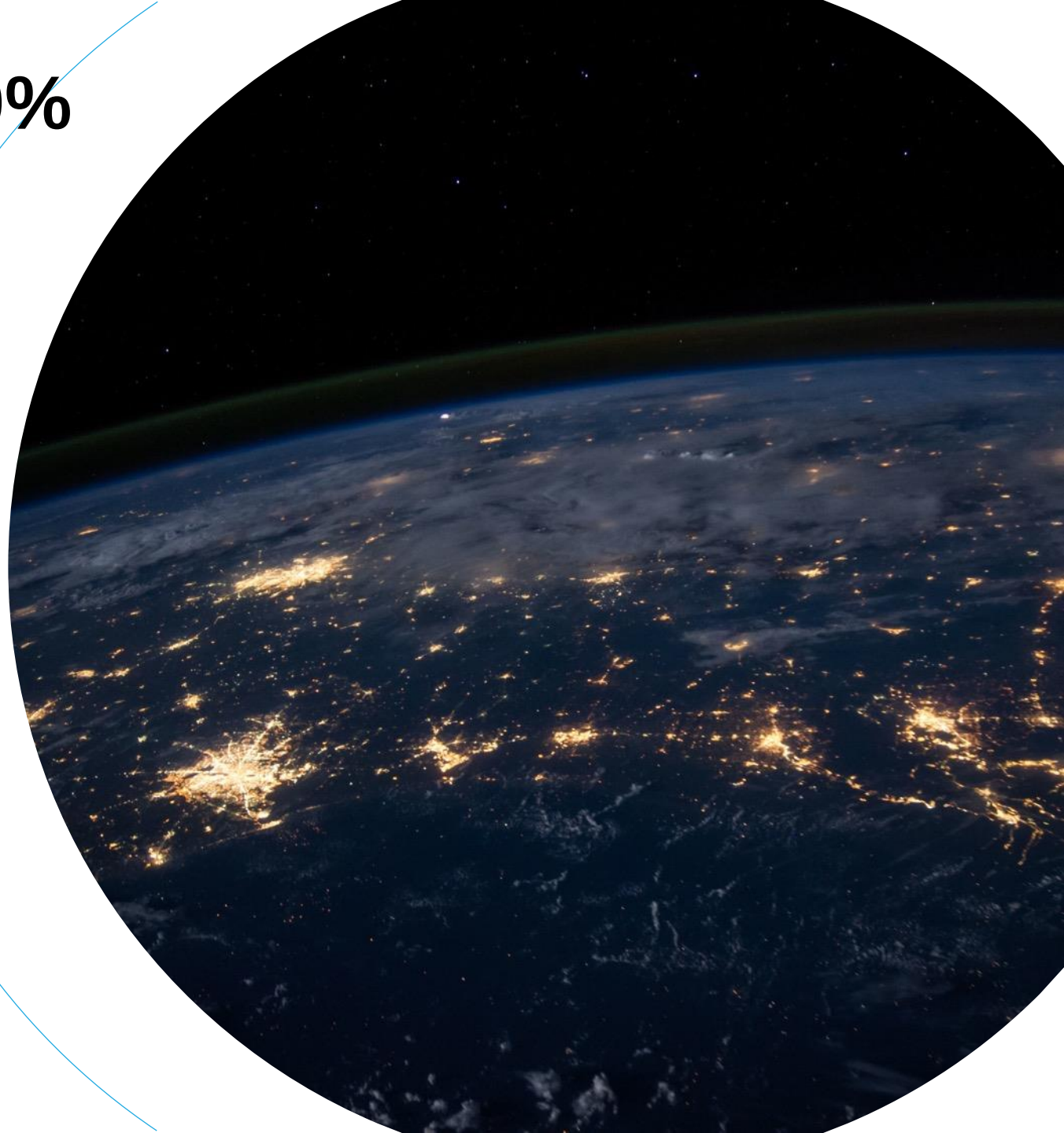
100% Clean Energy or 100% Clean Electricity:
The importance of sector coupling



ESIG 2024 Fall Technical Workshop

Providence, Rhode Island

Dr Christopher T M Clack, Vice President

integrated Energy Systems Planning

October 22nd, 2024

Pattern

ESIG

ENERGY SYSTEMS INTEGRATION GROUP

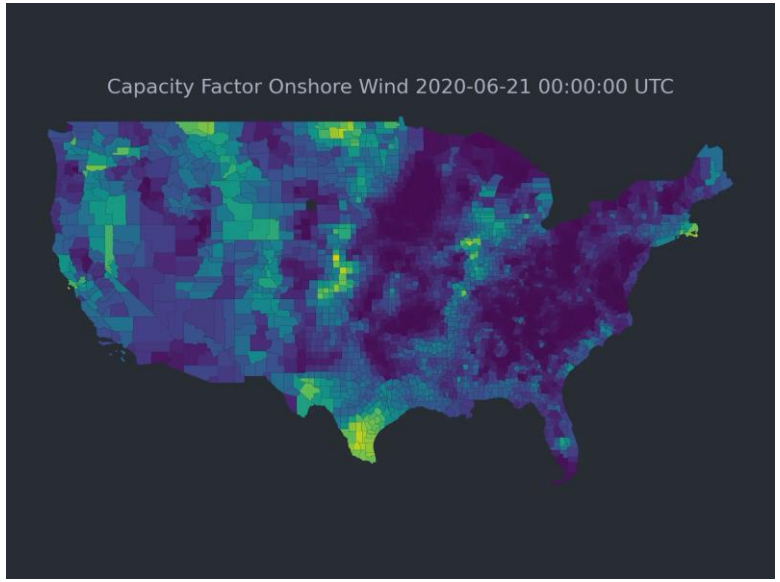
Pattern Energy

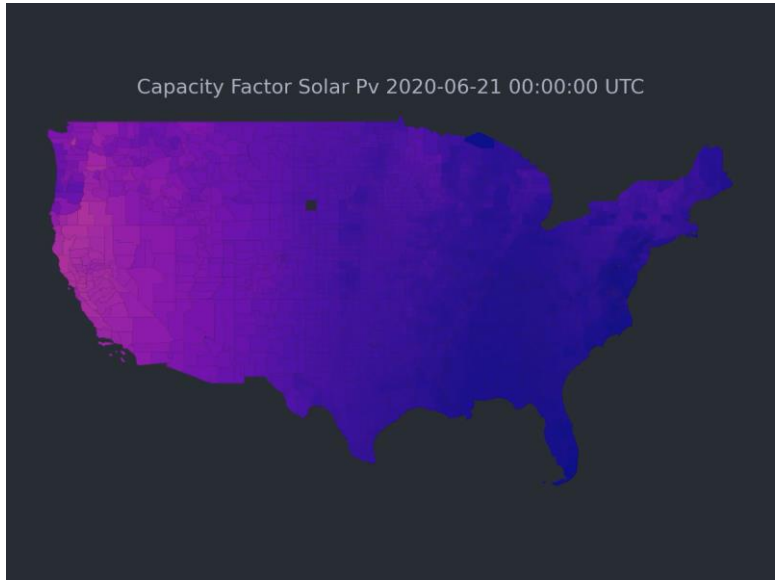
Pattern Energy is a leading renewable energy company that develops, constructs, owns, and operates high-quality wind and solar generation, transmission, and energy storage facilities. Our mission is to transition the world to renewable energy through the sustainable development and responsible operation of facilities with respect for the environment, communities, and cultures where we have a presence.

Our approach begins and ends with establishing trust, accountability, and transparency. Our company values of creative spirit, pride of ownership, follow-through, and a team-first attitude drive us to pursue our mission every day. Our culture supports our values by fostering innovative and critical thinking and a deep belief in living up to our promises.

Headquartered in the United States, Pattern has a global portfolio of more than 35 power facilities and transmission assets, serving various customers that provide low-cost clean energy to millions of consumers.

VCE, Pattern, Catalyst & GridLab release open-source dataset





Introducing the Resource Adequacy Renewable Energy (**RARE**) Power Dataset

First release is 2019 through 2023 hourly, county-granularity wind and solar PV capacity factors.

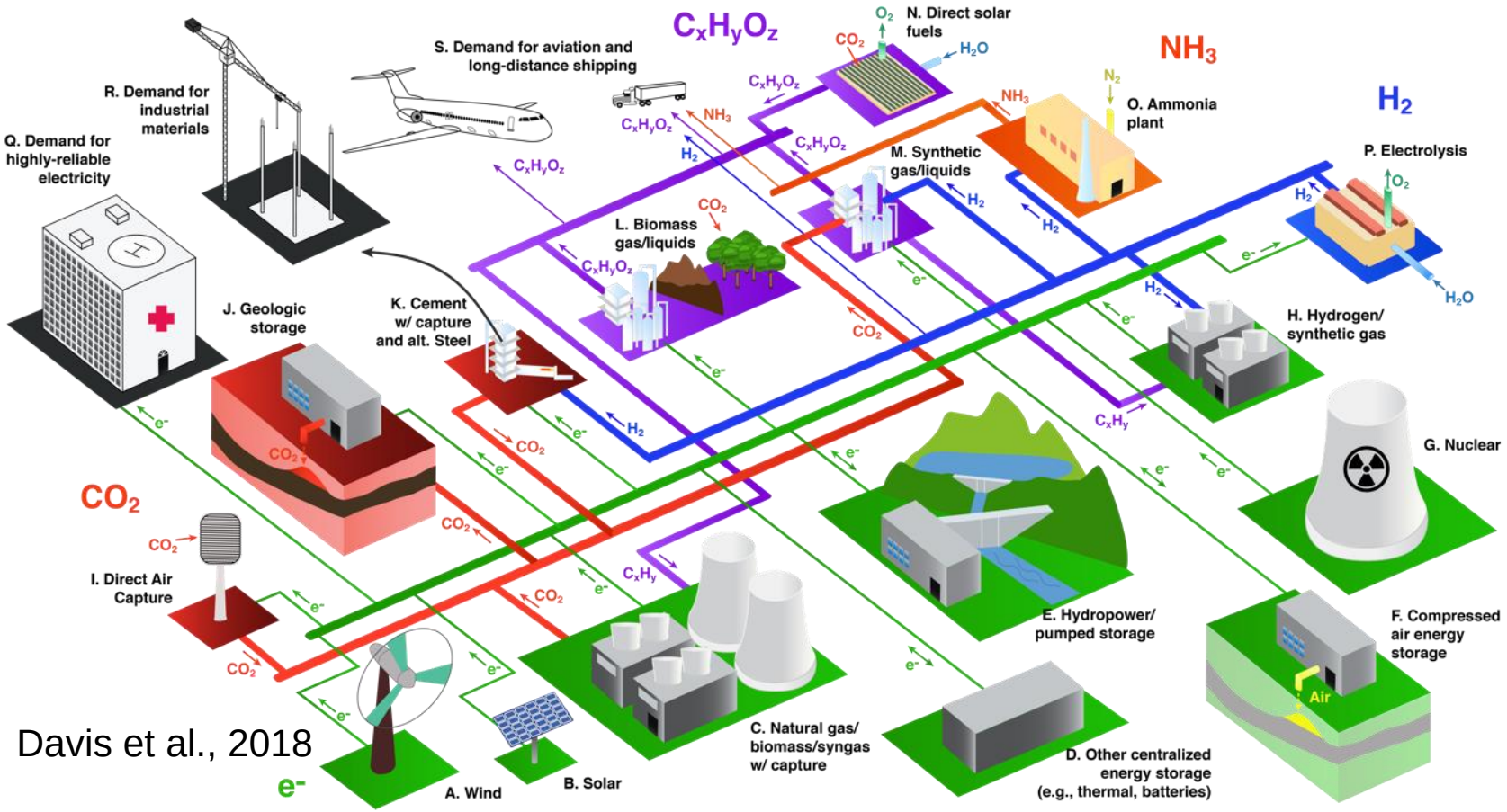
Second release in Q1 2025 will include 2014 through 2018. Annual releases while the HRRR remains operational at NOAA.

