Technoeconomic energy system data for modeling of India and the GCC countries

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Data Note

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Abstract

India has seen rapid increases in GDP, energy access, and population in recent decades, more than doubling its overall energy consumption since 2000. Meanwhile, India produces approximately 70% of its electricity from coal. With electricity demand only projected to grow in the coming years, the Government of India has pledged to install 450 GW of renewable energy by 2030. The Gulf Cooperation Council (GCC) countries[1], meanwhile, have comparatively small populations with excellent renewable energy resources, particularly solar. The ability to trade power between these two regions could potentially provide India with a highly reliable carbon-free power source. At the same time, it can motivate the shift to low carbon economy in the GCC and add a new market for its solar power. The provided data in this article relate to the current makeup of the energy systems of both regions, renewable resource potentials, and projections of future demand. The data have been compiled from numerous sources, mainly government and international agencies.

[1] GCC countries are Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates

Specifications Table

Subject area	*Energy and Sustainability*
More specific subject area	*Energy resource and capacity modelling*
Type of data	*Tables*
How data was acquired	*Databases, reports, analyses, and articles from various government agencies, international agencies, research institutions, and news outlets*
Data format	*Raw and analyzed*
Experimental factors	
Experimental features	
Data source location	*India, Bahrain, Kuwait, Oman, Saudi Arabia, Qatar, United Arab Emirates*
Data accessibility	*With the article and public repository: PLEXOS World 2015 https://doi.org/10.7910/DVN/CBYXBY*

Value Of The Data

- This compilation of data provides a resource for building a techno-economic energy model of India and the Gulf Cooperation Council (GCC) countries, namely Bahrain, Kuwait, Oman, Saudi Arabia, Qatar and the United Arab Emirates (UAE).
- The data can assist in energy system planning and expansion to 2050.
- Data collection for techno-economic modelling is often a painstaking process, requiring accurate data from many sources. The data provided in this article are relevant to any energy model in the aforementioned countries, thus allowing researchers to focus on their specific research goals.

Data

The data in this paper have been compiled to assist in building a base-level energy model for India and the GCC countries. The data have been collected from various country-specific and international sources. The data include installed and

planned generation and transmission capacity, renewable resource potentials, relevant costs, current and projected power demand, and other techno-economic parameters. Most datasets for India are region-specific. The regions used are according to regional power grids, as shown in Figure 1.

For the GCC countries, the data are on the national level except for Saudi Arabia which is split into four regions (R1: Central region, R2: Eastern region, R3: Southern Region and R4: Western Region). These four regions reflect the structure of the electricity system in Saudi Arabia and Saudi Electricity Company's (SEC's) classification as shown in Figure 2.

Table 1. Description of datasets provided in the article

Title	Description
Table 2	Installed non-renewable generation capacity in India
Table 3	Renewable installed capacities in India by state and region
Table 4	GCC installed capacity by fuel type
Table 5	GCC installed capacity by technology
Table 6	Planned coal generation capacity in India to 2025
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Table 16	Capital cost of new transmission in India
Table 17	Availability factors
Table 18	Hydropower capacity factors in India

Power generation

Non-renewable capacity in India

Table 2 displays non-renewable power generation capacity by region as of September 30, 2020 from [3]. Large hydro refers to hydropower plants greater than 25 MW. The data do not include captive capacity.

Table 2. Installed non-renewable generation capacity in India (GW)

Region	Coal	Gas	Diesel	Nuclear	Large Hydro
Northern Region	53.44	5.78	0	1.62	20.04
Western Region	73.74	10.81	0	1.84	7.56
Southern Region	44.36	6.49	0.43	3.32	11.77
Eastern Region	27.29	0.1	0	0	4.64
Northeastern Region	0.77	1.78	0.04	0	1.69

Renewable capacity in India

Table 3 displays installed renewable capacity in India as of December 31, 2019 (except biomass), according to [4]. Biomass capacities are as of October 31, 2020 according to [5]. Biomass includes independent power plants, bagasse cogeneration, and non-bagasse cogeneration. Small hydro includes hydropower plants below 25 MW.

