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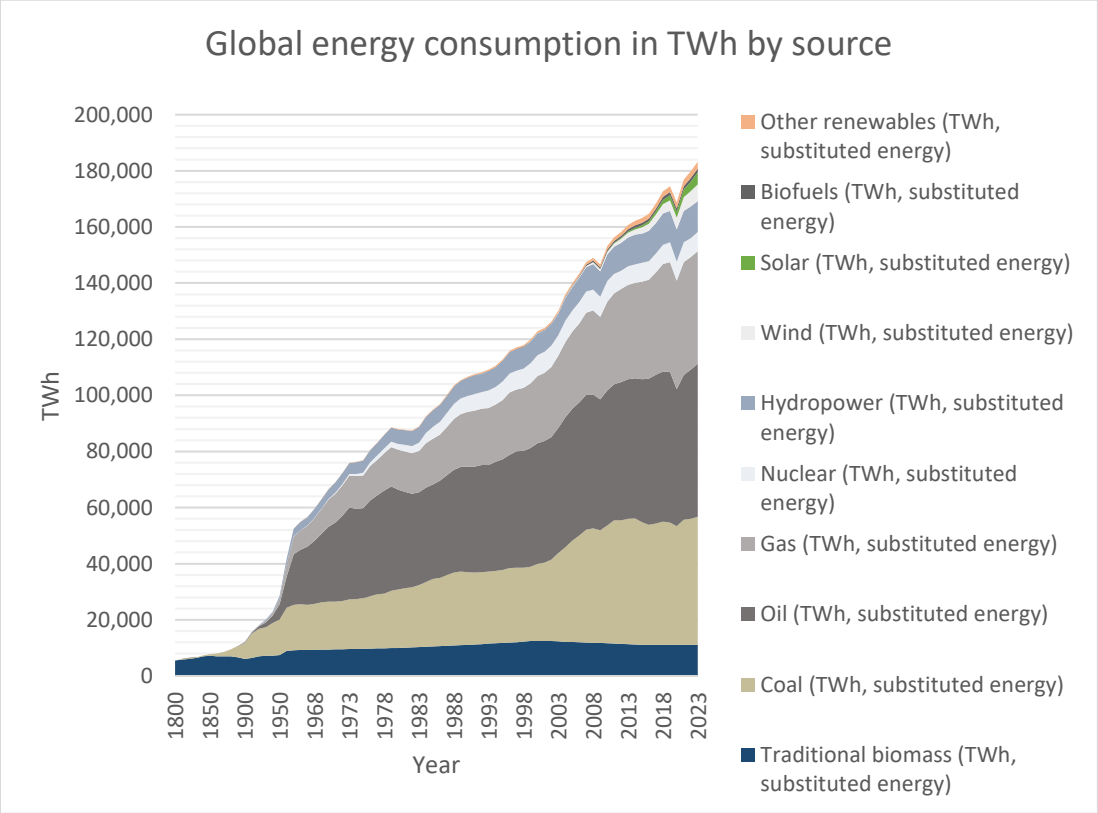
The Energy Transition

The big question I'm seeking to answer is whether renewables, such as nuclear, hydropower, wind, solar and biofuels could see a similarly rapid expansion as did coal in the early 1900s and oil and gas after WWII. Currently these renewables make up a total of 17.4% of total energy consumption in the world. At the same time, energy consumption increased by an average of 2% over the last 20 years and 1.5% over the last 10 years (including Covid lockdowns).[1] I'm using this low 1.5% energy consumption growth per year to estimate energy demand over the next 5-10 years. This would mean that by 2030 the world would consume 203.4k TWh of energy per year compared to 183k TWh of energy consumed in 2023 (includes compounding), and 205.6k TWh if we assume more similar rates compared to the last seven years, which included Covid lockdowns. Let's now look at each of these renewable energies, starting with nuclear.



