Global Progress Toward Renewable Electricity: Tracking the Role of Solar (Version 2)

Nancy M. Haegel, *Member, IEEE*, and Sarah R. Kurtz, *Fellow, IEEE*

***Abstract*—Renewable electricity continued to grow in 2021 despite energy demand and installation disruptions and anomalies associated with the ongoing global pandemic. In 2021, the combined contributions of photovoltaics and wind to electricity generation slightly exceeded that of nuclear power plants, advancing the contribution of carbon-free electricity sources globally to 38% of the total. Following its initial presentation in 2021 with data from 1990–2020, this periodic publication will continue to collect and update information from multiple sources and present it systematically as a convenient reference for IEEE JPV readers.**

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

I. Introduction

ELECTRICITY generation from renewable energy sources continued to grow in 2021, both in absolute magnitude and as a fraction of global generation, despite global energy and electricity use anomalies associated with the COVID-19 pandemic. Total electricity from all sources consumed globally in 2021 was ∼28,500 TWh, representing about 17.2% of total energy consumption, similar to 2020 [1]. The share of renewables power generation [hydro and nonhydro renewables, mainly wind and photovoltaics (PV)] approached 30%, illustrating both continued progress (that fraction was 24% just five years earlier) and the major challenge ahead. In contrast, the newly installed generating capacity in 2021 for hydro, PV, and wind, as Fig. 2(c) will show, was 79% of the global total. This is the sixth year in a row that these renewable electricity generating sources have constituted more than half of newly installed capacity. The 2022 BP Statistical Review of World Energy [1] reports that the increase in primary energy between 2019 and 2021 (8 EJ increase from 2019) was "entirely driven by renewable energy sources."

PV continues to play a growing role in this energy transition. Although fully vetted data will not be available until early 2023, multiple sources have reported that the milestone of 1 TW_{DC} global installed capacity was reached in the first half of 2022. Combined global electricity generation from wind and solar in 2021 (∼2900 TWh) was comparable to electricity generation from nuclear power plants (∼2800 TWh), representing another milestone. Combined non-CO_2 emitting generation sources (nuclear and combined renewables) contributed 38% of the world's electricity in 2021. The percentage of global electricity generated by PV, which we reported as 3.4% for 2020, is now 3.6%—major progress from less 0.15% of 2010, but also an indication of the deployment challenges ahead for PV to reach its potential.

The goal of this annual presentation is to present data, in consistent graphical and tabular form, on the global progress toward renewable energy. As previously discussed in the initial 2021 presentation [2], multiple entities and institutions provide this global energy data on a yearly basis. Different institutions have variations in original sources or methodologies and may change methodologies over time. Assembling this collection of frequently used and cited sources in one place illustrates both the major trends and the nature and degree of these variations.

We present the following three sets of graphs:

1) annual generation by broad fuel source for global electricity (see Section II);
2) yearly generation and newly installed capacity for specific fuel sources with a focus on renewables (see Section III); and
3) generation and capacity over time with a more detailed breakout of fuel sources, including PV (see Section IV).

Data are summarized from six primary sources: the Statistical Review of World Energy, published yearly by BP [1]; the international data presented by the U.S. Energy Information Administration (EIA) [3]; the World Nuclear Association [4], the International Energy Agency (IEA) [5]; the International Renewable Energy Agency (IRENA) [6], and REN21 [7]. Short summaries of the mission and history for these six organizations were provided in the Appendix of the 2021 publication [2].

II. Tracking Progress Toward Renewable Electricity

Fig. 1 shows yearly global electricity generation (a) and generating capacity (b) from 1990 to 2021. Source data are presented in Tables I and II, respectively, in the Appendix. Data from the Statistical Review of Energy, now in its 71st edition and the longest running compilation of global energy statistics

Manuscript received 27 August 2022; accepted 7 September 2022. Date of publication 26 September 2022; date of current version 28 November 2022. This work was supported by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy under Contract DE-AC36-08GO28308. *(Corresponding author: Sarah R. Kurtz.)*

Nancy M. Haegel is with the National Renewable Energy Laboratory, Golden, CO 80401 USA (e-mail: nancy.haegel@nrel.gov).

Sarah R. Kurtz is with the University of California Merced, Merced, CA 95343 USA, and also with the National Renewable Energy Laboratory, Golden, CO 80401 USA (e-mail: skurtz@ucmerced.edu).

Color versions of one or more figures in this article are available at https://doi.org/10.1109/JPHOTOV.2022.3206532.

