Global Progress Toward Renewable Electricity: Tracking the Role of Solar (Version 3)

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***Abstract*—2022 was a milestone year for photovoltaics (PV), with cumulative installed global capacity exceeding 1 TW. PV represented 56% of newly installed global electricity generating capacity for 2022, the second year in a row that this metric exceeded 50%. The combined contributions of nonhydro renewable electricity generation (solar, wind, tidal, geothermal, and biomass) was comparable to that of hydropower for the first time in history. However, the total combination of carbon-free generation sources (hydro, nuclear, and renewables) stayed constant at ∼38% of total electricity, with the annual growth in overall generation (∼2%) balancing the large fractional growth in solar (25%) and wind (14%). Following its initial publication in 2021 with 1990–2020 data, this annual article will continue to collect information from multiple sources and present it systematically as a convenient reference for IEEE JPV readers. This year, for the first time, we present data on the growth of storage capacity. We find that growth of stationary battery storage now exceeds growth of pumped hydropower storage. That same annual investment in new stationary batteries, however, is small compared to the growth of battery storage in electric vehicles.**

***Index Terms*—Net expansions, renewable energy sources, solar energy, solar power generation.**

I. Introduction

Electricity generation from renewable energy sources continued to grow in magnitude in 2022, and photovoltaics (PV) continued its growth both in magnitude and fractional contribution. Total electricity from all sources consumed globally in 2022 was ∼29 170 TWh, representing ∼17.2% of total energy consumption similar to 2020–2021 [1]. The share of renewable power generation (hydro and non-hydro renewables, mainly wind and PV) remained at ∼30%. Newly installed generating capacity in 2022 for hydro, PV, and wind, was 82% of the global total, as shown in Fig. 2(c), with PV at more than 50% of new installed generating capacity for the second year in a row. The 2022 BP Statistical Review of World Energy [1] reported that "wind and solar reached a record high of 12% share of power generation."

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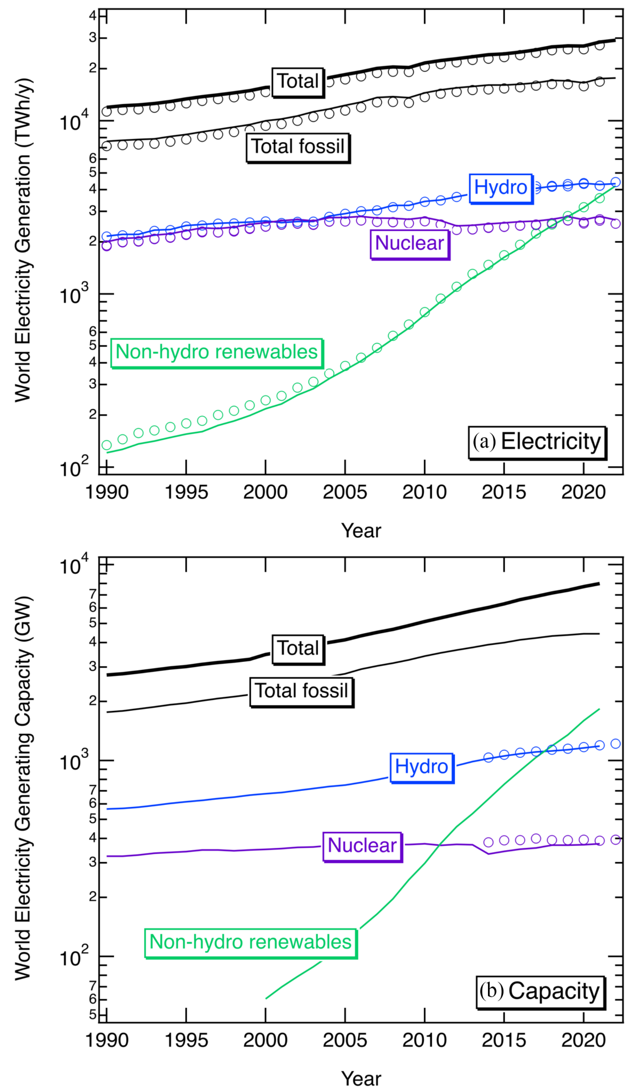

Fig. 1. (a) Annual electricity generation and (b) electricity generating capacity. Data are tabulated in Tables I and II with lines for the bolded data and open circles for the other sources.

PV is now the most rapidly growing generation technology in the energy transition. Reports based on estimated deployment rates suggesting that the TW_{DC} installed global capacity milestone had been achieved first appeared in March 2022 [2], and the 1 TW_{AC} milestone was also reached by the year's end. The percentage of global electricity generated by PV, which we reported as 3.6% for 2021, was 4.5% for 2022, based on the ratio of gross