Source: Our World in Data

[1] https://ourworldindata.org/energy-production-consumption

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Nuclear energy

Nuclear energy generates 2,602 TWh of energy per year, about 9% of the world's electricity demand and around 3.7% of the world's total energy demand in 2023 if the energy substitution method is used.[2] Global nuclear electricity production has grown only 30% since 1990 and peaked in 2006 at around 2,650 TWh.[3] Since 1990, as a direct result of the Chernobyl disaster in 1986, we have witnessed a shift from nuclear power plants being mostly built in North America and Europe to being mostly built in Asia. This shift is also in line with the gradual shift of manufacturing away from North America and Europe towards Asia & specifically China, as well as the rise of shale oil & gas in the USA, which made nuclear power comparatively expensive. Currently, there are 64 nuclear reactors under construction, 88 reactors planned, and 344 reactors proposed worldwide. Of all these 496 reactors, half of them are either being built, planned or proposed in China. Between 2024 and 2030, a total of 64 reactors are scheduled to come online with a capacity of 71GWe, compared to the current total capacity of 390GWe.[4] While there will be nuclear plants being decommissioned until 2030, most lifetimes of aging nuclear plants in the West are being extended, which is more than 50% cheaper than constructing a new one.[5] This could mean that over the next 5-6 years we will see nuclear energy grow by 15% to generate around 450GWe or 3,000TWh. This 400TWh growth compares to 20,000 TWh minimum total energy demand growth and hence would make up only 2% of the total energy growth needed by 2030 (or 3.87% of total energy demand vs. 3.72% in 2023).

[2] https://world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide , note that Our World in Data uses 6,824 TWh for the year 2023, around 2.6x higher than the actual data due to the energy substitution method used: https://ourworldindata.org/energy-substitution-method
[3] https://world-nuclear.org/our-association/publications/world-nuclear-performance-report/global-nuclear-industry-performance
[4] https://world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide
[5] https://www.reuters.com/graphics/EUROPE-ENERGY/NUCLEARPOWER/gdvzwweqkpw/

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Nuclear power plants under construction/planned/proposed

COUNTRY	REACTORS UNDER CONSTRUCTION		REACTORS PLANNED		REACTORS PROPOSED	
Country Profile)	No.	MWe gross	No.	MWe gross	No.	MWe gross
WORLD	64	71,397	88	84,942	344	365,050
China	30	34,661	41	44,660	158	186,450
India	7	5,900	12	8,400	28	32,000
Russia	4	3,988	14	8,930	36	37,716
Turkey	4	4,800	0	0	8	9,600
Egypt	4	4,800	0	0	0	0
Japan	2	2,756	1	1,385	8	11,562
Ukraine	2	1,900	2	2,500	7	8,750
Bangladesh	2	2,400	0	0	2	2,400
United Kingdom	2	3,440	2	3,340	2	2,300
South Korea	2	2,680	2	2,800	0	0
Brazil	1	1,405	0	0	8	8,000
France	1	1,650	0	0	6	9,900
Iran	1	1,057	2	1,417	6	5,200
Argentina	1	29	1	1,150	1	750
Slovakia	1	471	0	0	1	1,200
Poland	0	0	3	3,750	26	10,000
USA	0	0	0	0	13	10,500
Canada	0	0	2	400	9	5,700
Romania	0	0	2	1,440	6	462
Czech Republic	0	0	1	1,200	3	3,600
Mexico	0	0	0	0	2	2,000
Netherlands	0	0	0	0	2	2,000
Saudi Arabia	0	0	0	0	2	2,900
South Africa	0	0	0	0	2	2,400
UAE	0	0	0	0	2	2,800
Uzbekistan	0	0	0	0	2	2,400
Armenia	0	0	0	0	1	1,060
Ghana	0	0	0	0	1	1,000
Kazakhstan	0	0	0	0	1	1,200
Slovenia	0	0	0	0	1	1,200
Bulgaria	0	0	2	2,300	0	0
Hungary	0	0	2	2,400	0	0
Pakistan	0	0	1	1,170	0	0
Sweden	0	0	2	2,500	0	0