Table 3. Renewable installed capacities in India by state and region (MW)

Region/State	Grid-connected Solar	Rooftop Solar	Wind	Small hydro	Biomass
Eastern Region	**695.07**	**77.97**	**0**	**289.99**	**508.14**
Bihar	149.35	6.94	0	70.70	124.7
Jharkhand	38.40	13.57	0	4.05	4.3
Odisha	397.84	14.27	0	64.63	59.22
Sikkim	0.07	0.07	0	52.11	0
West Bengal	109.41	43.12	0	98.5	319.92
Northeast Region	**63.47**	**44.04**	**0**	**286.35**	**15.80**
Arunachal Pradesh	5.61	4.34	0	131.11	0
Assam	41.23	30.56	0	34.11	2
Manipur	4.58	4.55	0	5.45	0
Meghalaya	0.12	0.12	0	32.53	13.80
Mizoram	1.52	1.43	0	36.47	0
Nagaland	1.00	0.08	0	30.67	0
Tripura	9.41	2.96	0	16.01	0
Northern Region	**7646.15**	**688.45**	**4299.72**	**1597.31**	**3062.04**
Chandigarh	36.99	29.98	0	0	0
Delhi	156.12	109.80	0	0	0
Haryana	249.27	118.47	0	73.50	210.66
Himachal Pradesh	32.57	15.46	0	906.51	9.20
Jammu & Kashmir	19.30	10.81	0	180.48	0
Punjab	947.10	67.85	0	173.55	473.45
Rajasthan	4844.21	119.50	4299.72	23.85	121.25
Uttar Pradesh	1045.10	140.87	0	25.1	2117.26
Uttarakhand	315.49	75.71	0	214.32	130.22
Southern Region	**18390.31**	**491.95**	**18321.72**	**1878.78**	**3545.99**
Andhra Pradesh	3559.02	88.03	4092.45	162.11	483.67
Karnataka	7274.92	131.83	4753.40	1280.73	1887.3
Kerala	141.75	41.75	62.50	222.02	2.27
Puducherry	5.51	1.92	0	0	0
Tamil Nadu	3788.36	155.78	9285.27	123.05	1012.65
Telangana	3620.75	72.64	128.10	90.87	160.1
Western Region	**6922.6**	**582.31**	**14879.44**	**613.89**	**3013.95**
Chhattisgarh	231.35	10.39	0	76.00	244.9

Dadra & Nagar Haveli	5.46	0.48	0	0	0
Daman & Diu	16.56	0.39	0	0	0
Goa	4.78	3.83	0	0.05	0
Gujarat	2763.55	301.71	7359.22	62.35	77.3
Madhya Pradesh	2237.48	49.40	2519.89	95.91	107.35
Maharashtra	1663.42	216.11	5000.33	379.58	2584.4

GCC installed capacity

The power installed capacity data were obtained from [6] and calibrated with data from official agencies in each country for the base modeling year 2015 [7]–[9]. Table 4 shows a summary of installed capacity, while Table 5 elaborates on these figures, breaking them down by technology and, in the case of Saudi Arabia, by region.

Table 4. GCC installed capacity (GW) by fuel type

Country	Crude oil	Heavy Fuel Oil	Coal	Gas	Diesel	Solar	Total
Saudi Arabia	19.42	20.93	0	57.91	8.61	0	106.87
UAE	0	0.31	0	28.35	0.03	0.06	28.75
Qatar	0	0	0	8.56	0	0	8.56
Oman	0	0	0	7.74	0	0	7.74
Kuwait	8.75	0	0	8.43	0	0	17.18
Bahrain	0	0	0	3.92	0	0	3.92