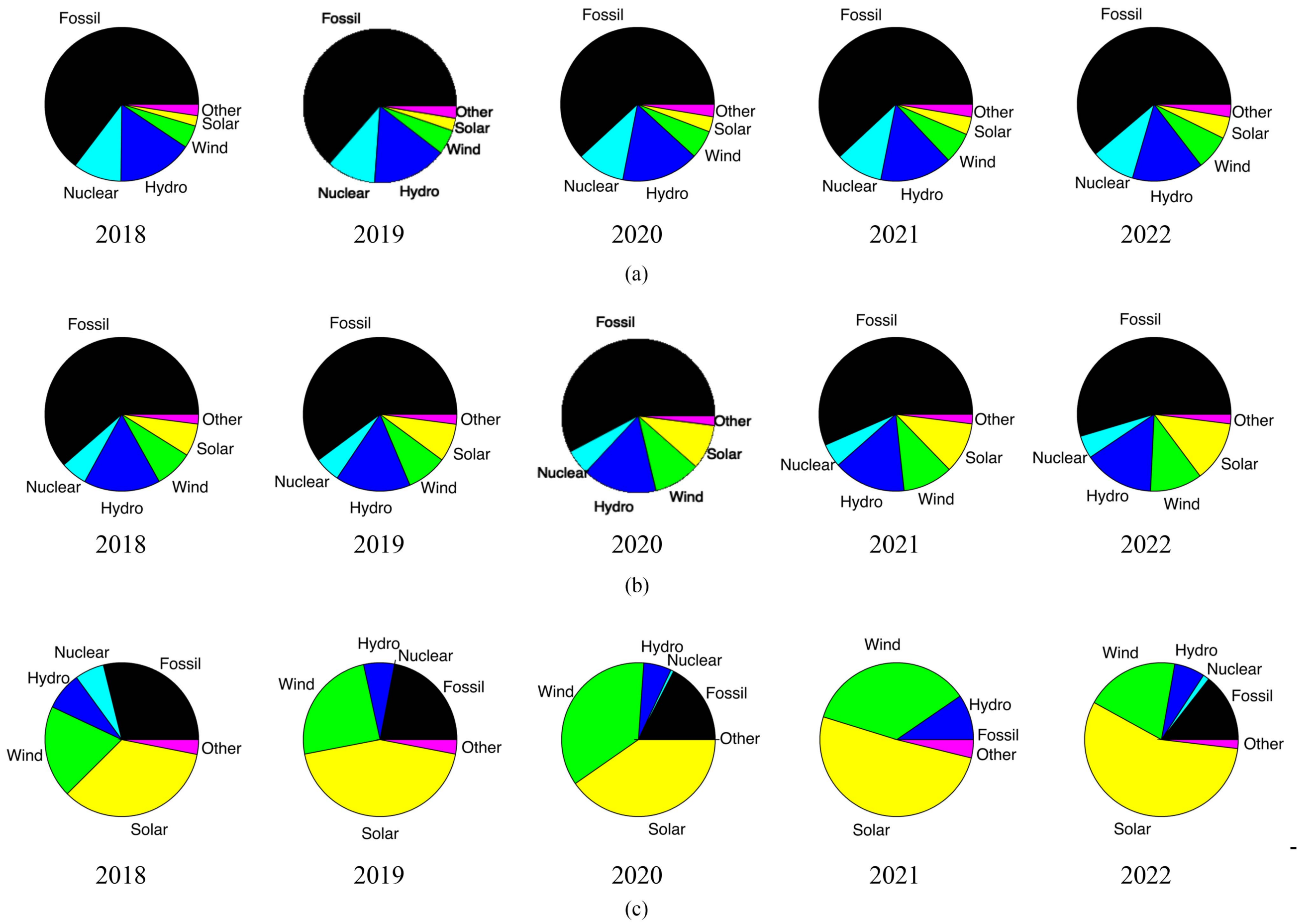

Fig. 2. (a) Pie charts showing global share of electricity generation by technology for the indicated years. Data taken from Tables I and VIII and summarized in Tables III–VII (see appendix for details). The "other" category includes biomass and geothermal. (b). Pie charts showing global share of electricity-generation capacity by technology for the indicated years. Data taken from Tables II and IX and summarized in Tables III–VII (see appendix for details). (c). Pie charts showing global share of net expansions of electricity-generation capacity by technology for the indicated years. Data taken from Tables II and IX and summarized in Tables III–VII (see appendix for details).

electricity generation from solar to gross electricity generation from all sources reported in [1], a remarkable 25% fractional growth. Global 2022 electricity generation from wind and solar combined (∼3430 TWh) was greater than electricity generation from nuclear power plants (∼2670 TWh), up a significant 18% from the previous year (∼2910 TWh). Non-CO_2 emitting generation sources (nuclear, hydro, and combined renewables) contributed 38% of the world's electricity in 2022, similar to 2021.

The goal of this annual article is to present data, in consistent graphical and tabular form, on the global progress toward renewable energy. As discussed in the initial 2021 publication [3], multiple institutions provide global energy data on a yearly basis. These organizations have varying missions and varying reporting times for annual updates. Different institutions also vary in their use of original sources and methodologies. Some may change methodologies over time, while others share reporting data. Assembling this collection of frequently cited sources in one place illustrates both major trends and the nature and degree of variations within the source group.

Here, we update the following three sets of graphs: annual generation by broad fuel source for global electricity (see Section II); yearly generation and newly installed capacity for specific fuel sources with a focus on renewables (see Section III); and generation and capacity over time with a more detailed breakout of fuel sources including PV (see Section IV). This year we also begin to track energy storage (see Section V). Data are included from six primary sources: the Energy Institute Statistical Review of World Energy, published in 2023 for the first time by the Energy Institute [1], taking over this respected resource after 71 years of publication by BP; the international data presented by the U.S. Energy Information Administration (EIA) [4]; the World Nuclear Association [5]; the International Energy Agency (IEA) [6]; the International Renewable Energy Agency (IRENA) [7]; and REN21 [8]. Short summaries of the mission and history for the six original organizations were provided in Appendix of the 2021 publication [3]. The Energy Institute is a professional membership organization, founded in 2003 (with precursor organizations dating back over 100 years), and home to a range of energy initiatives.

TABLE I
GLOBAL ELECTRICITY GENERATION BY TECHNOLOGY CATEGORY (TWH FOR INDICATED YEAR)