Source: World Nuclear Association

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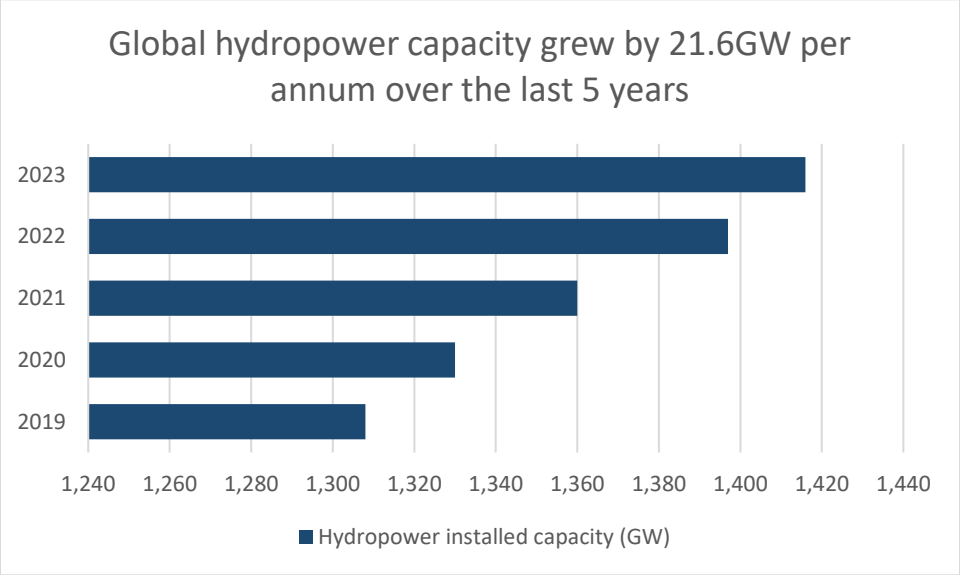
Hydropower energy

As of 2023, a total capacity of 1,416GW hydropower was installed and generated 4,185TWh[6] or 11,014TWh according to Our World in Data when applying the energy substitution method, which would equal around 6% of total world energy demand in 2023.[7] Nearly 1/3 of total hydropower is being generated by China (421GW installed capacity), followed by Brazil (110GW), the United States (102GW), Canada (83GW), Russia (56GW), India (52GW) and Japan (50GW).[8] According to the International Hydropower Association (IHA), 2023 has seen the lowest addition of convention hydropower in a century with only 7.2GW additions, while pumped storage hydropower (PSH) grew by 6.5GW installed capacity. The market is very much split into developed nations, which focus mostly on upgrading existing dams through PSH, and developing nations, of which China takes the lion share, which is beginning to focus on PSH as well, as a sign of the maturity of its hydropower market. The IHA expects to see annual additions of 20-25GW new installations by 2030. This would mean, we could see 154GW in newly installed capacity by 2030, which would add around 462TWh to the grid, bringing total hydropower energy to 4,647TWh by 2030 or 12,230TWh according to Our World in Data, or 6% of the expected energy consumption in 2030, the same as in 2023.



Source: International Hydropower Association

[6] https://acrobat.adobe.com/id/urn:aaid:sc:us:6ba5f8fc-5ad3-4d52-a83c-0931ce5fa119
[7] https://ourworldindata.org/energy-substitution-method
[8] https://acrobat.adobe.com/id/urn:aaid:sc:us:6ba5f8fc-5ad3-4d52-a83c-0931ce5fa119

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Wind energy

In 2023, a record 116GW of wind capacity has been installed, of which China made up 75GW or 65% and nearly 45% of total installed capacity.[9] The industry is expected to reach 2TW of installed capacity by 2030 (80-90% onshore, rest offshore), which would mean a doubling of current capacity in just 7 years.[10] This is a remarkable growth projection, since it took 40 years to reach 1TW of capacity[11]. However, recently more and more projects either faced delays or cancellations amid cost overruns and shortages of certain steel products and rare earth materials. This resulted as a direct consequence of China turbocharging its wind developments (& the Ukraine war, as Europe sourced most of its steel from Ukraine[12]). The nation has more than doubled its capacity from 210GW in 2019[13] to 471GW in 2023.[14] The U.S. & Canada have now slapped a 25% tariff on Chinese steel and Europe at least 18.1% due to fear of China dumping their excess steel on their markets amidst China's real estate slowdown, limiting any potential relief in recent price declines. China makes up 60% of the global wind turbine manufacturing capacity (in 2023)[15], hence assuming that the ongoing trade war with China is not worsening and projections of the Global Wind Energy Council prove to be correct, global wind energy supply will double from 2023 at 6,040TWh to 12,230TWh in 2030, increasing its total share of energy produced from 3.3% in 2023 to 5.9% in 2030.

