar and Wind Resource Data

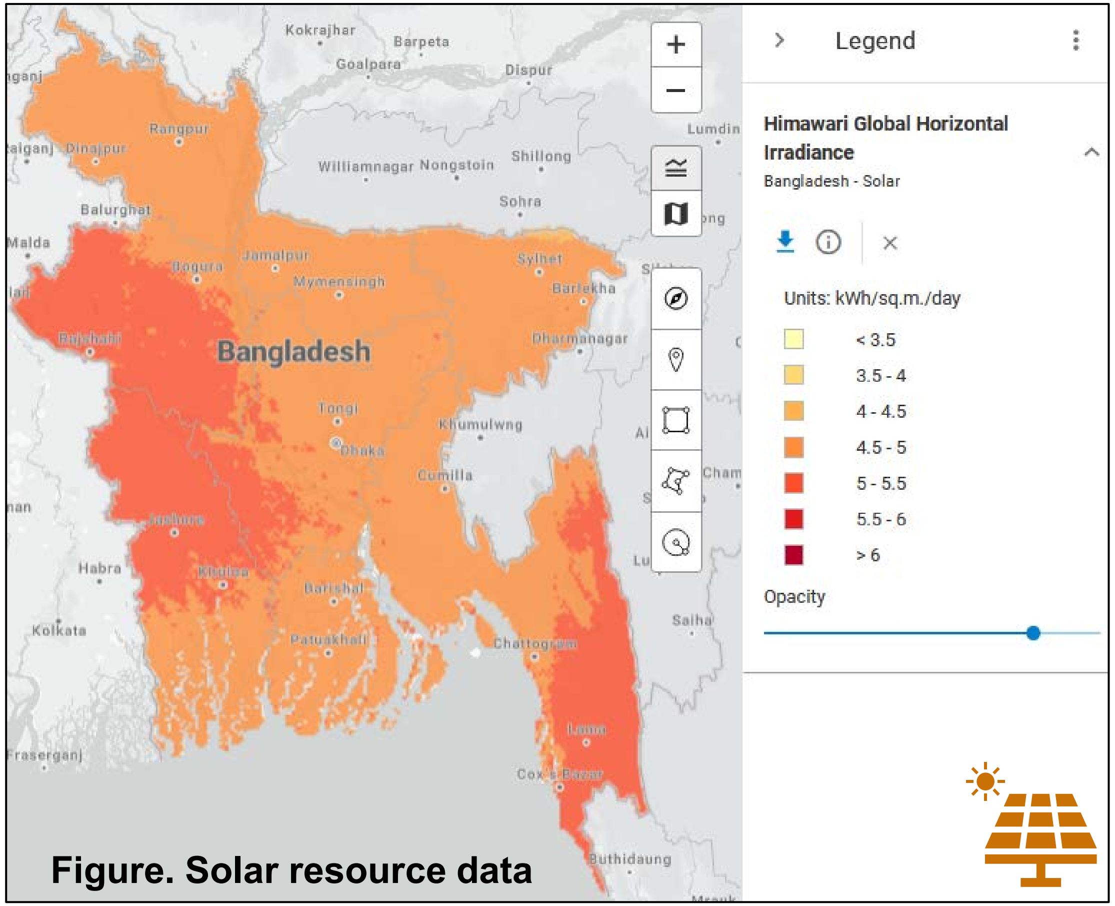

Figure. Solar resource data

Spatial resolution: 2 kilometer by 2 kilometer
Temporal resolution: 10 minutes
Timespan: 2015-2019

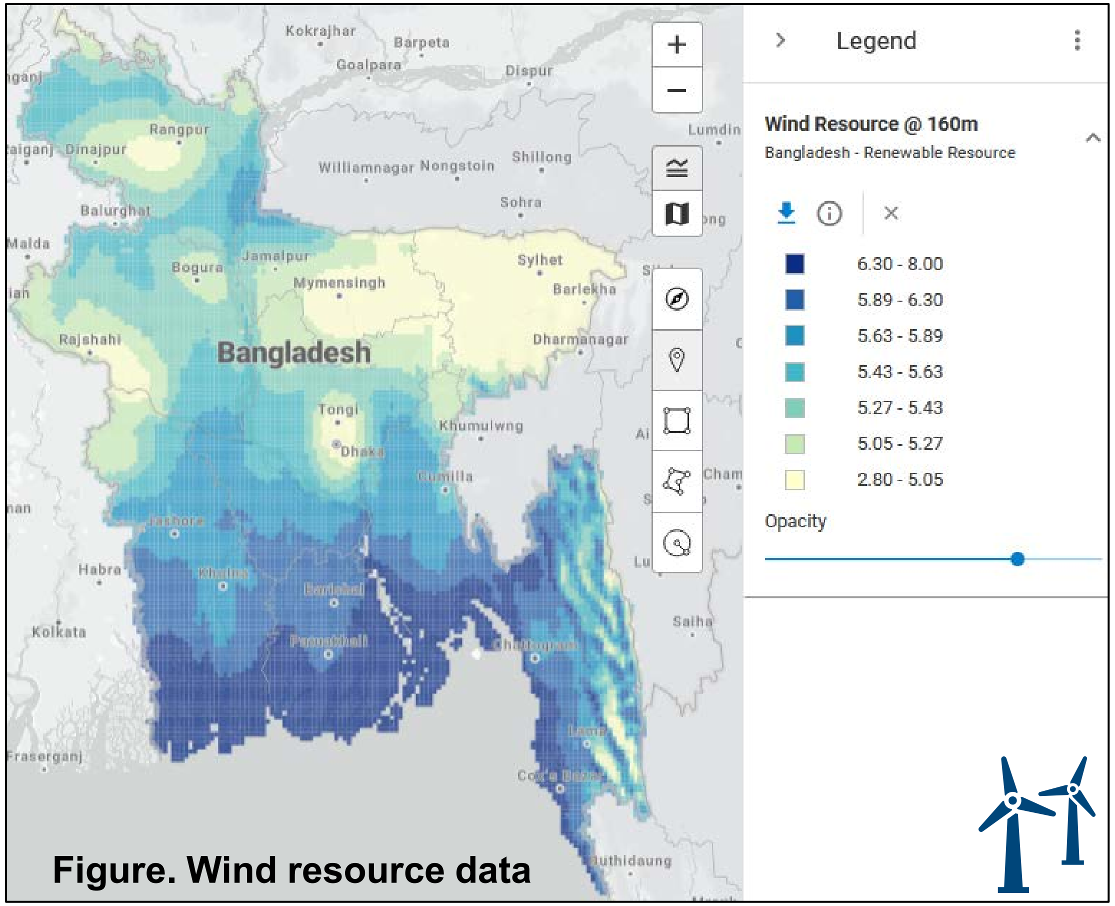

Figure. Wind resource data

Spatial resolution: 3 kilometer by 3 kilometer
Temporal resolution: 15 minutes
Timespan: 2014-2017

Sources: Maclaurin et al. (2022); NREL (2023)

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Potential Candidate Zones

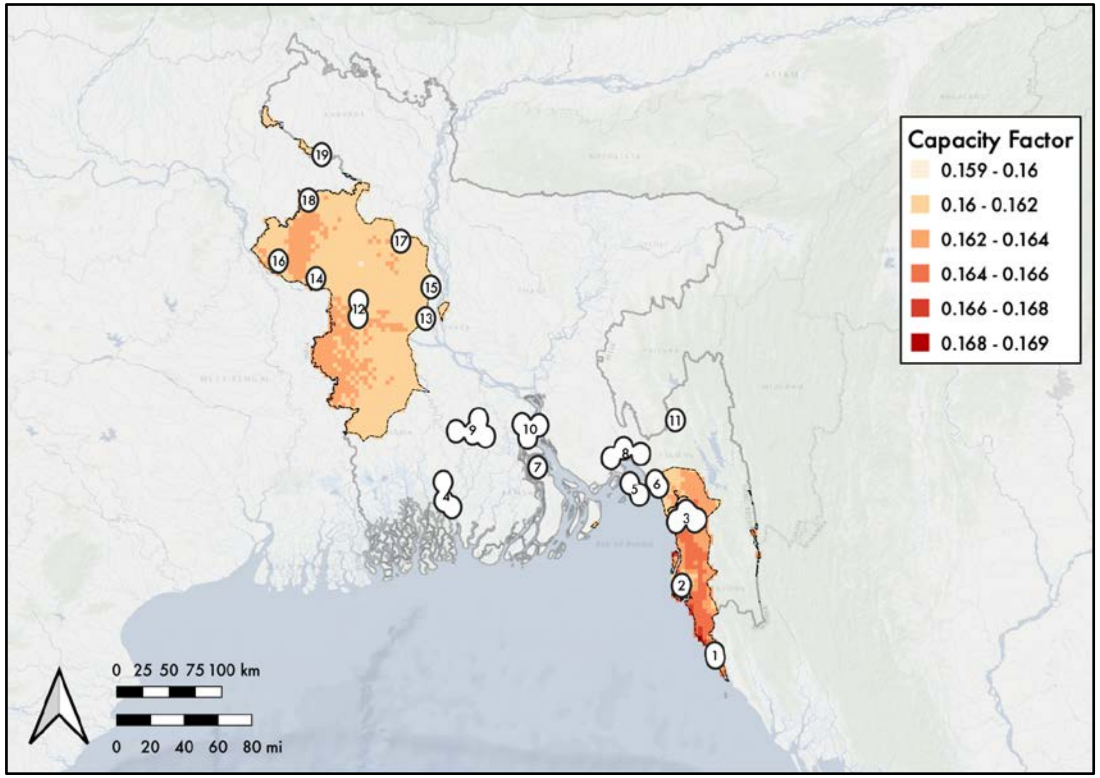

Figure. Potential candidates for renewable energy zones (REZs) in Bangladesh compared to solar PV study areas

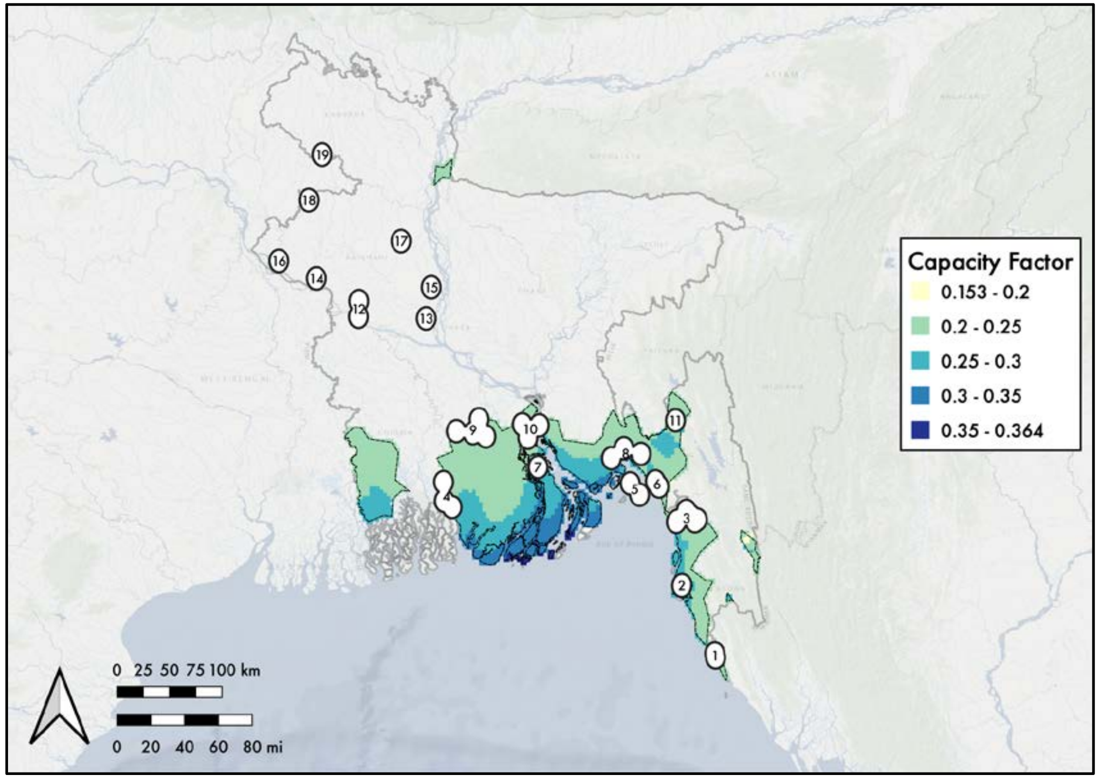

Figure. Potential candidates for renewable energy zones (REZs) in Bangladesh compared to wind study areas

Source: Joshi et al. (2023)

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Grid Integration Study Setup