Digital Object Identifier 10.1109/JPHOTOV.2022.3206532

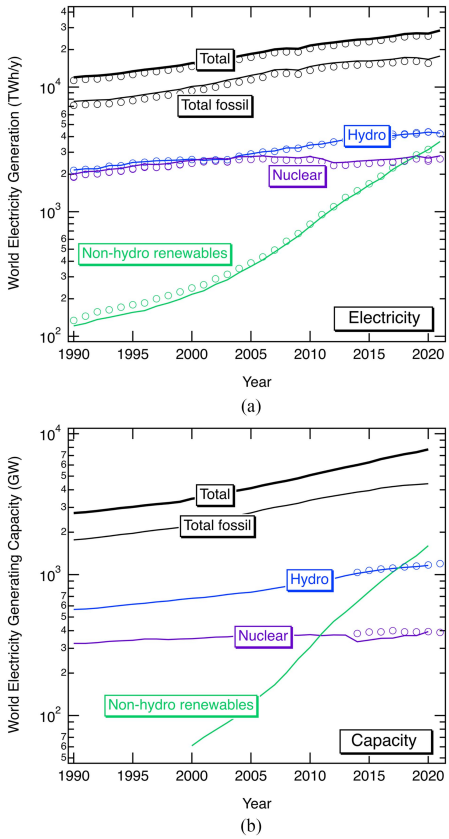

Fig. 1. (a) Annual electricity generation and (b) electricity generating capacity. Data are tabulated in Tables I and II with lines for the bolded data and open circles for the other sources.

[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. One sees that source variations, although of interest for detailed understanding and analysis, are not significant when assessing major trends over time.

Electricity generation, a measure of energy provided, is presented in terawatt hour, where 1 TWh $= 3.6 \times 10^{15}$ J. Installed nameplate capacity, commonly reported in watts, megawatts, or gigawatts depending on system size, 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 can 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 demand for electricity. Actual electricity generation [Fig. 1(a)] is the most relevant for understanding and tracking the evolution of the energy system in terms of contributing fuel sources. Capacity [Fig. 1(b)] allows one to understand and track global installations and new technology investment.

Different organizations report source data using different fuel subcategories. In Fig. 1, the BP values for fossil generation and capacity are determined by summing component data for oil, gas, coal, and "other" (where "other" is pumped hydro, nonrenewable waste, and statistical discrepancies) [1] 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 nonhydro renewable components (PV, wind, concentrating solar power, geothermal, etc.) were not uniformly reported in earlier years, though that situation is evolving rapidly. The EIA values are taken directly from the website [3] by selecting the desired categories.

Several upcoming transitions are worth noting in Fig. 1. Electricity generation from combined nonhydro renewables is poised to equal electricity generated from hydropower worldwide in 2022. The combination of non-CO_2 emitting generation sources could reach 50% of total global electricity generation in the next 10–12 years if recent growth rates of nonhydro renewables can be sustained or increased. Finally, as noted previously [2], continued projected growth in 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 data for the past five years (2017–2021) for (a) global fraction of electricity generation, (b) global fraction of electricity generating capacity, and (c) global 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 datasets to use for Fig. 2 and tabulated in Tables III–VII is detailed in the Appendix. Some values in Tables III–VII are not directly available and were derived indirectly from the references, as described in the Appendix.

The pie charts illustrate a persistent theme: we have a massive global system, dominated by fossil energy [see Fig. 2(a)], undergoing a rapid rate of change [see Fig. 2(c)]. We plot electricity generation, generating capacity, and net capacity expansions (new installation minus any decommissioning) to highlight both where we stand and the rate of change that will drive the future electricity generating mix. Combined renewables (solar, wind, hydro, geothermal, and biomass) constitute more than 60% of capacity expansions for the past five years. PV and wind combined alone are more than 50% of capacity expansion each year over

