Data Sources & Supplemental Material

Maria Vabson

October 16, 2025

Contents

1 Design Details

The data center design profiles are modifiable and output hourly demand and water use profiles based on various energy and water use metrics and standards of the technologies that are then used in the model.

1.1 Climate Regions

In order to more accurately model water and energy demand due to climate differences it is beneficial to designate the climate regions using the International Energy Conservation Code (IECC) climate regions as shown in Figure 1 and the data sourced from the US Energy Atlas [1]. The hottest region starts at 1 and then moves to mild and the coldest climate region labeled with the 7 [2].

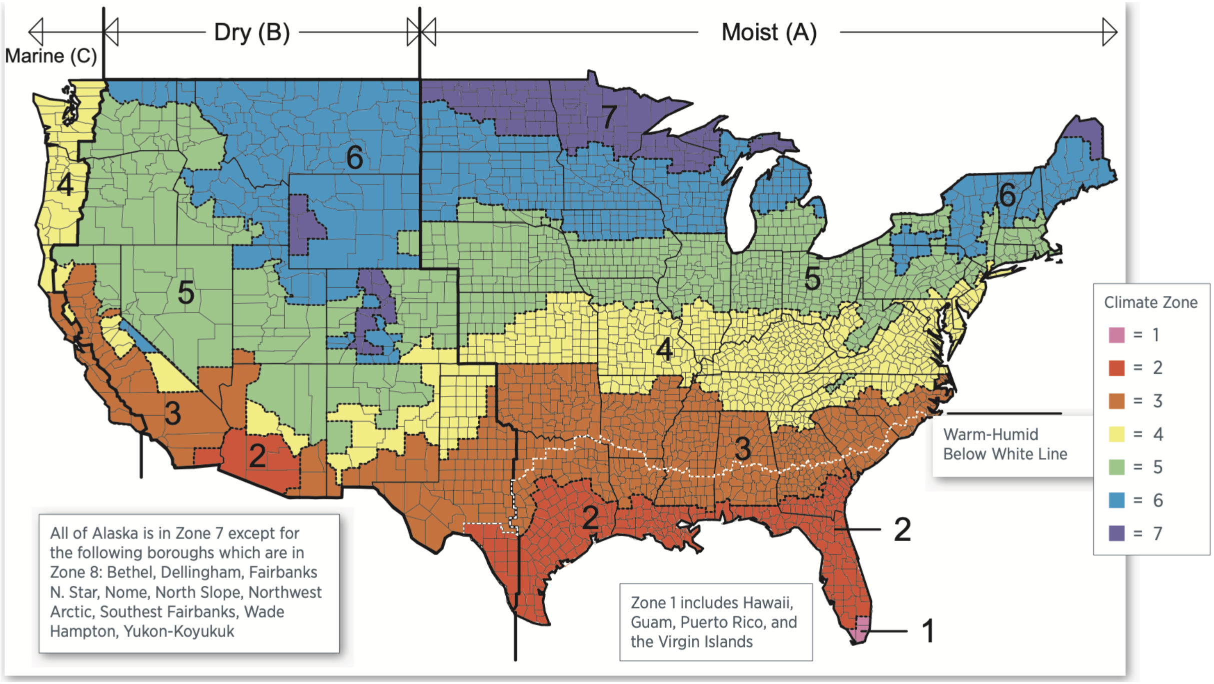

Figure 1: IECC climate regions by county [2]

1.2 Energy and Water Load Profiles

Currently data centers are utilizing a variety of different cooling technologies due to costs, space, and technological constraints. Typical metrics for the efficiencies of data centers are the Power Usage Effectiveness (PUE) and water usage effectiveness (WUE). The PUE is the data center's total electricity demand divided by the electricity demand of the IT equipment and typically dimensionless (kWh/kWh). WUE is the total water consumption of the data center divided by the electricity demand of the IT equipment measured in L per Kwh [3]. The most common cooling technologies used for hyperscale and AI specialized data centers include airside economizers with adiabatic cooling with either air or water cooled chillers, as well as IT Liquid cooling also utilizing air or water cooled chillers [3]. The exact PUE and WUE values used based on IECC climate zones for airside economizers with direct adiabatic cooling and water-cooled chillers for supplemental cooling are shown in Figure 2. The higher efficiency values are designated in red as being in the 5th quantile and have smaller PUE and WUE values on average. The data and Figure 2 are from the supplemental material document of the original report [4].