Data Processing

Raw Data → **Processed Data** → **Modeling Software**

Generators

Substations

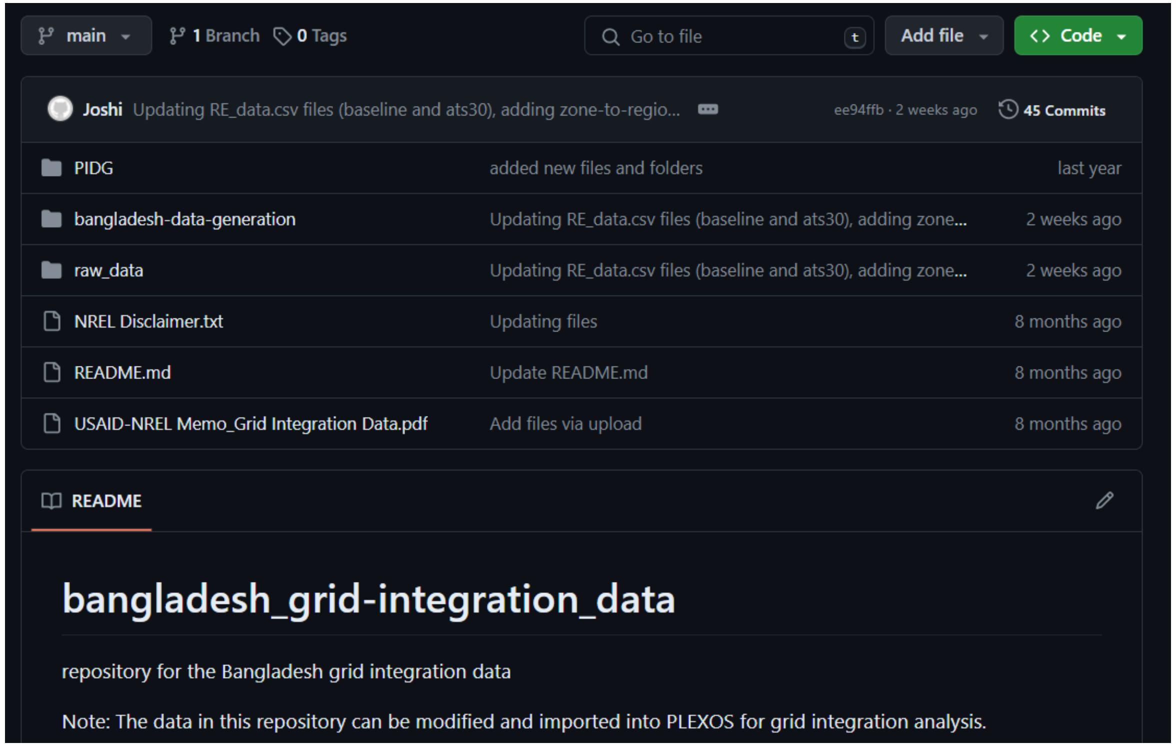
Transformers

Transmission Lines

Electricity Demand

Solar Resource

Wind Resource



Production Cost Model (PLEXOS)

Production Cost Model (PCM)

- Production cost models (PCMs) can optimize the scheduling and dispatching of all power plants and can incorporate several constraints imposed by generation and transmission.
- PCMs can simulate the hourly or sub-hourly chronological power grid operation.
- During each simulated time interval, the model selects the least-cost mix of generators needed to meet the electricity demand while maintaining adequate reserve capacity.
- In PCMs, power grid transmission can be simulated in a more simplified way (zonal) and a more detailed way (nodal) – this study used a nodal model.
- Nodal representation is useful when focusing on interactions and tradeoffs among transmission, demand-side, and supply-side resources.
- When are transmission interactions important in power system modeling?
  - When you expect significant price differences driven by real-time constraints in transmission capacity.
  - When transmission congestion is expected to impact the physical “dispatchability” of power.

Data Gaps and Recommendations

Assumptions made for the generator fleet:

- Minimum up time
- Minimum down time
- Maximum ramp up rate
- Maximum ramp down rate
- Start-up cost
- Heat rate (i.e., efficiency)

Data Recommendations:

- Ensure consistent naming conventions.
- Store and collect data in reproducible format.
- Implement processes for regular data updates.
- Collect additional data to support renewable energy analysis (see “assumptions made for the generator fleet”)

Study Regions and Scenarios

Figure. Regions of Bangladesh for grid integration analysis

Source: Alam et al. (2021)

Scenario	Year	Solar PV Capacity (MW)	Onshore Wind Capacity (MW)	Details
Baseline	2018	3	0	Based on data provided by PGCB and BPDB.
Current Grid	2024	700	60	Based on data provided by PGCB and BPDB, including additional coal and renewable energy capacity.
ATS30	2030	3061	750	Based on the Advanced Technology Scenario (ATS) projections in the IEPMP.

IEPMP = Bangladesh Integrated Energy and Power Master Plan 2023

Source: Bangladesh Ministry of Power, Energy, and Mineral Resources (2023)

Reserves Assumptions

- Assumed that approximately 5% of the electricity demand at each hour is held as reserves in the Baseline scenario and that approximately 6% of the electricity demand at each hour is held as reserves in the Current Grid and ATS30 scenarios.

- Assumed that the value of lost load (VOLL) is $1,000/MW.

- Representation of reserves is consistent with what is outlined in the Bangladesh Advancing Development and Growth through Energy (BADGE) Program Report on Automatic Generation Control (AGC) for Power Grid Bangladesh.

Source: USAID and PGCB (2024)

Case Study: Philippines

The following results are from the Philippines' interconnected Grid Integration and Renewable Energy Zones (REZ) Studies:

1. Achievability of RE goals with current transmission infrastructure.
2. Thermal power plant flexibility required to integrate RE.
3. Significance of curtailment of RE in grid operations.

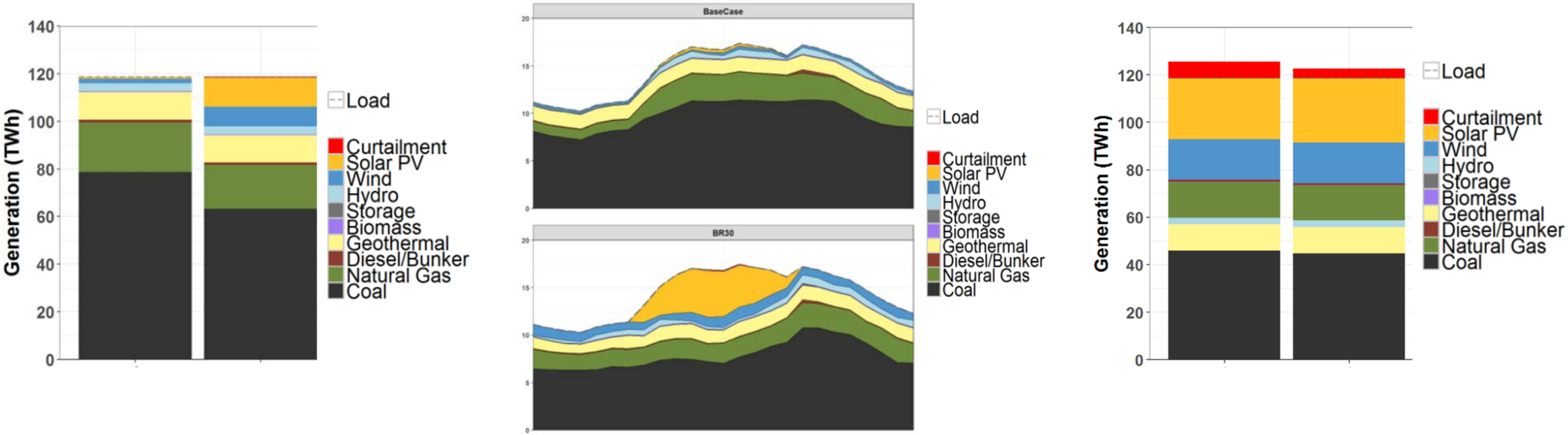


Figure. Key results from the Philippines' interconnected grid integration and renewable energy zones (REZ) studies

Source: Barrows et al. (2018)

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Baseline Scenario Results

Baseline Scenario: Demand and Capacity

Demand: 62,678 GWh

Fuel	Installed Capacity (MW)
Coal	524
Natural Gas	9,415
Heavy Fuel Oil (HFO)	3,443
High-Speed Diesel (HSD)	1,380
Hydropower	230
Solar PV	3
Wind	0
Imports	660
Total	**15,655**

Demand and capacities are based on data for 2017-2018 provided by PGCB and data from BPDB's 2017-2018 annual report.

Baseline Scenario: Annual Generation

- The *Energy Limits* sensitivity is designed to align with the annual generation values reported in the BPDB 2017-2018 annual report.
- The *Optimum Generation* sensitivity removes the energy generation limits and results in the lowest cost dispatch profile.
- Compared to the BPDB 2017-2018 annual report, the *Optimum Generation* sensitivity results in higher coal, gas, and power imports, and lower hydro, HFO, and HSD.
- The total annual generation values (GWh) across the Baseline scenarios remain the same.

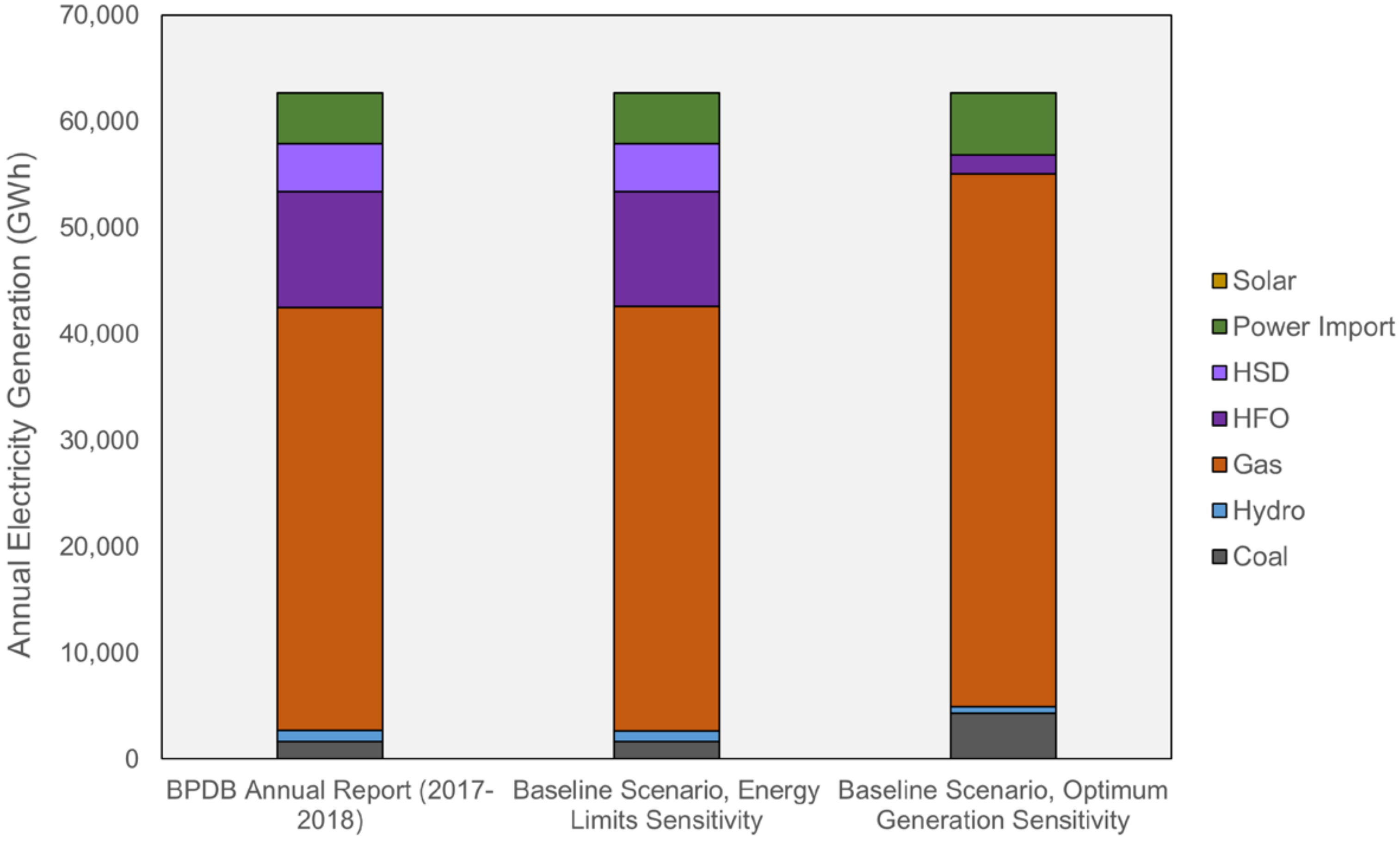

Figure. Annual electricity generation (GWh) by fuel for Baseline scenarios

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Baseline Scenario: Hourly Generation

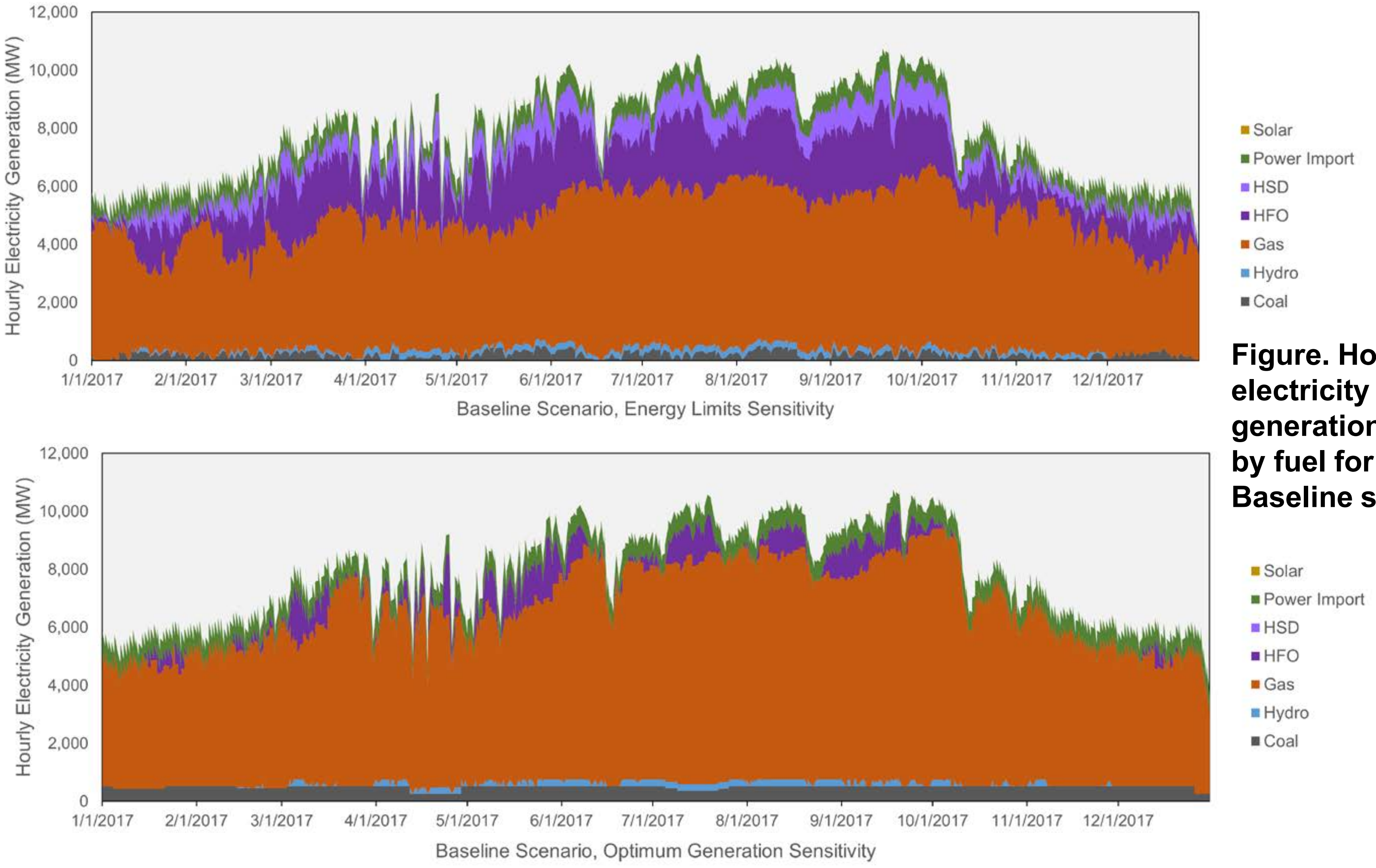

Figure. Hourly electricity generation (MW) by fuel for Baseline scenarios

- Compared to the *Energy Limits* sensitivity, the *Optimum Generation* sensitivity sees a flatter dispatch of coal and hydro (i.e., acting as baseload sources of electricity).
- In the *Optimum Generation* sensitivity, HFO and power imports are used to meet peak electricity demand.