Table 5. GCC installed capacity (GW) by technology

Country	Region	Fuel	Technology	Capacity
UAE	**National**	Heavy Fuel	steam cycle	0.31
		Natural gas	steam cycle	1.78
		Natural gas	open cycle gas turbine	5.64
		Natural gas	Combined cycle	20.93
		Diesel	Diesel Engine	0.03
		Solar	Solar Thermal (CSP)	0.06
		Total Capacity		**28.76**
Saudi Arabia	**Central Region**	Heavy Fuel	steam cycle	0.35
		Heavy Fuel	open cycle gas turbine	0.6
		Natural gas	open cycle gas turbine	4.97
		Natural gas	Combined cycle	1.2
		Crude Oil	steam cycle	0.46
		Crude Oil	open cycle gas turbine	7.89
		Crude Oil	combined cycle	1.65
		Diesel	steam cycle	0.35
		Diesel	open cycle gas turbine	1.04
		Diesel	Diesel Engine	0.02
	Eastern Region	Heavy Fuel	steam cycle	0.62
		Heavy Fuel	Diesel Engine	0.07
		Natural gas	steam cycle	13.45
		Natural gas	open cycle gas turbine	8.71
		Natural gas	Combined cycle	8.42
		Crude Oil	open cycle gas turbine	0.68
		Diesel	open cycle gas turbine	1.16
		Diesel	Diesel Engine	0.11
	Southern Region	Crude Oil	steam cycle	1.02
		Crude Oil	open cycle gas turbine	1.11
		Diesel	open cycle gas turbine	2.83
		Diesel	Diesel Engine	0.22
	Western Region	Heavy Fuel	steam cycle	18.49
		Heavy Fuel	open cycle gas turbine	0.8
		Natural gas	open cycle gas turbine	0.23
		Crude Oil	steam cycle	1.57

		Crude Oil	open cycle gas turbine	3.49
		Crude Oil	combined cycle	1.55
		Diesel	open cycle gas turbine	2.55
		Diesel	Diesel Engine	0.34
		Total Capacity		**85.94**
Oman	**National**	Natural gas	open cycle gas turbine	2.6
		Natural gas	Combined cycle	5.15
		Total Capacity		**7.74**
Kuwait	**National**	Crude oil	steam cycle	8.25
		Crude oil	open cycle gas turbine	0.5
		Natural gas	steam cycle	0.72
		Natural gas	open cycle gas turbine	3.87
		Natural gas	Combined cycle	3.84
		Total Capacity		**17.18**
Qatar	**National**	Natural gas	open cycle gas turbine	2.05
		Natural gas	Combined cycle	6.51
		Total Capacity		**8.56**
Bahrain	**National**	Natural gas	steam cycle	0.13
		Natural gas	open cycle gas turbine	0.7
		Natural gas	Combined cycle	3.1
		Total Capacity		**3.92**

Planned capacity

Table 6 shows new coal power plant capacity in India expected to go online in each region by 2025 according to [10]–[32]. Due to data gaps, some expected years of commissioning have been assumed. In these cases, which have been marked with an asterisk in Table 6, planned capacity can be considered to be allocated to a specific year. Total values of planned capacity to 2025 remain accurate (i.e. without regard to commissioning year).

Table 6. Annual planned coal generation capacity in India to 2025 (GW)

Expected Commissioning Year	Eastern Region	Northeastern Region	Northern Region	Southern Region	Western Region
2020	3.58	0	0	0	1.60
2021	1.98*	0	7.26*	8.92*	1.40
2022	5.32*	0	1.32	0	2.80*
2023	0	0	1.40	3.60	0
2024	0	0	0	0	0
2025	0	0	1.40	0	0
Total	10.88	0	11.38	12.52	5.8

Table 7 displays all planned nuclear capacity to 2025, according to [33]–[37]. Each value is a capacity addition in the given year and region.