Category	Fossil		Nuclear			Hydro			Non-hydro RE		Total	
Source	BP/EI	EIA	BP/EI	EIA	WNA	BP/EI	EIA	REN21	BP/EI	EIA	BP/EI	EIA
Year												
1985	6286	6043	**1489**	1426	1328	**1979**	1952		**79**	55	**9886**	9464
1986	6440	6104	**1595**	1519	1440	**2006**	1992		**86**	60	**10181**	9660
1987	6758	6399	**1735**	1655	1600	**2033**	1996		**92**	66	**10671**	10100
1988	6998	6614	**1891**	1796	1727	**2098**	2072		**95**	69	**11141**	10534
1989	7456	7054	**1945**	1845	1832	**2088**	2060		**108**	118	**11658**	11062
1990	7615	7141	**2001**	1910	1890	**2159**	2144		**121**	134	**11961**	11310
1991	7722	7244	**2096**	1998	1988	**2209**	2183		**127**	145	**12222**	11551
1992	7807	7288	**2112**	2017	2009	**2209**	2189		**136**	157	**12336**	11633
1993	7858	7367	**2185**	2083	2073	**2342**	2314		**142**	163	**12600**	11906
1994	8119	7568	**2226**	2127	2111	**2356**	2337		**148**	171	**12924**	12183
1995	8335	7804	**2323**	2211	2191	**2484**	2454		**156**	179	**13382**	12627
1996	8627	8066	**2407**	2293	2269	**2517**	2490		**161**	185	**13797**	13011
1997	8911	8347	**2390**	2273	2264	**2561**	2545		**174**	200	**14129**	13340
1998	9214	8621	**2431**	2317	2298	**2581**	2552		**185**	212	**14511**	13678
1999	9498	8831	**2524**	2394	2379	**2601**	2589		**199**	228	**14926**	14016
2000	10009	9346	**2581**	2451	2444	**2647**	2622		**217**	243	**15564**	14635
2001	10232	9572	**2654**	2518	2511	**2579**	2567		**232**	258	**15800**	14887
2002	10669	9993	**2696**	2547	2553	**2626**	2611		**261**	288	**16358**	15407
2003	11273	10518	**2641**	2519	2505	**2623**	2616		**284**	311	**16935**	15934
2004	11721	10979	**2761**	2620	2616	**2817**	2787		**325**	348	**17737**	16705
2005	12295	11460	**2769**	2627	2626	**2911**	2907		**364**	384	**18464**	17348
2006	12808	11976	**2803**	2661	2661	**3022**	3008		**411**	429	**19167**	18045
2007	13643	12782	**2746**	2610	2608	**3073**	3036		**475**	488	**20059**	18887
2008	13779	12870	**2738**	2599	2598	**3252**	3173		**550**	574	**20436**	19191
2009	13581	12701	**2699**	2562	2558	**3246**	3230		**637**	666	**20279**	19134
2010	14489	13713	**2768**	2629	2630	**3430**	3409		**759**	787	**21590**	20509
2011	15084	14326	**2652**	2518	2518	**3493**	3471		**904**	940	**22278**	21226
2012	15514	14695	**2471**	2347	2346	**3642**	3630		**1062**	1101	**22833**	21745
2013	15804	15036	**2490**	2364	2359	**3788**	3761		**1239**	1307	**23468**	22440
2014	16085	15155	**2541**	2420	2410	**3889**	3831		**1406**	1473	**24074**	22849
2015	16069	15356	**2575**	2448	2441	**3880**	3845	3940	**1631**	1673	**24309**	23293
2016	16259	15610	**2614**	2489	2477	**4014**	3983	4102	**1844**	1926	**24952**	23971
2017	16587	15948	**2637**	2517	2503	**4071**	4028	4185	**2176**	2238	**25699**	24691
2018	17129	16304	**2700**	2570	2563	**4190**	4161	4210	**2482**	2521	**26746**	25518
2019	17032	16251	**2796**	2669	2657	**4243**	4184	4306	**2794**	2821	**27100**	25887
2020	16548	15835	**2689**	2596	2553	**4359**	4323	4370	**3151**	3169	**26987**	25884
2021	17510	16833	**2803**	2698	2653	**4289**	4225	4218	**3665**	3577	**28520**	27295
2022	17677		**2679**		2545	**4334**		4429	**4204**		**29165**	

Source data for Table I can be found at:
https://www.energyinst.org/statistical-review
https://www.eia.gov/international/data/world/electricity/electricity-generation
https://www.world-nuclear.org/information-library/facts-and-figs/nuclear-generation-by-country.aspx
https://www.ren21.net/reports/global-status-report/

II. TRACKING PROGRESS TOWARD RENEWABLE ELECTRICITY

Fig. 1 shows yearly global electricity generation and generating capacity, from 1990 to 2022. Source data are presented in Tables I and II, respectively. Data from the Statistical Review of World Energy, 72nd edition [1], are indicated in Fig. 1(a) by solid lines, with open circles used to mark other data sources as indicated. For Fig. 1(b), solid lines represent the data in bold in Table II, with open circles used to mark the other data sources. Data source variations, of interest for detailed understanding and analysis, are seen in the tabulated data, but are not significant when plotted on the logarithmic scale over time.

Electricity generation [see Fig. 1(a)], a measure of energy provided, is presented in TWh, where 1 TWh = 3.6 x 10^{15} J. Installed nameplate capacity [see Fig. 1(b)] is the rated output of a generator or other electric power production equipment under specific conditions designated by the manufacturer. The "capacity factor" is the ratio of the actual output of a system or collection of systems under true operating conditions (reflecting, e.g., variable resource, facility downtime, performance variations, large scale climate effects, etc.) and the output of that electricity source operating continuously at its commercial product or plant rating. Capacity factors for electricity generating technologies vary significantly, both within a technology depending on the performance, and between technologies as determined by the physics of the particular energy conversion process and the variability of the electricity demand. Actual electricity generation [see Fig. 1(a)] is the most relevant information for understanding and tracking the evolution of the energy system in terms of contributing fuel sources. Installed capacity [see Fig. 1(b)] allows one to track the status of global installations and new technology investment.

Different organizations report source data using different fuel sub-categories. In Fig. 1, the Statistical Review values for fossil generation and capacity are determined by summing component data for oil, gas, coal and "other" (where "other" is pumped hydro, non-renewable waste and statistical discrepancies) to obtain a total fossil value. Nonhydro renewable totals are calculated by subtracting the sum of total fossil, nuclear, and hydro from the total electricity value. This addresses the fact that individual values for certain non-hydro renewable components

TABLE II
GLOBAL ELECTRICITY GENERATION CAPACITY BY TECHNOLOGY CATEGORY (GW)