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Baseline Scenario: Peak Demand Day

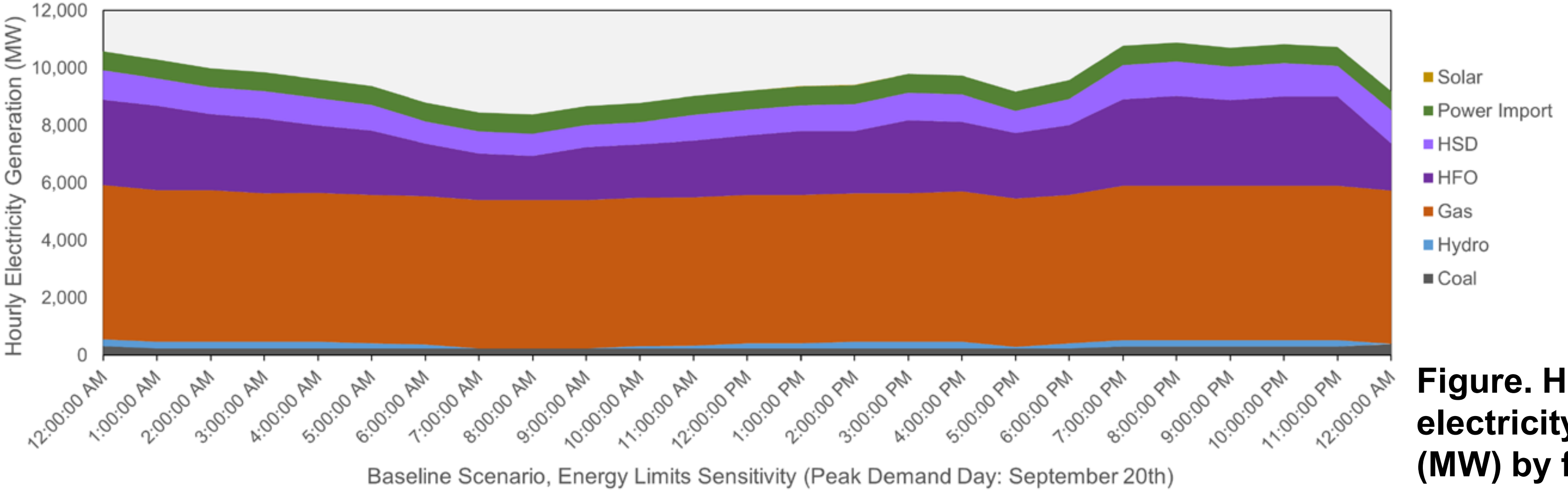
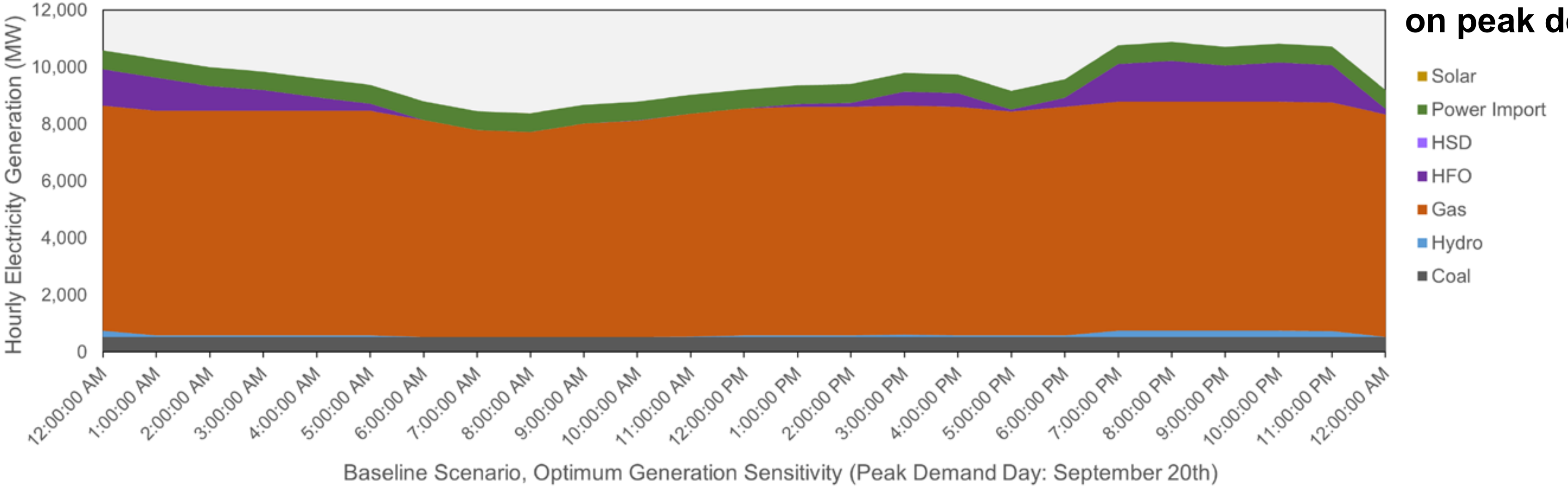


Figure. Hourly electricity generation (MW) by fuel for Baseline scenarios on peak demand day



- Peak demand is on September 20th at 8:00pm (10,833 MW).
- Compared to the *Energy Limits* sensitivity, the *Optimum Generation* sensitivity sees HFO ramping up (instead of both HSD and HFO ramping up) to meet the evening peak demand.

Baseline Scenario: Operating Costs

- Annual operating costs drop from 3.2 billion USD in the *Energy Limits* sensitivity to 2.3 billion USD in the *Optimum Generation* sensitivity (27% decrease).
- This reduction in operating costs is primary due to the decline in HFO and HSD generation, which are more expensive compared to coal and gas.
- Currently, the Bangladesh grid is thus not operating in a cost-efficient manner using security-constrained economic dispatch principles.

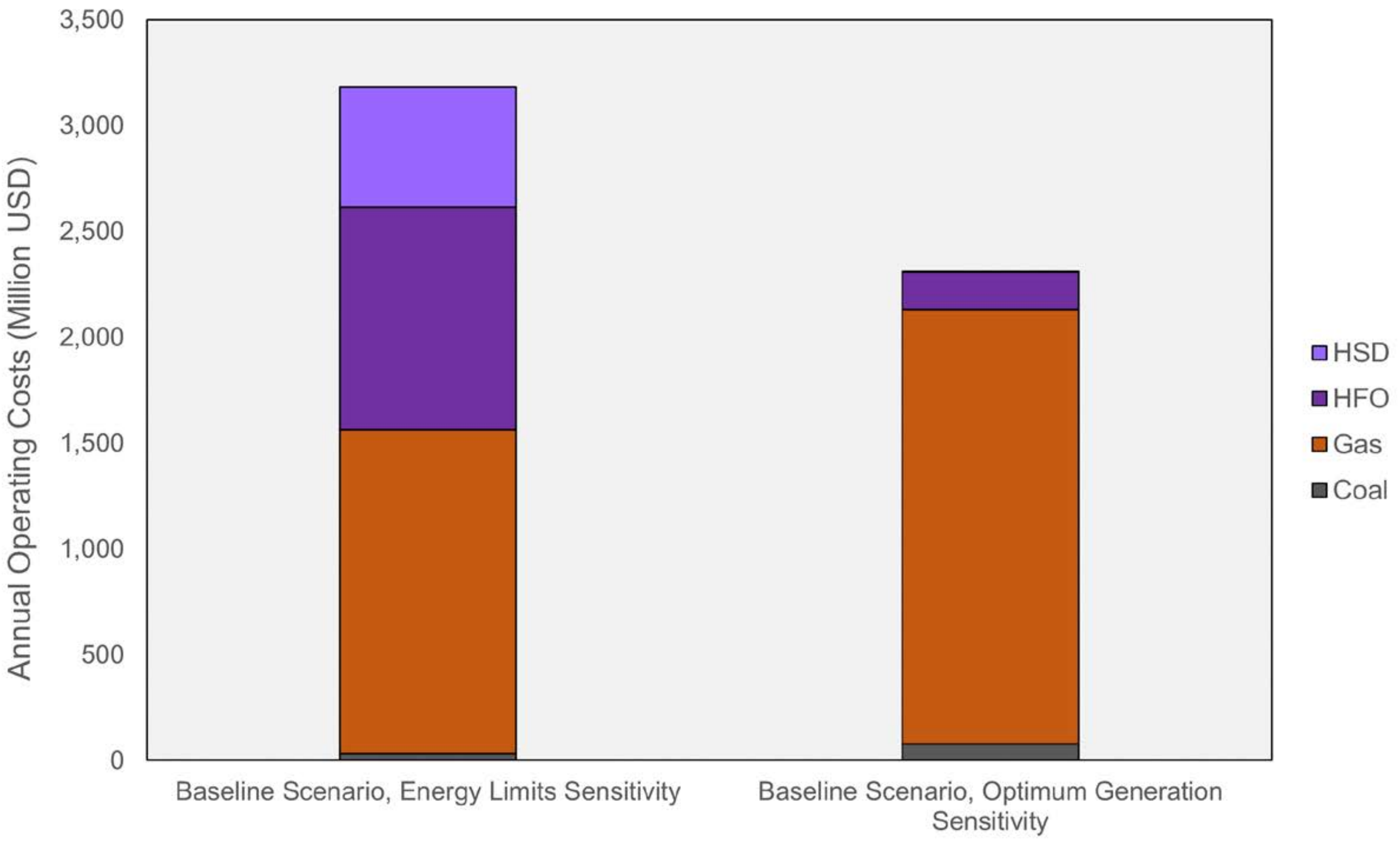


Figure. Annual operating costs (million USD) by fuel for Baseline scenarios

Baseline Scenario: Annual Emissions

- Annual CO_2 emissions slightly increase from 59 million metric tons in the *Energy Limits* sensitivity to 63 million metric tons in the *Optimum Generation* sensitivity (7% increase).
- This small increase in emissions is due to the increase in coal and gas generation in a least-cost system, whose rise in emissions offset the drop in emissions due to a reduction in oil (HFO and HSD) generation.
- As Bangladesh incorporates more renewables into its electricity system, the emissions (CO_2, NO_X, and SO_X) will all drop.

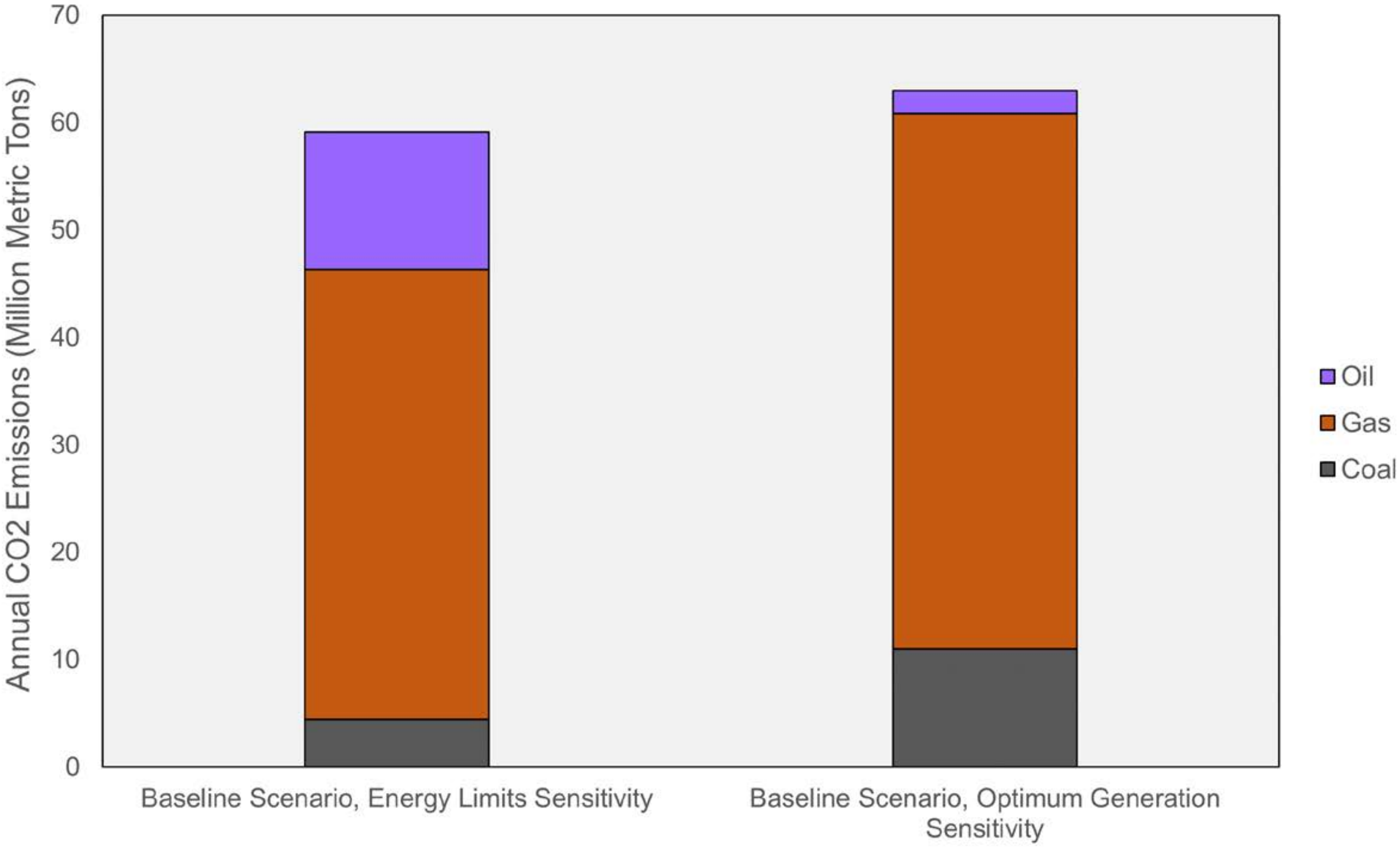


Figure. Annual CO_2 emissions (million metric tons) by fuel for Baseline scenarios