Use the QR code to get straight to the raw csv files

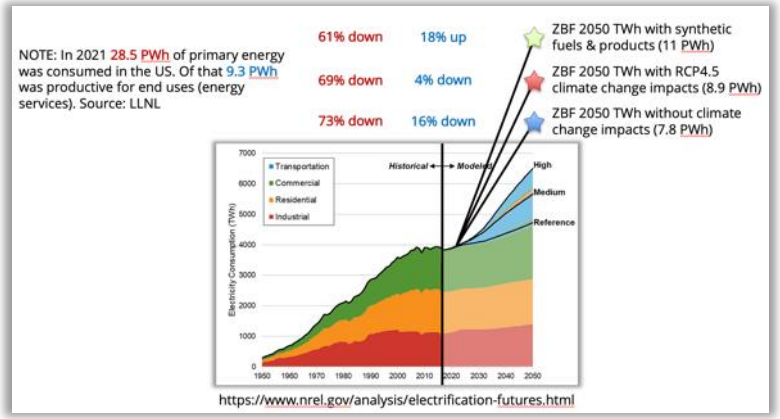
Please visit Catalyst Cooperative to download an exquisitely curated database of the data

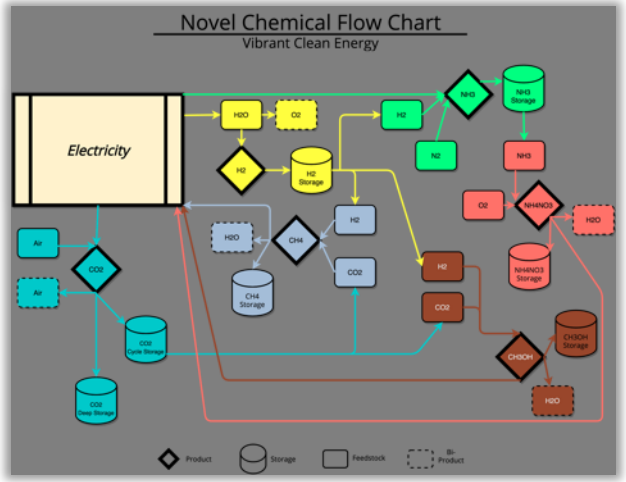
Weather-Informed energy Systems:

for design, operations & markets



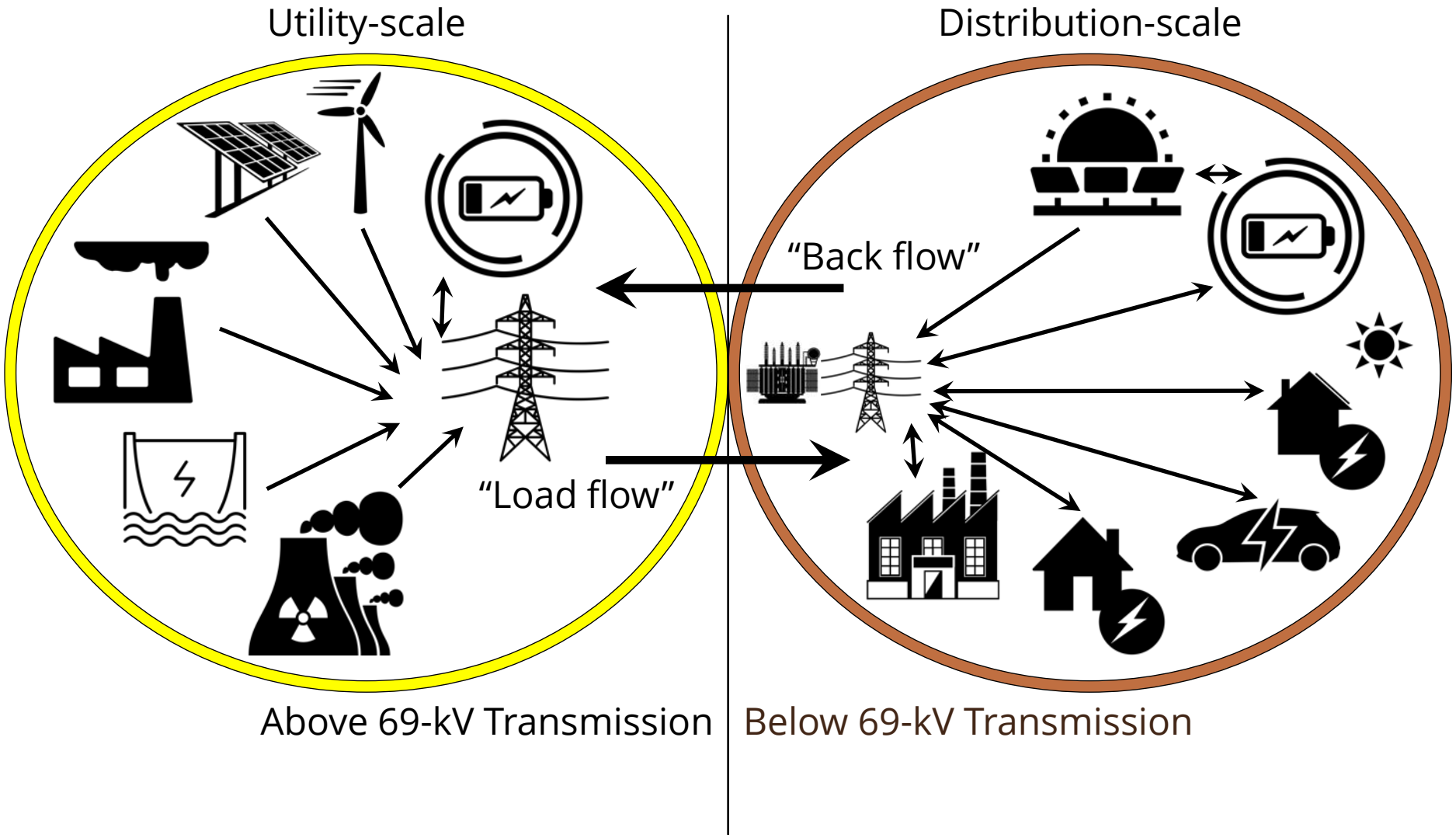
Davis et al., 2018



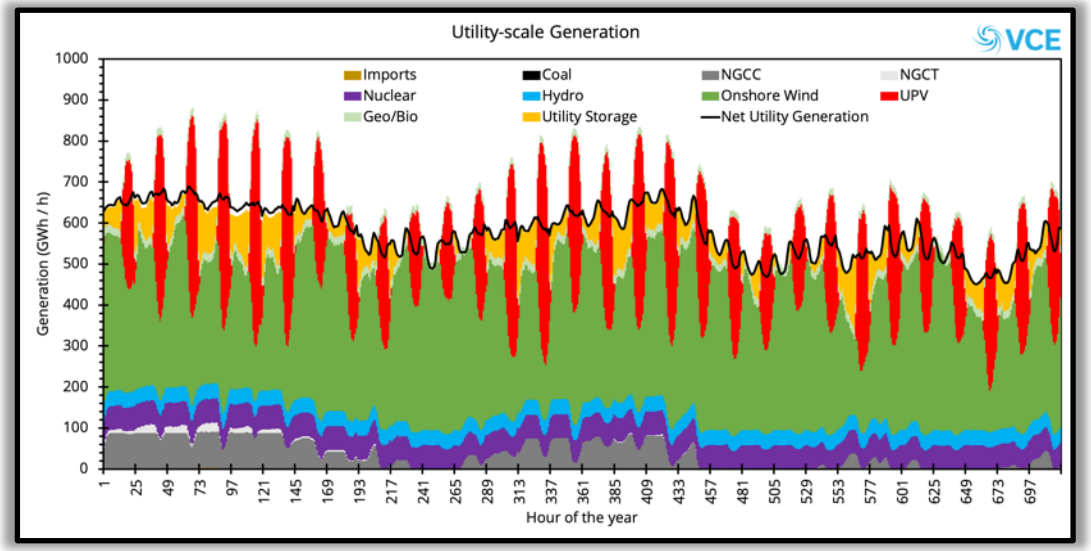


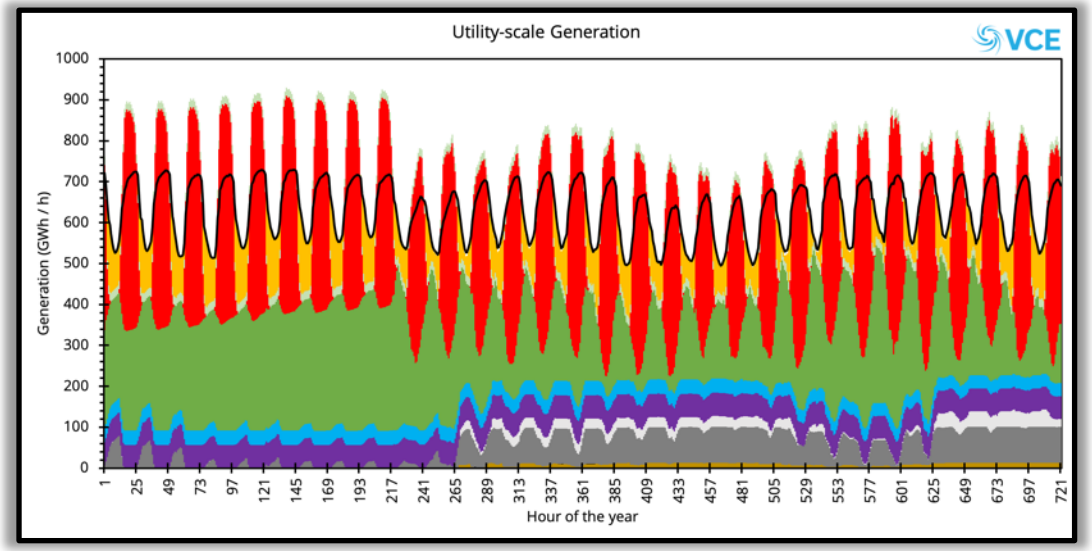
The modeling is designed to encompass as much of the energy economy as possible

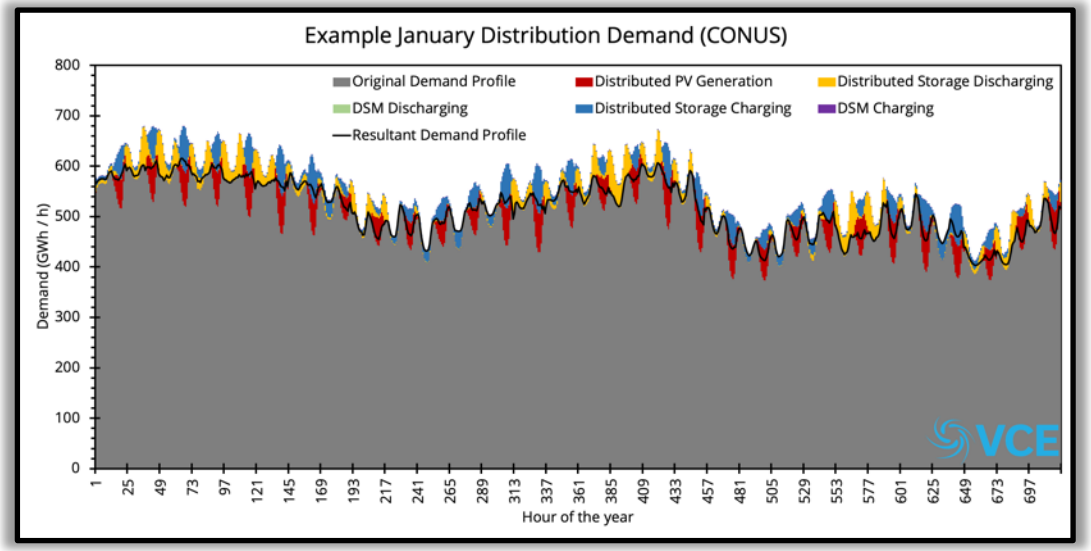
Distribution co-optimization is needed to understand electrification implications on pathways

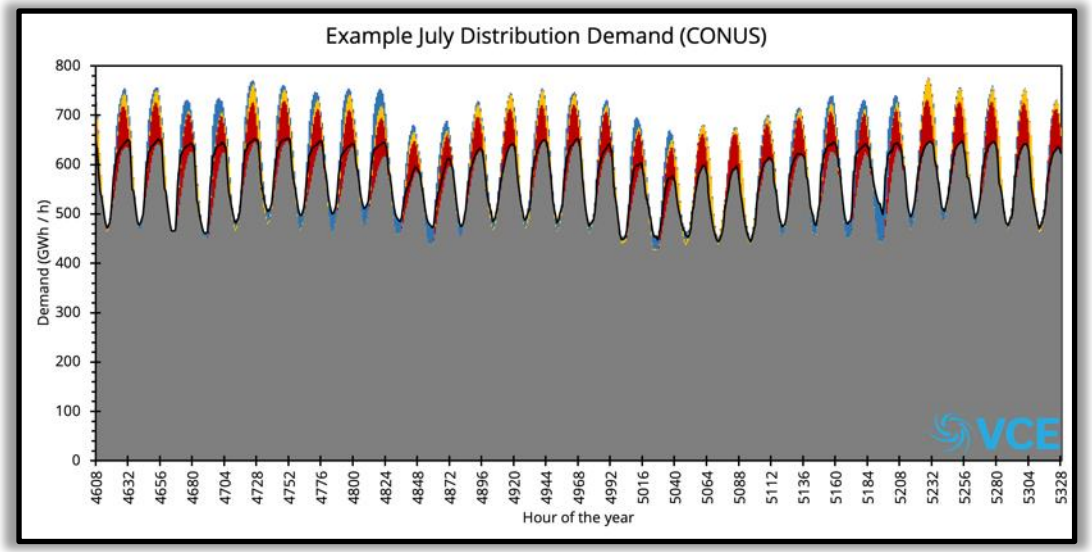


Distribution co-optimization is needed to understand electrification implications on pathways