Table 7. Planned nuclear generation capacity to 2025 in India (GW)

Expected Commissioning Year	Eastern Region	Northeastern Region	Northern Region	Southern Region	Western Region
2020	0	0	0	0	0
2021	0	0	0	0.5	1.4
2022	0	0	0	0	0
2023	0	0	1.4	2	0
2024	0	0	0	0	0
2025	0	0	1.4	2	0

Table 8 displays all planned nuclear capacity in the GCC with annual additions to 2025, according to [38], [39].

Table 8. Planned nuclear power annual capacity addition in UAE and Saudi Arabia (GW)

Expected Commissioning Year	UAE	SA
2020	0	0
2021	1.4	0
2022	1.4	0
2023	1.4	0
2024	1.4	0
2025	0	0
2040	0	18

Table 9. Renewable energy targets in GCC countries

Source: [40]

Country	Target	Year
KSA	9.5 GW of Renewables	2022
KSA	54 GW of renewables (41 GW solar, 9 GW Wind, 3 GW W2E and 1 GW Geo)	2040
UAE	24% clean energy	2021
UAE	7% of capacity (5 GW solar PV)	2030
Qatar	20% of capacity (1.8 GW)	2030
Kuwait	5% of generation	2020
Kuwait	15% of generation (5.7 GW CSP, 4.6 GW PV and 0.7 GW Wind)	
Bahrain	5% of capacity	2020

Renewable Resources in India

Table 10 displays renewable resource potentials in India aggregated by region [41].

Table 10. Estimated renewable resource potential in India by state and region (MW)

Region/State	Waste to Energy	Biomass power	Wind @ 100m	Small hydro	Cogeneration (bagasse)	Solar
Eastern Region	**253**	**1353**	**3095**	**1700**	**300**	**67879**
Bihar	73	619	0	527	300	12719
Jharkhand	10	90	0	228	0	18180
Odisha	22	246	3093	286	0	25780
Sikkim	0	2	0	267	0	4940
West Bengal	148	396	2	392	0	6260
Northeast Region	**16**	**258**	**0**	**2995**	**0**	**57782**
Arunachal Pradesh	0	8	0	2065	0	8650
Assam	8	212	0	202	0	14182
Manipur	2	13	0	100	0	10630
Meghalaya	2	11	0	230	0	5860
Mizoram	2	1	0	169	0	9090
Nagaland	0	10	0	182	0	7290
Tripura	2	3	0	47	0	2080
Northern Region	**451**	**3159**	**18770**	**8029**	**1900**	**336250**
Chandigarh	6	0	0	0	0	0
Delhi	131	0	0	0	0	2050
Haryana	24	1333	0	107	350	4560
Himachal Pradesh	2	142	0	3460	0	33840
Jammu & Kashmir	0	43	0	1707	0	111050
Punjab	45	0	0	578	300	2810
Rajasthan	62	0	18770	52	0	142310
Uttar Pradesh	176	1617	0	461	1250	22830
Uttarakhand	5	24	0	1664	0	16800
Southern Region	**313**	**3823**	**139983**	**5488**	**1200**	**107330**
Andhra Pradesh	123	578	44229	409	300	38440
Karnataka	0	1131	55857	3726	450	24700
Kerala	36	1044	1700	647	0	6110
Puducherry	3	0	153	0	0	0
Tamil Nadu	151	1070	33800	604	450	17670
Telangana	0	0	4244	102	0	20410
Western Region	**501**	**4734**	**140387**	**2911**	**1600**	**180900**

Chhattisgarh	24	236	77	1098	0	18270
Dadra & Nagar Haveli	0	0	0	0	0	0
Daman & Diu	0	0	0	0	0	0
Goa	0	26	1	5	0	880
Gujarat	112	1221	84431	202	350	35770
Madhya Pradesh	78	1364	10484	820	0	61660
Maharashtra	287	1887	45394	786	1250	64320

Transmission

Table 11 displays transmission capacity between India's regional grids as reported by the National Electricity Plan (NEP), 2017-2022 [42].