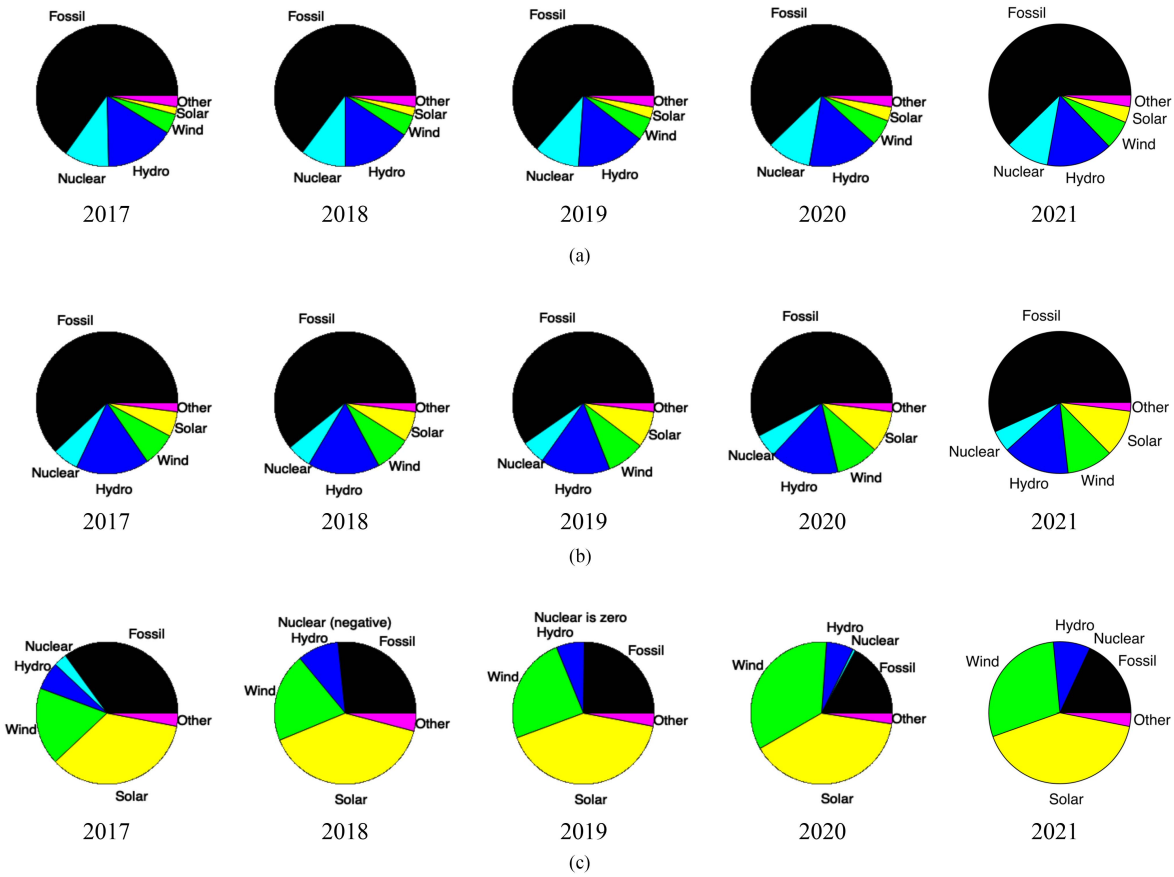

Fig. 2. (a) Pie charts showing global share of electricity generation by technology for the indicated years. Data taken from Tables I and VIII and summarized in Tables III–VII (see Appendix). The "other" category includes biomass and geothermal. (b) Pie charts showing global share of electricity-generation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

the same period. The growth in the fraction of wind and PV in the new capacity mix that was evident from 2017–2020 has leveled off in 2021. A number of factors, such as global supply chain and shipping disruptions, worldwide policy variations, regulations affecting PV imports in the United States, and global labor shortages, may all be involved. These will likely be the subject of future detailed analysis but may also be unique to the 2020–2021 period.

IV. Tracking the Role of PV

Fig. 3 again shows yearly global electricity generation (a) and generating capacity (b) from 1990 to 2021, but this time breaking out the contributing technologies to the "nonhydro renewables" from Fig. 1. Source data are presented in Tables VIII and IX, respectively. In Fig. 3(a), the solid lines again represent data from the work in [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. As discussed previously, different organizations have different mission goals and focus and report source data using different fuel subcategories. 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.

The rapid growth in solar PV and wind since 2000, detailed in the pie charts for recent years, has led to a number of major milestones in the current decade. According to the work in [1], global electricity generated from PV exceeded 1000 TWh in 2021 for the first time in history. New PV installation continued to grow in absolute value, though the percentage growth from the previous year decreased significantly. Solar PV and wind installed global capacity are now comparable and both will likely reach 1 TW_{DC} in 2022, which is of note given the complementary nature of PV and wind for electricity generation in many markets.

Five different sources for solar (BP, EIA, IEA, IRENA, and REN21) are presented in Table IX and utilized in Figs. 2 and 3. Variations in these values can arise for multiple reasons. Among these are the following:

1) variations in reporting PV capacity as W_{DC} or W_{AC};
2) 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
3) changing methodologies in source reporting.

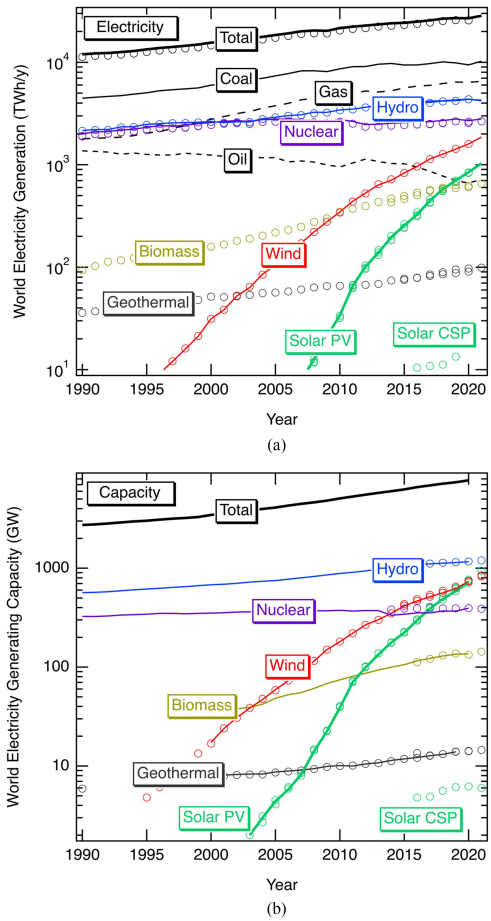

Fig. 3. (a) Annual electricity generation and (b) Electricity generating capacity by fuel. Data are tabulated in Tables VIII and IX (see Appendix) with lines for the bolded data and open circles for the other sources.