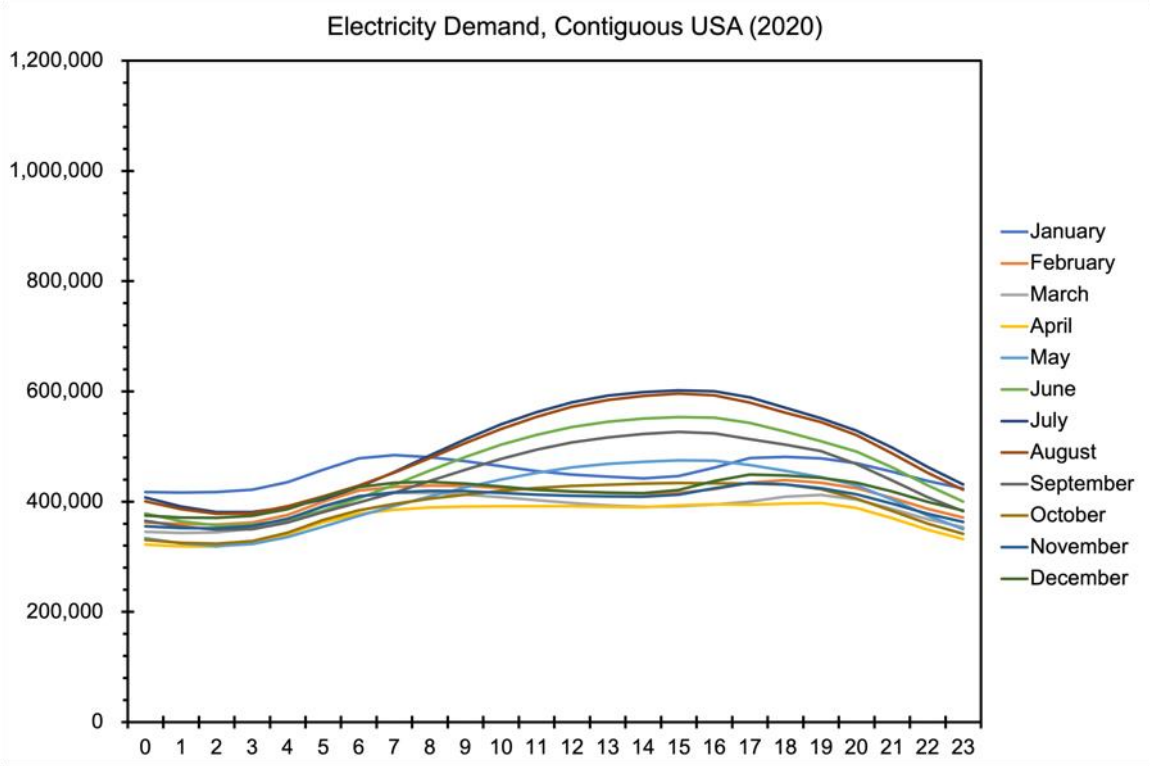


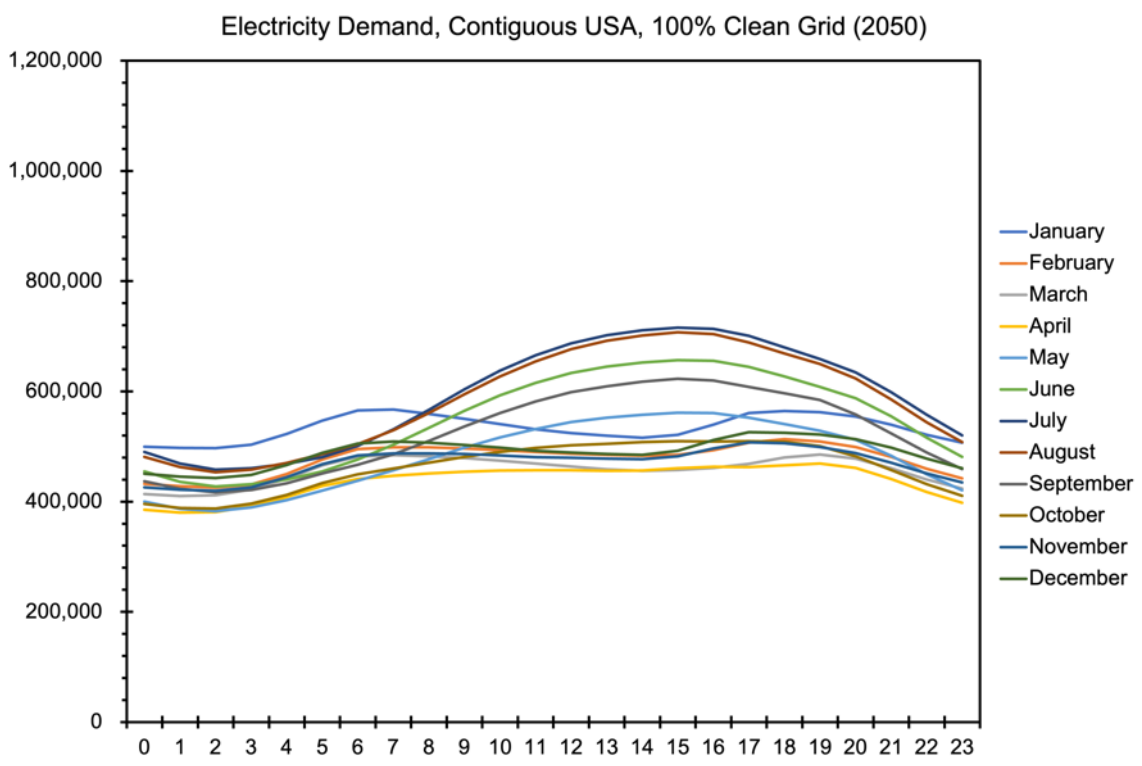






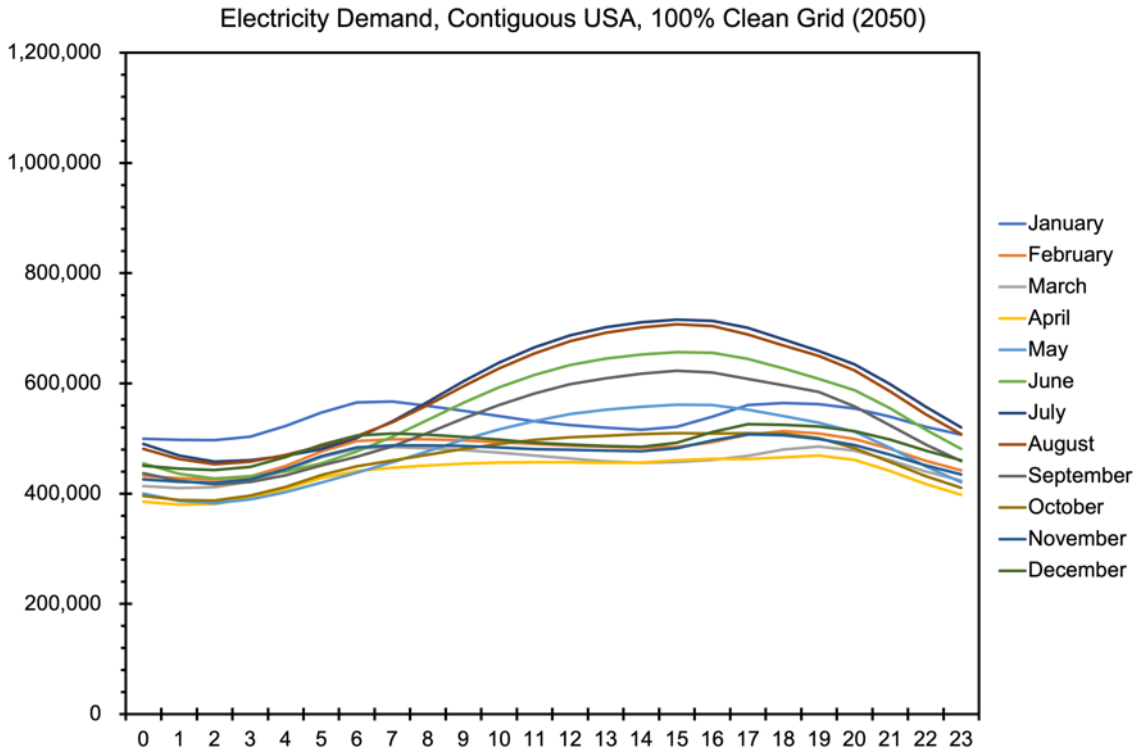
How Clean Electricity Change Demands

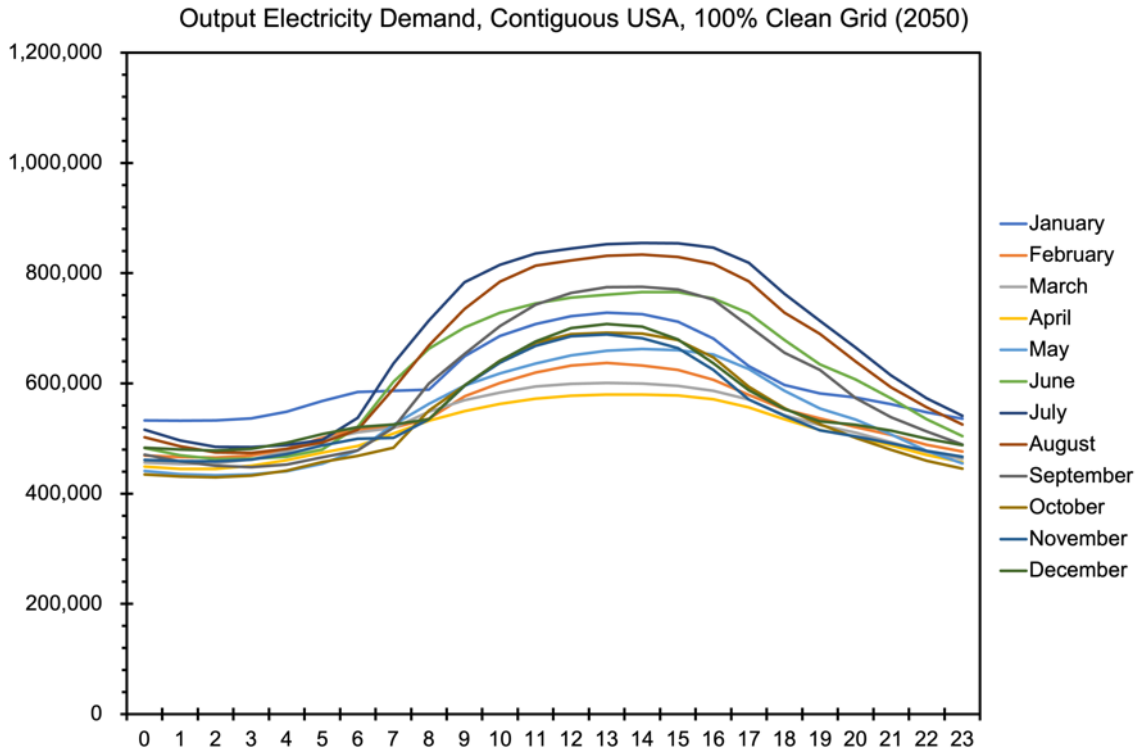




Using weather as a crucial input, demand data is built that is physically correlated to the supply and transmission weather-driven components

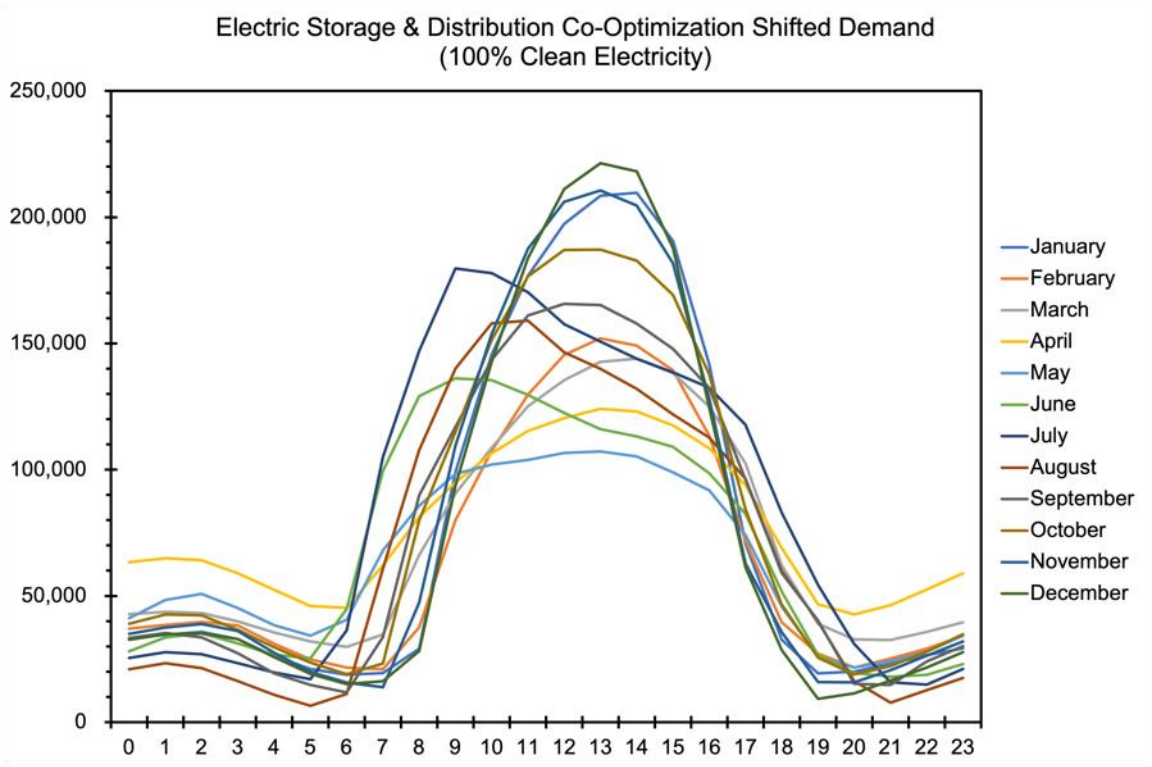
How Clean Electricity Change Demands





The storage & distribution co-optimization alters the exogenous demand to create a new dynamic (weather-informed) demand

