humanity of the third millenium under assumption of exponential growth

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Abstract

There are many methods for modeling the growth of humanity, many conflicting and some producing unusual conclusions such as infinities at certain points in time - here I take the simplest approach and match the relevant data between the years 1900 and 2021/2023 to an exponential curve in these areas:

total population, life expectancy, GDP (global total & per capita), energy consumption (global total & per capita).

Results are presented as plots showing the curve and the real data together, as well as plots & tables showing resulting values for the future between years 2000 and 3000.

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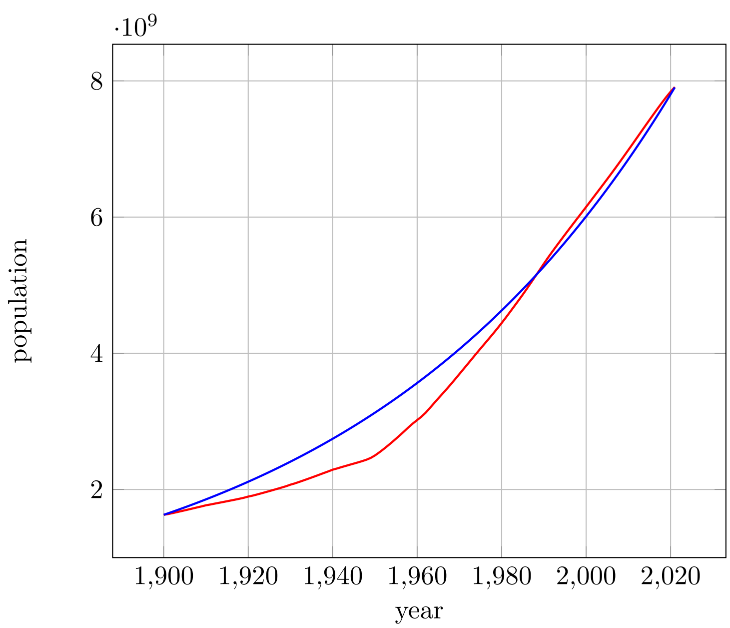
1 exponential human population growth

There is a common assumption that infuriates many people, that the growth of human population is exponential - it's rather obvious that whatever the environment might be, only so many people could be supported by it, and the growth should have an end, whether that is by turning out to be logistical growth or continuing exponentially till some hard limit is surpassed that in consequence results in decreasing population numbers again. The trends observed in the growth in human population do not support exponential growth, the growth seen historically is faster than exponential, in the modern day birth rates are dropping significantly suggesting population numbers might even drop, and the accuracy of predictions of future human populations is famously laughable - and I cannot help but add to that, because for the lack of a better method I too will model the population growth as exponential.

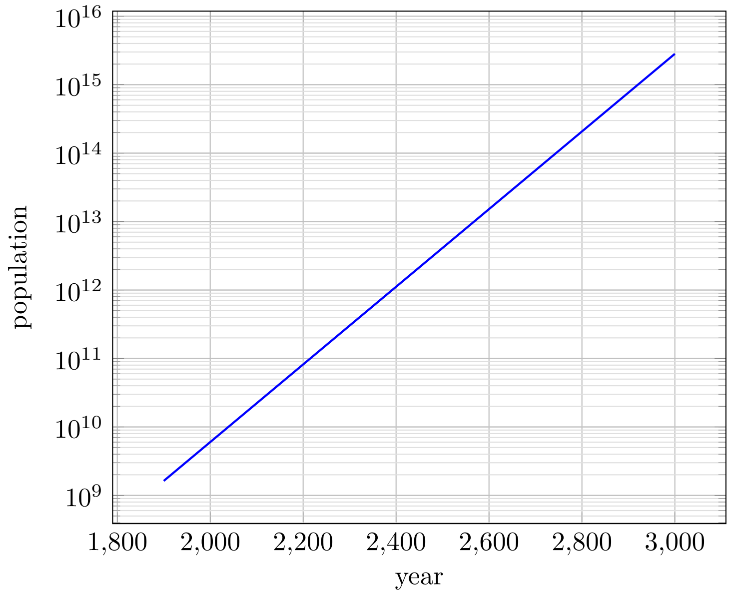
Below in red I've plotted the population across past years since 1900, well past the industrial revolution, my data comes from Our World In Data. In blue ploted is a function:

$$y = 1627883132 \times 1.01314982563501^{x-1900}$$

Which is simply exponential growth from the starting number of people (1627883132) in 1900 that both plots begin at, multiplied by 1.01314982563501 for every passing year to represent $\approx 1.315\%$ increase in population per year.