[9] https://wwindea.org/AnnualReport2023
[10] https://gwec.net/globalwindreport2023/
[11] https://gwec.net/wp-content/uploads/2023/04/GWEC-2023_interactive.pdf
[12] https://www.ics-shipping.org/news-item/supply-chain-and-turbine-operation-challenges-pose-threat-to-renewable-fuel-generation/
[13] https://chinaenergyportal.org/en/2019-electricity-other-energy-statistics-preliminary/
[14] https://wwindea.org/AnnualReport2023
[15] https://gwec.net/wp-content/uploads/2023/04/GWEC-2023_interactive.pdf

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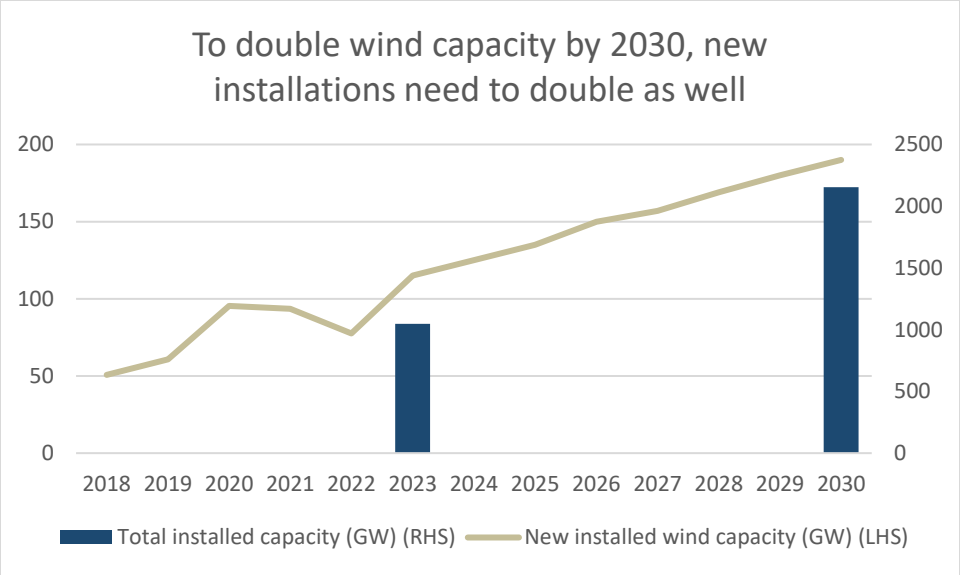
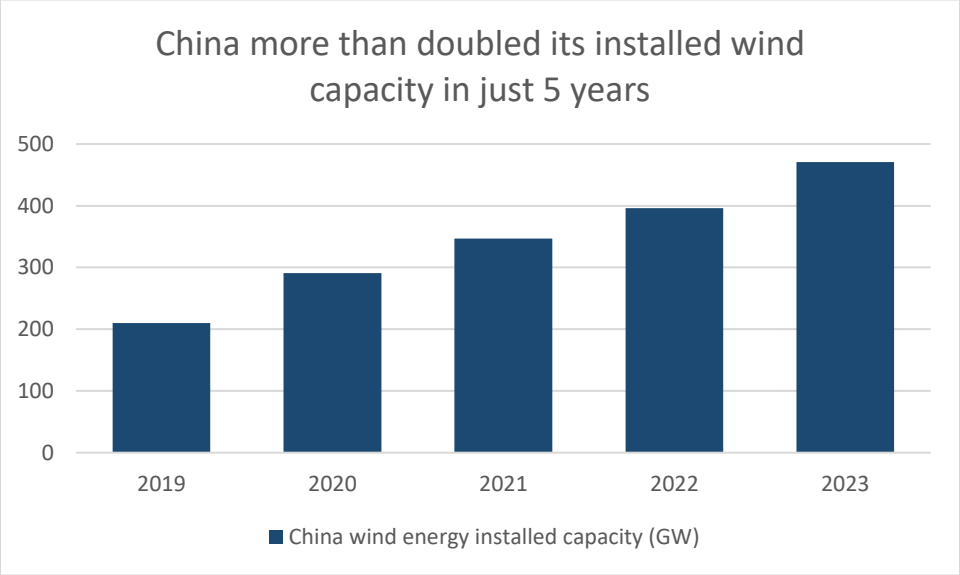