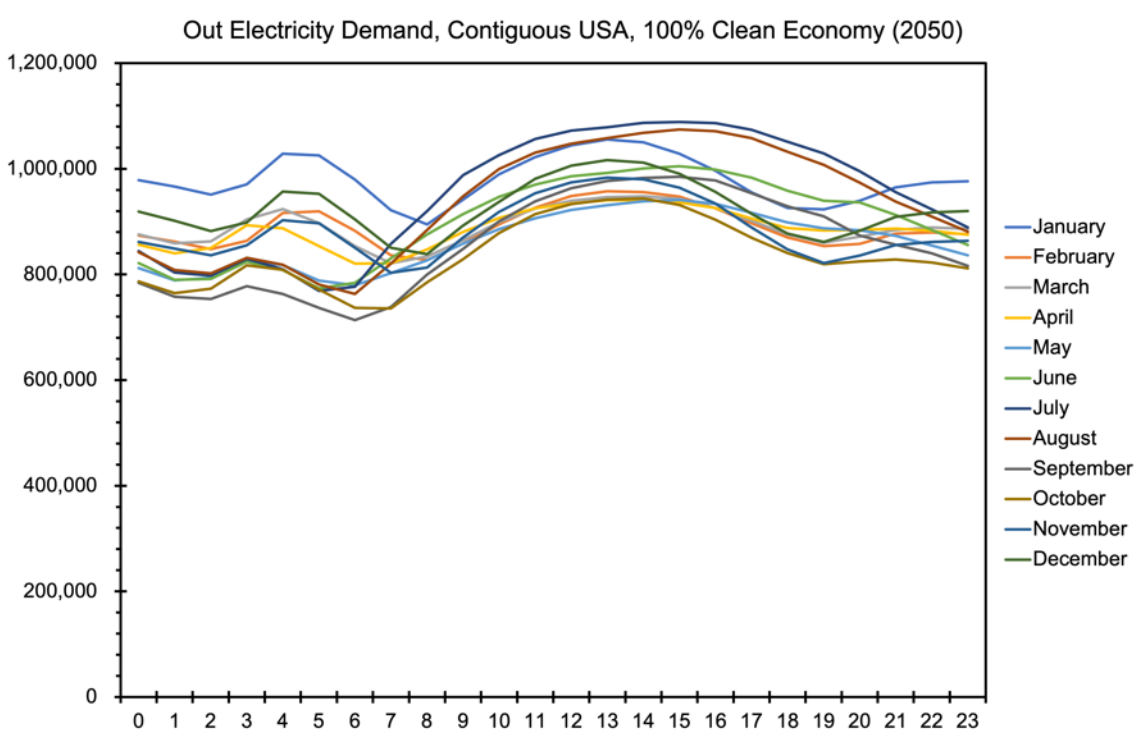
How Clean Electricity Change Demands

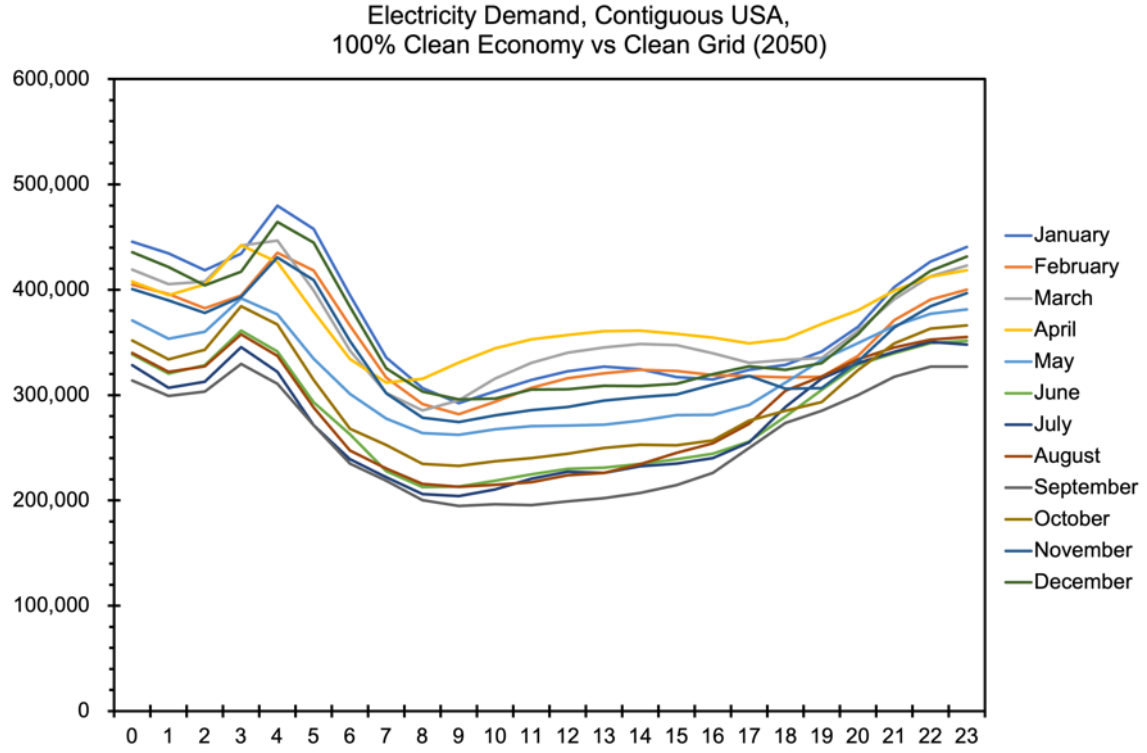


Average of Demand Hour of Day (ET)	Month January	February	March	April	May	June	July	August	September	October	November	December
0	33,162	37,038	42,757	63,377	41,118	28,081	25,468	20,890	33,380	38,950	34,967	32,704
1	34,636	38,498	43,714	64,986	48,373	33,614	27,735	23,307	35,244	42,635	37,483	34,847
2	35,714	39,645	43,276	64,079	50,832	35,156	26,952	21,434	33,586	42,260	38,837	35,185
3	32,832	38,281	39,841	58,905	45,174	31,193	23,353	16,221	27,217	36,595	36,159	32,887
4	26,066	31,039	35,484	52,357	38,385	26,694	19,725	10,803	19,358	29,727	27,461	25,745
5	21,027	24,854	31,931	46,009	34,320	25,354	17,016	6,451	14,691	23,623	19,902	19,141
6	18,804	21,608	29,754	45,311	40,553	44,785	36,279	11,216	11,764	19,024	15,714	15,133
7	19,449	20,991	34,700	62,072	68,075	99,495	105,036	60,784	33,641	23,236	13,889	16,268
8	29,069	37,569	66,217	81,215	85,728	129,096	147,085	107,780	89,894	79,934	47,358	28,197
9	99,052	79,926	90,506	94,902	98,310	136,166	179,746	140,080	116,990	114,915	109,460	93,683
10	145,522	107,402	108,728	106,462	102,010	135,412	177,793	157,975	143,526	151,374	153,748	142,771
11	176,780	129,747	125,103	115,337	103,823	129,583	170,269	159,067	161,061	176,604	187,484	183,862
12	197,419	145,489	135,501	120,428	106,616	122,449	157,606	146,509	165,700	187,015	206,137	211,195
13	208,543	152,021	142,685	124,044	107,245	116,056	150,725	139,898	165,245	187,192	210,534	221,398
14	209,635	149,093	143,982	123,058	105,302	113,209	143,929	132,002	157,883	182,772	204,623	218,190
15	190,533	139,374	138,231	117,550	98,908	109,043	138,595	121,914	147,877	169,200	181,703	187,790
16	141,765	113,380	125,015	108,435	91,823	98,551	132,417	112,700	132,321	137,805	128,147	124,604
17	70,699	71,841	102,521	93,826	74,131	82,543	117,765	96,356	96,054	84,389	62,848	61,352
18	32,619	39,523	62,044	68,942	45,787	51,743	82,935	59,707	59,060	46,609	35,625	28,471
19	19,371	27,182	38,960	46,692	25,867	26,558	54,388	39,944	40,238	25,542	15,878	9,250
20	20,031	21,581	32,724	42,653	21,648	19,524	30,917	16,175	15,203	18,876	15,807	11,409
21	23,103	25,174	32,530	46,317	24,087	17,933	15,786	7,724	14,746	22,171	20,615	16,433
22	26,579	29,093	35,811	52,571	27,952	18,753	14,839	12,727	23,998	27,989	26,347	21,641
23	29,166	34,151	39,521	58,970	34,315	23,055	21,087	17,514	30,137	34,853	32,005	27,662

This manifests as additional demand for almost all hours throughout the year; but with the largest increases when there is an abundance of VRE supply

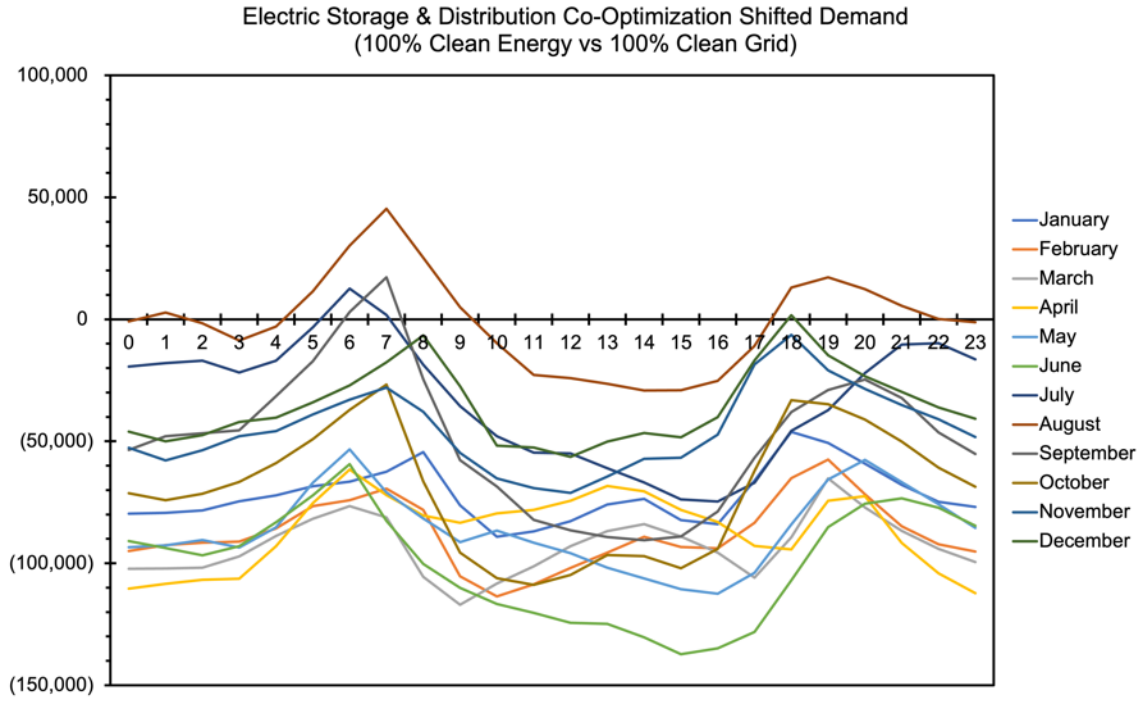
How Clean Economy Changes Demands





Through electrification (and hydrogen) the electricity demand grows by over 50% compared with the clean electricity goals. Additionally, the timing of those demands also shifts, changing the periods of scarcity.