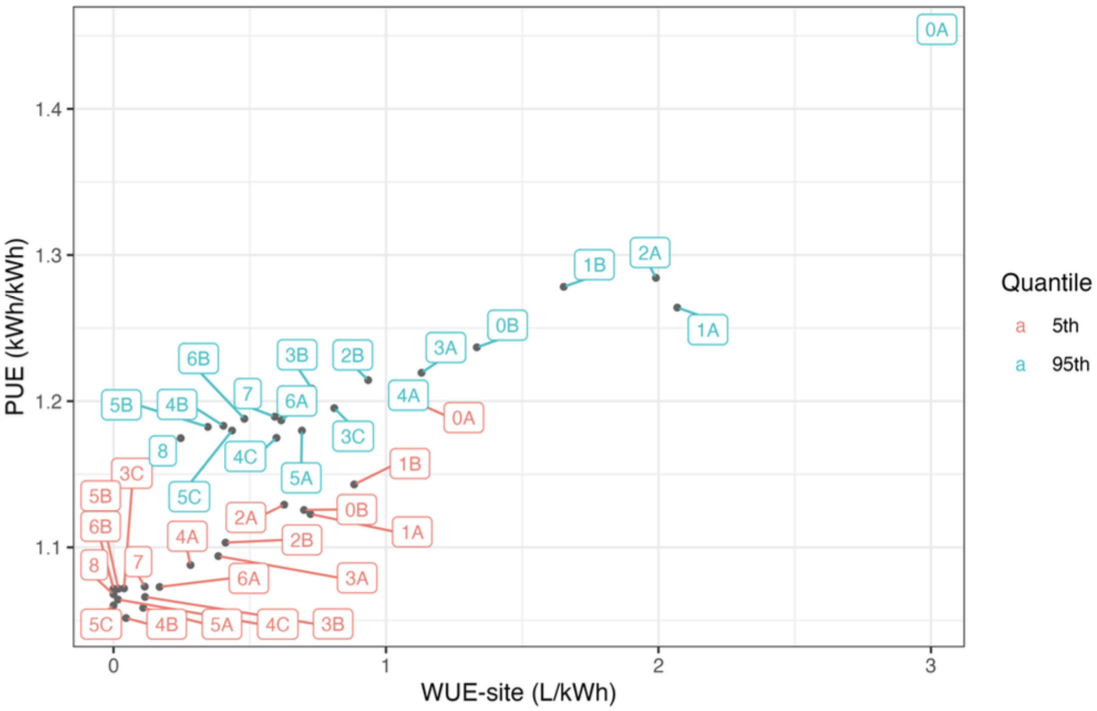

Figure 2: PUE and WUE for data centers using airside economizers and direct adiabatic cooling and using water-cooled chillers as supplemental cooling based on climate region. Distinguished in color by the quantile of operating efficiency, either in the 5th or 95th quantile [4].

1.3 Energy Storage

The storage types and associated parameters are the same as the ones used by the other project.

1.4 Renewable Energy Availability

Supply curves from NREL are used for total capacity (MW), capacity factors (decimal value), and the distance spur and reinforcement (km). Each location point is based on a 11.5 km grid-cell.