Those with interests in pursuing these variations can find further details in the primary sources.

We also note that 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. However, the rapid growth in PV since 2005 has made PV the increasingly dominant contributor to solar-generated electricity, a trend that continued in 2021. Tables VIII and IX indicate whether solar data are 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. Conclusion

2021 was another PV milestone year in several regards. Total global electricity generation from PV exceeded 1000 TWh, with $\sim$ 190 TWh of that added in 2021 representing an 18% increase from 2020. PV installed capacity reached a new high, and PV and wind now contribute electricity at a level comparable to nuclear power. Year to year changes from 2020, however, are unusual on a global scale for multiple reasons. For the first time since the 2008 recession and only the second time since 1985 (the starting point for Table I), global electricity generation dropped going from 2019 to 2020, according to updated data in the BP Statistical Review of World Energy [1], and then rebounded significantly in 2021. Global travel, supply chain, and shipping disruptions were also widespread.

PV continues to grow but still represented less than 4% of global electricity generation in 2021. This average of course reflects large variations in the use of the solar resource and PV technology around the globe. The continued growth of both wind and PV point to a future where synergies between these two technologies, with growing use of storage, can lead the way to a clean, sustainable energy system as well as increased electrification and efficiency across all energy sectors. In future publications, we intend to begin tracking global storage capacity, currently less than 200 GW worldwide, but predicted to grow rapidly in the next 5–10 years.

The broad PV R&D community continues to play a significant role. This has included ongoing technology and reliability advances, such as the rapid transition to passivated emitter and rear contact as the dominant Si technology and continued efficiency improvements. 2021 also saw increased attention to materials use, sustainability, and future supply chain challenges, as well as global cooperation in research and development of increasingly sophisticated modeling and understanding of the role of PV in the future energy system. Sustaining future growth will require continued progress in all these areas as we continue to track progress in renewable energy as a whole, PV as a key technology, and the energy transformation that will determine our future.

Appendix

The sources of the data reported in Figs. 1–3 were described in the Appendix of Version 1 [2]. The same sources [the Statistical Review of World Energy, the Energy Information Association (EIA), the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA), the World Nuclear Association (WNA), and REN 21 (renewables now)] were consulted for Version 2, following the release of the 71st Statistical Review of World Energy on June 28, 2022. Updated data from other sources are as of July 21, 2022.

We note that most 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 2 tables. Minor changes in generation and new capacity numbers for earlier years are updated in the tables, but we did not recreate the pie charts for Fig. 2(a) and (b), since these changes are minor and generally insignificant on a fractional basis. A review of updates, for example, in the BP Statistical Review of World Energy data for global electricity consumption, nonhydro renewable electricity generation, solar electricity generation, and PV capacity (AC), show variations generally of 1% or less in the data from 2016 to 2020. Interestingly, there is no pattern of decreasing fractional change with time. Solar generation numbers revised down while PV capacity numbers revised up. This historical revision can be another source of confusion when comparing values cited from different sources over time. The