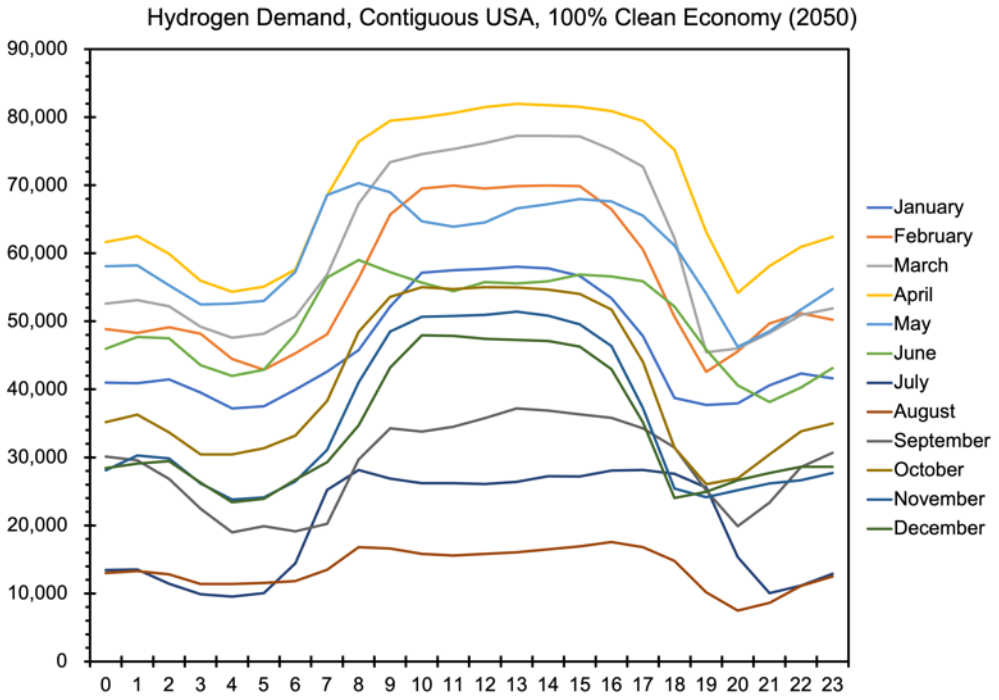
How Clean Economy Changes Demands



Average of Demand	Month											
Hour of Day (ET)	January	February	March	April	May	June	July	August	September	October	November	December
0	(79,601)	(94,993)	(102,203)	(110,412)	(93,439)	(90,847)	(19,410)	(890)	(53,516)	(71,308)	(52,636)	(46,052)
1	(79,287)	(92,517)	(102,175)	(108,391)	(92,612)	(93,785)	(17,965)	2,789	(47,968)	(74,119)	(57,869)	(49,991)
2	(78,379)	(91,524)	(101,829)	(106,792)	(90,430)	(96,712)	(16,976)	(1,630)	(46,687)	(71,501)	(53,668)	(47,430)
3	(74,636)	(91,156)	(97,177)	(106,275)	(93,487)	(93,014)	(21,796)	(8,720)	(45,503)	(66,598)	(47,908)	(42,091)
4	(72,121)	(85,691)	(88,795)	(92,942)	(85,284)	(83,170)	(16,902)	(2,943)	(31,502)	(58,914)	(45,819)	(40,353)
5	(68,427)	(76,617)	(81,695)	(75,398)	(66,991)	(72,102)	(3,261)	11,505	(17,140)	(49,117)	(39,025)	(34,063)
6	(66,583)	(74,178)	(76,547)	(61,607)	(53,253)	(59,386)	12,636	30,188	2,970	(37,118)	(32,951)	(27,067)
7	(62,427)	(69,403)	(81,195)	(72,041)	(70,938)	(82,594)	1,734	45,283	17,278	(26,753)	(27,918)	(17,559)
8	(54,449)	(78,125)	(105,594)	(80,430)	(81,653)	(100,259)	(18,580)	25,303	(24,577)	(66,378)	(37,852)	(6,630)
9	(76,279)	(105,328)	(116,985)	(83,434)	(91,324)	(110,068)	(35,561)	4,959	(57,715)	(95,626)	(54,734)	(27,420)
10	(89,122)	(113,615)	(108,346)	(79,554)	(86,586)	(116,666)	(47,863)	(9,785)	(68,574)	(106,128)	(65,267)	(51,809)
11	(86,923)	(108,659)	(101,198)	(78,153)	(91,582)	(120,318)	(54,667)	(22,833)	(82,220)	(108,809)	(69,129)	(52,592)
12	(82,703)	(101,953)	(92,950)	(74,402)	(95,879)	(124,364)	(54,973)	(24,093)	(86,428)	(104,826)	(71,121)	(56,349)
13	(75,849)	(95,587)	(86,798)	(68,270)	(101,782)	(124,823)	(61,001)	(26,470)	(89,227)	(96,629)	(64,427)	(50,107)
14	(73,593)	(89,132)	(83,952)	(70,478)	(106,210)	(130,344)	(66,896)	(29,217)	(90,591)	(97,056)	(57,209)	(46,560)
15	(82,320)	(93,282)	(89,045)	(78,125)	(110,568)	(137,264)	(73,821)	(29,074)	(89,067)	(102,038)	(56,730)	(48,318)
16	(83,927)	(93,884)	(95,633)	(83,099)	(112,454)	(134,856)	(74,629)	(25,255)	(78,792)	(94,040)	(47,237)	(40,119)
17	(66,151)	(83,348)	(105,879)	(92,901)	(103,889)	(128,145)	(66,960)	(10,919)	(56,756)	(62,114)	(18,444)	(16,788)
18	(46,185)	(65,079)	(89,403)	(94,318)	(84,032)	(106,997)	(45,743)	13,061	(38,044)	(33,093)	(6,385)	1,687
19	(50,634)	(57,505)	(65,221)	(74,344)	(65,614)	(85,148)	(37,173)	17,235	(28,954)	(34,750)	(20,964)	(14,735)
20	(59,189)	(71,691)	(77,094)	(72,524)	(57,659)	(75,547)	(22,031)	12,396	(24,607)	(41,124)	(28,548)	(23,357)
21	(67,910)	(84,812)	(86,653)	(91,626)	(66,715)	(73,346)	(10,353)	5,487	(32,293)	(50,129)	(35,119)	(29,692)
22	(74,827)	(92,238)	(94,085)	(104,060)	(75,830)	(77,176)	(9,796)	171	(46,323)	(60,835)	(40,937)	(36,081)
23	(76,877)	(95,163)	(99,519)	(112,211)	(85,487)	(84,603)	(16,403)	(1,239)	(55,208)	(68,631)	(48,241)	(40,732)

Despite a substantial growth in overall demand, the storage and distribution co-optimization reduces input demand in almost all hours (particularly in summer).

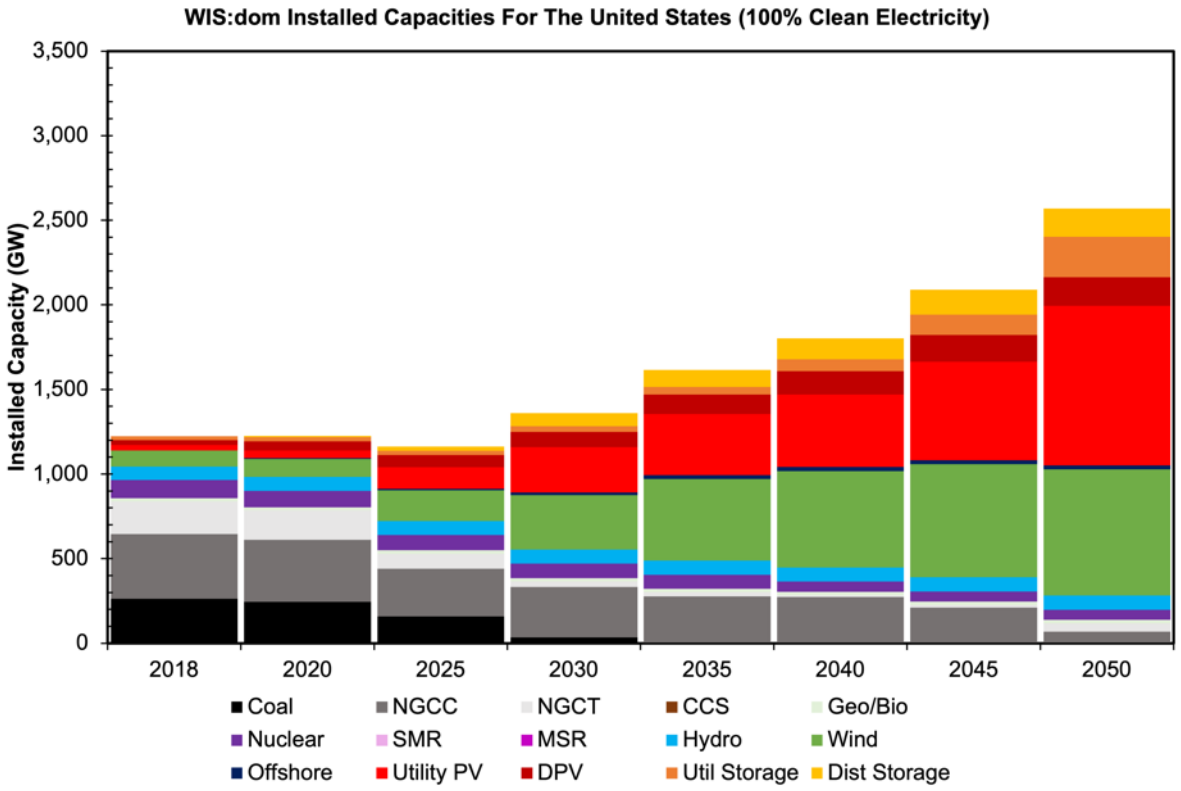
How Clean Economy Changes Demands

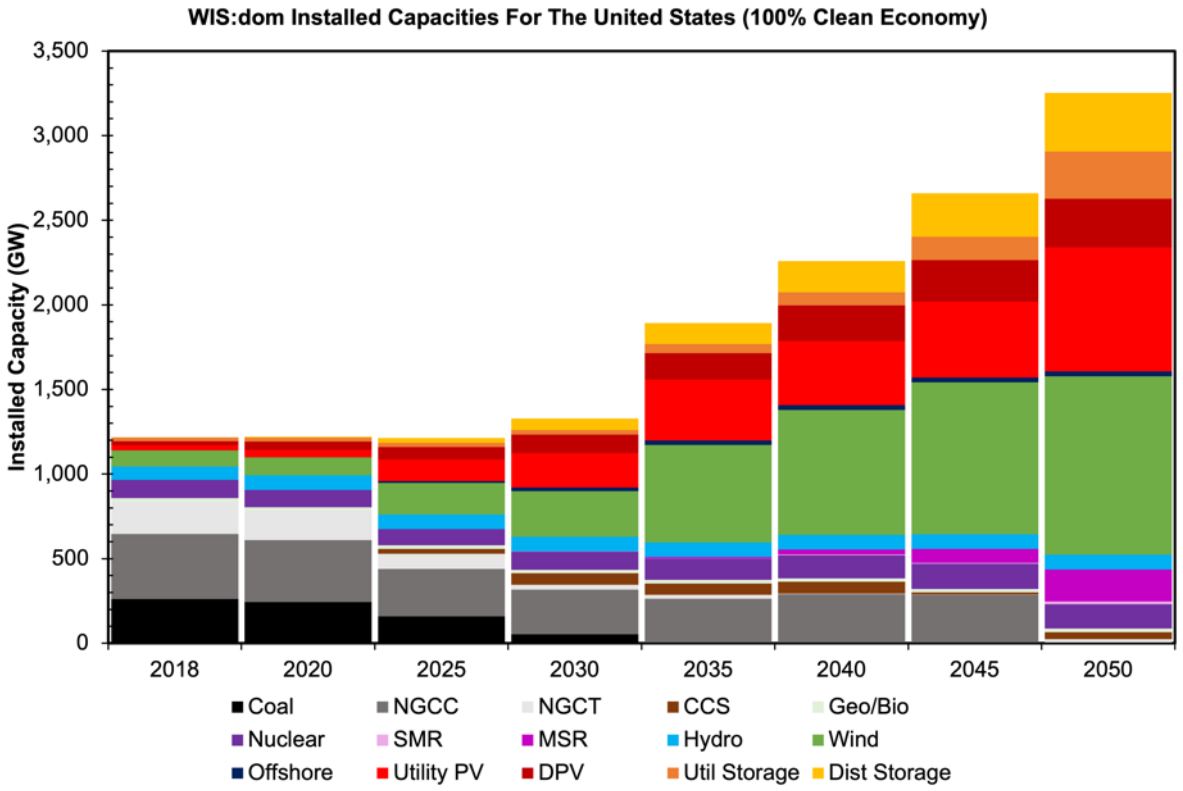


Average of Demand Hour of Day (ET)	Month January	February	March	April	May	June	July	August	September	October	November	December
0	40,988	48,838	52,609	61,659	58,089	45,957	13,465	12,994	30,129	35,162	28,092	28,419
1	40,912	48,297	53,126	62,513	58,222	47,686	13,527	13,290	29,562	36,305	30,294	29,103
2	41,464	49,128	52,195	59,933	55,273	47,510	11,449	12,820	26,842	33,658	29,856	29,453
3	39,506	48,183	49,192	55,958	52,499	43,553	9,882	11,377	22,462	30,438	26,166	26,277
4	37,214	44,482	47,595	54,328	52,593	41,982	9,560	11,378	18,988	30,427	23,811	23,425
5	37,510	42,876	48,162	55,082	53,016	42,890	10,042	11,546	19,901	31,362	24,127	23,904
6	39,948	45,287	50,718	57,613	57,280	48,156	14,453	11,824	19,117	33,192	26,483	26,719
7	42,599	48,092	56,863	68,516	68,559	56,433	25,205	13,495	20,248	38,308	31,126	29,283
8	45,750	56,352	67,295	76,379	70,309	59,016	28,140	16,788	29,697	48,458	41,034	34,697
9	52,157	65,696	73,372	79,490	68,946	57,208	26,872	16,608	34,283	53,593	48,499	43,187
10	57,141	69,509	74,563	79,935	64,694	55,695	26,211	15,816	33,809	55,005	50,656	47,952
11	57,511	69,935	75,318	80,620	63,896	54,410	26,192	15,588	34,499	54,739	50,795	47,859
12	57,717	69,536	76,197	81,503	64,536	55,769	26,076	15,806	35,779	55,036	50,934	47,425
13	58,020	69,861	77,277	81,951	66,592	55,556	26,411	16,073	37,205	54,967	51,410	47,288
14	57,778	69,957	77,271	81,783	67,205	55,898	27,246	16,505	36,892	54,664	50,844	47,121
15	56,677	69,856	77,168	81,515	67,978	56,882	27,217	16,934	36,341	54,045	49,543	46,264
16	53,378	66,466	75,262	80,909	67,637	56,591	28,078	17,558	35,807	51,736	46,354	42,945
17	47,812	60,559	72,734	79,445	65,533	55,893	28,169	16,788	34,262	44,033	37,232	35,151
18	38,732	50,659	62,198	75,219	61,148	52,169	27,589	14,797	31,467	31,436	25,433	24,044
19	37,702	42,577	45,469	63,119	54,076	45,844	25,589	10,182	25,146	26,051	24,143	24,956
20	37,932	45,571	46,023	54,190	46,265	40,592	15,338	7,478	19,905	26,931	25,180	26,641
21	40,583	49,698	48,312	58,135	48,524	38,129	10,036	8,634	23,357	30,448	26,170	27,719
22	42,326	51,192	50,936	60,926	51,739	40,286	11,173	11,119	28,597	33,817	26,658	28,633
23	41,628	50,236	51,879	62,403	54,746	43,111	12,892	12,490	30,669	34,992	27,705	28,639

A new additional demand for hydrogen appears in the 100% clean economy (the model never selects hydrogen for electricity production).