The wind data is based on the 2023 land-based wind supply curves from NREL [5]. The solar data is based on the 2023 utility scale photovoltaics (UPV) [6]. The wind and solar data both use the 2030 open access moderate supply curve data. There is limited, moderate, and open access option. There is additional offshore wind, as well as new datasets for land-based wind and solar for 2024. They also contain an associated regional capital cost multiplier (ratio) to capture taxes, labor, and land lease regional differences.

The geothermal data takes the 2024 Enhanced Geothermal Systems (EGS) at 4500 meter (m) depth data [7]. There is potential for further addition of different geothermal data such as Hydrothermal at 3500 m, EGS at 5500 m, and EGS at 6500 m using the same source.

1.4.1 County Level Hourly Capacity Factors for Solar and Wind

The 2024 county level hourly renewable energy capacity factors (as a decimal) are from the NREL Regional Energy Deployment System (ReEDS) model [8]. The UPV data is used for solar and the onshore wind data is for the wind data. The data can be selected for open, limited, or reference regions based on regulation of land use and other policies. Currently the limited datasets are used. There is also an offshore wind dataset which could be added for consideration in the future.

1.5 Energy Costs

The capital and operations and maintenance (O&M) costs for wind, solar, and nuclear technologies are from the US Energy Information Administration's (EIA) 2023 Annual Energy Outlook [9]. The base overnight cost which includes project contingency costs is used for the capital expenditure value. For future, this EIA data is available by 25 regions in the US.

For fuel costs of the natural gas, the values are taken from the EIA "Table 8.4. Average Power Plant Operating Expenses for Major U.S. Investor-Owned Electric Utilities, 2013 through 2023 (Mills per Kilowatthour)" [10]. This is combines the operations, maintenance, and fuel costs which are all just put into the variable O&M category. The 2023 value is used.

Parameter	**Wind**	**Solar**	**Nuclear**	**Nuclear SMR**	**Natural Gas**
Capital Expenditures	2,098 (2022$/kW) [9]	1,448 (2022$/kW) [9]	7,406 (2022$/kW) [9]	7,590 (2022$/kW) [9]	
Fixed O&M	29.64 (2022$/kWyr) [9]	17.16 (2022$/kWyr) [9]	136.91 (2022$/kW/yr) [9]	106.92 (2022$/kWyr) [9]	
Variable O&M	0 (2022$/MWh) [9]	0 (2022$/MWh) [9]	2.67 (2022$/MWh) [9]	3.38 (2022$/MWh) [9]	26.47 (2023$/MWh) [10]
Lifetime (yrs)	25 [11]	25 [12]	60 (80 max) [13]	60 [13]	40 [14]

Table 1: Assumptions and values used for modeling onsite generation and their prices.

The information for geothermal technology is primarily sourced from NREL's 2024 report on Energy Potential and Supply curves [15] and shown in Table 2.

Parameter	**Hydrothermal Binary (3.5 km)**	**EGS Binary (4.5 km)**	**EGS Binary (5.5 km)**	**EGS Flash (6.5km)**
Drilling Cost ($/well) [15]	3,130,258	3,864,018	4,592,983	5,317,153
Capital Expenditures (2022$/kW) [15]	4,479.83	4,538.36		2,756.22
Fixed O&M (2022$/kWyr) [15]	126	119		99
Variable O&M (2022$/MWh) [9]	1.31			
Plant Efficiency (%) [15]	80			
Lifetime (yrs) [13]	25			

Table 2: Assumptions and costs used for geothermal energy.

1.6 Transmission

This section encompasses the transmission lines that need to be built out, their length, the cost of construction, and the prices of electricity from the grid. In addition, the cost of adding transmission must also include upgrading or adding new substations for the size of the proposed loads of data centers.