Let us consider the following millenium, and go all the way out to the year 3000 using this same roughly 1.315% growth per year:



Here are some precise numbers to be extracted from this:

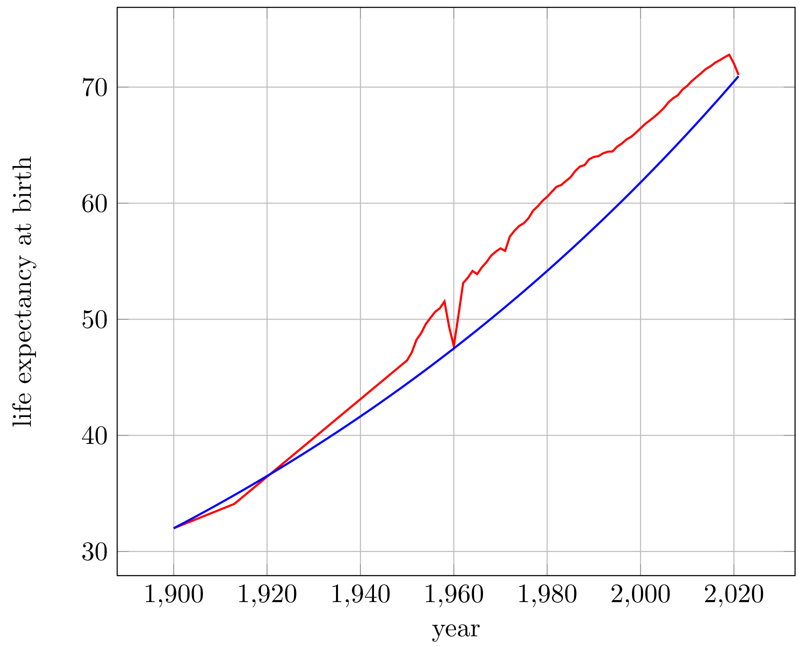
year	exact population	rough population	order of magnitude
2000	6 011 607 607	6×10^9	billions
2050	11 552 456 090	11.5×10^9	tens of billions
2100	22 200 258 306	22.2×10^9	tens of billions
2150	42 662 050 824	42.7×10^9	tens of billions
2200	81 983 306 474	82×10^9	tens of billions
2250	157 546 634 788	157.5×10^9	hundreds of billions
2300	302 756 051 205	302.8×10^9	hundreds of billions
2350	581 803 772 987	581.8×10^9	hundreds of billions
2400	1 118 047 447 489	1.12×10^{12}	trillions
2450	2 148 542 434 542	2.15×10^{12}	trillions
2500	4 128 836 037 678	4.13×10^{12}	trillions
2600	15 247 373 503 074	15.2×10^{12}	tens of trillions
2700	56 307 006 773 998	56.3×10^{12}	tens of trillions
2800	207 936 075 758 080	207.9×10^{12}	hundreds of trillions
2900	767 886 877 297 784	767.9×10^{12}	hundreds of trillions
3000	2 835 728 500 580 920	2.8×10^{15}	quadrillions

2 exponential life expectancy at birth

Below in red I've ploted the global average life expectancy at birth between years 1900 and 2021 according to Our World In Data, and in blue an exponential function:

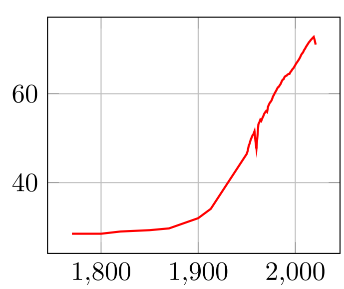
$$y = 32 \times 1.006613662^{x-1900}$$

Which represents a starting point at year 1900 with 32 years life expectancy at birth, and growth of roughly 0.66% per year.