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Current Grid Scenario Results

Current Grid Scenario: Demand and Capacity

Demand: 88,450 GWh

Fuel	Installed Capacity (MW)
Coal	2,370
Natural Gas	9,415
Heavy Fuel Oil (HFO)	3,443
High-Speed Diesel (HSD)	1,380
Hydropower	230
Solar PV	700
Wind	60
Imports	660
Total	**18,258**

Demand and capacities are based on data for 2018 provided by PGCB, data from BPDB's 2017-2018 annual report and 2022-2023 annual report, and current capacity data from the Bangladesh Advancing Development and Growth (BADGE) program.

Current Grid Scenario: Annual Generation

- In the Current Grid scenario, generation increases for all technologies except for hydropower and imports, which remain the same as in the Baseline scenario.
- Renewable energy (solar, wind, and hydropower) accounts for only approximately 2% of annual generation in the Current Grid scenario.
- Compared to the BPDB Annual Report (2022-2023), coal, gas, and renewable energy generation increase while HFO, HSD, and imports decrease in the Current Grid scenario, which represents a least-cost dispatch of the grid.

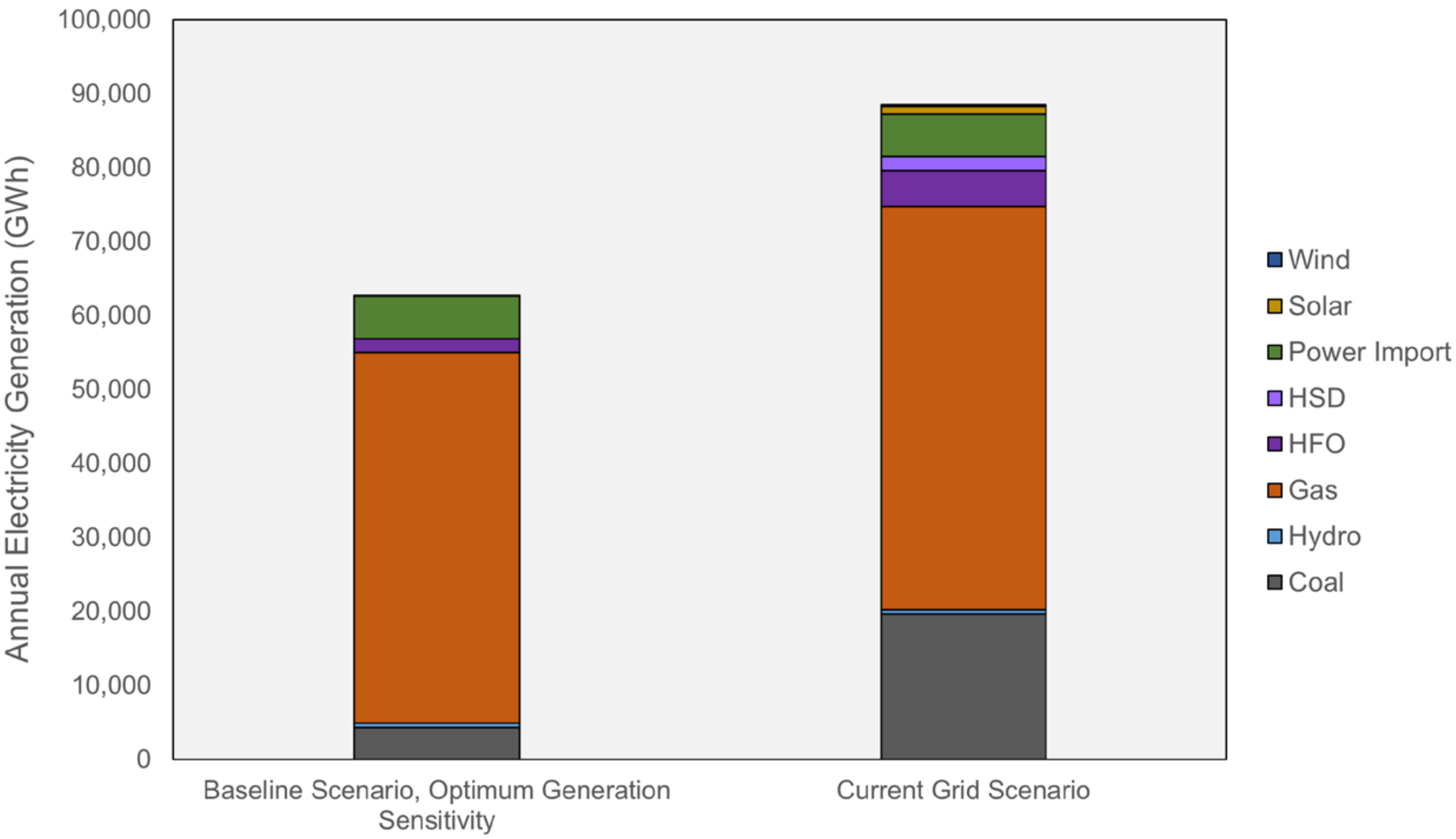

Figure. Annual electricity generation (GWh) by fuel for Baseline and Current Grid scenarios

Current Grid Scenario: Hourly Generation

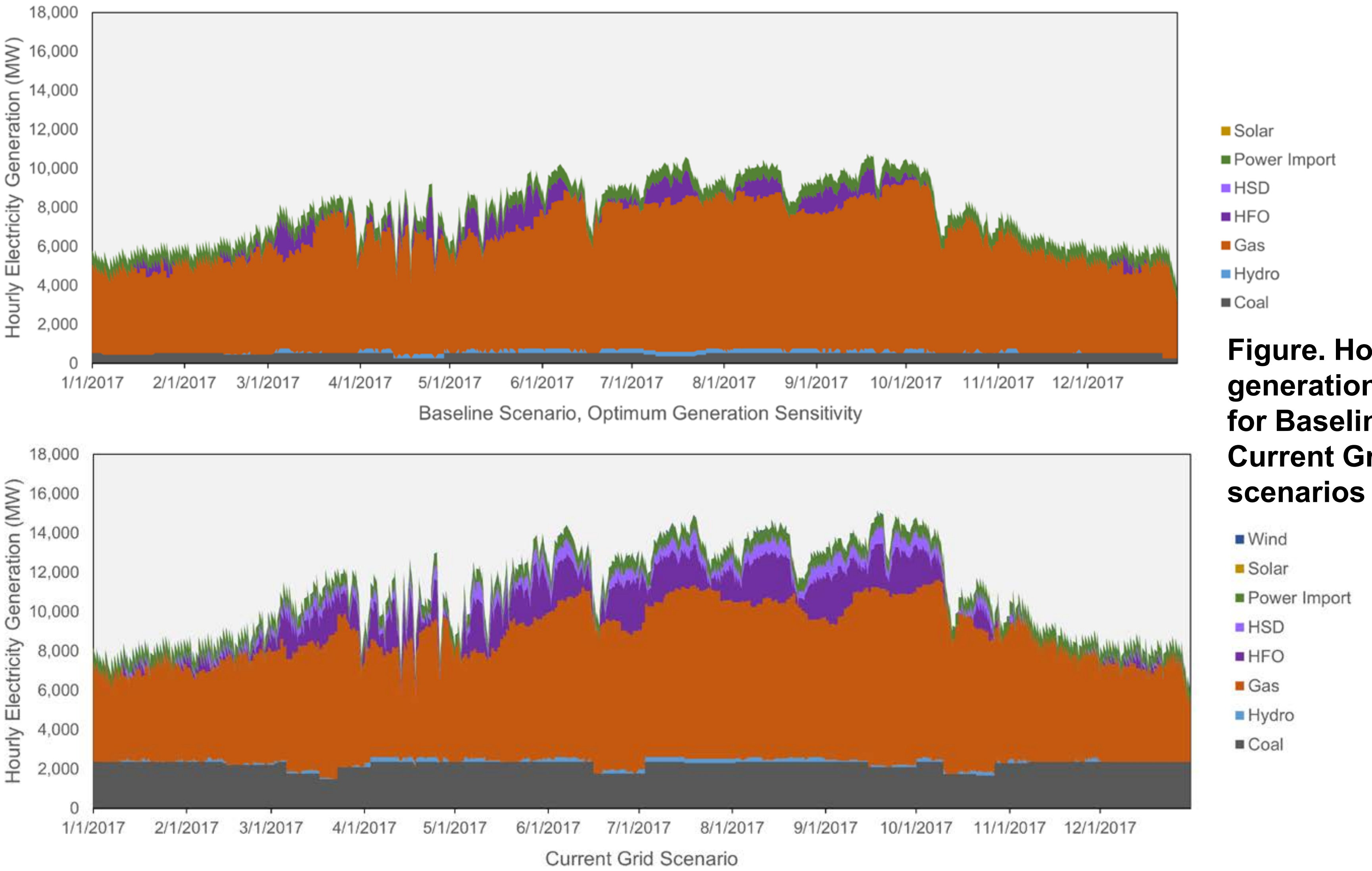

Figure. Hourly electricity generation (MW) by fuel for Baseline (top) and Current Grid (bottom) scenarios

- In the Current Grid scenario, HFO, HSD, and imports meet peak demand, with their largest contribution in the summer months.
- Coal and hydropower generation remain mostly flat throughout the year, and wind generation is higher in the summer months.

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Current Grid Scenario: Peak Demand Day

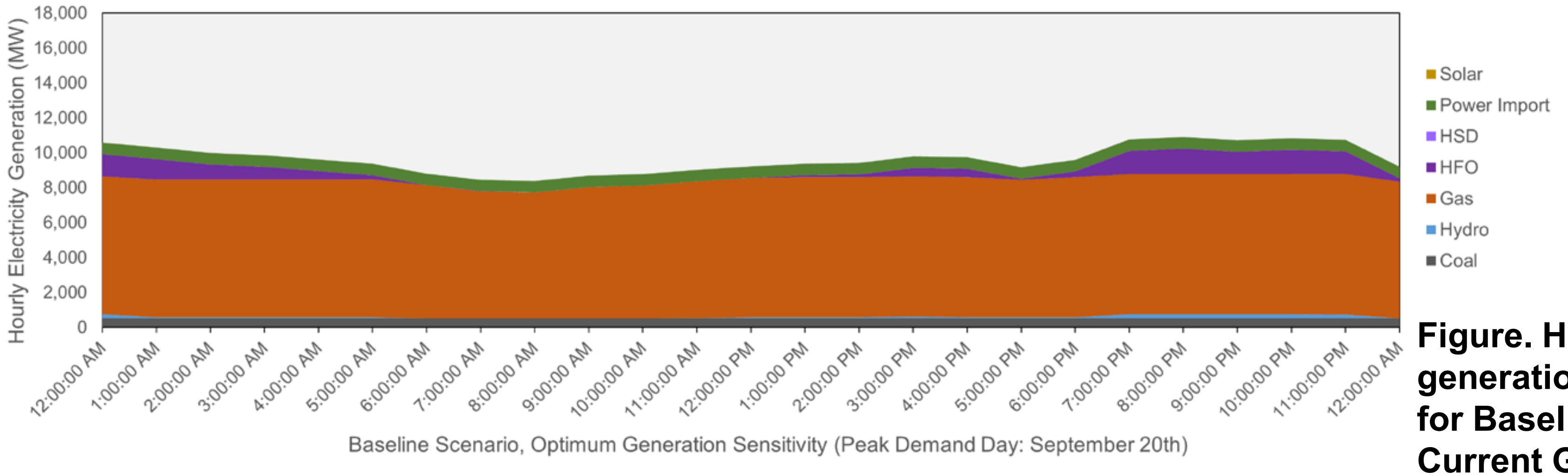
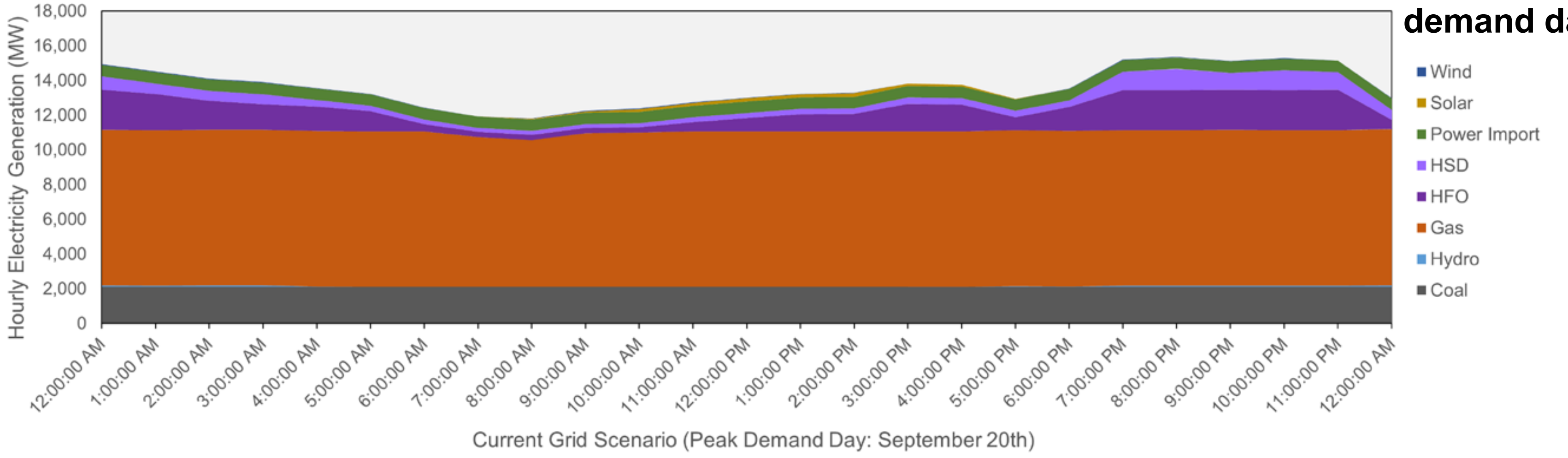


Figure. Hourly electricity generation (MW) by fuel for Baseline (top) and Current Grid (bottom) scenarios on peak demand day



- Daily demand in the Bangladesh grid peaks in the evening, between 6pm and 11pm.
- In the Current Grid scenario, this daily peak demand is met by a combination of HFO, HSD, and imports, while HSD is not a factor in the Baseline scenario.