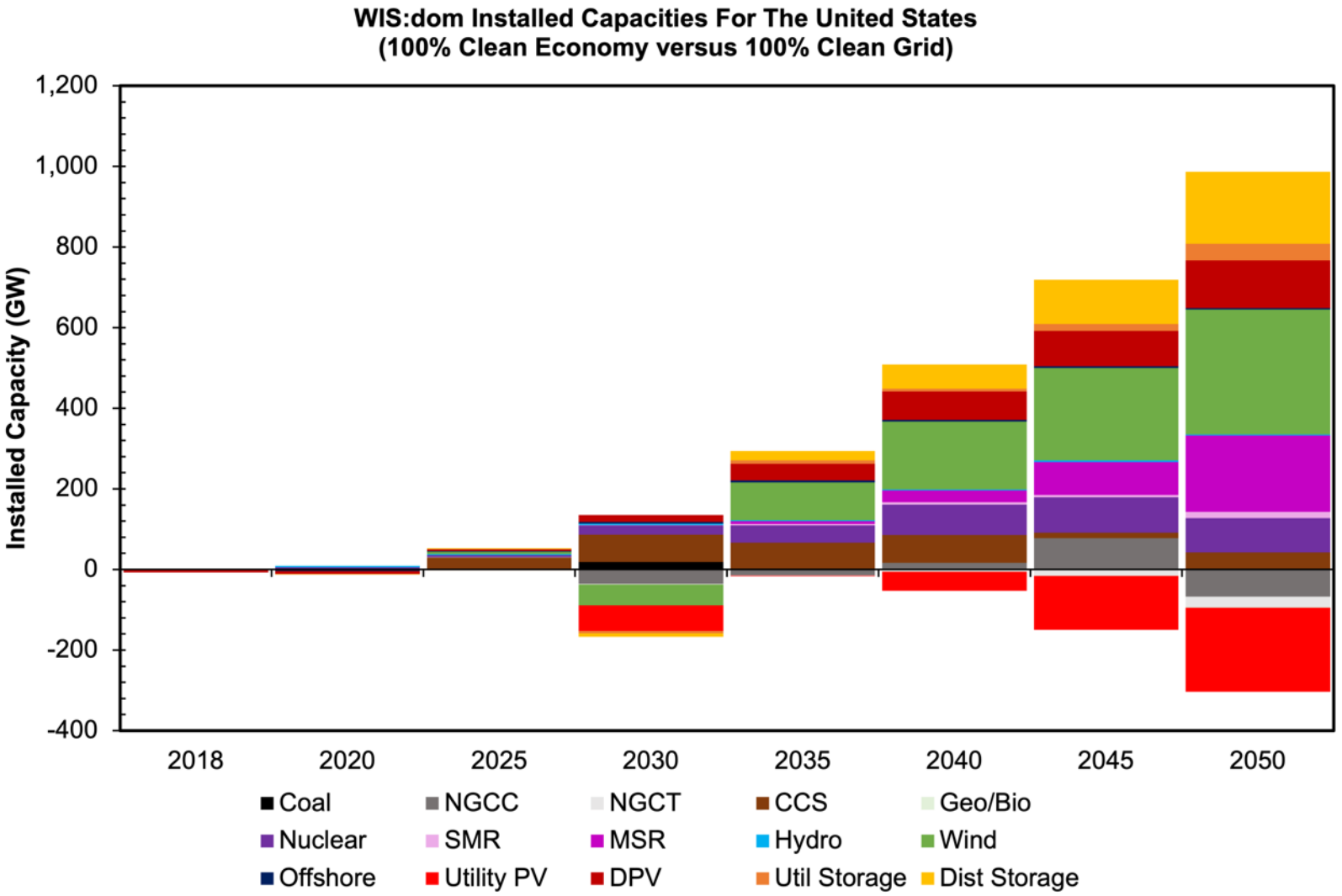
How Clean Economy Changes Supply





The supply of electricity dramatically increases in both 100% clean electricity & clean economy. However, we see a much bigger increase in VREs in the clean economy, as well as a small reliance on dispatchable clean generation.

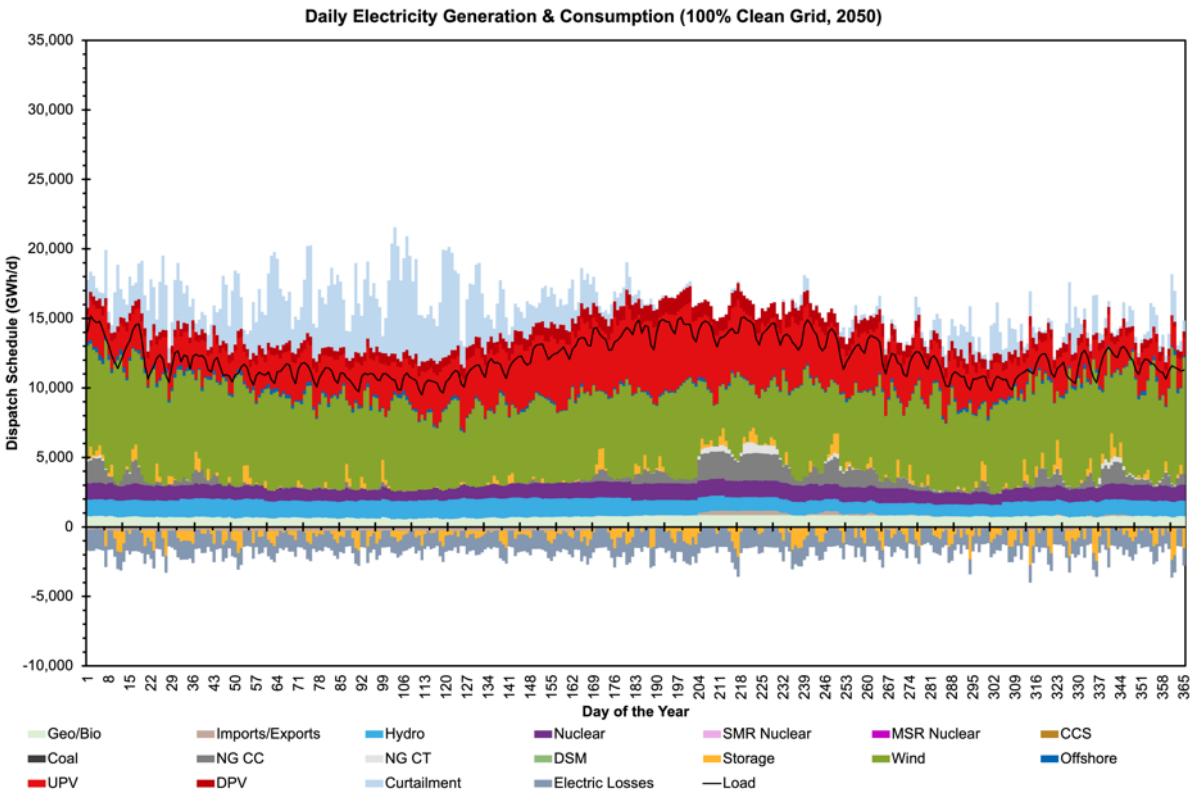
How Clean Economy Changes Supply

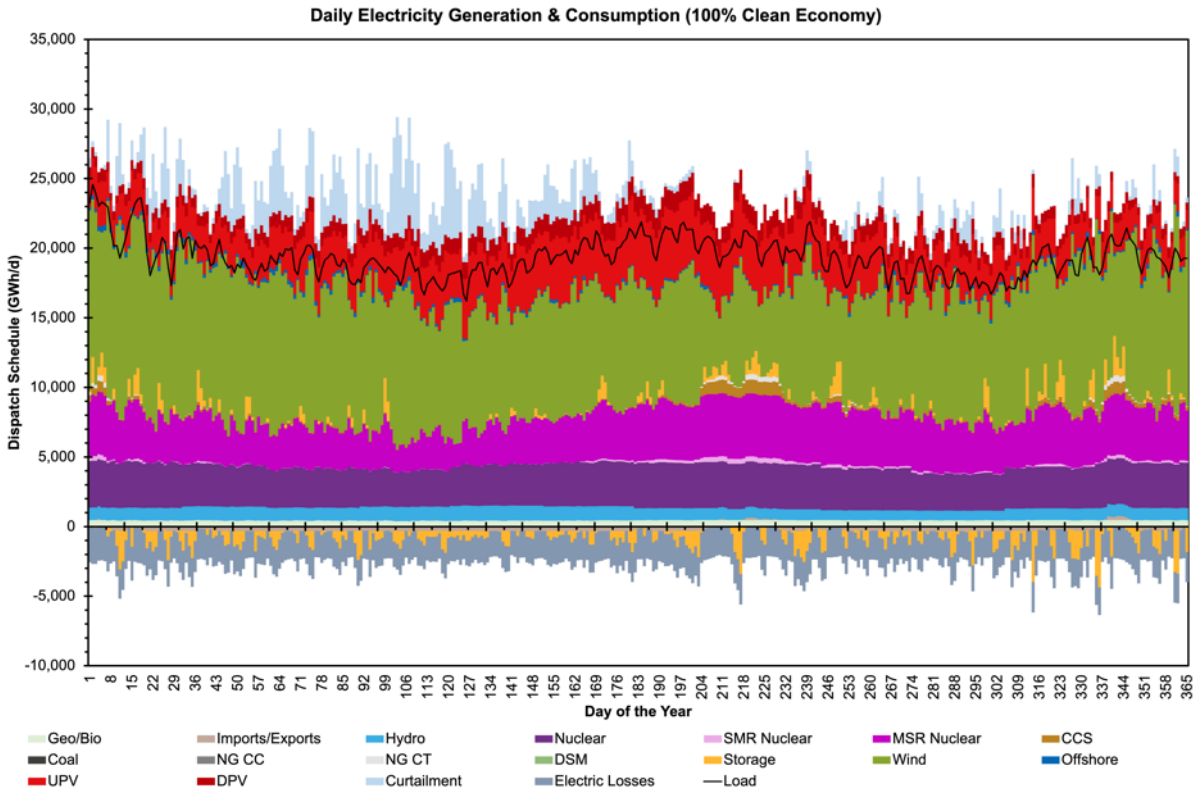


We see a reduction in solar PV (utility-scale) and a big increase in wind as well as distributed solar and storage. Note we see the model deploying clean dispatchable generation, and keeping/relicensing traditional nuclear assets.

Note, without the distribution co-optimization, we saw significant additional overbuild of firming generation and renewables that increased costs to customers.