Category	Fossil	Nuclear		Hydro		Non-hydro RE	Total
Source	EIA	EIA	WNA	EIA	REN21	EIA	EIA
Year							
1985	1566	253		538			2393
1986	1597	278		552			2466
1987	1626	299		569			2537
1988	1668	312		583			2605
1989	1727	320		573			2686
1990	1764	325		566			2736
1991	1792	325		570			2773
1992	1832	329		578			2830
1993	1877	336		591			2899
1994	1925	339		604			2968
1995	1962	342		616			3022
1996	2022	349		626			3100
1997	2074	349		640			3165
1998	2117	346		650			3218
1999	2168	349		666			3291
2000	2279	352		677		61	3481
2001	2361	355		687		70	3587
2002	2476	360		702		79	3732
2003	2578	362		720		89	3866
2004	2682	368		738		101	4008
2005	2773	370		750		121	4137
2006	2925	372		773		141	4337
2007	3040	372		799		164	4508
2008	3146	372		829		197	4679
2009	3266	372		860		246	4884
2010	3413	376		888		299	5119
2011	3544	369		914		377	5349
2012	3662	373		942		459	5585
2013	3775	372		987		536	5820
2014	3905	333	382	1024	1036	636	6051
2015	4002	344	391	1056	1071	756	6314
2016	4135	352	392	1084	1095	888	6623
2017	4220	358	400	1106	1112	1038	6889
2018	4328	370	392	1121	1135	1189	7175
2019	4379	370	392	1137	1150	1354	7407
2020	4433	372	394	1160	1168	1600	7735
2021	4436	376	389	1186	1197	1841	8013
2022			394		1220		

Source data for Table II can be found at:
https://www.eia.gov/international/data/world/electricity/electricity-capacity
https://world-nuclear.org/information-library/facts-and-figures/world-nuclear-power-reactors-archive/world-nuclear-power-reactors-anduranium-requ-(14).aspx for the latest number
https://www.ren21.net/reports/global-status-report/

(PV, wind, concentrating solar power, geothermal, etc.) were not uniformly reported in earlier years, though that situation has evolved rapidly. The EIA values are taken directly from the website [4] by selecting the desired categories.

Several trends are clearly illustrated in Fig. 1. As noted, electricity generation from combined non-hydro renewables in 2022 was almost the same as electricity generated from hydropower worldwide. Combined generation from nuclear power plants decreased slightly. Finally, as previously discussed [3], continued projected growth in non-hydro renewables, specifically PV and wind, compared to the growth rate in total electricity, suggests major potential for future electrification of other energy sectors, with corresponding benefits to overall efficiency and decarbonization.

III. Tracking the Rate of Change

In Fig. 2(a)–(c), we plot global data for the past five years (2018–2022) for: fraction of electricity generation by source; fraction of current electricity generating capacity; and fraction of net expansions of electricity generating capacity for the given year. Data for fossil, nuclear, and hydro are drawn from Table I and are summarized by year in Tables III –VII. Data for wind, solar and other technologies are drawn from Table VIII and also summarized in Tables III–VII, with the electricity generation data in Fig. 2(a) taken from Tables I and VIII and the electricity-generation capacity data in Fig. 2(b) taken from Tables II and IX. The net expansions of the electricity-generating capacity data in Fig. 2(c) are obtained by subtracting the data in Fig. 2(b) for each year from the following year. The choice of data sets to use for Fig. 2 and tabulated in Tables III–VII is detailed in Appendix. Some values in Tables III–VII are not directly available and were calculated from multiple source data as described in Appendix. Data sources used for the most recent year pie charts (2022) are driven in part by the time frames in which various sources release new data.

The pie charts illustrate a major ongoing theme: the global electricity system continues to be dominated by fossil energy [see Fig. 2(a), but is undergoing an increasingly rapid rate of change [see Fig. 2(c)]. We plot electricity generation, generating

TABLE III
GLOBAL 2018 DATA SUMMARY FOR CREATING PIE CHARTS IN FIG. 2

Technology	Electricity (TWh)	Electricity (%)	Capacity (GW)	Capacity (%)	Net expansion (GW)	Net expansion (%)
Fossil	17,129	64.8%	4,328	61.4%	159	28.9%
Nuclear	2,700	10.2%	392	5.6%	34	6.2%
Hydro	4,190	15.8%	1,135	16.1%	44	8.0%
Wind	1,270	4.8%	564	8.0%	107	19.4%
Solar	576	2.2%	483	6.9%	190	34.5%
Other*	636	2.5%	144	2.0%	17	3.1%
Total	26,501	100%	7,046	100%	551	100%

*Biomass and Geothermal

TABLE IV
GLOBAL 2019 DATA SUMMARY FOR CREATING PIE CHARTS IN FIG. 2

Technology	Electricity (TWh)	Electricity (%)	Capacity (GW)	Capacity (%)	Net expansion (GW)	Net expansion (%)
Fossil	17,032	63.4%	4,379	60.2%	51	22.0%
Nuclear	2,796	10.4%	392	5.4%	0	0.0%
Hydro	4,243	15.8%	1,150	15.8%	15	6.5%
Wind	1,421	5.3%	621	8.5%	57	24.6%
Solar	705	2.6%	585	8.0%	102	44.0%
Other*	668	2.5%	151	2.1%	7	3.0%
Total	26,865	100%	7,278	100%	232	100%

*Biomass and Geothermal

TABLE V
GLOBAL 2020 DATA SUMMARY FOR CREATING PIE CHARTS IN FIG. 2

Technology	Electricity (TWh)	Electricity (%)	Capacity (GW)	Capacity (%)	Net expansion (GW)	Net expansion (%)
Fossil	16,548	61.9%	4,433	58.5%	54	17.6%
Nuclear	2,689	10.1%	394	5.2%	2	0.7%
Hydro	4,359	16.3%	1,168	15.4%	18	5.9%
Wind	1,594	6.0%	732	9.7%	111	36.3%
Solar	854	3.2%	710	9.4%	125	40.8%
Other*	703	2.6%	147	1.9%	-4	-1.3%
Total	26,747	100%	7,584	100%	323	100%

*Biomass and Geothermal

TABLE VI
GLOBAL 2021 DATA SUMMARY FOR CREATING PIE CHARTS IN FIG. 2

Technology	Electricity (TWh)	Electricity (%)	Capacity (GW)	Capacity (%)	Net expansion (GW)	Net expansion (%)
Fossil	17,510	61.9%	4,436	56.5%	3	1.1%
Nuclear	2,803	9.9%	389	5.0%	-5	-1.9%
Hydro	4,289	15.2%	1,195	15.2%	27	10.3%
Wind	1,854	6.6%	825	10.5%	93	35.6%
Solar	1,059	3.7%	843	10.7%	133	51.0%
Other*	751	2.7%	157	2.0%	10	3.8%
Total	28,266	100%	7,845	100%	261	100%