Table 11. Inter-regional transmission links in India (GW)

Inter-regional corridors	Capacity in 2017	Addition expected during 2017-2022	Required by 2021-22
West-North	15.42	21.3	36.72
Northeast-North	3	0	3
East-North	21.03	1.5	22.53
East-West	12.79	8.4	21.19
East-South	7.83	0	7.83
West-South	12.12	11.8	23.92
East-Northeast	2.86	0	2.86
Total	**75.05**	**43**	**118.05**

Installed transmission capacity for all of India was obtained from India's NEP [42]. Regional transmission capacities listed below have been inferred based on the proportion of installed generation capacity in each region, and should be used for reference purposes only [3]. Country-level data remain accurate.

Table 12. Transmission capacity in India (GW)

Region	Capacity in 2017	Addition expected during 2017-2022	Required by 2021-22
All India	721.27	383.69	1104.96
Northern Region	193.08	102.71	295.79
Western Region	236.41	125.76	362.17
Southern Region	217.74	115.83	333.58
Eastern Region	64.92	34.54	99.46
Northeastern Region	8.97	4.77	13.74

The GCC countries are connected with each other through the GCC interconnector. The transmission capacity of the interconnector varies between countries and the following table shows the existing capacity of each trans-border line [43], [44]:

Table 13. GCC interconnector capacity per country

Interconnector	Capacity (MW)
Kuwait - GCC[2]	1200
KSA - GCC	1200
UAE - GCC	900
Oman - UAE	400
Qatar - GCC	750
Bahrain - GCC	600

Demand

Table 14 shows an annual demand projection for India and each region, with the projected Compound Annual Growth Rate (CAGR) for All-India in each year.

Table 14. India annual electricity demand projection, Business as usual scenario (PJ)

Sources: Own elaboration using data from [45]–[48]

Year	All-India[3]	Eastern Region	Northeast Region	Northern Region	Southern Region	Western Region	CAGR (All-India)
2015	4011.87	460.33	53.47	1243.94	1044.38	1208.58	
2016	4114.54	472.11	54.84	1275.78	1071.10	1239.51	
2017	4367.97	520.86	57.13	1361.71	1137.13	1289.89	
2018	4588.43	561.68	59.36	1433.84	1193.54	1338.67	
2019	4647.64	580.10	59.73	1455.71	1208.81	1341.93	
2020	4415.25	560.16	56.46	1386.37	1148.80	1262.17	-5%
2021	4649.26	598.82	59.17	1463.75	1210.42	1315.76	5.3%
2022	4863.13	635.66	61.58	1535.21	1266.87	1362.40	4.6%
2023	5111.15	677.91	64.37	1617.80	1332.25	1417.34	5.1%
2024	5371.82	722.88	67.25	1704.59	1400.86	1474.70	5.1%
2025	5645.78	770.64	70.22	1795.73	1472.85	1534.72	5.1%
2026	5933.71	821.24	73.28	1891.51	1548.52	1597.45	5.1%
2027	6210.23	871.17	76.16	1983.91	1621.16	1656.02	4.66%
2028	6499.62	923.82	79.15	2080.70	1697.11	1716.96	4.66%
2029	6802.50	979.32	82.26	2182.10	1776.50	1780.36	4.66%
2030	7119.50	1037.81	85.49	2288.31	1859.47	1846.35	4.66%
2031	7451.27	1099.46	88.85	2399.57	1946.18	1915.03	4.66%
2032	7798.50	1164.42	92.35	2516.24	2036.88	1986.32	4.66%
2033	8161.91	1232.96	96.01	2638.58	2131.72	2060.25	4.66%
2034	8542.25	1305.34	99.81	2766.87	2230.84	2136.87	4.66%
2035	8940.32	1381.81	103.78	2901.39	2334.44	2216.25	4.66%
2036	9356.94	1462.70	107.92	3042.45	2442.67	2298.41	4.66%
2037	9778.00	1528.53	112.78	3179.36	2552.59	2401.84	4.5%
2038	10218.01	1597.31	117.86	3322.43	2667.45	2509.92	4.5%
2039	10677.83	1669.19	123.16	3471.94	2787.49	2622.87	4.5%
2040	11158.33	1744.30	128.70	3628.18	2912.92	2740.90	4.5%
2041	11660.45	1822.80	134.49	3791.45	3044.01	2864.24	4.5%
2042	12185.17	1904.82	140.55	3962.07	3180.99	2993.13	4.5%
2043	12733.51	1990.54	146.87	4140.36	3324.13	3127.82	4.5%
2044	13306.51	2080.11	153.48	4326.67	3473.72	3268.57	4.5%
2045	13905.31	2173.72	160.39	4521.37	3630.03	3415.66	4.5%
2046	14531.04	2271.54	167.60	4724.84	3793.38	3569.36	4.5%