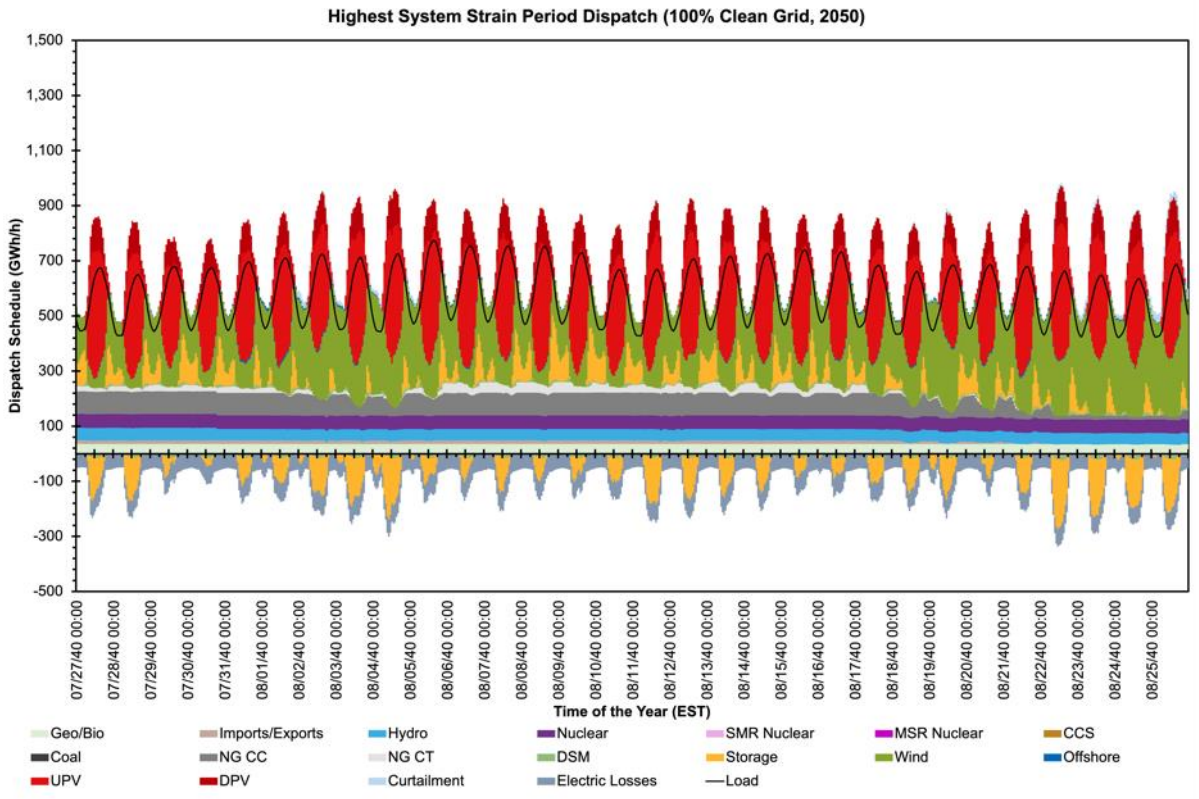
How Clean Economy Changes Supply

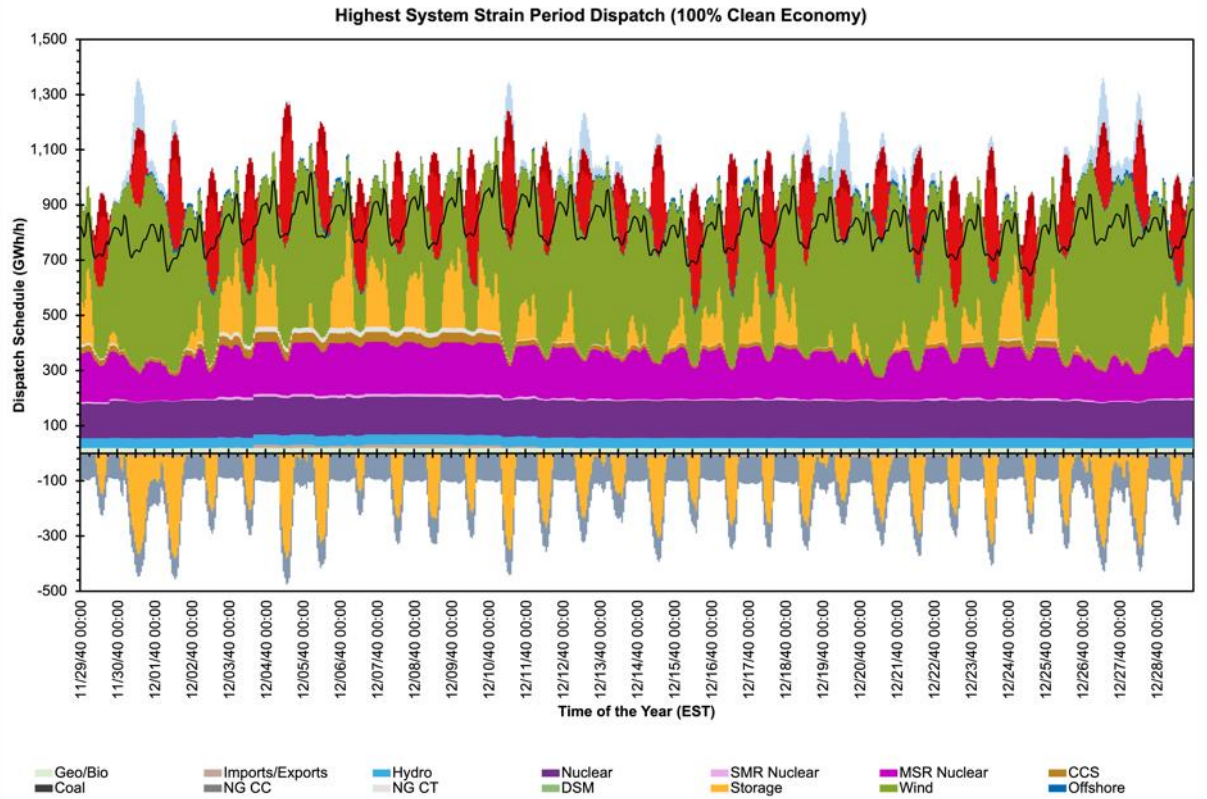




More demand that is more flexible allows the 100% clean economy to generate more electricity via VREs, but there is an increase in clean dispatchable generation because of the inter-annual variability of the weather impacting both supply and demand simultaneously

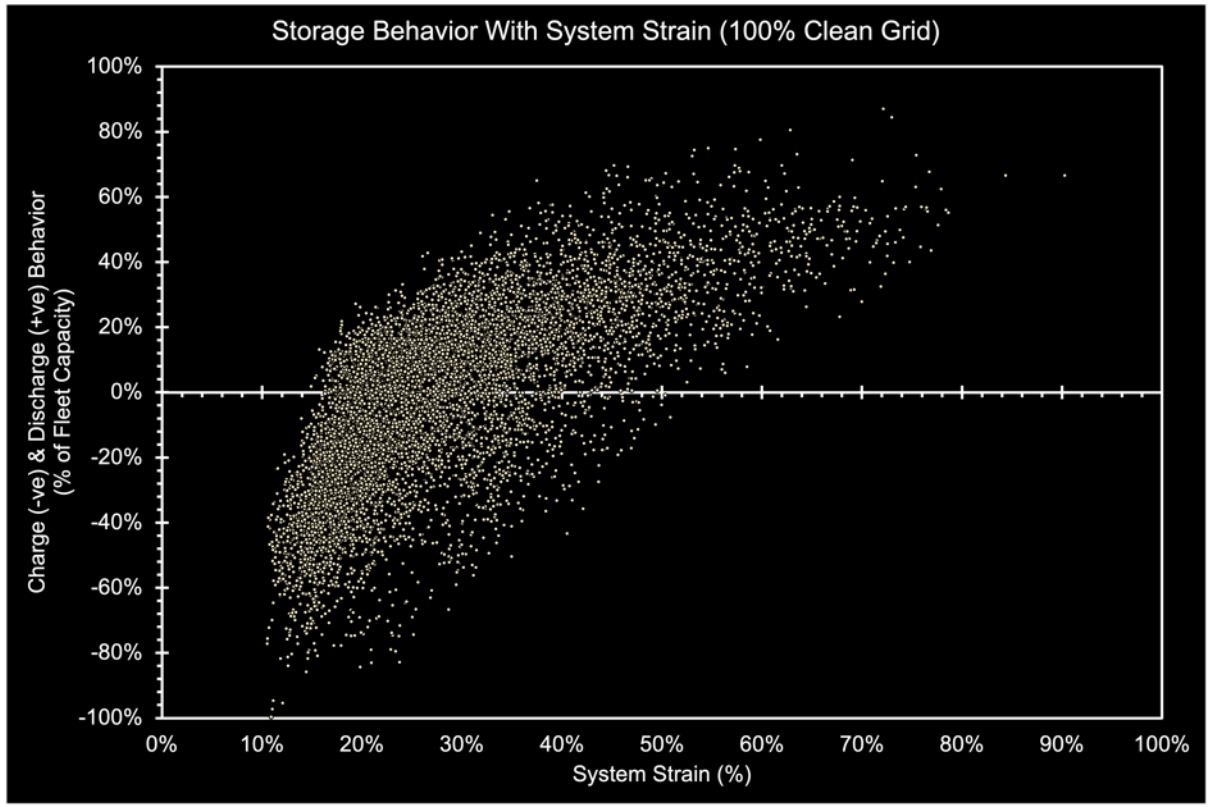
How Each System Deals with Scarcity Events

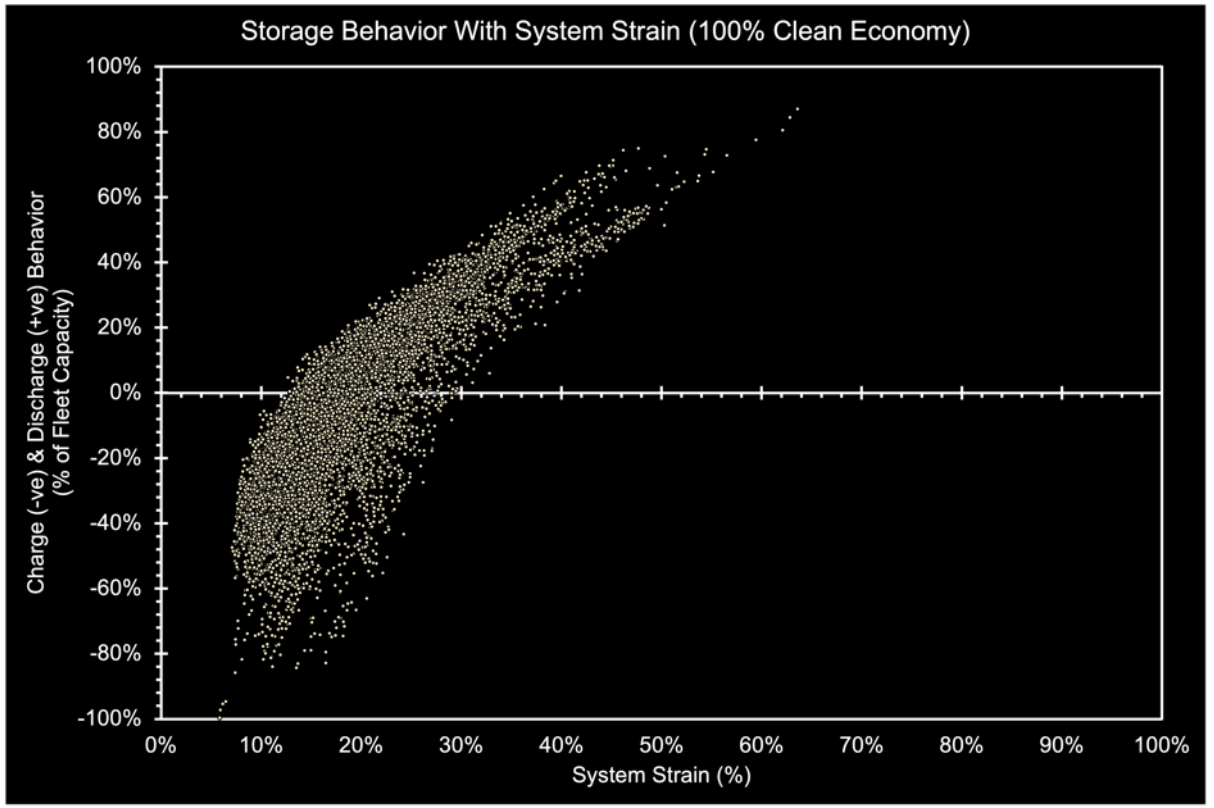




The most scarce/stressed period in 100% Clean Grid in in the height of summer just after sunset, and lasts about a week. For the 100% Clean Economy this happens in early winter (usually) and also lasts about a week. Its typically a combination of low winds following a storm.

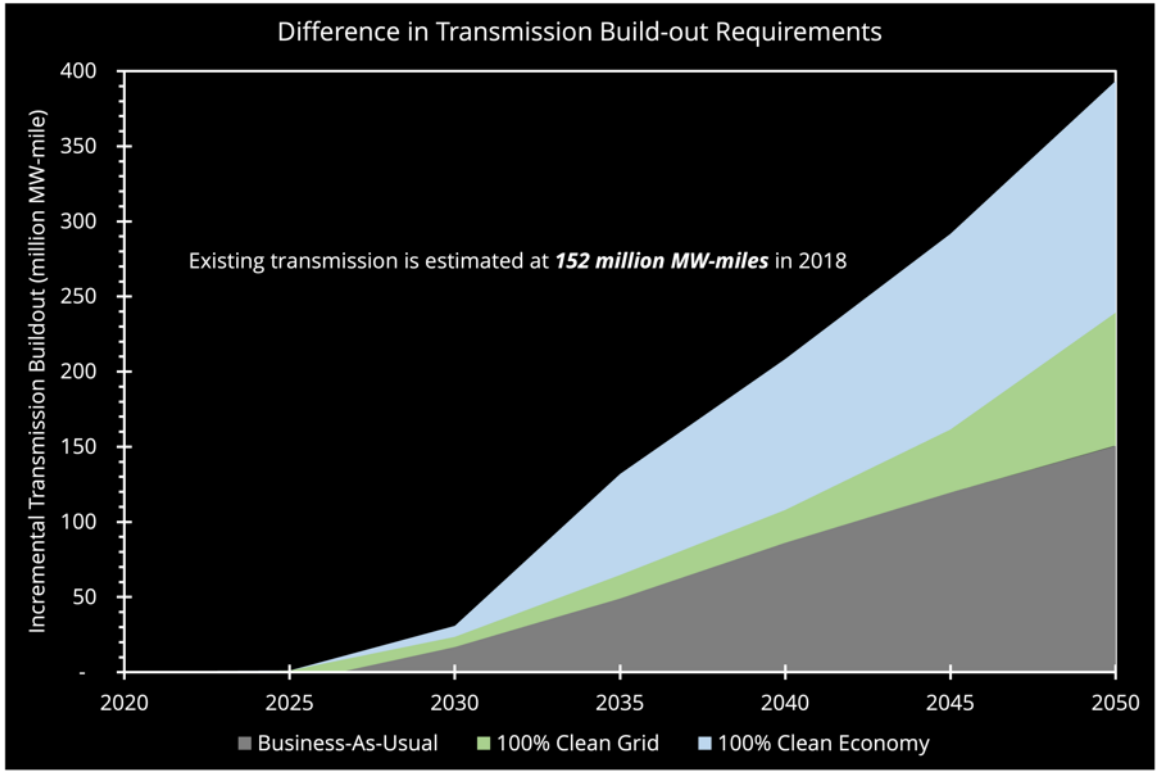
How Each System Deals with Scarcity Events