*Biomass and Geothermal

TABLE VII
GLOBAL 2022 DATA SUMMARY FOR CREATING PIE CHARTS IN FIG. 2

Technology	Electricity (TWh)	Electricity (%)	Capacity (GW)	Capacity (%)	Net expansion (GW)	Net expansion (%)
Fossil	17,677	61.2%	4,490**	54.6%**	54**	14.4%
Nuclear	2,679	9.3%	394	4.8%	5	1.3%
Hydro	4,334	15.0%	1,219	14.8%	24	6.4%
Wind	2,105	7.3%	899	10.9%	74	19.8%
Solar	1,323	4.6%	1053	12.8%	210	56.1%
Other*	777	2.7%	164	2.0%	7	1.9%
Total	28,895	100%	8,219	100%	340	100%

*Biomass and Geothermal
**Estimated

TABLE VIII
GLOBAL ELECTRICITY GENERATION BY FUEL (TWH FOR INDICATED YEAR); TOTAL, NUCLEAR, AND HYDRO ARE TABULATED IN TABLE I(A)

Fuel	Coal	Gas	Oil	Wind		Solar (all))		Solar (PV)		Biomass		Geothermal	
Source	BP/EI	BP/EI	BP/EI	BP/EI	EIA	BP/EI	EIA	IEA	IRENA	EIA	REN21	EIA	REN21
Year													
1985	**3748.4**	**1426.3**	**1110.8**	**0.1**	0.1		0.0			31.7		22.4	
1986	**3839.0**	**1432.7**	**1168.3**	**0.1**	0.1		0.0			34.3		25.0	
1987	**4058.1**	**1516.5**	**1183.2**	**0.2**	0.2		0.0			38.2		26.9	
1988	**4200.7**	**1540.9**	**1256.6**	**0.3**	0.3		0.0			40.4		27.2	
1989	**4377.0**	**1728.5**	**1350.2**	**2.6**	2.6	**0.3**	0.3			81.7		32.8	
1990	**4460.2**	**1789.7**	**1364.7**	**3.6**	3.6	**0.4**	0.4			93.9		35.7	
1991	**4557.1**	**1815.2**	**1349.9**	**4.1**	4.1	**0.5**	0.5	0.09		102.7		36.9	
1992	**4649.9**	**1829.4**	**1328.2**	**4.7**	4.6	**0.5**	0.5	0.10		113.3		38.1	
1993	**4727.9**	**1863.8**	**1266.6**	**5.7**	5.6	**0.6**	0.6	0.13		116.7		39.0	
1994	**4891.9**	**1925.1**	**1302.1**	**7.1**	7.3	**0.6**	0.7	0.15		123.0		38.9	
1995	**5038.9**	**2036.4**	**1259.9**	**8.3**	7.9	**0.6**	0.7	0.17		131.5		38.1	
1996	**5279.7**	**2101.6**	**1245.7**	**9.2**	9.3	**0.7**	0.8	0.20		133.8		40.6	
1997	**5395.6**	**2271.1**	**1244.6**	**12.0**	12.1	**0.7**	0.8	0.23		143.9		42.0	
1998	**5511.3**	**2408.5**	**1294.6**	**15.9**	16.1	**0.8**	0.9	0.28		149.0		44.6	
1999	**5630.9**	**2600.7**	**1266.7**	**21.2**	21.3	**0.9**	1.0	0.35		156.4		47.7	
2000	**5991.9**	**2772.5**	**1244.8**	**31.4**	31.3	**1.1**	1.2	0.6		158.7		51.4	
2001	**6071.6**	**2950.9**	**1209.4**	**38.4**	38.4	**1.4**	1.5	0.8		166.8		51.0	
2002	**6323.0**	**3152.0**	**1193.6**	**52.4**	52.7	**1.8**	1.9	1.1		180.9		51.8	
2003	**6768.4**	**3302.7**	**1201.4**	**63.3**	64.5	**2.3**	2.3	1.4		190.3		53.5	
2004	**6989.4**	**3551.7**	**1179.7**	**85.6**	84.6	**3.0**	3.0	1.8		203.8		55.7	
2005	**7361.1**	**3741.5**	**1192.8**	**104.6**	104.2	**4.2**	4.2	2.5		218.8		56.4	
2006	**7763.0**	**3959.9**	**1084.7**	**133.5**	133.4	**5.8**	5.7	3.7		231.5		57.8	
2007	**8253.8**	**4284.5**	**1104.5**	**171.5**	171.3	**7.8**	7.7	5.3		248.2		60.4	
2008	**8270.2**	**4428.0**	**1081.1**	**221.4**	221.4	**12.7**	12.6	7.3	11.9	276.8		63.1	
2009	**8118.1**	**4460.6**	**1001.8**	**276.8**	277.8	**21.1**	21.0	11.7	20.1	301.1		65.1	
2010	**8639.9**	**4883.8**	**965.4**	**346.4**	339.4	**33.9**	33.6	32.0	32.1	348.1		64.8	
2011	**9083.9**	**4937.6**	**1062.3**	**440.7**	435.1	**65.6**	66.3	63.7	62.4	372.0		65.8	
2012	**9114.4**	**5256.8**	**1142.3**	**530.5**	521.5	**101.5**	104.2	98.8	96.3	407.1		67.0	
2013	**9583.6**	**5136.1**	**1084**	**635.5**	645.1	**138.6**	146.7	139.4	131.4	445.6		68.4	
2014	**9761.9**	**5293.9**	**1029.6**	**705.9**	717.3	**197.3**	202.2	184.5	183.7	479.7	429	73.2	
2015	**9414.4**	**5636.0**	**1018.9**	**831.4**	827.4	**256.0**	260.2	251	242.2	507.6	464	77.1	75
2016	**9435.7**	**5880.6**	**942.8**	**962.1**	957.3	**328.4**	341.5	329	314.6	547.2	504	79.2	78.5
2017	**9722.0**	**5995.8**	**869.0**	**1141.5**	1127.1	**445.5**	445.1	443	425.3	582.6	555	81.7	85
2018	**10102.5**	**6259.7**	**767.1**	**1269.5**	1263.5	**575.8**	569.8	589	549.7	601.2	581	85.3	89.3
2019	**9871.5**	**6452.7**	**707.9**	**1420.6**	1399.1	**705.2**	701.0	679	676.2	632.2	591	87.5	95
2020	**9472.2**	**6418.3**	**657.8**	**1594.0**	1590.5	**854.4**	849.1	826	830.7	637.5	602	90.7	97
2021	**10211.1**	**6565.6**	**733.5**	**1854.1**	1807.8	**1059.3**	1036.2	1026	1034	640.0	656	91.8	99
2022	**10317.2**	**6631.4**	**728.6**	**2104.8**		**1322.6**		1293			672		