Source: Global Wind Energy Council



Source: Global Wind Energy Council

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Solar energy

By 2023, total installed solar capacity has reached 1.4TW, doubling from 720GW installed capacity in 2020, growing faster in percentage terms than any other energy source.[16] This growth was led by 447GW of installed capacity in 2023 alone, of which China accounted for more than half at 253GW.[17] In 2023, solar made up 2.3% of total energy consumed. By extrapolating the 2024-2028 medium scenario of solar installed capacity growth, it is expected that total solar capacity will grow to 7.4TW by 2030, a 5.3x increase over 2023.[18] If this scenario does indeed play out as expected, solar energy would increase from 2.3% of total energy consumed to 11.1% by 2030. While this would present a phenomenal growth rate, there are some headwinds, which makes this figure potentially appear overly optimistic. China has officially met its target of growing 1,200GW of renewable energy by 2030 early in July 2024.[19] At the same time, the industry is plagued with overcapacity leading all Chinese solar firms to post losses and there are concerns on certain solar installation's effectiveness in parts of China, which might translate into less energy per GW installed. If we assume growth will plateau here at say 500GW per year, solar power will only grow to 10,661TWh by 2030 and make up 5.2% of total energy use – less than half of the current estimate. Same as for wind and nuclear power, it will all depend on China, but when losses start to mount, there will always be a correction with bankruptcies in the pipeline.[20] Polysilicon producer Daqo, for instance, has reduced its full year production outlook to 210k-220k MT compared to 280k-300k MT before.[21]

[16] https://www.irena.org/Energy-Transition/Technology/Solar-energy
[17] https://www.solarpowereurope.org/insights/outlooks/global-market-outlook-for-solar-power-2024-2028/detail
[18] https://www.solarpowereurope.org/insights/outlooks/global-market-outlook-for-solar-power-2024-2028/detail
[19] https://climateenergyfinance.org/wp-content/uploads/2024/07/MONTHLY-CHINA-ENERGY-UPDATE-_-China-to-Achieve-its-2030-Energy-Target-in-July-2024.pdf
[20] https://www.pv-tech.org/daqo-q1-net-income-drops-71-expects-many-market-players-to-go-bankrupt/
[21] https://www.dqsolar.com/2024-08-26-Daqo-New-Energy-Announces-Unaudited-Second-Quarter-2024-Results