1.6.1 Transmission Lines

The transmission and distribution is aggregated. The capacity of the line needed to connect a load and its nearest substation depends on the possible amount of energy being transferred and the distance it must be transferred. However, for this study, the rated voltage needed will depend on the maximum amount of electricity needed from the grid, not just the total data center capacity since the model includes energy generation on site as well, and not on the distance. This is a good proxy since we are minimizing transmission distance and thus the rated voltage being based on the delivered power range will be sufficient and the main factor driving the necessary capacity for this analysis. The power ranges are shown in Table 3 and the expected transmission rating is based on power capacity rounded up to ensure sufficient capacity in the lines. The capacity of transmission will depend on the energy profile for the specific datacenter and site. It will be based on the operations of the data center. However, this could be modified to support the entire data center capacity entirely by the grid, but this is much more expensive and transmission construction is a lengthy process. Also, the goal is to add generation to alleviate strain on the existing grid and infrastructure. So, in order to determine the costs of building additional transmission, the distance needed will be multiplied by the cost of the corresponding line needed for that location.

Rated Voltage (kV)	Delivered Power Range (MW)	Delivered Power Used(MW)
69	12-13	< 15
138	47-52	< 50
230	134-145	< 145
345	325-425	< 425
500	850-1075	< 1075
765	2200-2300	< 2300

Table 3: Transmission line characteristics for typical 60-Hz overhead lines [16].

1.6.2 Transmission Distance

The transmission distance (km) is taken from the NREL supply curves, selecting the solar distance, and then wind or geothermal if any of them are not available for that location [5]–[7]. The distance was calculated using the renewable energy potential eXchange tool (reVX) least-cost-path algorithm to find the lowest-cost route from the prospective site to an existing electrical substation ("NREL/reVX: reV 0.8.0 Compatibility + Misc Updates" n.d.) [15]. This allows us to to determine the length of the line necessary and is converted to miles for further analysis.

1.6.3 Transmission Construction Cost

This model implements double circuit spur line prices from the ERCOT/WECC UT Austin tech report as they are typically used especially for 345, 138, and 69 kV lines [17]. Those prices, as shown in Table 4 are scaled regionally using the relationships from Table 5. The prices are converted to a multiplier to account for regional differences, all assuming pastureland terrain though. Both sources also report a multiplier based on terrain which could be interesting to implement in the future if a relevant land use designator could be found or created, and which the NREL source more likely has.

Rated Voltage (kV)	Double-circuit cost [USD 2017 /mile]
69	1,696,200
138	1,642,200
230	1,536,400
345	2,150,300

500	3,071,750
765	3,071,750*

Table 4: Cost of transmission line per mile (USD 2017/mile) [17]

Voltage (kV)	Prospective Site Capacity (MW)	SCE (CAISO, NYISO, ISONE, PJM, NPCC, WECC)	MISO (SPP)	Southeast (SERC, ERCOT)
138	205	$2,327,709	$1,615,100	$1,099,072
Multiplier		2.1179	1.4695	1

Table 5: Assumptions and values used for modeling transmission line costs [15]

So, in total for transmission construction costs, at each location, the distance is multiplied by the transmission line cost of the necessary line and multiplied by the regional multiplier.

1.6.4 Substation Construction Cost

It does not seem out of the ordinary for large factories, cryptocurrency mining facilities, manufacturing facilities, and new data centers to require nearby substation upgrading or even construction of a substation for itself. Especially for large facilities, it is more common now for new substations to be built nearby to support the additional load, and in our case even generation. For the purpose of the study the new substation cost is used, but both upgrade and new development costs are shown in Table 6 with data from a 2018 MISO cost estimation guide [18]. The new substation cost represents adding 4 new line positions. The substation upgrade represents adding one line. Both scenarios include contingencies and Allowance for Funds Used During Construction (AFUDC) [18]. The voltage rating selected is the same as the transmission capacity selected and described in the previously.