Source data for Table VIII can be found at:
https://www.energyinst.org/statistical-review
https://www.eia.gov/international/data/world/electricity/electricity-generation
https://www.ren21.net/reports/global-status-report/
https://public.tableau.com/views/IRENARETimeSeries/Charts?:embed=y&:showVizHome = no&publish = yes&:toolbar=no
https://www.iea.org/energy-system/renewables/solar-pv

capacity and net capacity expansions (new installation minus any decommissioning) to highlight both where we stand and the new installations that will drive the future electricity generating mix. Nonfossil generation sources (solar, wind, hydro, geothermal, and nuclear) constitute more than 80% of capacity expansions for the past three years. PV and wind combined are more than 75% of capacity expansion each year over the same period.

One interesting thing to note in Fig. 2(c) is that, based on the updates in the international installed capacity numbers from EIA for 2020 and 2021, the "new installations" fraction of fossil-based generation sources for 2021 is very small—an increase of only 3 GW (from 4433 GW to 4436 GW), though other sources suggest this will rebound for 2022. It will be interesting to monitor if the EIA 2021 value for fossil generation capacity increases as the data mature. This is a common pattern and would increase fossil fractional growth for that year. However, it may also be the case that new construction, for both coal and natural gas facilities, was delayed in 2021, due to the pandemic and supply chain issues. This would suggest that the reported all-time high in demand for coal-fired electricity (10 440 TWh, 36% of total electricity) in 2022 as reported by IEA [9] was accomplished via increasing utilization of existing assets. Finally, although we are not tracking these categories separately, it is interesting to note that five tidal stream devices (2.7 MW) and six wave power devices (165 kW) were deployed in 2022 [8]. While these numbers are negligible on the overall scale, they do illustrate the growing diversity of renewable energy sources.

IV. TRACKING THE ROLE OF PV

Fig. 3 shows yearly global electricity generation and generating capacity, from 1990 to 2022, but now breaking out the contributing technologies to the "nonhydro renewables" from Fig. 1. Source data are presented in Table VIII and IX, respectively. In Fig. 3(a), the solid lines again represent data from [1], with open circles used to mark other data sources. For Fig. 3(b), solid lines represent the data in bold in Table IX, with open circles used to mark the other data sources. We note again that source variations, although of interest for detailed understanding and analysis, are relatively minor when assessing major trends over the time frames of interest for the global energy transformation.

According to [1], electricity generated globally from PV in 2022 was 1322.6 TWh, continuing its rapid growth trajectory.

TABLE IX
GLOBAL ELECTRICITY-GENERATING CAPACITY BY TECHNOLOGY (GW). TOTAL, NUCLEAR, AND HYDRO ARE TABULATED IN TABLE I(B)

Fuel	Wind			Solar (all)	Solar (PV)				Biomass		Geothermal		
Source	BP/EI (AC)	EIA (AC)	REN21 (AC)	EIA (AC)	IRENA (AC)	BP/EI (AC)	REN21 (DC)	IEA (DC)	EIA (AC)	REN21 (AC)	BP/EI (AC)	EIA (AC)	REN21 (AC)
Year													
1985													
1986													
1987													
1988													
1989													
1990											5.9		
1991													
1992								0.05					
1993								0.065					
1994								0.09					
1995	4.8							0.11			6.8		
1996	6.1					**0.2**		0.15					
1997	7.6					**0.2**		0.2					
1998	9.9					**0.3**		0.27					
1999	13.4					**0.4**		0.37					
2000	16.9	**17.3**		**1.0**	0.8	**0.8**		0.57	**33.8**		8.2	**8.4**	
2001	24	**23.9**		**1.2**	1.1	**1.1**		0.79	**36.3**		7.9	**8.1**	
2002	30.7	**30.8**		**1.5**	1.4	**1.4**		1.2	**38.1**		8.1	**8.2**	
2003	38.7	**38.5**		**2.0**	2.0	**2.0**		1.6	**39.5**		8.2	**8.3**	
2004	47.7	**47.0**		**3.0**	3.1	**3.1**		2.7	**42.3**		8.2	**8.3**	
2005	58.4	**59.2**		**4.4**	4.5	**4.5**		4.1	**48.4**		8.6	**8.7**	
2006	73.2	**73.0**		**5.8**	6.1	**6.1**		5.9	**52.6**		8.8	**8.9**	
2007	91.6	**91.6**		**8.2**	8.5	**8.5**		8.0	**55.2**		9.0	**9.1**	
2008	115.6	**115.2**		**14.1**	14.7	**14.7**		14.3	**57.8**		9.3	**9.4**	
2009	150.1	**150.0**		**21.9**	22.8	**22.8**		22.4	**64.2**		9.8	**9.9**	
2010	181.1	**180.4**		**38.3**	40.3	**41.6**		39.3	**70.1**		10.0	**10.1**	
2011	220.2	**220.0**		**69.8**	72.2	**73.9**		70.4	**76.4**		10.1	**10.0**	
2012	267.3	**267.9**		**98.6**	101.6	**104.2**		100.0	**81.4**		10.5	**10.7**	
2013	300	**301.5**		**134.4**	136.6	**140.5**		137.6	**88.7**		10.7	**11.0**	
2014	349.5	**349.3**		**179.9**	176.1	**180.7**		177.6	**95.2**		11.2	**11.4**	
2015	416.3	**415.8**	433	**227.7**	224.1	**228.9**		228.0	**100.3**		11.8	**12.1**	
2016	467	**466.4**	487	**299.8**	296.1	**301.1**	303	304.7	**109.2**	112	12.1	**12.4**	13.5
2017	514.4	**514.2**	539	**394.9**	390.9	**395.9**	405	407.4	**115.6**	121	12.7	**13.0**	12.8
2018	564.5	**564.2**	591	**488.2**	483.5	**489.3**	512	511.7	**122.2**	131	13.2	**13.5**	13.2
2019	620.8	**620.8**	650	**590.7**	585.9	**592.2**	621	632.2	**127.6**	137	13.9	**14.1**	14.0
2020	731.7	**731.4**	745	**716.8**	713.9	**720.4**	767	767.0	**137.2**	133	14.1	**14.4**	14.2
2021	824.2	**823.1**	829	**853.1**	855.2	**861.5**	942	910	**149.2**	143		**14.7**	14.5
2022	898.8		906		1046	**1053.1**	1185	1185		149			14.6