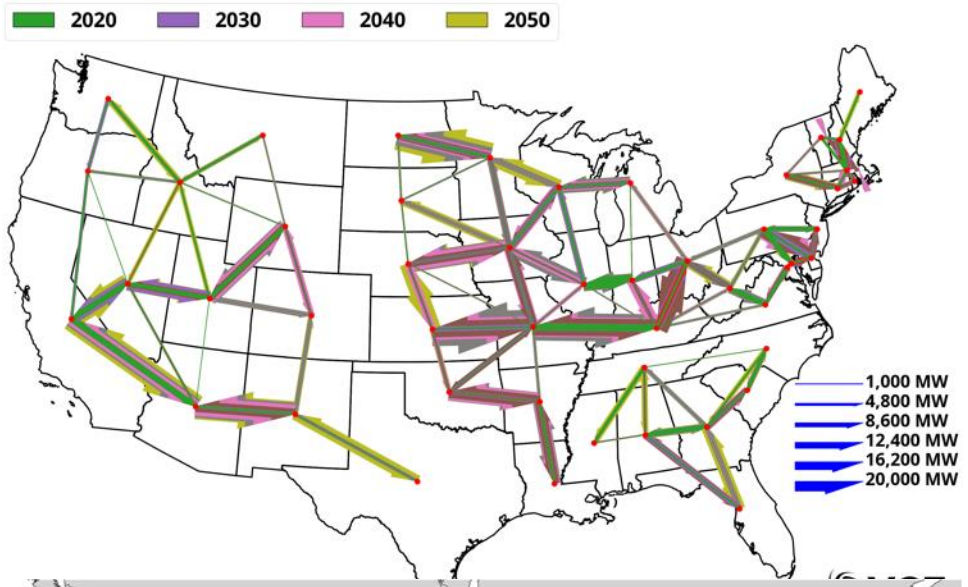


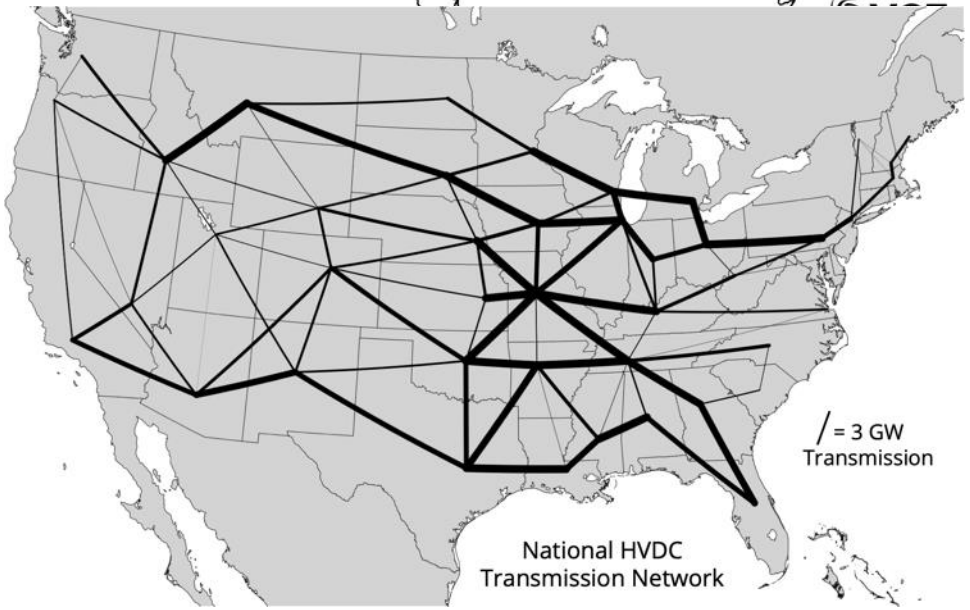


The 100% Clean Economy has much fewer hours when the system is stressed. In fact, on average the system is only over 60% stressed 0.03% of the hours. In contrast, the 100% Clean Grid is over 60% stressed 1.9% of hours.

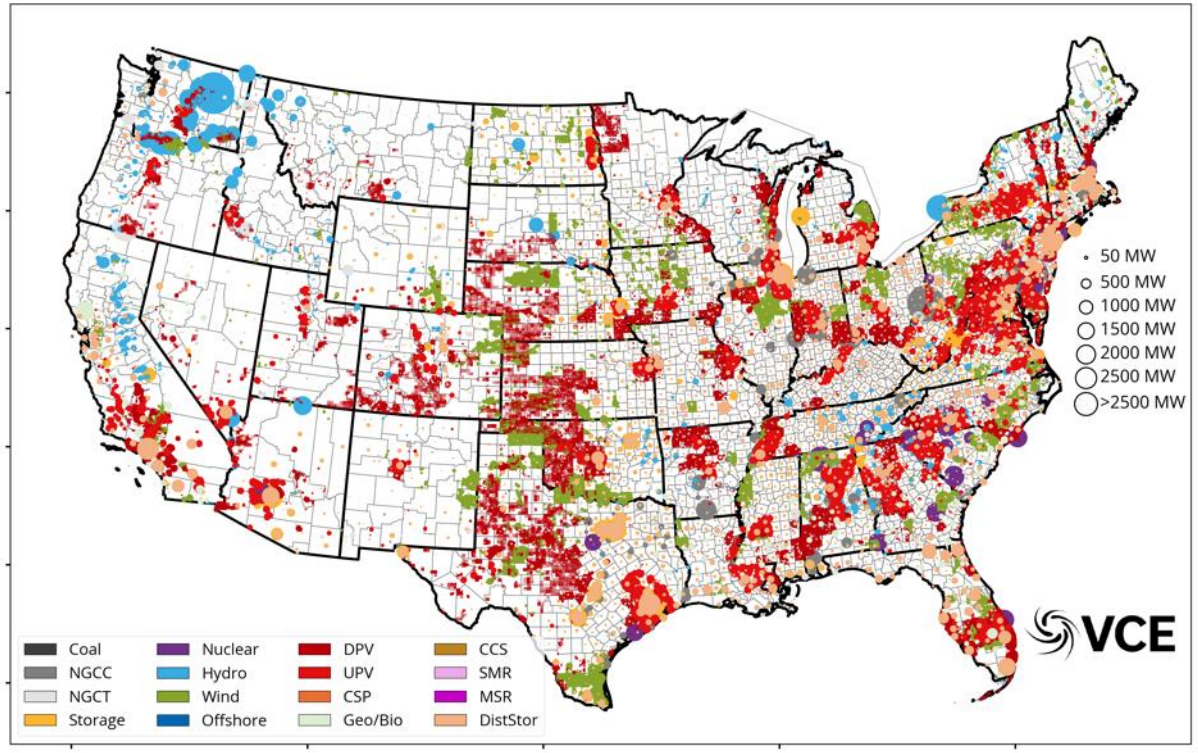
How Does Transmission Compare?

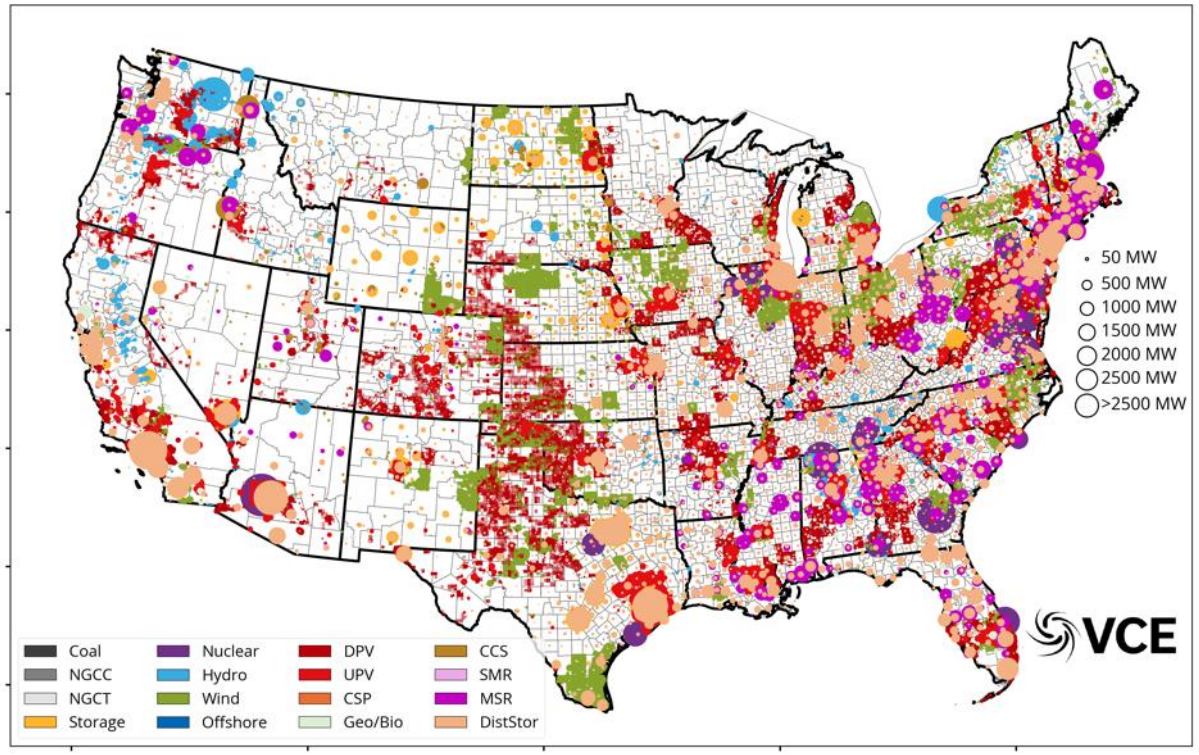






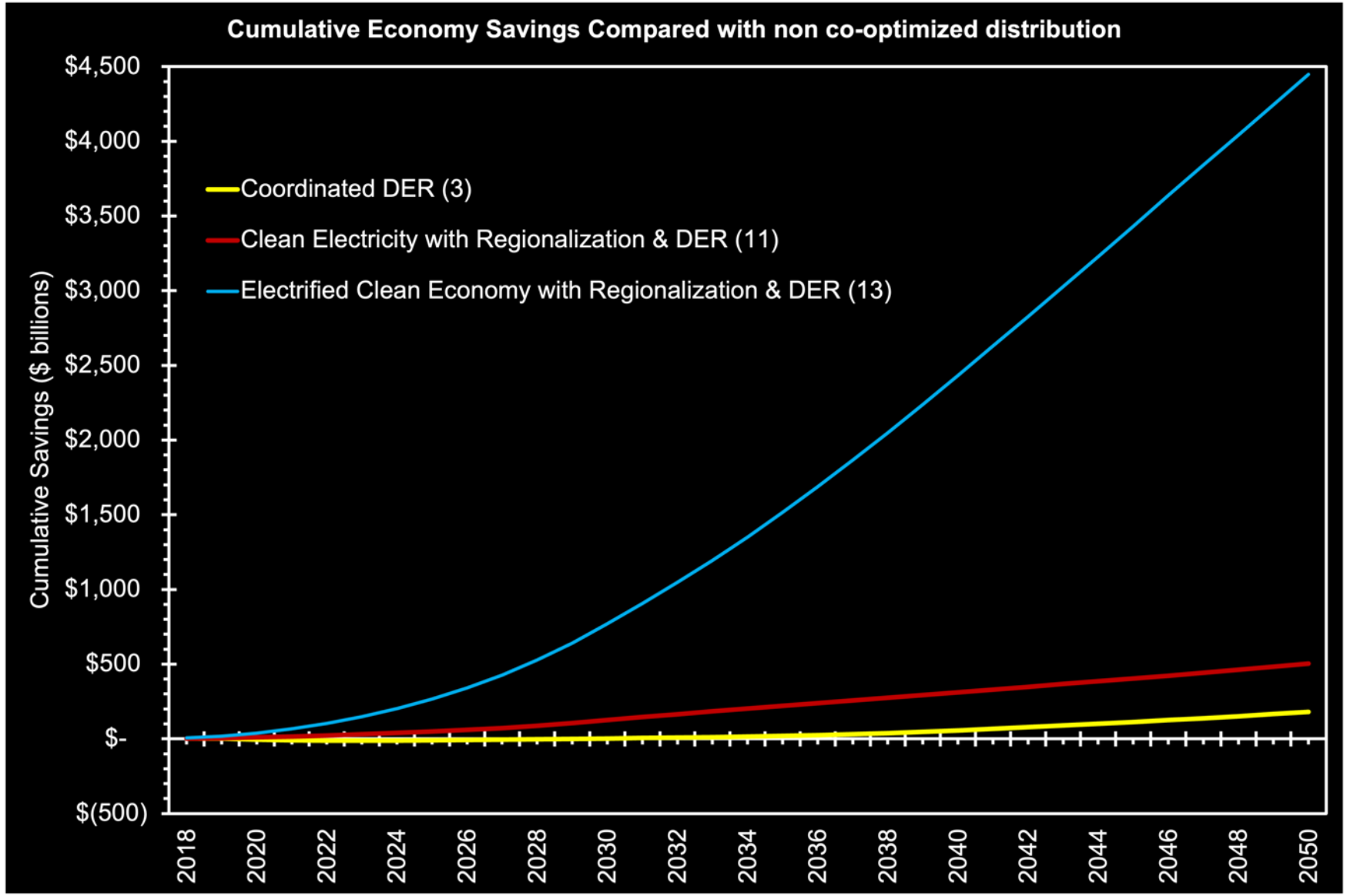
How Does Generator Siting Compare?





There is more wind generation being sited in the 100% Clean Economy, this is primarily placed in the great plains, we do see substantial reductions in solar PV in the populated states, which might reduce public resistance.

How Does System Costs Compare?



By 2050, there is $30 billion in annual heating cost savings

By 2050, there is $200 billion in annual transportation cost savings

Through 2050, the average retail rates are lower by 3.23¢/kWh

Thank You

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More Download Options for the RARE Power Dataset

The Resource Adequacy Renewable Energy (**RARE**) Power Dataset

- Zenodo archive of the input data (CSVs)
  https://doi.org/10.5281/zenodo.13937522
- Zenodo archive of PUDL v2024.10.0, the first release containing VCE RARE (as Parquet):
  https://doi.org/10.5281/zenodo.13957372
- Jupyter notebook on Kaggle with some examples of accessing the Parquet data:
  https://www.kaggle.com/code/catalystcooperative/04-renewable-generation-profiles
- VCE RARE data source documentation page in the PUDL docs:
  https://catalystcoop-pudl.readthedocs.io/en/nightly/data_sources/vcerare.html
- General PUDL data access instructions:
  https://catalystcoop-pudl.readthedocs.io/en/nightly/data_access.html
- Direct HTTPS download link for the (1.5GB) VCE RARE Parquet output:
  https://s3.us-west-2.amazonaws.com/pudl.catalyst.coop/v2024.10.0/out_vcerare__hourly_available_capacity_factor.parquet
- PUDL in the AWS Open Data Registry, for those comfortable with cloud storage:
  https://registry.opendata.aws/catalyst-cooperative-pudl/