Voltage (kV)	69	115	138	161	230	345	500
New Substation Site Cost ($Million$ $)	5.7	6.8	7.8	8.9	10.8	18.7	31.4
Substation Upgrade Cost ($Million$ $)	1.6	1.9	2.3	2.6	3.1	5.4	8.8

Table 6: Assumptions and values used for modeling transmission line costs [18]

1.6.5 Electricity Prices

For the energy that is taken from the grid and not directly from the on-site generation built, there must be an associated electricity price. So, the average retail electricity prices (2023 cents/kWh) from the US EIA are used [19]. The data is for 2023, but released in 2024. Thus, the electricity prices from the grid are based on the state that the location is in.

1.7 Telecommunications

Data centers require huge amounts of data transmission. There are several types of fiber optical cables typically used to distribute the necessary capacity of data. However, typical values will be used for consistency and to understand the bigger picture. The key factors in calculating the telecommunications construction are based on the distance of the location from existing fiber and the cost to construct fiber optic cables. By 2023 approximately 46% of locations in the US were serviceable by fiber with coverage reaching 62% in urban areas and still at 31% in rural areas [20].

1.7.1 Telecommunications Distance

To calculate the length of new fiber needed for a site location of interest, the shortest distance to the nearest existing fiber node must be found. The data of US long haul fiber nodes used is from 2015 [21], but is a good estimate for the output of data center locations are typically desired to be near population centers and built infrastructure. So, the distance is determined by minimum geodesic distance to the cities from the US long haul fiber node data. The distance is then presented in miles (mi). In the future, for more accurate distances the nodes could be connected using road map data between linked nodes, possibly. However, this is a good estimate for the typical capital expansion costs of the infrastructure.

1.7.2 Telecommunication Construction Costs

The associated capacity and installation costs for underground fiber deployment is presented in Table 7 with values from the Fiber Broadband Association [20]. Underground deployment is more expensive, but this source also has costs for aerial deployment which could be substituted in. These costs include the labor and material costs. These costs are then multiplied by the distance of the data center location from the nearest fiber node calculated above.

Location	**Extremely Rural**	**Rural**	**Suburban**	**Urban**
Distance from city node (mi)	50+	< 50	< 20	<5
Aerial Cost ($/foot)	-	5.00	8.00	6.54
Underground Cost ($/foot)	12.50	14.63	14.59	23.25
Underground Cost ($/mile)	66,000	77,246.4	77,035.2	122,760

Table 7: Fiber Deployment Median Cost (Labor and Materials Only) [20]

1.8 Water

Due to the proprietary nature of water network distribution system network data, there is not an open source of the data that we have been able to find so far. So, this model does not currently include the cost of construction additional water pipelines that could be used for cooling and the other needs of the data center.

Instead, going back to the climate zones mentioned at the beginning. The amount of water used by the data center is calculated using the WUE depending on the climate zone, which helps reflect that often hotter regions would need to demand more water. However, to determine the cost of the water the further calculations are conducted.

1.8.1 Water Cost

To determine the cost of the water use of the prospective data center, the PNNL's water price rates from a 2023 report are used [22]. They have regional distinctions that are used to determine the water prices as shown in Figure 3. The data is taken from their "Table A.1. Water Utility Volume Charge in 2021$ per kGal for Large Industrial Consumers" [22]. The most recent year they have is 2021, which is selected, and if not a value from 2019, 2016, or if neither available then 2014 is used instead. They have prices for the listed cities seen in Figure 3.

The cost for a specific location is determined by using the cost of the closest city within the same state, and if there is not a city in the same state, then the closest city within the same region.