Source data for Table IX can be found at:
https://www.energyinst.org/statistical-review
https://www.eia.gov/international/data/world/electricity/electricity-capacity
https://www.ren21.net/reports/global-status-report/
https://public.tableau.com/views/IRENARETimeSeries/Charts?:embed=y&:showVizHome=no&publish=yes&:toolbar=no
https://iea-pvps.org/snapshot-reports/snapshot-2023/
https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023

PV-generated electricity exceeded 1000 TWh in 2021 for the first time in history, after decades of development, but could reach 2000 TWh within just a couple years. It is also interesting to note from Fig. 3(b) that PV and wind are now at very comparable global installed capacities, with wind reaching the 1 TW milestone in June 2023 [10]. Wind produced 2015 TWh of electricity, reflecting its higher average capacity factor. Over 200 GW of PV was added globally in 2022.

Five different sources for solar (Statistical Review of World Energy, EIA, IEA, IRENA and REN21) are given in Table IX. Variations here can arise for multiple reasons. Among these are: variations in reporting PV capacity as W_{DC} or W_{AC}: differences that arise in reports of PV shipments versus installations, variations in cross-border electricity accounting, or handling of the balance between new and retired resources; and changing methodologies in source reporting. Those with interests in pursuing these variations can find further details in the primary sources.

Reporting of *solar* electricity and capacity has been composed in the past of contributions from both PV and solar thermal power, depending on the source. As discussed last year, the rapid growth in PV since 2005 has made PV the increasingly dominant contributor to this broader solar category, a trend that accelerated in 2022. Tables VIII and IX indicate whether solar data is a combination of these technologies or PV only. These tables also indicate our assessment of which data are W_{DC} or W_{AC}. However, we note that there may be inconsistencies in the documentation of dc and ac PV ratings and that some sources may include a mixture of ac and dc data.

V. TRACKING ENERGY STORAGE

Pumped hydropower is the dominant energy storage technology supporting the electricity grid. However, Fig. 4 shows how its dominance is beginning to change. While pumped hydropower is and will continue to be the largest storage asset in the near future, with $\sim$ 175 GW of global storage capacity in 2021, batteries (e.g., lithium batteries) are now being installed at a rate that exceeds the typical expansion of pumped hydropower. Fig. 4 plots EIA data for the cumulative global pumped hydropower

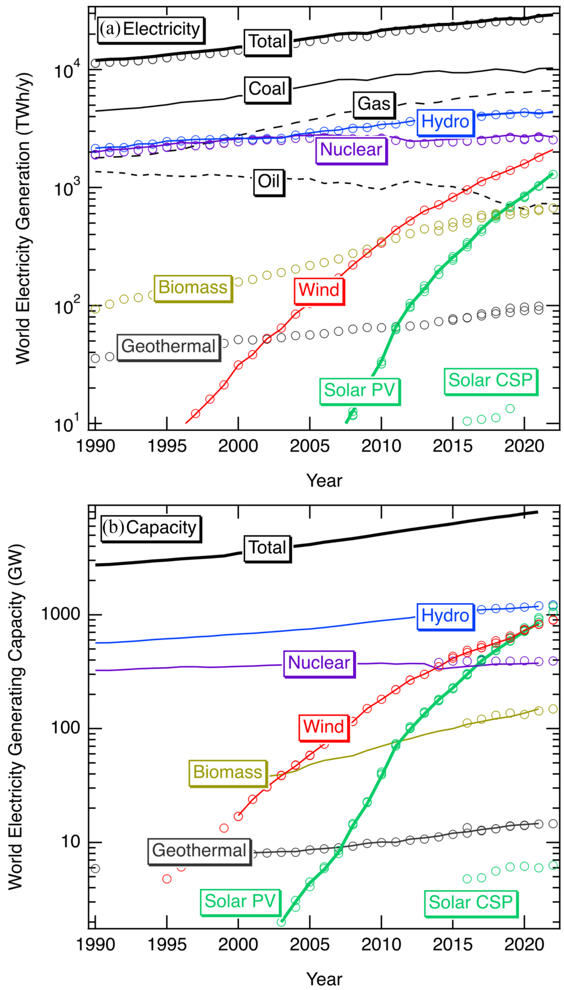

Fig. 3. (a) Annual electricity generation and (b) electricity generating capacity by fuel. Data are tabulated in Tables VIII and IX (see appendix) with lines for the bolded data and open circles for the other sources.