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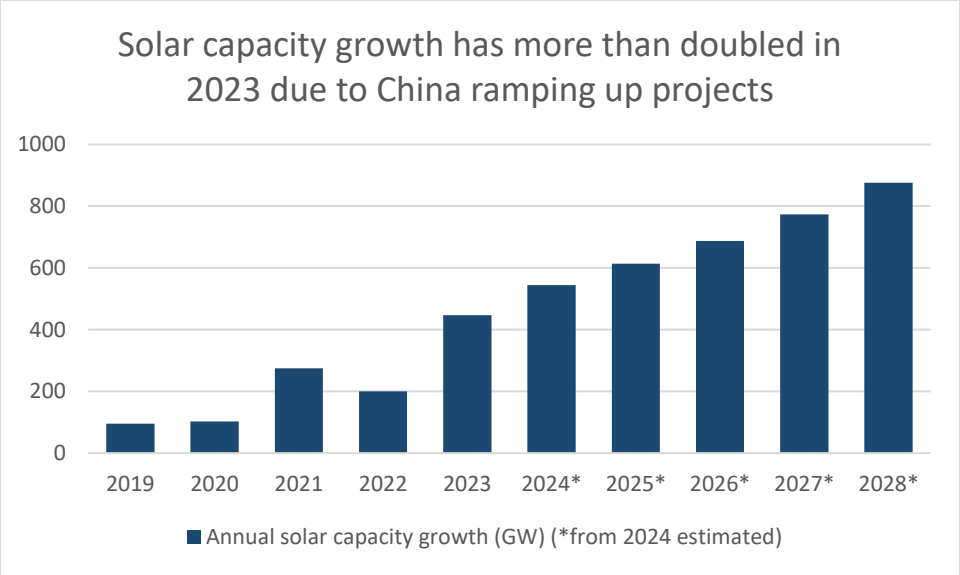
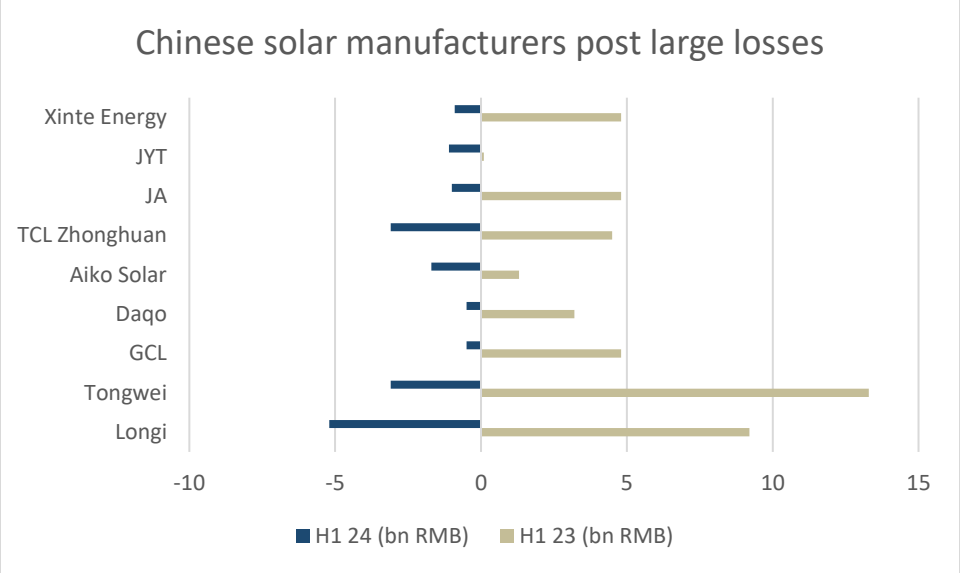


Source: IRENA, Solar Power Europe



Source: Individual companies

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Biofuel/methane energy

Biofuels currently make up only 0.7% of energy demand in 2023 with 1,318TWh. There are multiple different types of biofuels. Most importantly, one should separate those biofuels that can be mixed with oil/liquids (biofuels) and those that can be used to generate electricity/gas (biomethane). The IEA Bioenergy platform expects total biofuels & biomethane production capacity to climb more than 4-fold between 2023 and 2030.[22] Around 62% of this growth is expected to come from biomethane via anaerobic digestion, i.e. manure. What stands out is that there is very little growth in biofuel capacity to produce liquids, such as sustainable aviation fuel (SAF) or biodiesel (transesterification & hydrotreatment). Transesterification and hydrotreatment make up around 30% of the growth. The problem is that there is simply not enough cooking oil to make all planes fly with SAF. For example, in Spain around 72% of cooking oil from hospitality is already being recycled.[23] The U.S. and China only recycle 25% and 15% respectively of their hospitality's cooking oil[24]. Hence, even if they would grow this to 75%, the U.S. would supply 2.55bn gallons compared to 0.85bn gallons today. In 2019, however, total aviation fuel demand stood at 96bn gallons.[25] Meanwhile, food waste recycling rates are already at 43% in the UK and has maintained this level for over a decade without any growth.[26] SAF also still requires at least 50% of regular jet fuel[27], while being over 2x more expensive.[28] Overall, it would surprise me to see a 4x rise in biofuels/methane by 2030, as this segment has been growing very slowly and its end products often come with a much higher price tag. If this was the case, by 2030 biofuels/biomethane would account for 2.7% of the world's energy demand.