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

Category	Fossil		Nuclear			Hydro			Non-hydro RE		Total	
Source	BP	EIA	BP	EIA	WNA	BP	EIA	REN21	BP	EIA	BP	EIA
Year												
1985	**6335**	6041	**1489**	1426	1328	**1980**	1952		**79**	54	**9880**	9460
1986	**6491**	6101	**1595**	1518	1440	**2007**	1992		**86**	59	**10175**	9656
1987	**6807**	6396	**1735**	1654	1600	**2034**	1996		**92**	65	**10665**	10096
1988	**7053**	6610	**1891**	1795	1727	**2099**	2073		**95**	68	**11135**	10529
1989	**7517**	7052	**1945**	1843	1832	**2088**	2060		**107**	117	**11654**	11058
1990	**7681**	7136	**2001**	1909	1890	**2159**	2144		**121**	134	**11957**	11304
1991	**7791**	7238	**2096**	1996	1988	**2209**	2183		**127**	145	**12218**	11543
1992	**7879**	7281	**2112**	2016	2009	**2209**	2188		**136**	157	**12330**	11625
1993	**7931**	7359	**2185**	2082	2073	**2342**	2314		**142**	163	**12592**	11897
1994	**8193**	7561	**2226**	2125	2111	**2356**	2337		**148**	171	**12917**	12174
1995	**8421**	7787	**2322**	2210	2191	**2484**	2453		**156**	179	**13375**	12608
1996	**8713**	8048	**2407**	2292	2269	**2517**	2490		**161**	185	**13789**	12991
1997	**9004**	8327	**2390**	2271	2264	**2561**	2546		**174**	200	**14121**	13318
1998	**9314**	8617	**2431**	2316	2298	**2581**	2551		**185**	212	**14503**	13671
1999	**9603**	8824	**2524**	2393	2379	**2601**	2590		**199**	227	**14918**	14009
2000	**10119**	9340	**2581**	2450	2444	**2647**	2620		**217**	244	**15556**	14627
2001	**10336**	9566	**2654**	2517	2511	**2579**	2566		**232**	259	**15789**	14878
2002	**10774**	9986	**2696**	2546	2553	**2626**	2604		**261**	289	**16345**	15392
2003	**11387**	10511	**2642**	2518	2505	**2623**	2615		**284**	314	**16924**	15927
2004	**11836**	10967	**2762**	2619	2616	**2817**	2785		**324**	350	**17727**	16692
2005	**12421**	11449	**2769**	2625	2626	**2911**	2905		**364**	388	**18454**	17337
2006	**12931**	11964	**2803**	2660	2661	**3022**	3006		**411**	433	**19155**	18035
2007	**13766**	12769	**2746**	2608	2608	**3073**	3048		**474**	492	**20046**	18888
2008	**13898**	12858	**2738**	2597	2598	**3251**	3171		**550**	578	**20422**	19179
2009	**13697**	12684	**2699**	2560	2558	**3246**	3228		**637**	667	**20265**	19117
2010	**14622**	13620	**2769**	2630	2630	**3429**	3403		**761**	793	**21571**	20417
2011	**15215**	14239	**2653**	2518	2518	**3493**	3464		**908**	946	**22257**	21139
2012	**15637**	14547	**2471**	2345	2346	**3642**	3624		**1068**	1096	**22806**	21585
2013	**15928**	14898	**2491**	2364	2359	**3788**	3755		**1245**	1301	**23435**	22291
2014	**16207**	15023	**2541**	2409	2410	**3889**	3826		**1413**	1471	**24032**	22698
2015	**16201**	15203	**2576**	2440	2441	**3878**	3840	3940	**1637**	1674	**24271**	23128
2016	**16448**	15429	**2614**	2469	2477	**4013**	3987	4102	**1850**	1925	**24915**	23773
2017	**16758**	15685	**2637**	2484	2503	**4070**	4017	4185	**2182**	2249	**25624**	24395
2018	**17305**	16102	**2701**	2544	2563	**4183**	4153	4210	**2489**	2538	**26659**	25300
2019	**17210**	16094	**2796**	2657	2657	**4231**	4203	4306	**2799**	2852	**27001**	25769
2020	**16703**	15541	**2694**	2638	2553	**4346**	4354	4370	**3147**	3154	**26889**	25651
2021	**17735**		**2800**		2653	**4274**		4218	**3657**		**28466**	

Source data for Table 1 can be found at:
http://www.bp.com/statisticalreview
https://www.eia.gov/international/data/world/electricity/electricity-generation
https://www.world-nuclear.org/information-library/facts-and-figures/reactor-database.aspx
https://www.ren21.net/reports/global-status-report/

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**			**2394**
1986	**1597**	**278**		**552**			**2466**
1987	**1627**	**299**		**569**			**2537**
1988	**1668**	**312**		**583**			**2605**
1989	**1727**	**320**		**573**			**2686**
1990	**1764**	**325**		**566**			**2736**
1991	**1792**	**325**		**570**			**2773**
1992	**1833**	**329**		**578**			**2831**
1993	**1877**	**336**		**591**			**2899**
1994	**1926**	**339**		**604**			**2969**
1995	**1962**	**342**		**616**			**3022**
1996	**2021**	**349**		**626**			**3099**
1997	**2073**	**349**		**640**			**3164**
1998	**2115**	**346**		**650**			**3216**
1999	**2165**	**349**		**666**			**3288**
2000	**2251**	**351**		**679**		**61**	**3454**
2001	**2328**	**355**		**688**		**70**	**3555**
2002	**2436**	**360**		**703**		**79**	**3693**
2003	**2549**	**362**		**723**		**89**	**3840**
2004	**2643**	**367**		**738**		**101**	**3969**
2005	**2741**	**370**		**750**		**122**	**4106**
2006	**2885**	**372**		**773**		**142**	**4299**
2007	**3002**	**372**		**799**		**165**	**4470**
2008	**3097**	**372**		**825**		**201**	**4629**
2009	**3206**	**371**		**855**		**252**	**4824**
2010	**3370**	**375**		**884**		**305**	**5077**
2011	**3499**	**369**		**909**		**382**	**5305**
2012	**3613**	**373**		**937**		**465**	**5537**
2013	**3730**	**372**		**982**		**542**	**5777**
2014	**3853**	**334**	382	**1020**	1036	**639**	**5999**
2015	**3949**	**343**	391	**1051**	1071	**758**	**6258**
2016	**4113**	**353**	392	**1082**	1095	**893**	**6605**
2017	**4212**	**354**	400	**1106**	1112	**1042**	**6879**
2018	**4305**	**369**	392	**1125**	1135	**1196**	**7162**
2019	**4356**	**369**	392	**1140**	1150	**1361**	**7395**
2020	**4415**	**394**	394	**1162**	1168	**1604**	**7742**
2021			389		1195		