2047	15184.94	2373.75	175.14	4937.45	3964.09	3729.98	4.5%
2048	15868.26	2480.57	183.03	5159.64	4142.47	3897.83	4.5%
2049	16582.34	2592.20	191.26	5391.82	4328.88	4073.23	4.5%
2050	17328.54	2708.85	199.87	5634.46	4523.68	4256.53	4.5%

GCC Annual Electricity Demand Projections, Business as Usual Scenario

The electricity demand projections are based on the historical growth in demand in each of the GCC countries obtained from official reports [7]–[9], [49]–[57]. Further explanation of the approach is given in the 'Experimental Design, Material and Methods' section of the report.

Table 15. Annual electricity demand projection for GCC countries (PJ)

Year	KSA-R1	KSA-R2	KSA-R3	KSA-R4	UAE	OMN	QTR	KWT	BHN
2015	285.6	283.7	96.0	310.5	458.51	112.66	149.40	245.83	62.1
2016	291.0	289.1	97.8	316.4	466.55	114.99	152.30	252.30	61.4
2017	296.4	294.4	99.6	322.3	484.39	124.45	164.00	262.03	64.8
2018	301.9	299.8	101.5	328.2	498.70	129.43	172.49	267.43	64.9
2019	307.3	305.2	103.3	334.1	513.43	134.61	177.24	272.94	65.8
2020	312.7	310.6	105.1	340.0	528.59	139.99	182.13	278.56	66.6
2021	318.1	316.0	106.9	345.9	544.21	145.59	187.15	284.29	67.5
2022	323.7	321.5	108.8	352.0	560.28	151.41	192.30	290.15	68.4
2023	329.4	327.2	110.7	358.1	576.83	157.47	197.61	296.12	69.3
2024	335.1	332.9	112.6	364.4	593.87	163.77	203.05	302.22	70.3
2025	341.0	338.7	114.6	370.8	611.42	170.32	208.65	308.45	71.2
2026	347.0	344.6	116.6	377.3	629.48	177.13	214.40	314.80	72.1
2027	353.0	350.7	118.7	383.9	648.07	184.22	220.31	321.28	73.1
2028	359.2	356.8	120.7	390.6	667.22	191.59	226.38	327.90	74.1
2029	365.5	363.1	122.9	397.4	686.92	199.25	232.63	334.65	75.1
2030	371.9	369.4	125.0	404.4	707.22	207.22	239.04	341.54	76.1
2031	376.8	374.3	126.7	409.7	728.11	215.51	245.63	348.57	77.1
2032	382.7	380.1	128.6	416.1	749.61	224.13	252.40	355.75	78.1
2033	388.6	386.0	130.6	422.5	771.76	233.09	259.36	363.08	79.2
2034	394.4	391.8	132.6	428.9	794.56	242.42	266.50	370.55	80.2
2035	400.3	397.6	134.5	435.3	818.03	252.11	273.85	378.18	81.3
2036	406.2	403.5	136.5	441.6	842.19	262.20	281.40	385.97	82.4
2037	412.1	409.3	138.5	448.0	867.07	272.69	289.16	393.92	83.5
2038	417.9	415.1	140.5	454.4	892.68	283.59	297.13	402.03	84.6
2039	423.8	421.0	142.4	460.8	919.05	294.94	305.32	410.31	85.7
2040	429.7	426.8	144.4	467.2	946.20	306.73	313.73	418.76	86.8
2041	435.5	432.6	146.4	473.6	974.15	319.00	322.38	427.38	88.0
2042	441.4	438.5	148.4	479.9	1002.92	331.76	331.27	436.18	89.2
2043	447.3	444.3	150.3	486.3	1032.55	345.03	340.40	445.16	90.3
2044	453.1	450.1	152.3	492.7	1063.05	358.84	349.78	454.33	91.6
2045	459.0	456.0	154.3	499.1	1094.45	373.19	359.43	463.69	92.8
2046	464.9	461.8	156.3	505.5	1126.78	388.12	369.33	473.24	94.0
2047	470.8	467.6	158.2	511.9	1160.07	403.64	379.51	482.98	95.3