Current Grid Scenario: Operating Costs

- Annual operating costs increase for the Current Grid scenario due to the higher electricity demand that needs to be met, and the subsequent increase in fossil fuel energy generation (i.e., an increase in coal, gas, HFO, and the addition of HSD to the dispatch mix).

- Compared to the Baseline scenario, the per unit energy cost ($/MWh) increases in the Current Grid scenario from approximately $36.83/MWh to approximately $37.94/MWh. This increase in energy costs is driven by the increase in fossil fuel generation, as renewable energy generation remains low in the Current Grid scenario.

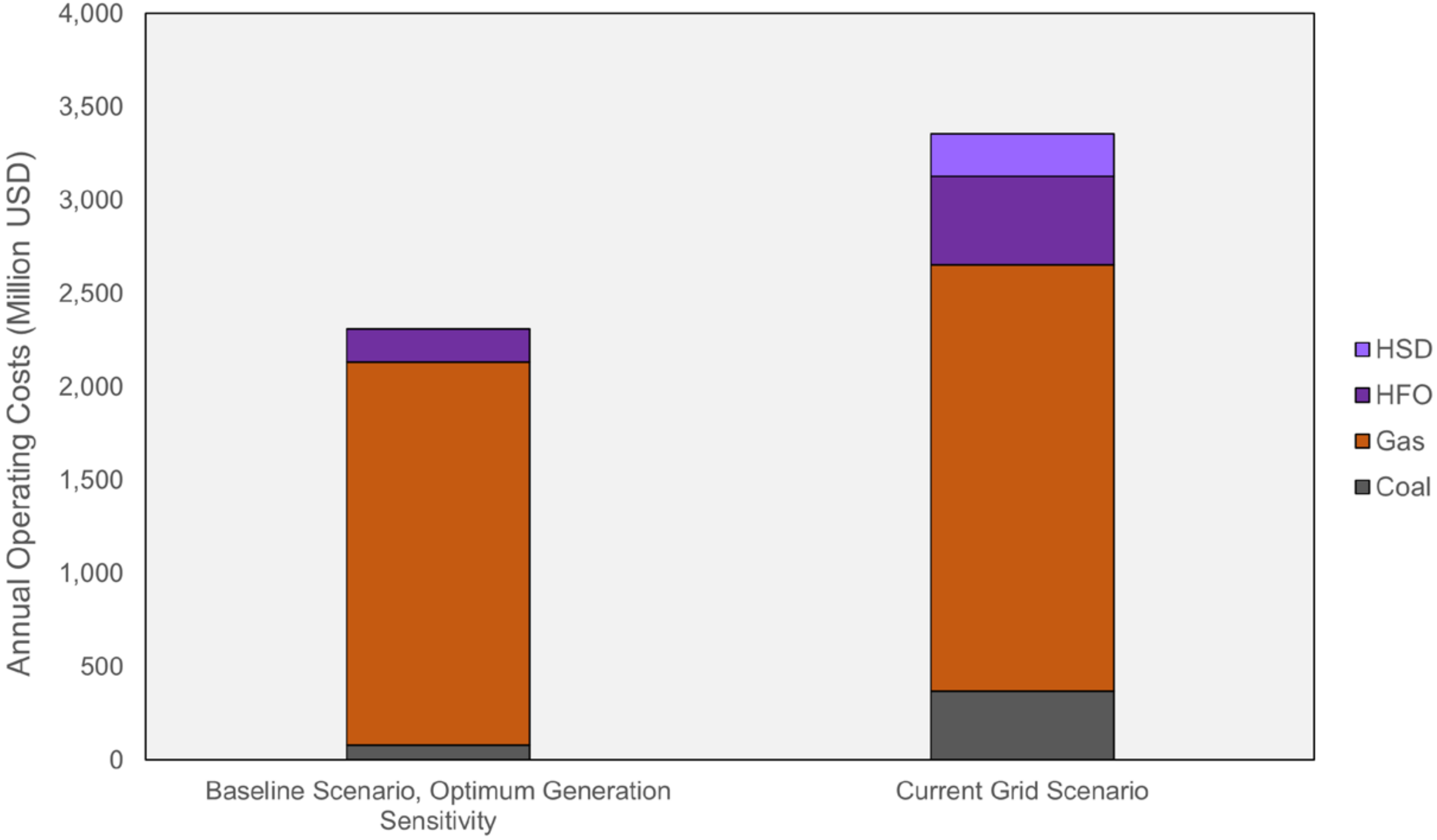


Figure. Annual operating costs (million USD) by fuel for Baseline and Current Grid scenarios

Current Grid Scenario: Annual Emissions

- To meet the 41% increase in annual electricity demand from the Baseline scenario to the Current Grid scenario, annual CO_2 emissions increase by 81%.

- In addition to the increase in overall CO_2 emissions, the CO_2 emissions per unit of electricity (kg/MWh) increases from approximately 1,005 kg/MWh in the Baseline scenario to approximately 1,285 kg/MWh in the Current Grid scenario.

- Per-unit emissions (kg/MWh) also increase for NO_x and SO_x for the Current Grid scenario compared to the Baseline scenario, attributed to the rise in coal power generation.

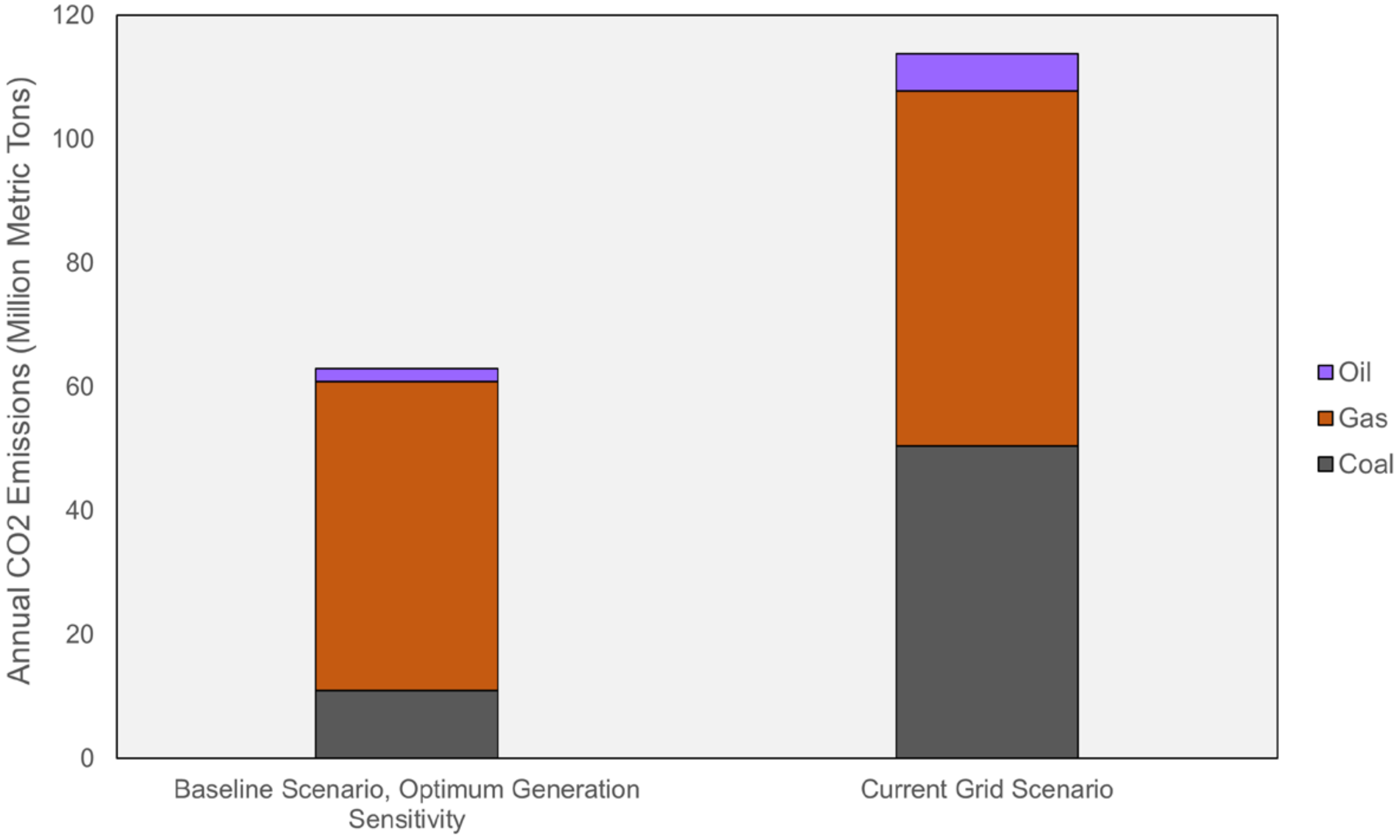


Figure. Annual CO_2 emissions (million metric tons) by fuel for Baseline and Current Grid scenarios

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ATS30 Scenario Results

ATS30 Scenario: Demand and Capacity

Demand: 188,000 GWh

Fuel	Installed Capacity (MW)
Coal	2,370
Natural Gas	15,800
Heavy Fuel Oil (HFO)	3,443
High-Speed Diesel (HSD)	1,380
Hydropower	230
Solar PV	3061
Wind	750
Imports	4,140
Nuclear	2,400
Total	**33,574**

Demand and capacities are based on data for 2018 provided by PGCB, data from BPDB's 2017-2018 annual report, ATS30 targets from the IEPMP 2023, and demand data for the ATS In-Between Scenario from the IEPMP 2023.

ATS30 Scenario: Annual Generation

- In the ATS30 scenario, annual solar PV generation is 3,783 GWh and annual wind generation is 1,907 GWh. Including hydropower, renewable energy accounts for 3% of electricity demand, only an increase of 1% from the Current Grid scenario.

- In the ATS30 scenario, the addition of nuclear energy to the Bangladesh grid contributes approximately 21,024 GWh (11%) of electricity annually.

- In the ATS30 scenario, coal generation decreases by approximately 29% compared to the Current Grid scenario as its electricity contribution is replaced with more imports, renewables, and natural gas.