The REN21 number for Hydro was 1197 GW, reported on page 27 and 1195 GW, reported on page 50.
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-and-uranium-requireme.aspx
https://www.ren21.net/reports/global-status-report/

TABLE III
GLOBAL 2017 DATA SUMMARY FOR CREATING PIE CHARTS IN FIG. 2

Technology	Electricity (TWh)	Electricity (%)	Capacity (GW)	Capacity (%)	Net expansion (GW)	Net expansion (%)
Fossil	16,758	65.2%	4,212	62.3%	94	36.1%
Nuclear	2,637	10.3%	400	5.9%	8	2.9%
Hydro	4,070	15.8%	1,112	16.4%	17	6.2%
Wind	1,140	4.4%	514	7.6%	47	17.2%
Solar	446	1.7%	390	5.8%	94	34.7%
Other*	640	2.5%	134	2.0%	8	2.9%
Total	25,691	100%	6,762	100%	268	100%

*Biomass and Geothermal

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

Technology	Electricity (TWh)	Electricity (%)	Capacity (GW)	Capacity (%)	Net expansion (GW)	Net expansion (%)
Fossil	17,305	64.8%	4,305	61.3%	74	35.6%
Nuclear	2,700	10.1%	392	5.6%	-8	-3.1%
Hydro	4,183	15.6%	1,135	16.2%	23	8.8%
Wind	1,270	4.8%	564	8.0%	50	19.2%
Solar	577	2.2%	483	6.9%	98	35.6%
Other*	670	2.5%	144	2.1%	10	3.8%
Total	26,705	100%	7,023	100%	247	100%

*Biomass and Geothermal

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

Technology	Electricity (TWh)	Electricity (%)	Capacity (GW)	Capacity (%)	Net expansion (GW)	Net expansion (%)
Fossil	17,210	63.6%	4,356	60.0%	59	22.0%
Nuclear	2,796	10.3%	392	5.4%	0	0.0%
Hydro	4,231	15.6%	1,150	15.9%	15	6.5%
Wind	1,421	5.2%	621	8.6%	58	24.6%
Solar	704	2.6%	585	8.1%	98	44.0%
Other*	686	2.5%	151	2.1%	7	3.0%
Total	27,048	100%	7,255	100%	237	100%

*Biomass and Geothermal

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

Technology	Electricity (TWh)	Electricity (%)	Capacity (GW)	Capacity (%)	Net expansion (GW)	Net expansion (%)
Fossil	16,703	62.1%	4,415	58.3%	55	18.8%
Nuclear	2,694	10.0%	394	5.2%	2	0.6%
Hydro	4,346	16.2%	1,168	15.5%	18	6.4%
Wind	1,596	5.9%	732	9.7%	111	35.5%
Solar	846	3.1%	710	9.4%	127	39.9%
Other*	699	2.6%	147	1.9%	8	-1.3%
Total	26,884	100%	7,568	100%	323	100%

*Biomass and Geothermal

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

Technology	Electricity (TWh)	Electricity (%)	Capacity (GW)	Capacity (%)	Net expansion (GW)	Net expansion (%)
Fossil	17,735	62.3%	4,478	56.8%	63	19.6%
Nuclear	2,800	9.8%	389	4.9%	-5	-1.6%
Hydro	4,274	15.0%	1,195	15.2%	27	8.4%
Wind	1,862	6.5%	825	10.5%	93	29.0%
Solar	1,033	3.6%	843	10.7%	133	41.4%
Other*	755	2.7%	157	2.0%	10	3.1%
Total	28,459	100%	7,889	100%	321	100%

*Biomass and Geothermal

TABLE VIII
GLOBAL ELECTRICITY GENERATION BY FUEL (TWH FOR INDICATED YEAR)