2048	476.6	473.4	160.2	518.2	1194.34	419.79	389.98	492.93	96.5
2049	482.5	479.3	162.2	524.6	1229.62	436.58	400.73	503.08	97.8
2050	488.4	485.1	164.1	531.0	1265.94	454.04	411.77	513.44	99.1

Miscellaneous Data

Table 16 displays the unit cost of transmission based on the expected cost of capacity for the NEP [42].

Table 16. Capital cost of new transmission in India

Cost (USD/kW)
839

The availability factors presented below are global values, with the exception of conventional nuclear power, which shows a historical value for India.

Table 17. Availability factors

Technology	Value	Source
Coal-fired power plant	0.92	[58]
Open cycle gas-fired power plant	0.92	[59]
Combined cycle gas-fired power plant	0.92	[59]
Diesel generator	0.92	[60]
Nuclear power plant	0.95	[61]
Pumped storage hydropower plant	0.98	[62]
Small hydropower plant (SHP)	0.98	[62]
Biomass cogeneration power plant	0.93	[63]
Geothermal	0.9	[64]
Waste to Energy	0.62	[65]

Table 18. Hydropower capacity factors in India

Source: [66]

Season	Season Average (%)
Winter, Dec.-Feb.	12.24
Pre-monsoon, Mar.-May	21.09
Monsoon, Jun.-Sep.	65.53
Post-monsoon, Oct.-Nov.	26.81

Additional Data

Examples of necessary data not listed above include demand profile, capacity factors, capital costs, fixed costs, variable costs, and operational life. These can be obtained directly from the PLEXOS World 2015 dataset, accessible at the following link: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/CBYXBY

Global Data

Additional necessary data have been obtained from sources that are not location-specific, namely for power plant availability factors and emission ratios. Average availability factors for several technologies can be obtained from IEA-ETSAP. Emission factors were sourced from WRI GHG Emission Factors Compilation.

[2] Kuwait, Bahrain, Qatar and UAE are interconnected through Saudi Arabia which hosts the main GCC interconnector. Oman is connected to GCCIA through the UAE grid.

[3] All-India demand includes Lakshadweep and Andaman & Nicobar Islands

Experimental Design, Material, And Methods

Data for India's energy system were collected mainly from reports by government agencies, namely Ministry of Power (MoP), Ministry of New and Renewable Energy (MNRE), Central Electricity Authority (CEA), and Ministry of Statistics and Program Implementation (MOSPI). Other data sources include The Energy and Resources Institute (TERI), International Energy Agency (IEA), World Resources Institute (WRI), and numerous local news publications.

Non-renewable power generation capacity by region (Table 2) was obtained from CEA [3]. Large hydropower is not considered among renewable capacity, while small hydropower is considered renewable. Renewable capacities (Table 3) were obtained from MNRE [4] and aggregated by region. Installed and planned transmission capacities (Tables 11 and 12) were obtained from the MoP National Electricity Plan (NEP), Volume II Transmission [42]. Renewable resource potentials were obtained from MOSPI Energy Statistics 2020 [41] and aggregated by region.