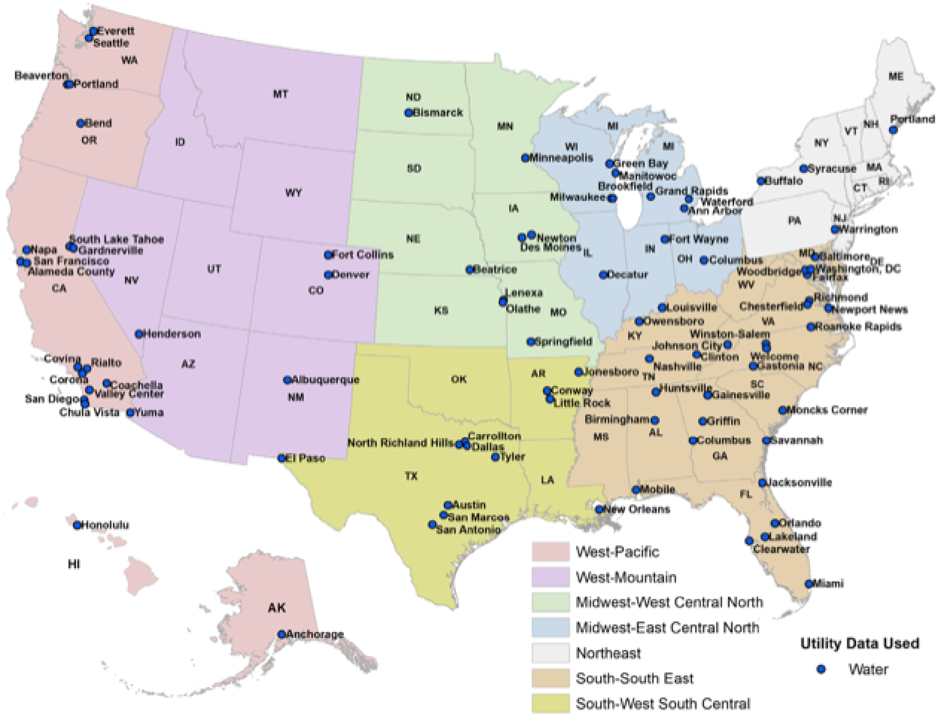

Figure 3: The Map of the US used to distinguish cost of water for different regions [22].

1.8.2 Water Stress Risk

The water risk data was created by Kuzma et al. [23]. They created a score for different measurements of water risk weather based on water stress, water depletion, water table decline, etc.. So, using their generalized score for water risk from a scale of 0 to 5 and having a different weight for each in the model to discourage siting in water stressed regions.

1.9 Natural Gas

Natural gas is another generation source of interest for collocation purposes.

1.9.1 Natural Gas Pipeline Distance

The pipeline data is from the US EIA which was originally published in 2020 [24]. This is used to calculate the shortest distance from the site of interest to nearest natural gas pipeline.

1.9.2 Natural Gas Pipeline Cost

The cost of constructing the new pipelines depends on the diameter of the pipeline and subsequently the distance of the pipeline needed. These costs are sourced from the 2018 The Interstate Natural Gas Association of America (INGAA) infrastructure report [25]. Their data is based on their regional distinctions for capital costs as shown in Figure 4.

To costs used are taken from their "Exhibit 30: Projected Annual CAPEX by Region and Category, Constant Unit Cost Case (Million 2016$)" table with the final values used for this model shown in Table 8. This CAPEX cost includes surface and lease equipment, storage, transport, and the pipelines themselevs.

1.9.3 Natural Gas Prices

The fuel prices are reflected in the variable O&M category as shared in Table 1.