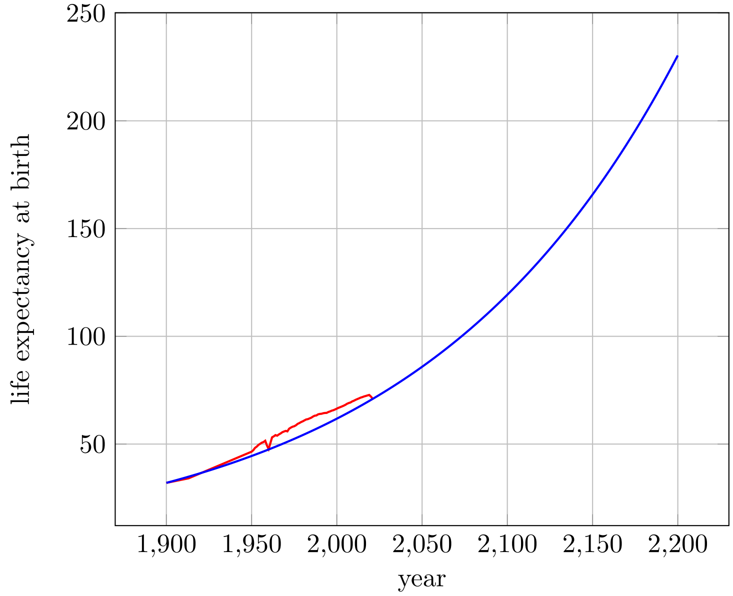


I should say, at least to my eye, the real data very much does not feel like it follows exponential growth, rather it looks more like it follows simple linear growth, but even more than that I would say the shape of the curve here is just very hard to guess because it doesn't even remotely look like any of the simple mathematical functions I know.

In the years before 1900 which I had not included above for industrial revolution reasons it becomes pretty much flat, showing little change as the years pass, making the actual curve look more like 2 straight lines that touch each other at an angle rather than any kind of gradual, let alone exponential growth.



Once again, let's extend this into the future, but for reasons you will see below I'm only going to extend this out to the year 2200 this time, and since the range is small enough for the real data to be visible I am including it again in red.



Here are some precise numbers to be extracted from this:

year	life expectancy at birth	increase over previous year
2020	70.58 y	0.4637 y
2030	75.39 y	0.4953 y
2040	80.53 y	0.5291 y
2050	86 y	0.5651 y
2060	91.88 y	0.6036 y
2070	98.14 y	0.6448 y
2080	104.82 y	0.6887 y
2090	111.97 y	0.7356 y
2100	119.59 y	0.7858 y
2110	127.74 y	0.8393 y
2120	136.45 y	0.8965 y
2130	145.75 y	0.9576 y
2137	152.63 y	1 y

It is a little pointless to continue past the year 2137 in this model as at this year, life expectancy begins to grow by more than 1 year every year, granting everyone born past that point theoretical immortality. The more widely known name for this effect is "longevity escape velocity" for those more interested.

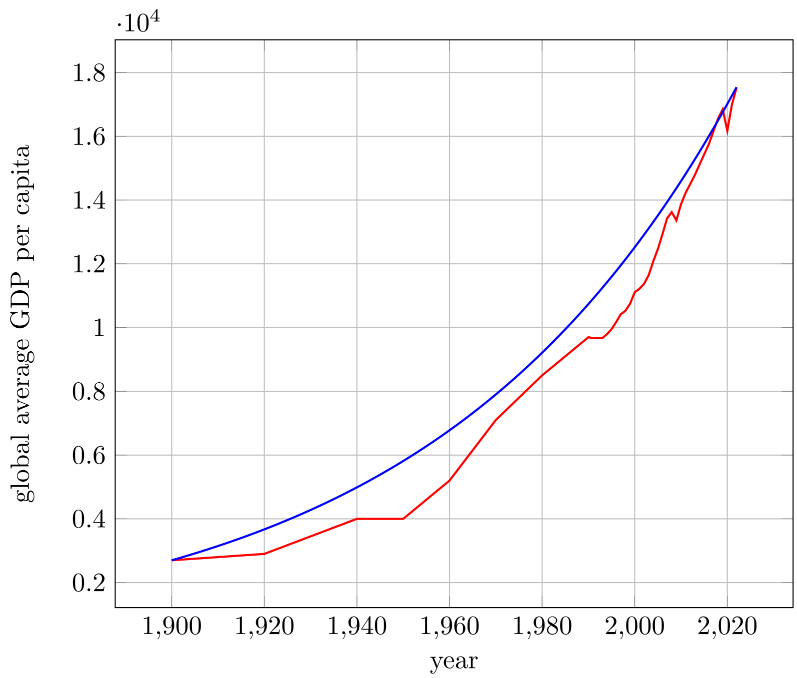
3 exponential GDP per capita growth

Going into this chapter it's important to remember that GDP per capita is not the same as the amount of money an average person earns, nor even really implies that money still exists in whatever society we are contemplating here - you might think of it as factoring in not just your personal earnings but costs to maintain the roads you drive on or the bus you take to work & such.