Fuel	Coal	Gas	Oil	Wind		Solar (all))		Solar (PV)		Biomass		Geothermal	
Source	BP	BP	BP	BP	EIA	BP	EIA	IEA	IRENA	EIA	REN21	EIA	REN21
Year													
1985	**3748.3**	**1426.3**	**1108.9**	**0.1**	0.1		0			31.2		22.3	
1986	**3838.9**	**1432.7**	**1166.3**	**0.1**	0.1		0			33.8		24.9	
1987	**4057.9**	**1516.5**	**1181.1**	**0.2**	0.2		0			37.7		26.7	
1988	**4200.4**	**1540.9**	**1254.4**	**0.3**	0.3		0			40		27.2	
1989	**4376.7**	**1728.5**	**1347.0**	**2.6**	2.6	**0.3**	0.3			81.1		32.9	
1990	**4460.0**	**1789.7**	**1364.7**	**3.6**	3.6	**0.4**	0.4			93.7		35.8	
1991	**4556.5**	**1815.3**	**1350.1**	**4.1**	4.1	**0.5**	0.5	0.09		102.6		37.1	
1992	**4648.5**	**1829.4**	**1328.3**	**4.7**	4.6	**0.5**	0.5	0.10		113.2		38.2	
1993	**4724.6**	**1863.8**	**1266.7**	**5.7**	5.6	**0.6**	0.6	0.13		116.6		39.2	
1994	**4890.3**	**1925.1**	**1302.2**	**7.1**	7.3	**0.6**	0.7	0.15		122.9		39.0	
1995	**5037.4**	**2037.0**	**1259.9**	**8.3**	7.9	**0.6**	0.7	0.17		131.3		38.3	
1996	**5278.0**	**2100.9**	**1246.0**	**9.2**	9.3	**0.7**	0.8	0.20		133.6		40.7	
1997	**5393.6**	**2271.2**	**1244.7**	**12.0**	12.1	**0.7**	0.8	0.23		143.5		42.1	
1998	**5504.1**	**2408.3**	**1295.1**	**15.9**	16.1	**0.8**	0.9	0.28		148.7		44.7	
1999	**5622.3**	**2599.9**	**1267.4**	**21.2**	21.3	**0.9**	1.0	0.35		156.1		47.9	
2000	**5986.1**	**2772.8**	**1242.6**	**31.4**	31.3	**1.1**	1.2	0.6		158.3		51.6	
2001	**6066.3**	**2950.9**	**1207.6**	**38.4**	38.4	**1.4**	1.5	0.8		166.5		51.2	
2002	**6316.8**	**3155.7**	**1188.5**	**52.3**	52.7	**1.8**	1.9	1.1		180.6		52.0	
2003	**6762.1**	**3308.6**	**1193.8**	**63.3**	64.5	**2.3**	2.4	1.4		189.8		53.7	
2004	**6985.8**	**3563.9**	**1169.3**	**85.6**	84.6	**3.0**	3.0	1.8		203.2		55.8	
2005	**7357.7**	**3762.7**	**1173.3**	**104.6**	104.2	**4.2**	4.2	2.5		218.1		56.6	
2006	**7759.8**	**3977.8**	**1067.7**	**133.5**	133.4	**5.8**	5.7	3.7		230.8		58.0	
2007	**8250.5**	**4302.9**	**1086.9**	**171.5**	171.3	**7.8**	7.7	5.3		247.8		60.6	
2008	**8265.9**	**4447.4**	**1062.8**	**221.4**	221.4	**12.7**	12.7	7.3	11.9	276.8		63.3	
2009	**8115.2**	**4468.5**	**994.5**	**276.8**	277.8	**21.1**	21.0	11.7	20.1	299.7		65.3	
2010	**8634.3**	**4888.4**	**952.5**	**346.4**	341.7	**33.9**	33.6	32.0	32.1	347.9		64.6	
2011	**9075.8**	**4949.5**	**1041.0**	**440.4**	436.9	**65.6**	66.4	63.7	62.4	371.5		65.5	
2012	**9107.2**	**5244.6**	**1137.2**	**530.5**	524.8	**101.5**	104.2	98.8	96.3	395.8		66.0	
2013	**9576.6**	**5127.8**	**1076.3**	**635.5**	646.4	**138.6**	146.7	139.4	131.4	434.3		67.2	
2014	**9752.3**	**5278.9**	**1027.1**	**705.9**	720.1	**196.4**	201.6	184.5	183.7	468.7	429	71.7	
2015	**9406.5**	**5622.2**	**1021.7**	**831.3**	831.7	**254.7**	262.7	244.9	242.2	496.3	464	75.7	75
2016	**9423.5**	**5858.4**	**949.5**	**962.1**	960.6	**327.6**	343.6	320.9	314.6	535.2	504	77.3	78.5
2017	**9716.7**	**5957.9**	**862.2**	**1140.4**	1132.1	**445.5**	460.5	431.0	425.3	567.1	555	79.7	85
2018	**10097.7**	**6206.6**	**776.5**	**1270.0**	1274.1	**576.2**	573.9	555.6	549.7	598.1	581	83.0	89.3
2019	**9863.1**	**6421.0**	**700.6**	**1420.5**	1425.7	**703.9**	700.3	681.0	676.2	630.8	591	86.0	95
2020	**9439.3**	**6371.7**	**661.7**	**1596.4**	1594.6	**846.2**	840.3		830.7	620.8	602	90.6	97
2021	**10244.0**	**6518.5**	**720.3**	**1861.9**		**1032.5**					656		99

Source data for Table VIII can be found at:
http://www.bp.com/statisticalreview
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/data-and-statistics/data-tables?country=WORLD&energy=Electricity&year=2018

Note: Total, nuclear, and hydro are tabulated in Table I.