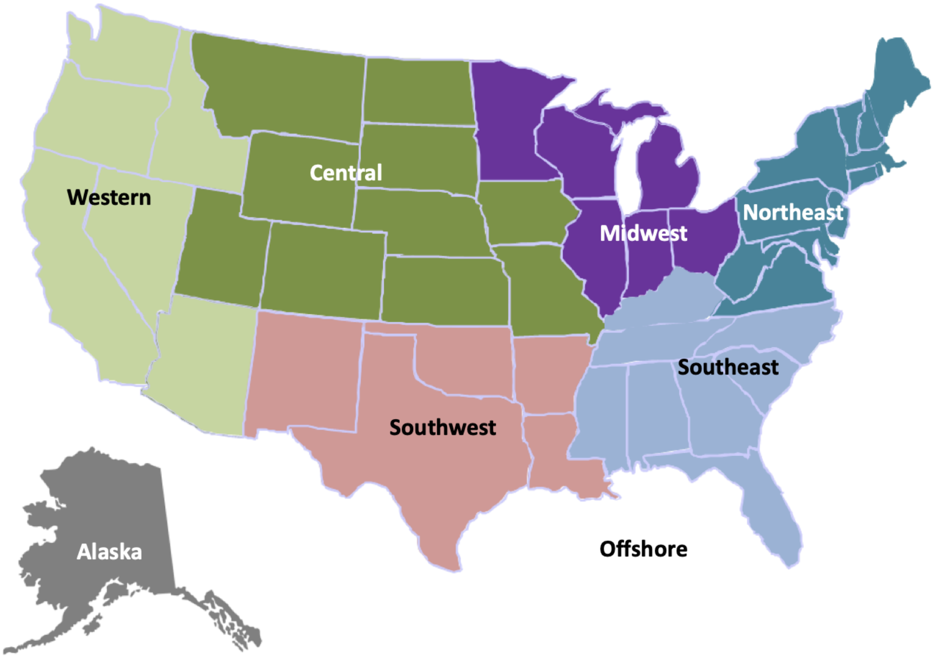

Figure 4: The Map of the US used to distinguish capital costs for natural gas pipeline construction [25].

	Central	Midwest	Northeast	Southeast	Southwest	West	Offshore	Alaska
Total Investment (Million 2016 $)	3,303	1,509	6,518	5,924	9,388	294	7,523	18

Table 8: CAPEX used for natural gas pipeline, constant unit case [25]

References

[1] PNNL, *Climate Zones - DOE Building America Program*, 2015. **url**: https://atlas.eia.gov/datasets/eia::climate-zones-doe-building-america-program/about.

[2] M. Baechler, T. Gilbride, P. Cole, M. Hefty **and** K. Ruiz, *Building America Best Practices, Volume 7.3 - Guide to Determining Climate Regions by County*, 2015. **url**: https://www.energy.gov/eere/buildings/articles/building-america-best-practices-series-volume-73-guide-determining-climate.

[3] A. Shehabi, A. Hubbard, A. Newkirk **andothers**, "2024 United States Data Center Energy Usage Report," **december** 2024. **url**: https://eta-publications.lbl.gov/sites/default/files/2024-12/lbnl-2024-united-states-data-center-energy-usage-report.pdf.

[4] N. Lei, J. Lu, A. Shehabi **and** E. Masanet, "The water use of data center workloads: A review and assessment of key determinants," *Resources, Conservation and Recycling*, **jourvol** 219, **page** 108 310, 2025. DOI: https://doi.org/10.1016/j.resconrec.2025.108310.

[5] NREL, *United States Land-based Wind Supply Curves 2023*, **june** 2023. DOI: 10.25984/2428990. **url**: https://data.openei.org/submissions/6119.

[6] NREL, *United States Utility-Scale PV Supply Curves 2023*, **june** 2023. **url**: https://data.openei.org/submissions/6001.

[7] W. Trainor-Guitton, P. Pinchuk, K. Menon **andothers**, *United States Geothermal Supply Curves 2024*, Geothermal Data Repository, National Renewable Energy Laboratory, https://gdr.openei.org/submissions/1732, Accessed: 2025-09-09, 2025. **url**: https://gdr.openei.org/submissions/1732.

[8] NREL, *2024 County-Level Hourly Renewable Capacity Factor Dataset for the ReEDS Model*, 2024. **url**: https://catalog.data.gov/dataset/2024-county-level-hourly-renewable-capacity-factor-dataset-for-the-reeds-model.

[9] *Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2023*, 2023. **url**: https://www.eia.gov/outlooks/aeo/assumptions/pdf/elec_cost_perf.pdf.

[10] EIA, *Average Power Plant Operating Expenses for Major U.S. Investor-Owned Electric Utilities, 2013 through 2023 (Mills per Kilowatthour)*. **url**: https://www.eia.gov/electricity/annual/html/epa_08_04.html.