Below in red I've ploted the global average GDP per capita (expressed in international dollars at 2017 prices) between years 1900 and 2022 according to Our World In Data, and in blue an exponential function:

$$y = 2700 \times 1.015450028^{x-1900}$$

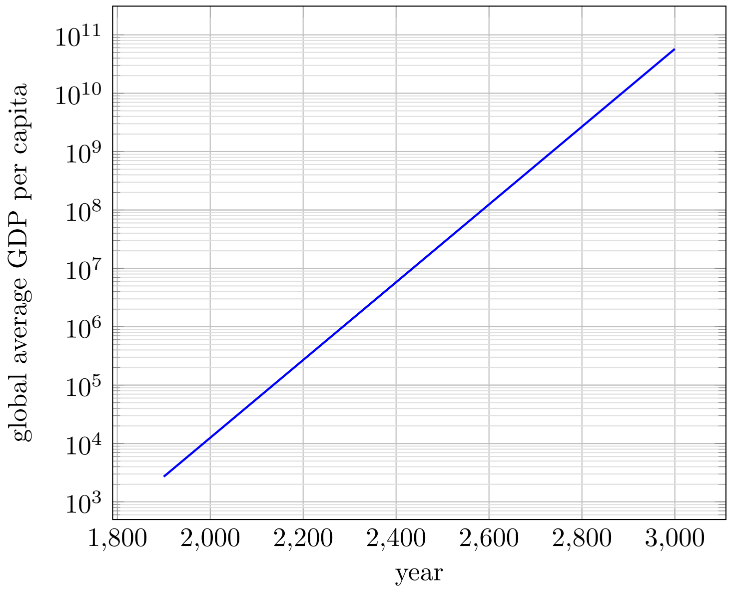
Which represents a starting point at year 1900 with 2700 international-$, and growth of roughly 1.545% per year.



This is appears to be a quicker rise than the population growth. There is also a third assumption I am forced to make given the two I've already made - if the number of people is growing exponentially, and the gross domestic product per person is also growing exponentially, then total global (universal?) GDP per capita must necessarily be also growing exponentially as just those 2 functions multiplied.

If I were to graph it here it would be some function $y = a \times 1.028803019^{(x-b)}$ or at least close to it, else the model is self-inconsistent.

Let us again consider this roughly 1.545% per year growth through the following millenium and go all the way to the year 3000:



Here are some precise numbers to be extracted from this:
(once again, in international dollars, at 2017 prices)

year	exact GDP p.c.	rough GDP p.c.	order of magnitude
2000	12 508.9 $	12.5×10^3 $	tens of thousands
2050	26 924.47 $	26.9×10^3 $	tens of thousands
2100	57 952.87 $	58×10^3 $	tens of thousands
2150	124 739.13 $	124.7×10^3 $	hundreds of thousands
2200	268 491.49 $	268.5×10^3 $	hundreds of thousands
2250	577 907.5 $	577.9×10^3 $	hundreds of thousands
2300	1 243 901.89 $	1.2×10^6 $	millions
2350	2 677 404.09 $	2.7×10^6 $	millions
2400	5 762 908.41 $	5.8×10^6 $	millions
2450	12 404 221.5 $	12.4×10^6 $	tens of millions
2500	26 699 142.17 $	26.7×10^6 $	tens of millions
2600	123 695 214.67 $	123.7×10^6 $	hundreds of millions
2700	573 071 075.94 $	573×10^6 $	hundreds of millions
2800	2 654 997 276.55 $	2.7×10^9 $	billions
2900	12 300 412 347.57 $	12.3×10^9 $	tens of billions
3000	56 986 929 989.15 $	57×10^9 $	tens of billions

4 exponential global total GDP

As mentioned in the previous section, given the population growth and average GDP per capita growth rates, the total GDP growth rate is expected to be 2.88% per year.

Below in red I've ploted the global total GDP (expressed in international dollars at 2017 prices) between years 1900 and 2022 according to Our World In Data, and in blue an exponential function:

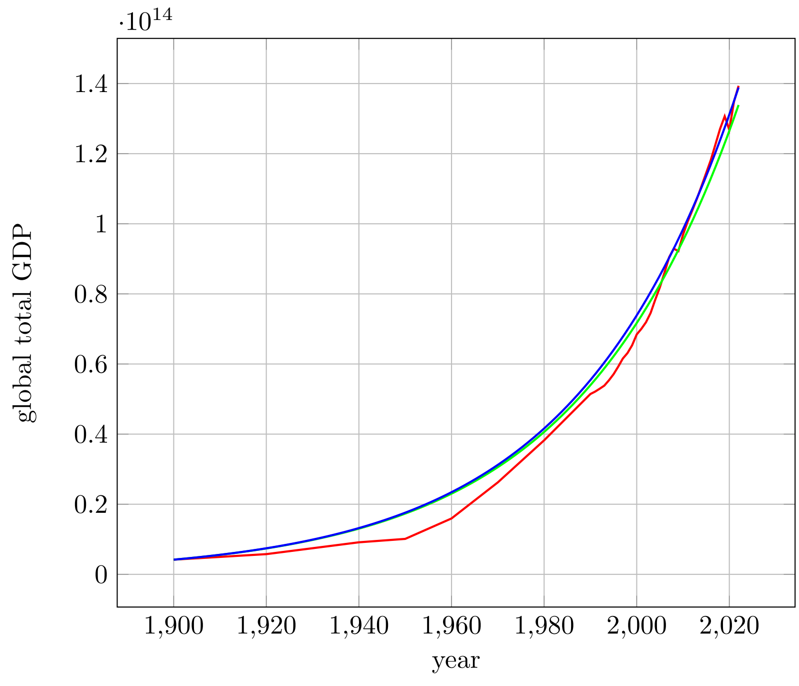
$$y = 4188242000000 \times 1.029144185^{x-1900}$$