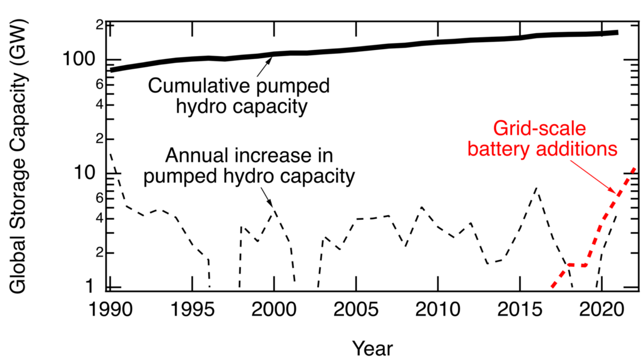

Fig. 4. Global pumped-hydro storage capacity (EIA, thick black line) and annual changes in storage capacity. The dashed black line indicates the differences in thick black line, while the dashed red line indicates the additions of grid-scale batteries as reported by the IEA. [11].

capacity as a thick black line. The annual changes in the pumped hydropower capacity are shown by a dashed black line, reflecting new additions and a few retirements. Installations of grid-scale batteries reported by IEA [11] are indicated by the dashed red line, reaching 11 GW in 2022, almost 4x the 3 GW average annual increase in pumped hydropower capacity between 1991 and 2021. Batteries installed behind the meter are not included

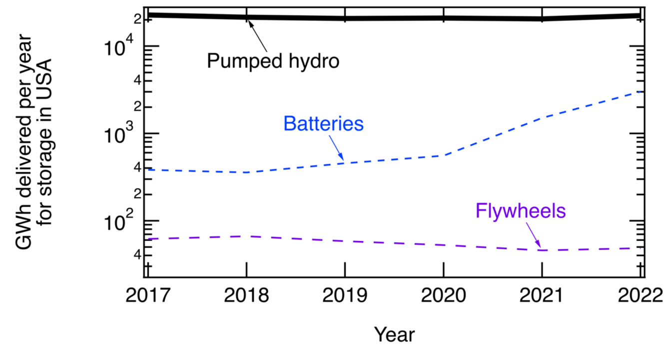

Fig. 5. Electricity delivered by grid-scale storage assets in the United States, as reported by the EIA 923. [12].

in the values for Fig. 4, suggesting that the total installation rate of batteries is actually higher than shown.

While Fig. 4 tracks the installed power capacity for storage, a better metric may be the amount of electricity that is delivered by these assets. We were unable to find a public data set estimating the electricity from batteries globally, but, noting that the United States hosts a substantial fraction of the grid-scale batteries, Fig. 5 shows the electricity delivered from three storage technologies from 2017 to 2022 as reported by the EIA [12]. The electricity from flywheels and batteries is partially used for ancillary services, but this capacity is being increasingly used to shift solar electricity for use after the sun sets. This new use may explain the doubling of electricity from batteries seen for both 2021 and 2022.

While the growth of batteries for stationary storage has been spectacular, the global fleet of electric vehicles (EV) already represents a larger energy storage capacity than the stationary storage. The IEA estimates that EVs sold in 2022 had batteries with a total of 550 GWh of capacity [13]. While it is challenging to compare vehicle and stationary storage, the total power rating of 11 GW of stationary batteries presented earlier represents ∼ 22 to 33 GWh of energy capacity based on commonly cited lithium battery power-to-energy ratios (∼2–3) [14]. One sees that energy storage capacity is substantially larger today in the EV fleet than in grid-scale stationary applications. We will begin to present the storage data in table form as more of the primary data sources begin tracking that information.

VI. Conclusion

2022 was a globally recognized milestone year in PV due to the achievement and then rapid eclipse of the 1 TW benchmark for solar capacity. Total global electricity generation from PV of 1323 TWh, with ∼ 263 TWh of that added in 2022, reflected a ∼25% increase in just one year. Despite lingering supply chain and tariff/trade issues around the globe, PV advanced dramatically in 2022, contributing 56% of newly installed global electricity generating capacity.

At the same time, PV provided just ∼ 5% of 2022 global electricity generation. However, new levels of penetration of PV were achieved on electricity grids around the world, reaching or exceeding 20% in leading markets such as California, South Australia and Hawaii [15]. At the end of 2022, nine countries had PV penetration levels on their national grids in excess of 10% [16]. PV is at the cusp of the energy transformation, with the next 5-10 years playing a critical role in determining our ability to reach 2035 and 2050 decarbonization goals.

Batteries are increasingly being used to shift the time when the solar electricity is delivered, especially in those locations where solar exceeds 20% of the generated electricity. Worldwide, batteries are now being added for grid storage faster than pumped hydropower storage is added. The rapid growth of batteries for grid storage parallels the even larger growth in using batteries to power EVs.

The global PV R&D community continues to play a significant role. PV device innovation continues [17], and commercial products continue to advance in both performance and reliability. Reliability and module lifetime play a major role in reducing projections for the amount of both virgin materials required and end-of-life waste anticipated. A growing body of work is addressing the need for a circular economy for PV, identifying key levers for sustainability and anticipating raw materials and supply chain needs for multi TW scale. R&D needs are being identified to develop new approaches to recycling and materials recovery.

In addition to the growth documented here for utility, commercial and residential PV, opportunities for "PV Everywhere" (e.g., integrated with agriculture, broadly integrated into buildings, on reservoirs, etc.) are also growing, as the world increasingly recognizes the critical interactions between energy generation and sustainable ecosystems for air, land and water. We anticipate seeing these new visions for PV impact its growth in the future.

Appendix

The sources of the data reported in Figs. 1–3 were described in detail in the Appendix of Version 1 [3]. The same sources, as enumerated in Section I, were consulted for Version 3, following the release of the 72nd Statistical Review of World Energy on June 26, 2023. Updated data from other sources were downloaded July 1 or 2, 2023.

As previously noted, many of these sources revise their data in retrospect, as new information comes in and/or reporting accuracy increases. Where updated tabulated data are available for download, we have incorporated updates from previous years into our Version 3 tables. The data presented in Figs. 1–3 are tabulated in Tables I–IX. The selection of data for Tables III–VI has little effect on the creation of Fig. 2(a) and (b) but can have a greater effect on the appearance of Fig. 2(c).

The electricity data in Fig. 2(a) and Tables III–VII were taken from The Statistical Review of World Energy. The capacity data in Fig. 2(b) and Table II used WNA data for nuclear, Statistical Review of World Energy data for wind and solar and REN21 data for hydro, biomass and geothermal.

EIA fossil fuel capacity data for 2022 are not yet available, and the Statistical Review of World Energy does not include fossil capacity information, requiring the use of additional sources to create the 2022 pie chart in Fig. 2(c). Because of a change in data presented in the REN21 documents, this year we used data from the Global Energy Monitor organization [18]. Data in their Global Coal Plant and Global Gas Plant trackers were used to estimate the change in fossil capacity from 2021 to the end of 2022.

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