[11] T. Stehly, P. Duffy **and** D. Mulas Hernando, "2022 cost of wind energy review [slides]," National Renewable Energy Laboratory (NREL), Golden, CO (United States), techreport, 2023. **url**: https://docs.nrel.gov/docs/fy24osti/88335.pdf.

[12] V. Ramasamy, J. Zuboy, M. Woodhouse **andothers**, "Us solar photovoltaic system and energy storage cost benchmarks, with minimum sustainable price analysis: Q1 2023," NREL, techreport, 2023. **url**: https://docs.nrel.gov/docs/fy23osti/87303.pdf.

[13] "Geovision: Harnessing the Heat Beneath Our Feet," US Department of Energy, techreport, 2019. **url**: https://www.energy.gov/sites/prod/files/2019/06/f63/GeoVision-full-report-opt.pdf.

[14] "Capital Cost and Performance Characteristics for Utility-Scale Electric Power Generating Technologies," EIA, techreport, 2025. **url**: https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capital_cost_AEO2025.pdf.

[15] A. Lopez, G. R. Zuckerman, P. Pinchuk **andothers**, "Renewable Energy Technical Potential and Supply Curves for the Contiguous United States: 2024 Edition," NREL, techreport, 2025. **url**: https://docs.nrel.gov/docs/fy25osti/91900.pdf.

[16] J. D. Glover, T. J. Overbye **and** M. S. Sarma, *Power system analysis & design*. Cengage Learning, 2017.

[17] J. Andrade **and** R. Baldick, "Estimation of Transmission Costs for New Generation," The Energy Institute of the University of Texas, techreport, **january** 2017. **url**: https://energy.utexas.edu/sites/default/files/UTAustin_FCe_TransmissionCosts_2017.pdf.

[18] MISO, "Transmission and Substation Project Cost Estimation Guide for MTEP 2018," MISO, techreport, 2018. **url**: https://cdn.misoenergy.org/Transmission-and-Substation-Project-Cost-Estimation-Guide-for-MTEP-2018144804.pdf.

[19] EIA, *State Electricity Profiles 2023*, 2024. **url**: https://www.eia.gov/electricity/state/.

[20] *Fiber Deployment Annual Report*, 2023. **url**: https://fiberbroadband.org/wp-content/uploads/2024/01/Fiber-Deployment-Annual-Report-2023_FBA-and-Cartesian.pdf.

[21] R. Durairajan, P. Barford, J. Sommers **and** W. Willinger, "InterTubes: A study of the US long-haul fiber-optic infrastructure," **in***Proceedings of the 2015 ACM Conference on Special Interest Group on Data Communication* 2015, **pages** 565–578. **url**: https://doi.org/10.1145/2829988.2787499.

[22] S. R. Unger, E. M. Kilgannon, D. B. Elliott, K. A. Cort **and** K. L. Stoughton, "Water and Wastewater Annual Price Escalation Rates for Selected Cities Across the United States: 2023 Edition," Pacific Northwest National Laboratory (PNNL), Richland, WA (United States), techreport, 2023. **url**: https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-34006.pdf.

[23] S. Kuzma, M. F. Bierkens, S. Lakshman **andothers**, *Aqueduct 4.0: Updated decision-relevant global water risk indicators*. World Resources Institute Washington, DC, USA, 2023.

[24] EIA, *Natural Gas Interstate and Intrastate Pipelines*, 2020. **url**: https://atlas.eia.gov/datasets/eia::natural-gas-interstate-and-intrastate-pipelines/about.

[25] K. Petak, J. Manik **and** A. Griffith, "North American Midstream Infrastructure through 2035: Significant Development Continues," *Interstate Natural Gas Association of America (INGAA)*, 2018. **url**: https://ingaa.org/wp-content/uploads/2018/06/34658.pdf.