Capital cost of transmission in India (Table 16) was calculated based on the projected cost of installing new capacity as dictated by the NEP [42] during the 2017-2022 period.

Hydropower capacity factors for India (Table 18) were synthesized from monthly 15-year average capacity utilization for over 200 hydropower plants in India from the PLEXOS World dataset [66].

The electricity demand projection for India in Table 14 was developed considering the effect of COVID-19 lockdowns in 2020. Historical demand data to 2019 was obtained from CEA [48]. The framework for the projection was obtained from

CEA's *Long Term Electricity Demand Forecasting Report* Partial Adjustment Model (PAM) [45], with adjustments being made to reflect the effects of the pandemic. Using the relationship between GDP growth and demand growth from PAM as a reference, a 5% year-on-year (YoY) decrease in demand was assumed for 2020 based on an estimated 7.7% drop in GDP [46]. In 2021, the IMF predicts India's GDP to jump 11.5%, and 6.8% in 2022 [47]. Demand increases of 5.3% and 4.6% have been assumed for 2021 and 2022, respectively. Thereafter, the projection uses Compound Annual Growth Rates (CAGR) of 5.1% to 2026 and 4.66% to 2036, according to the PAM's Business As Usual scenario with 7.3% annual GDP growth. From 2037-2050 the CAGR is assumed to decrease slightly to 4.5% due to continued decoupling of GDP from energy use.

To determine the demand by region, the All-India projection described above was split according to the regional proportions of total demand projected in the PAM. Because the PAM only includes years 2016-2036, year 2015 uses the regional breakdown ratio for 2016, and years 2037-2050 use the ratio for 2036.

Data for the GCC energy system were collected mainly from the utilities and institutes in each country as well as the publicly available datasets such as PLATTS database [6]. The latest reports by the GCC government agencies were also revised. To name a few examples: the ministry of energy in Saudi Arabia (moenergy.gov.sa), the ministry of energy and Infrastructure in the UAE (moei.ae), Oman Power and Water Procurement Company (omanpwp.om), Qatar General Electricity and Water Corporation “KAHRAMAA” (km.qa).

The residual capacities in each GCC country were compiled using the PLATTS database then calibrated with the data from local ministry and/or electricity utility in each country (Table 4 and Table 5). The power infrastructure in the GCC consists mainly of thermal power plants since the contribution of renewables is still insignificant in the GCC. However, each country has its own sustainability roadmap which in some cases (i.e UAE) is translated into specific capacity targets of renewable installations in the coming years (Table 9).

The techno-economic characteristics of the power plants were based on the average values obtained from four sub-regions in Saudi Arabia [67]. This dataset was complemented by data from international sources such as IEA-ETSAP. The same values were assumed for the other GCC countries since no country-specific data could be found from publicly available sources.

The data for the existing GCC interconnector were obtained from the GCC Interconnection Authority [6], [7]. This includes mainly the transmission capacity in each interconnector as shown in Table 13.

The electricity demand projections for the GCC countries were developed based on historical demand data and future projections obtained from local utilities in the six countries. For example in the case of the UAE, the historical data obtained from the Ministry of Energy and Infrastructure shows an average annual growth of electricity demand by 6% from 2008-2017 [8]. A moderate or a conservative growth of electricity demand was assumed for the period of 2018 - 2050 at 3%. Which is half the historical growth and it is close to the growth rate assumed by Abu Dhabi utility. According to Oman’s power utility (OPWP), the average annual growth in electricity demand was at a rate of 8% during 2011-2017 reaching a level of 125 PJ in 2017 [55], [68]. An annual average growth of 4% assumed for the period 2018-2050. A similar approach was followed for the other countries (Bahrain, Kuwait and Qatar). For the case of KSA, electricity demand projections were segregated by the four regions to match the existing power infrastructure. The electricity demand for the period 2019-2030 was based on the projections developed in the study [67] then extrapolated for the other years.

Declarations

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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