[22] https://www.ieabioenergy.com/blog/publications/recent-ec-report-explores-what-is-needed-to-expand-the-industrial-capacity-for-advanced-biofuels-production/
[23] https://www.repsol.com/en/energy-and-the-future/future-of-the-world/oil-culinary-treasure-can-and-should-be-recycled/index.cshtml
[24] https://oilandenergyonline.com/articles/all/supply-and-demand-report-used-cooking-oil/
[25] https://www.greenairnews.com/?p=5103
[26] https://www.gov.uk/government/statistics/local-authority-collected-waste-management-annual-results/local-authority-collected-waste-management-annual-results-202223
[27] https://www.bp.com/en/global/air-bp/news-and-views/views/what-is-sustainable-aviation-fuel-saf-and-why-is-it-important.html
[28] https://www.reuters.com/sustainability/us-sustainable-aviation-fuel-production-target-faces-cost-margin-challenges-2023-11-01/

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Estimated growth in biofuels/biomethane by 2030

Technology/Feedstock category	Production capacity (Mtoe/y)	
	2023	2030
Biomethane from anaerobic digestion	3.2	15
Transesterification of e.g. brown grease	1.06	1.5
Transesterification of intermediate crops	-	2.8
Hydrotreatment of tall oil	0.14	0.2
Hydrotreatment of intermediate crops	-	2.4
Lignin boost of fatty acids	-	0.1
Advanced ethanol	0.13	0.3
ATJ	-	0.1
Gasification + methanol	0	0.2
Gasification + SNG	0	0.6
Gasification + FT	-	0.1
Pyrolysis	0.04	0.2
HTL	0	0
Total advanced biofuels/biomethane	4.57	23.6

Source: IEA Bioenergy

Conclusion

In conclusion, I have prepared two tables below, which depict global energy consumption in TWh in 2023 compared to 2030. The first table is my personal estimate, which takes into account the estimates of the individual agencies and my personal adjustments due to supply and demand constraints and costs. I believe that my assumptions are still heavily weighted towards renewables and given the problems we see with Chinese solar profitability and wind projects being cancelled across the globe due to cost overruns, are likely overstated as well. The overly optimistic numbers from the agencies regarding renewable capacity growth would drastically reduce CO2 emissions by 2030. It would also decrease prices for coal, oil and gas. China, which has made up more than 50% of the renewable capacity growth in recent years, has already achieved their renewable capacity growth for 2030 in 2024, and hence would likely start looking at cost/benefits more, especially as overcapacity in a weak economic environment is likely leading to mass bankruptcies. This makes fossil fuel still attractive as an investment, as demand is more

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likely to outpace supply compared to renewables, which often require more expensive, fixed price mechanisms, such as CfDs. However, there is much more so a risk of significant energy oversupply as the investment in energy overall increases.

Energy consumption by source in 2023 vs. 2030 (personal assumptions)

	Traditional biomass (TWh)	Coal (TWh)	Oil (TWh)	Gas (TWh)	Nuclear (TWh)	Hydropower (TWh)	Wind (TWh)	Solar (TWh)	Biofuels (TWh)	Other renewables (TWh)	Total energy demand (TWh)
2023	11,111	45,565	54,564	40,102	6,824	11,014	6,040	4,264	1,318	2,428	183,230
2030	11,111	47,000	57,000	45,000	7,868	12,396	9,540	10,661	2,000	3,000	205,576
Growth	-	3%	4%	12%	15%	13%	58%	150%	52%	24%	12%
Growth 2016-23	-	7%	5%	14%	2%	2%	135%	385%	40%	41%	11%

Source: Our World in Data, individual agencies of energy source

Energy consumption by source in 2023 vs. 2030 (renewable agencies assumptions)

	Traditional biomass (TWh)	Coal (TWh)	Oil (TWh)	Gas (TWh)	Nuclear (TWh)	Hydropower (TWh)	Wind (TWh)	Solar (TWh)	Biofuels (TWh)	Other renewables (TWh)	Total energy demand (TWh)
2023	11,111	45,565	54,564	40,102	6,824	11,014	6,040	4,264	1,318	2,428	183,230
2030	11,111	40,000	50,000	41,000	7,868	12,396	12,230	22,540	5,534	3,000	205,679
Growth	-	-12%	-8%	2%	15%	13%	102%	429%	320%	24%	12%
Growth 2016-23	-	7%	5%	14%	2%	2%	135%	385%	40%	41%	11%

Source: Our World in Data, individual agencies of energy source

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