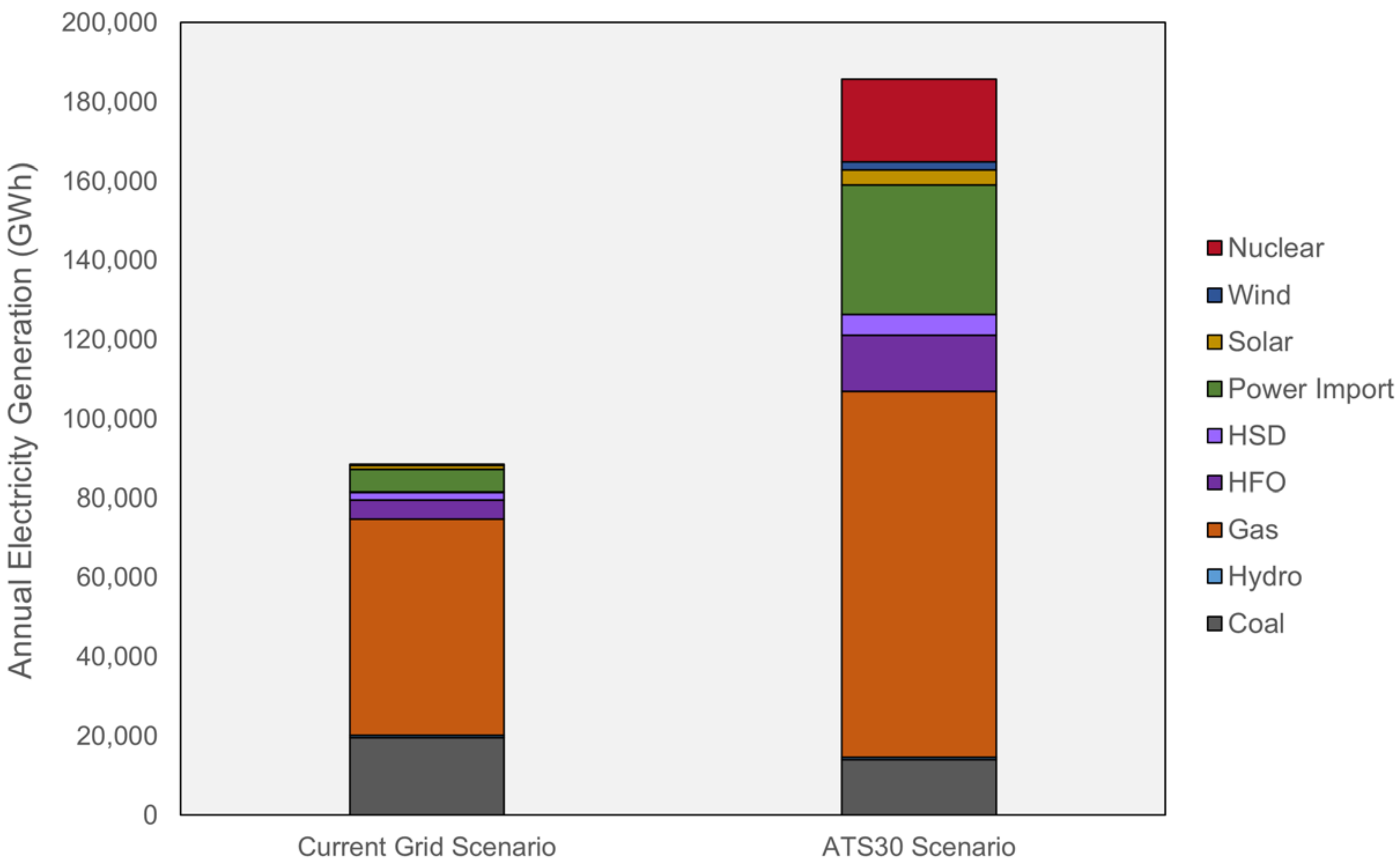


Figure. Annual electricity generation (GWh) by fuel for Current Grid and ATS30 scenarios

ATS30 Scenario: Hourly Generation

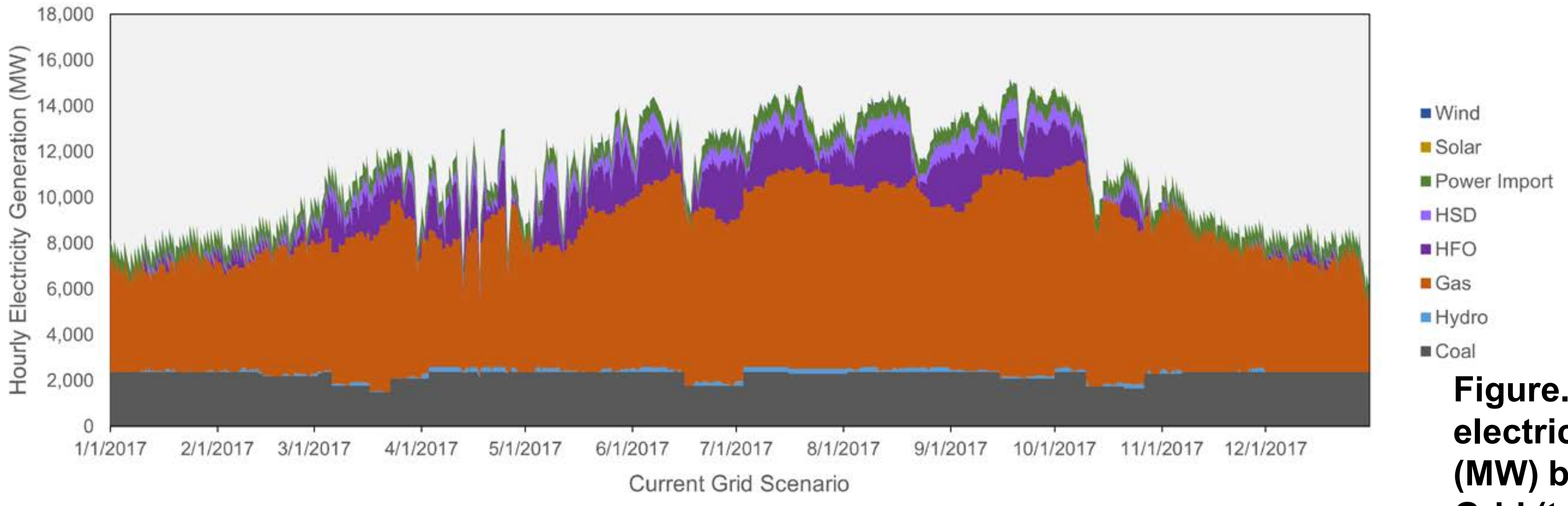
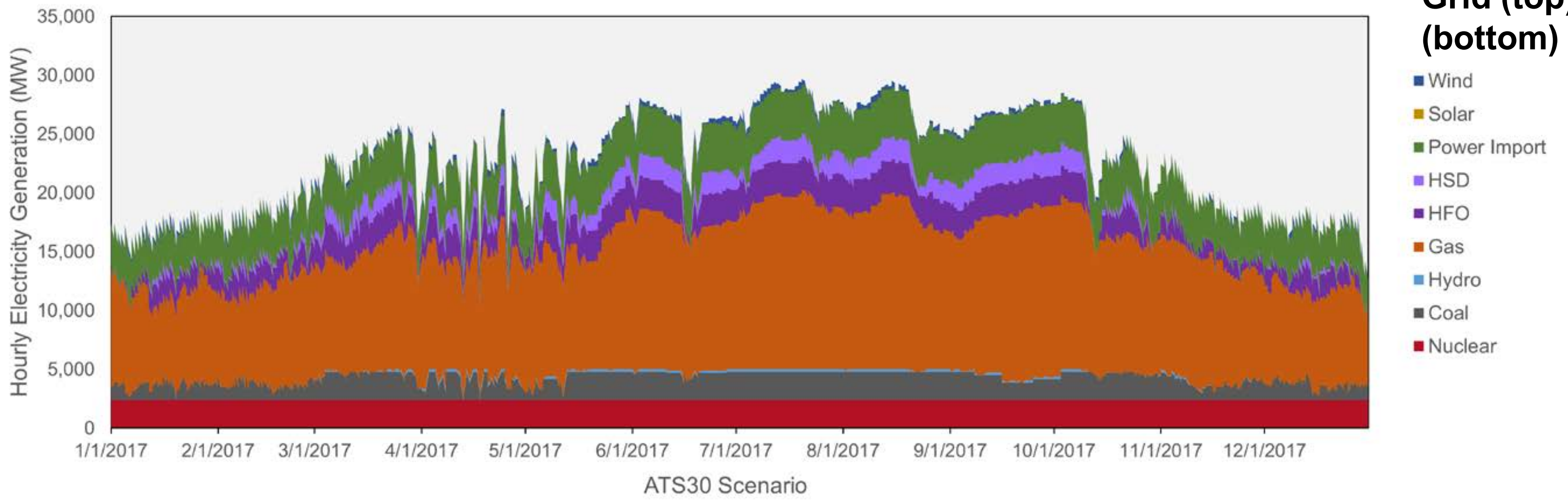


Figure. Hourly electricity generation (MW) by fuel for Current Grid (top) and ATS30 (bottom) scenarios



- ❖ Nuclear energy provides constant baseload power of 2,400 MW for every hour in the ATS30 scenario.
- ❖ In the ATS30 scenario, there is unserved energy of approximately 2,185 GWh (roughly 1.2% of annual electricity demand).

ATS30 Scenario: Peak Demand Day

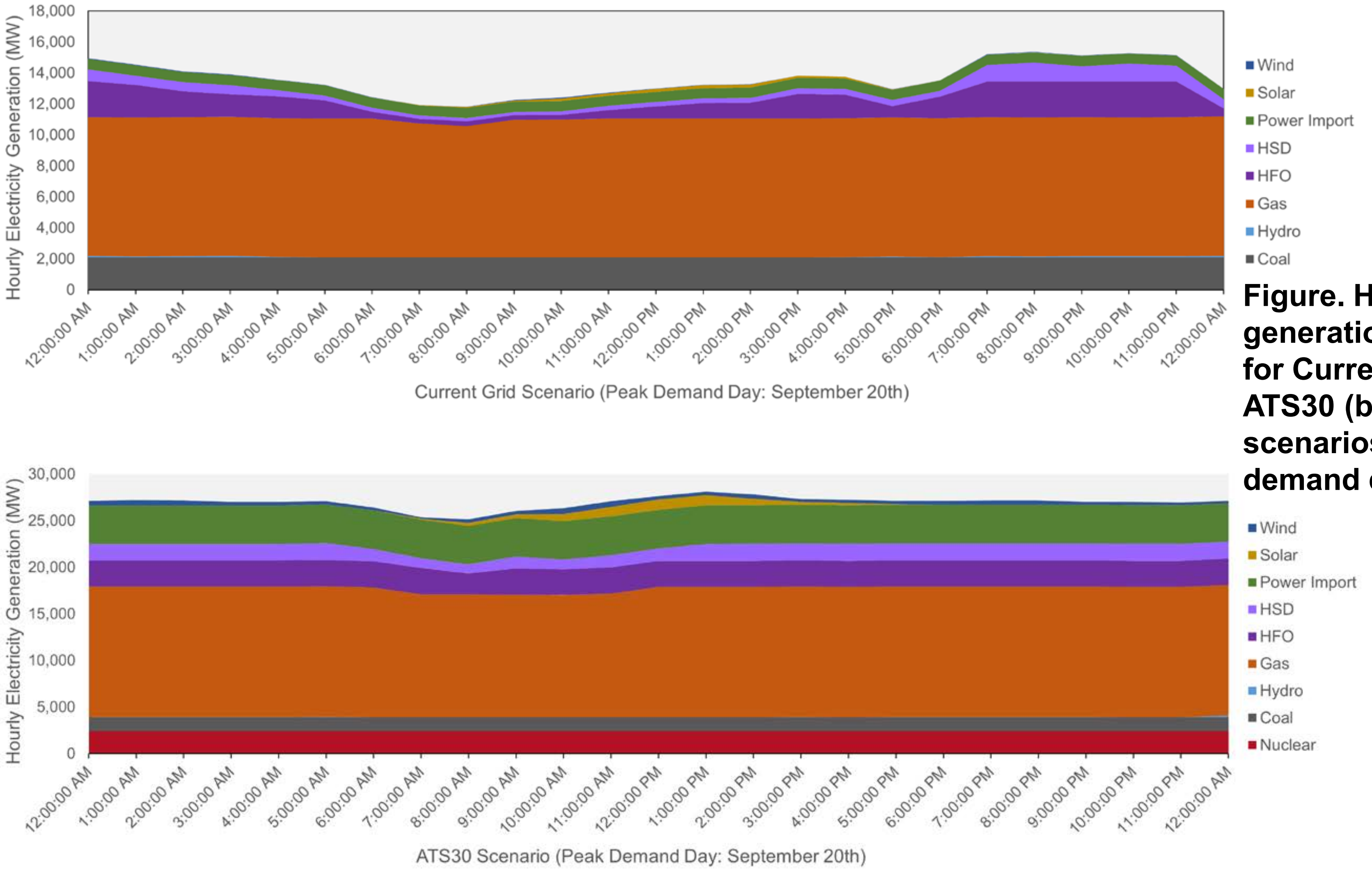


Figure. Hourly electricity generation (MW) by fuel for Current Grid (top) and ATS30 (bottom) scenarios on peak demand day

- In the ATS30 scenario, solar PV and wind contribute to meeting peak electricity demand at midday.
- However, the electricity grid is not able to meet overall peak electricity demand in the ATS30 scenario due to insufficient transmission capacity.

ATS30 Scenario: Operating Costs

- The per unit energy cost ($/MWh) in the ATS30 scenario is approximately $37.52/MWh, which is a slight decrease compared to the Current Grid scenario and a slight increase compared to the Baseline scenario.

- The overall annual operating costs do not increase in proportion to the increase in electricity demand from the Current Grid scenario to the ATS30 scenario due to the addition of lower cost renewables such as solar PV and wind.