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). While we were forced to mix data from different sources to create Fig. 2, we attempted to be consistent from year to year in our methodology so that the trends would be clear. The electricity data in Fig. 2(a) and Tables III–VII were taken from BP except the biomass and geothermal data, which were taken from REN21. The capacity data in Fig. 2(b) and Table II used WNA data for nuclear, BP data for wind, and solar and REN21 data for hydro, biomass, and geothermal. The fossil capacity data were taken from EIA for the earlier years and estimated for the later years by noting the REN21 assessment of the fraction of capacity additions that could be related to fossil.

TABLE IX
GLOBAL ELECTRICITY-GENERATING CAPACITY BY TECHNOLOGY (GW)

Fuel	Wind			Solar (all)	Solar (PV)				Biomass		Geothermal		
Source	BP (AC)	EIA (AC)	REN21 (AC)	EIA (AC)	IRENA (AC)	BP (AC)	REN21 (DC)	IEA (DC)?	EIA (AC)	REN21 (AC)	BP (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		0.57	**32.6**		8.2	**8.3**	
2001	24	**23.9**		**1.2**		1.1		0.79	**35.0**		7.9	**8.1**	
2002	30.7	**30.8**		**1.5**		1.4		1.2	**36.9**		8.1	**8.2**	
2003	38.7	**38.5**		**2.0**		2.0		1.6	**39.0**		8.2	**8.3**	
2004	47.7	**47.0**		**3.0**		3.1		2.7	**41.9**		8.2	**8.3**	
2005	58.4	**59.2**		**4.4**		4.5		4.1	**47.9**		8.6	**8.7**	
2006	73.2	**73.0**		**5.8**		6.1		5.9	**52.2**		8.8	**8.9**	
2007	91.6	**91.6**		**8.2**		8.5		8.0	**54.8**		9.0	**9.1**	
2008	115.6	**115.2**		**14.1**		14.7		14.3	**60.4**		9.3	**9.4**	
2009	150.1	**150.0**		**22.4**		22.8		22.4	**68.0**		9.8	**9.9**	
2010	180.9	**180.4**		**38.8**	40.3	40.3		39.3	**74.1**		10.0	**10.1**	
2011	220.1	**219.9**		**70.4**	72.2	72.2		70.4	**80.9**		10.1	**10.0**	
2012	266.9	**268.4**		**99.1**	101.7	101.7		100.0	**87.2**		10.5	**10.5**	
2013	299.8	**302.7**		**134.1**	137.2	137.2		137.6	**94.2**		10.7	**10.8**	
2014	349.3	**349.3**		**177.1**	175.6	175.6		177.6	**100.5**		11.2	**11.4**	
2015	416.2	**414.8**	433	**223.2**	223.2	223.2		228.0	**106.1**		11.8	**11.8**	
2016	466.9	**467.5**	487	**297.1**	295.2	295.2	303	304.7	**115.6**	112	12.1	**12.2**	13.5
2017	514.2	**513.9**	539	**390.2**	390.2	390.2	405	407.4	**122.2**	121	12.7	**12.7**	12.8
2018	563.5	**562.8**	591	**487.5**	483	483.0	512	511.7	**129.7**	131	13.2	**13.1**	13.2
2019	621.3	**622.4**	650	**588.1**	584.6	584.7	621	632.2	**134.2**	137	13.9	**13.9**	14.0
2020	731.8	**735.9**	745	**716.0**	710.7	710.3	767	767.0	**135.7**	133	14.1	**14.1**	14.2
2021	824.9		845		848.4	843.1	942			143			14.5

Source data for Table IX can be found at:
https://www.eia.gov/international/data/world/electricity/electricity-capacity
http://www.bp.com/statisticalreview
https://www.ren21.net/reports/global-status-report/
https://iea-pvps.org/wp-content/uploads/2022/01/IEA-PVPS-Trends-report-2021-4.pdf

Note: Total, nuclear, and hydro are tabulated in Table I.

ACKNOWLEDGMENT

The authors would like to thank Ron Sinton, Robert Margolis, and David Feldman for helpful discussions and collaborative efforts in recent years. The views expressed in this article does not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes. The authors thank the University of California for providing the funds for Open Access publication.

REFERENCES

[1] "BP Statistical Review of World Energy," 71st edition, 2022. [Online]. Available: BP. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

[2] N. M. Haegel and S. R. Kurtz, "Global progress toward renewable electricity: Tracking the role of solar," *IEEE J. Photovolt.*, vol. 11, no. 6, pp. 1335–1342, Nov. 2021.

[3] "EIA electricity generation data." Accessed: Sep. 18, 2022. [Online]. Available: https://www.eia.gov/international/data/world/electricity/electricity-generation

[4] "World nuclear association homepage." Accessed: Sep. 18, 2022. [Online]. Available: https://world-nuclear.org/

[5] "IEA electricity data." [Online]. Available: https://www.iea.org/fuels-and-technologies/electricity

[6] "IRENA homepage." Accessed: Sep. 18, 2022. [Online]. Available: https://www.irena.org/

[7] "REN21 homepage." Accessed: Sep. 18, 2022. [Online]. Available: https://www.ren21.net/