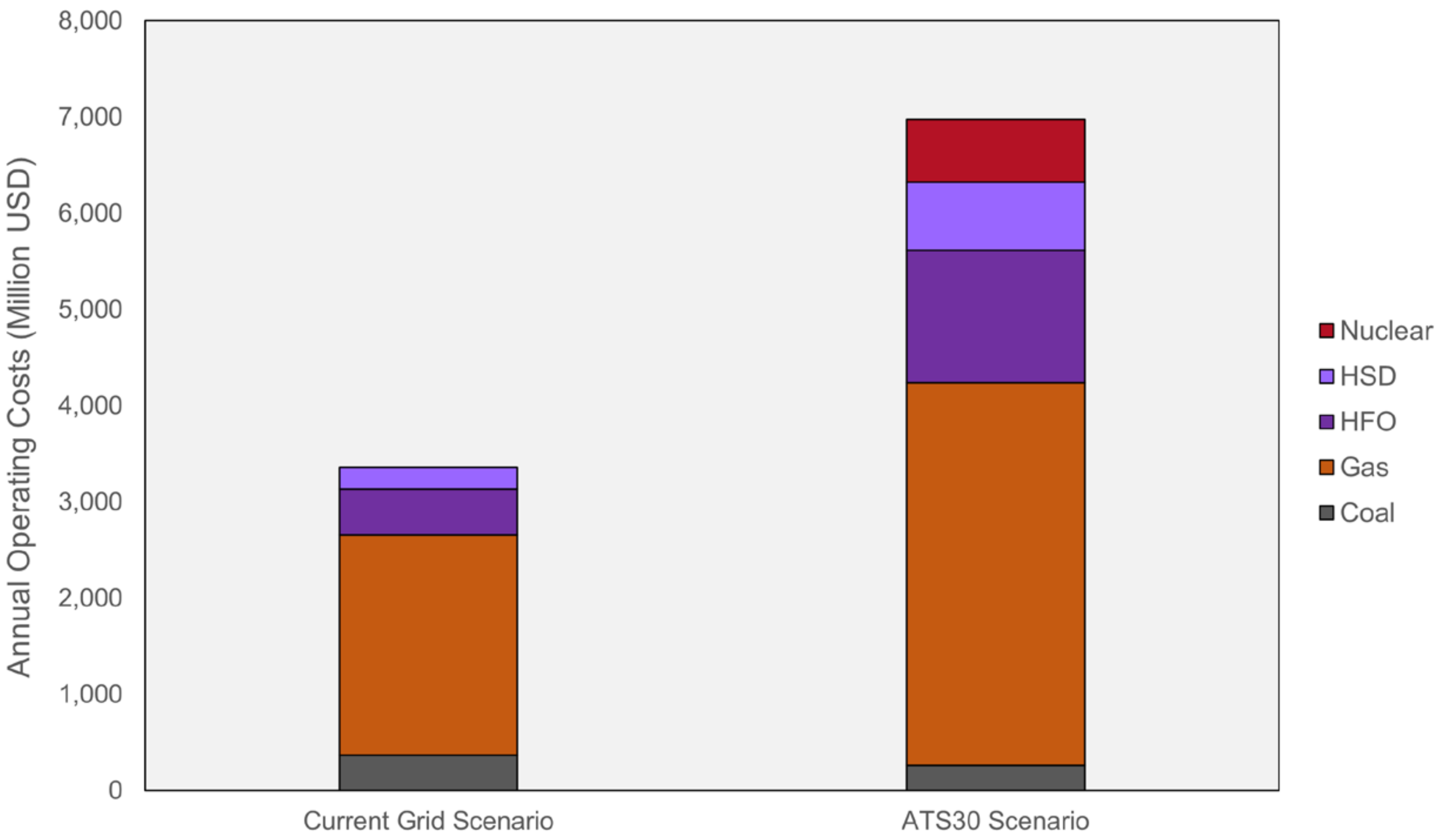


Figure. Annual operating costs (million USD) by fuel for Current Grid and ATS30 scenarios

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ATS30 Scenario: Annual Emissions

- Despite the increase in overall CO_2 emissions, the CO_2 emissions per unit of electricity (kg/MWh) decreases from approximately 1,285 kg/MWh in the Current Grid scenario to approximately 837 kg/MWh in the ATS30 scenario.

- The overall annual emissions do not increase in proportion to the increase in electricity demand from the Current Grid scenario to the ATS30 scenario due to the addition of zero-emissions resources such as solar PV, wind, and nuclear.

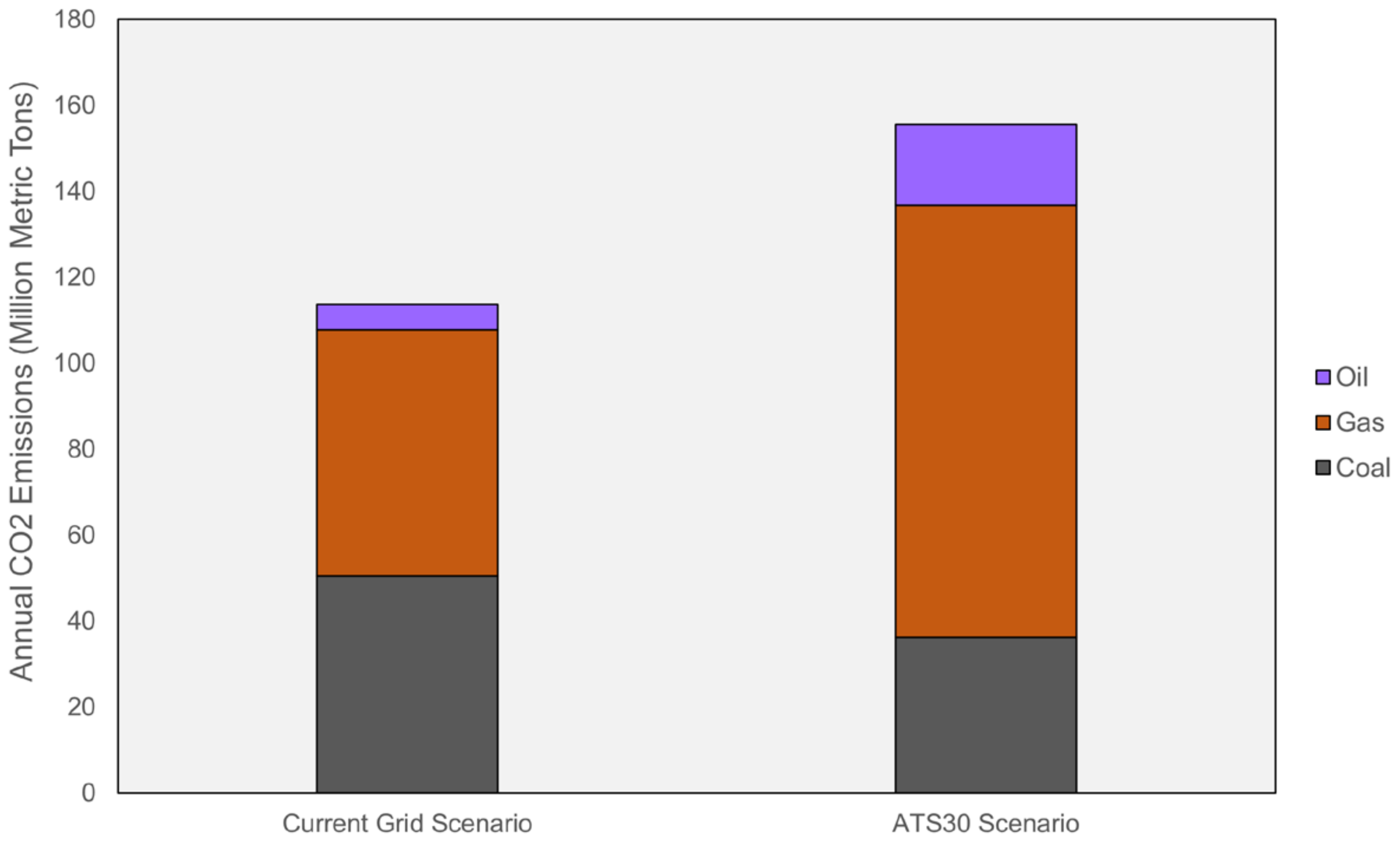


Figure. Annual CO_2 emissions (million metric tons) by fuel for Current Grid and ATS30 scenarios

ATS30 Scenario: RE Contribution by Region

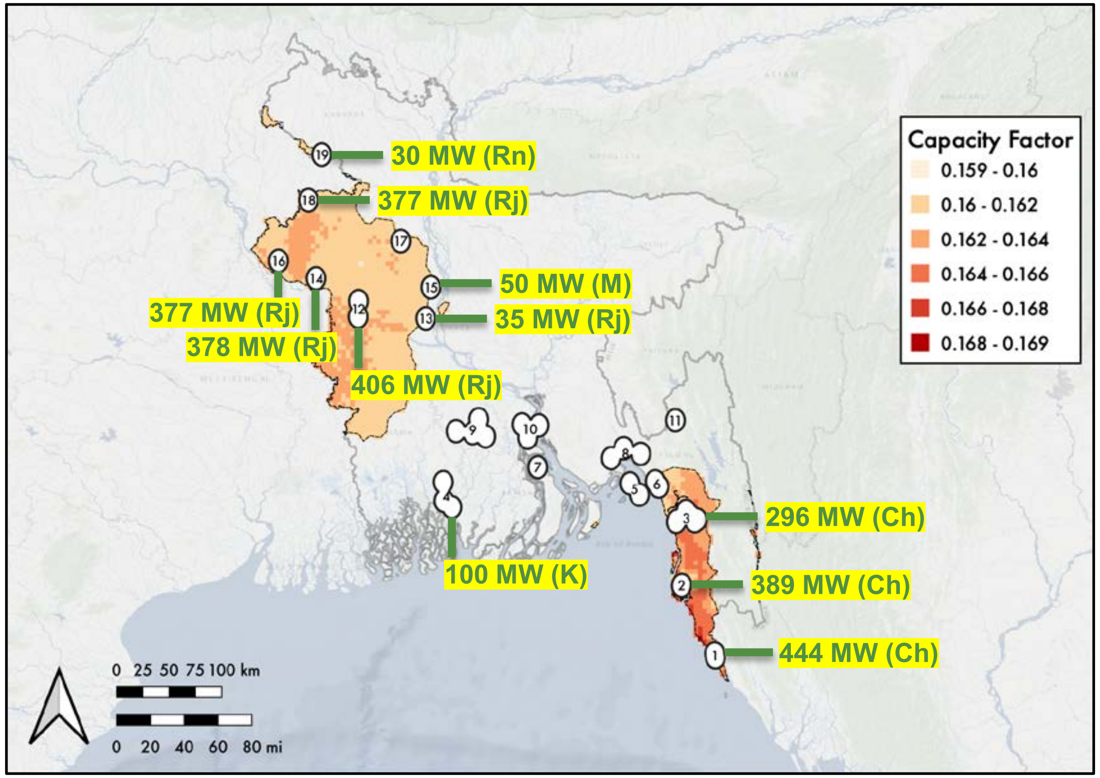


Figure. Modeled solar PV capacity by region for ATS30 scenario

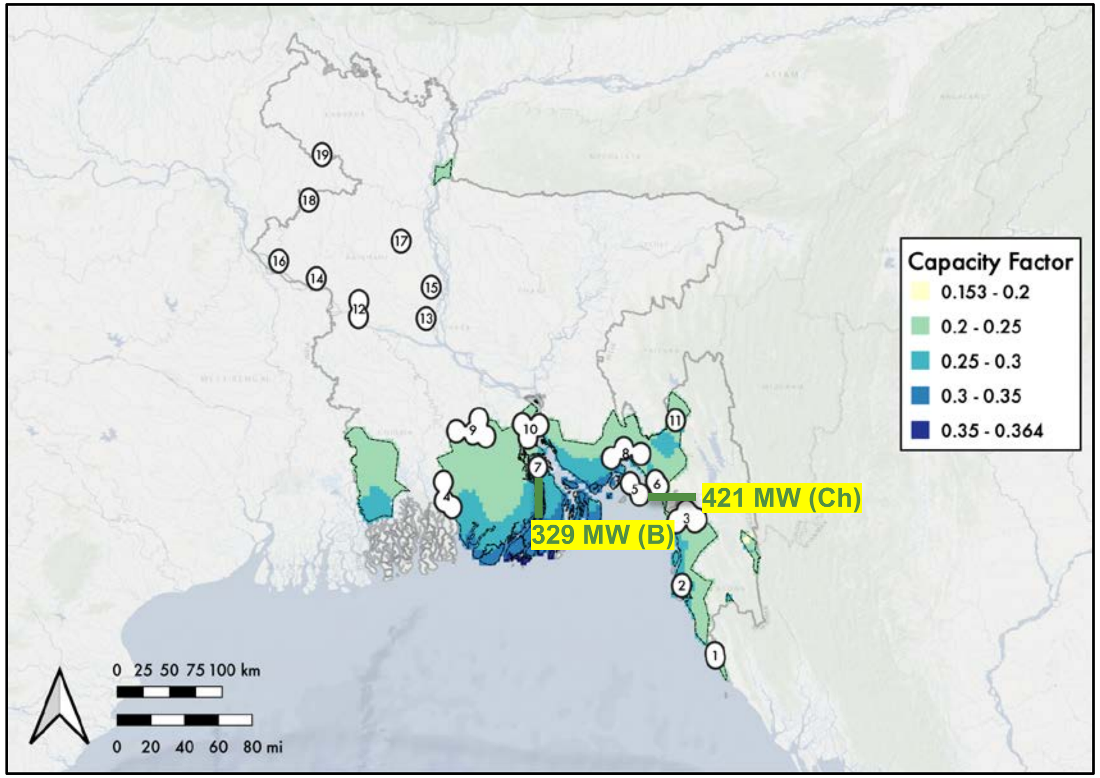
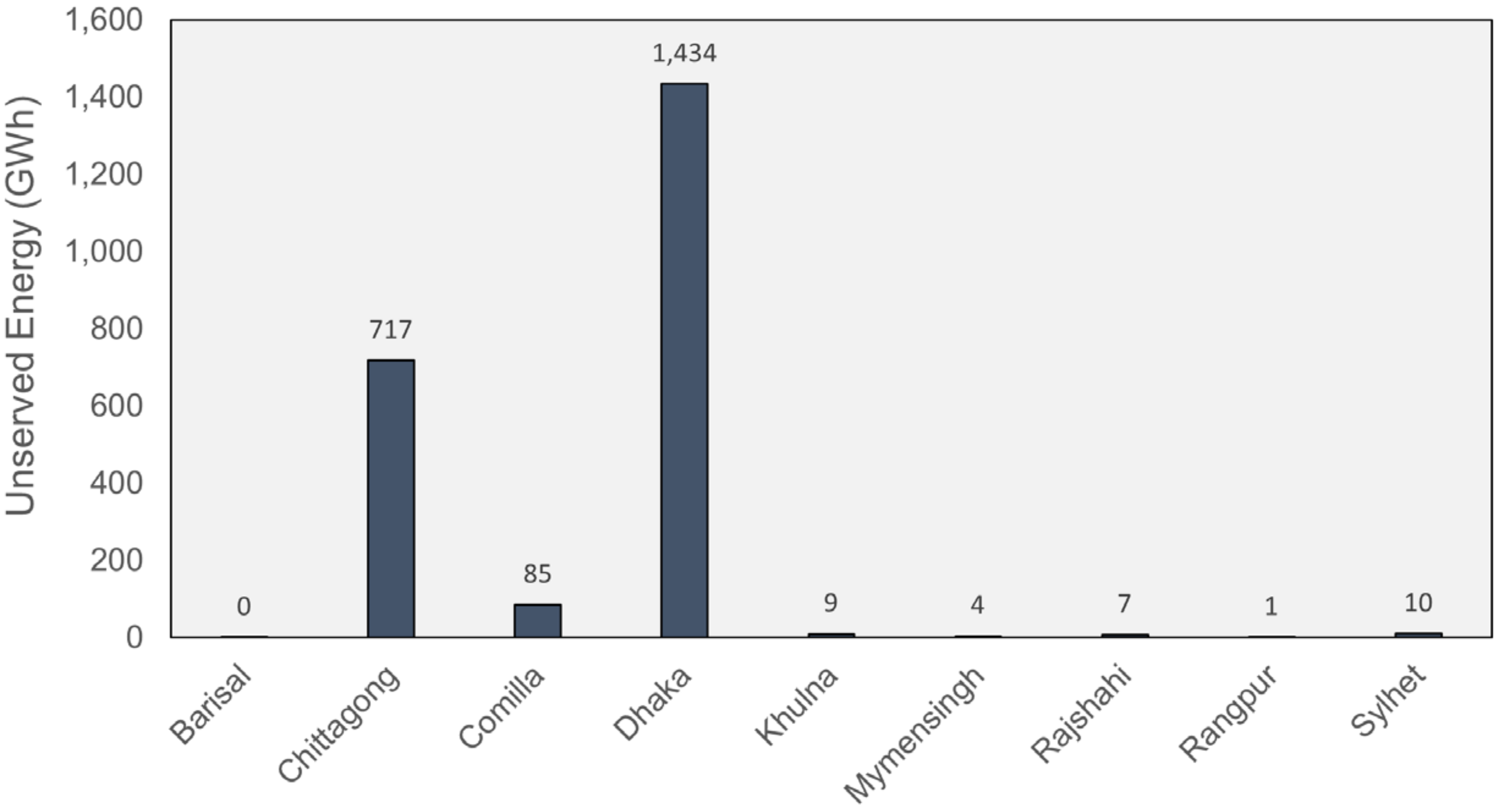


Figure. Modeled wind capacity by region for ATS30 scenario

Solar PV and wind capacities are assigned to renewable energy zones based on regions with the least cost and according to available technical potential capacities, in order to meet the ATS30 targets. Locations for existing projects are also accounted for.

ATS30 Scenario: Unserved Energy by Region

Figure. Annual unserved energy for each region in Bangladesh in ATS30 scenario



- ❖ The total annual unserved energy in Bangladesh is approximately 2,265 GWh in the ATS30 scenario due to insufficient transmission capacity.
- ❖ Most of the unserved energy occurs in the Dhaka region (63%), followed by the Chittagong region (32%).

ATS30 Scenario: Interregional Transmission Congestion

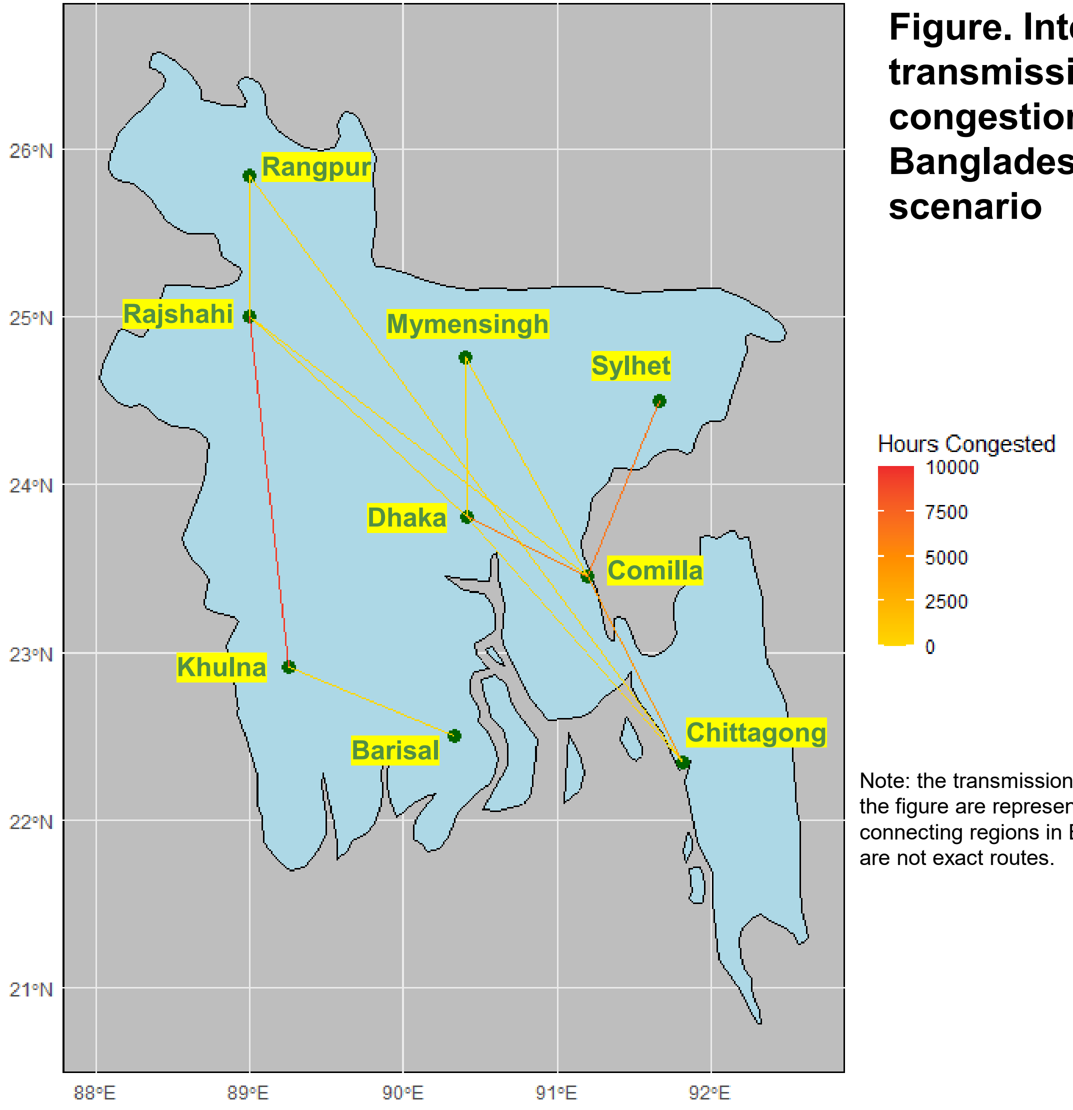


Figure. Interregional transmission congestion in Bangladesh in ATS30 scenario

Note: the transmission routes shown in the figure are representative lines connecting regions in Bangladesh and are not exact routes.

- Interregional transmission congestion is highest between the Rajshahi and Khulna regions (9,402 total hours for all interregional transmission lines combined), followed by the Sylhet-Comilla corridor (6,442 total hours) and the Dhaka-Comilla corridor (5,792 total hours).
- Intraregional transmission congestion is highest within the Dhaka region, followed by the Khulna region and the Rajshahi region.

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Key Takeaways

Key Takeaways: Baseline Scenario

Scenario	Year	Solar PV Capacity (MW)	Onshore Wind Capacity (MW)	Details
Baseline	2018	3	0	Based on data provided by PGCB and BPDB

- ✓ A cost-optimal Baseline scenario dispatch for the Bangladesh grid results in higher coal, gas, and power imports and lower hydro, HFO, and HSD generation (with low levels of wind and solar in the system).
- ✓ A cost-optimal Baseline scenario dispatch for the Bangladesh grid results in a flatter generation profile for coal and hydro, which act as baseload sources of electricity.
- ✓ A cost-optimal Baseline scenario dispatch for the Bangladesh grid results in annual operating cost savings of approximately 0.9 billion USD compared to historical generation patterns.

Key Takeaways: Current Grid Scenario

Scenario	Year	Solar PV Capacity (MW)	Onshore Wind Capacity (MW)	Details
Current Grid	2024	700	60	Based on data provided by PGCB and BPDB, including additional coal and renewable energy capacity.

- ✓ A cost-optimal Current Grid scenario dispatch for the Bangladesh grid results in lower HFO and HSD generation and higher solar and wind generation compared to what is currently reported in the BPDB annual reports, suggesting that there is room for increased cost-effective integration of renewables in the immediate future (however, overall levels of renewable energy penetration remain low).

- ✓ The Current Grid scenario, with high levels of fossil fuels and low levels of renewables, results in higher per-unit costs of energy compared to the Baseline and ATS30 scenarios. This result suggests that increasing the deployment of renewables further could help bring down overall energy costs.

Key Takeaways: ATS30 Scenario

Scenario	Year	Solar PV Capacity (MW)	Onshore Wind Capacity (MW)	Details
ATS30	2030	3061	750	Based on the Advanced Technology Scenario (ATS) projections in the IEPMP

- ✓ The total annual operating costs and emissions do not increase in proportion to the increase in electricity demand from the Current Grid scenario to the ATS30 scenario due to the addition of lower cost and cleaner renewables such as solar PV and wind.
- ✓ In the ATS30 scenario, there is unserved energy of approximately 2,185 GWh (roughly 1.2% of annual electricity demand) due to transmission congestion in particular regions. Unserved energy is highest in the Dhaka region.
- ✓ It could be feasible for Bangladesh to meet the ATS30 targets without any unserved energy with a modest expansion of transmission capacity; however, renewable energy only comprises approximately 3% of annual electricity generation in this scenario, which is still significantly lower than the targets set by the government. Thus, there is room to increase the buildout of renewables further.

Renewable Energy Desk for Grid Operators

Real-Time Desk | **Renewable Energy Desk** | Generation Desk | Transmission Desk

Renewable Energy Desk

Technology
- T&D integration
- DER dashboard
- Composite Behind the meter/ Distributed energy resources load
- IBR modeling

Real-Time Operation
- Economic dispatch
- Reserves
- Load forecasting
- Renewable forecasting

Operation Planning
- Medium-term generator scheduling & dispatch
- Grid analysis
- Distribution network reliability
- Distributed energy resources limitation on distribution
- Coordination

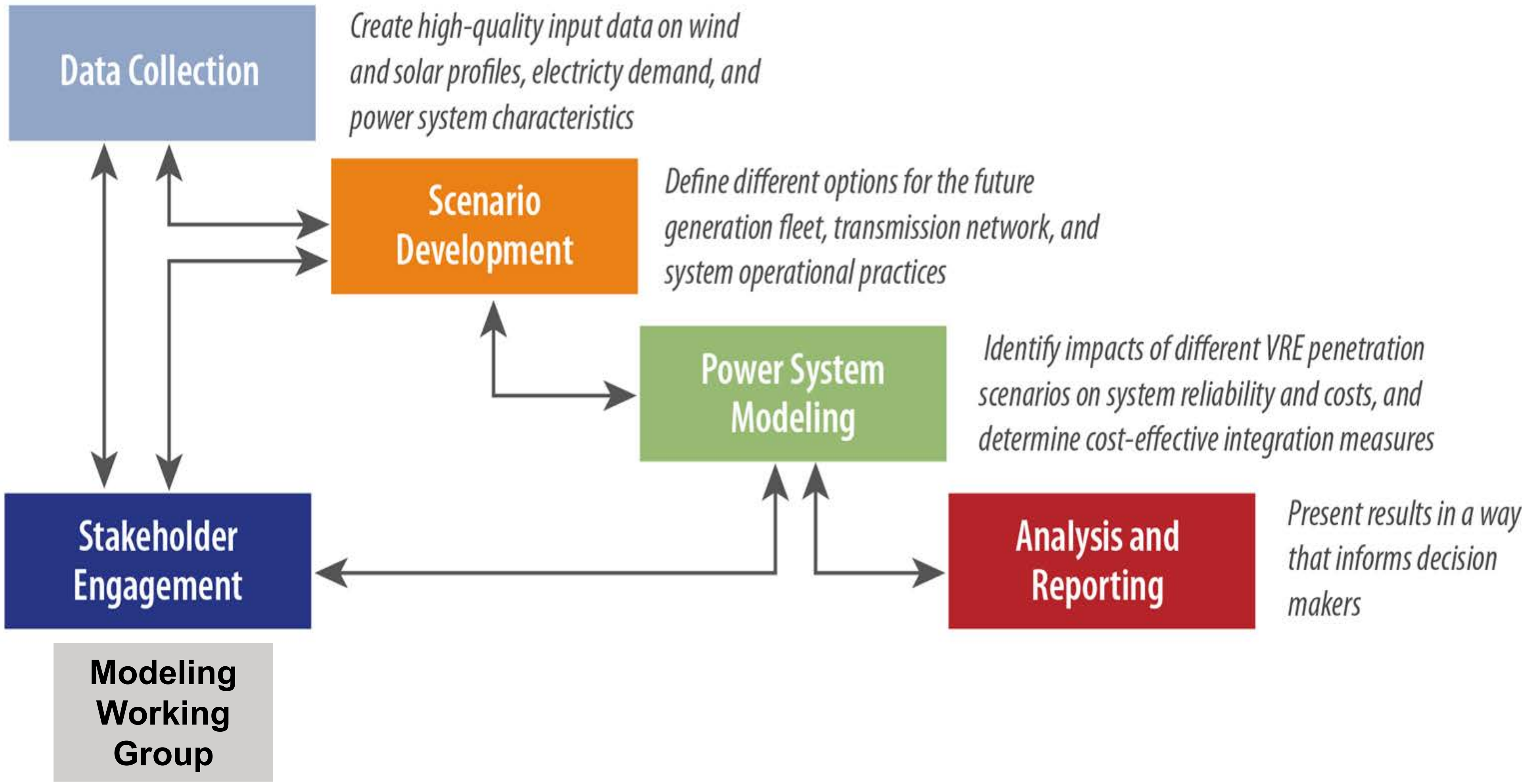
Capacity Expansion
- Integrated resource planning platform
- Flexibility and reserve
- Renewable data
- Load modeling

Workforce & Facility
- In-house energy management system support
- Disaster control center
- Cybersecurity
- Training

Regulatory
- Grid flexibility options
- Workforce development
- Tariff structure
- RE forecasting framework
- Plan/project approval

Source: De Silva et al. (2024)

Grid Integration Study Workflow



Source: Katz and Chernyakhovskiy (2020)

Thank you

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