Which represents a starting point at year 1900 with 2700 international-$, and growth of roughly 2.91% per year.

Additionally I've plotted in green the function mentioned previously which I deduced from the population and GDP per capita growth:

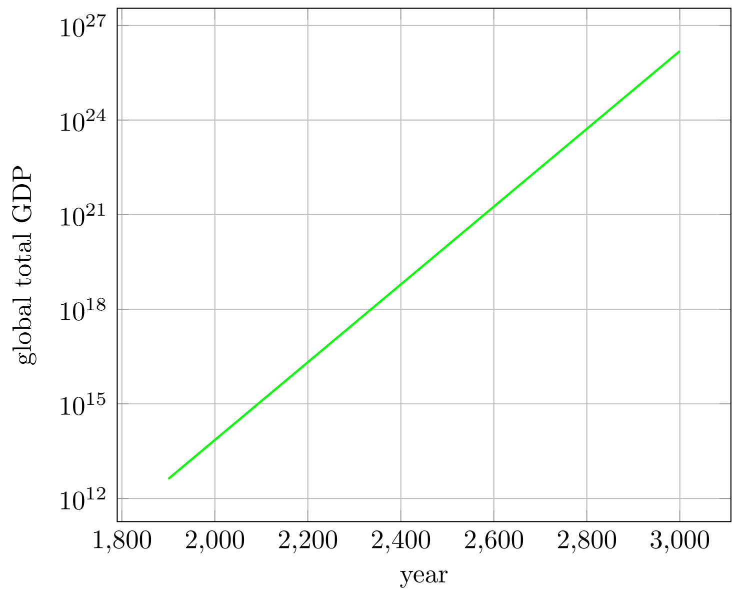
$$y = 4188242000000 \times 1.028803019^{x-1900}$$

Which represents growth at 2.88% per year from the same starting point.



As can be seen, the data is consistent with previous predictions. The blue curve intersects the final point of the data here (year 2022) as it should given how it is calculated, while the green deduced from population and gdp per capita data intersects the point for 2021 year, possibly reflecting the fact my data for global average gdp per capita runs from 1900 to 2021 and not 2022.

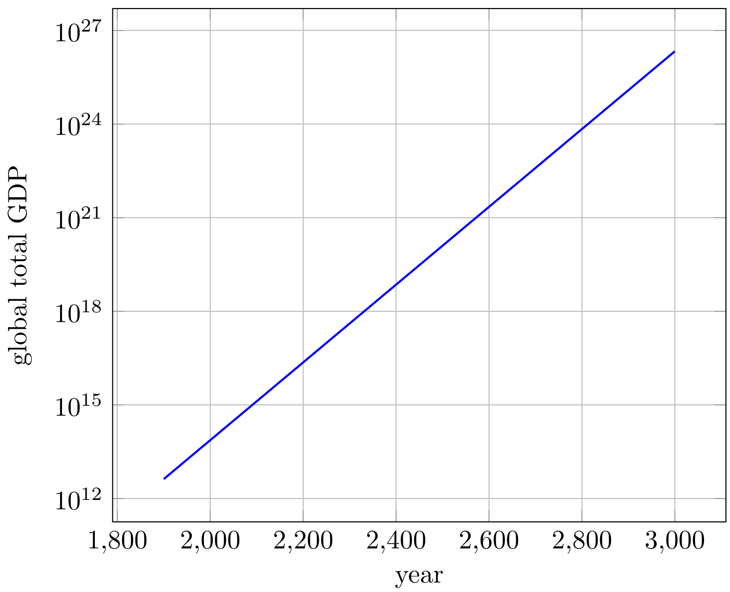
Let's extrapolate the found rates of growth - both 2.88% and 2.91% - all the way to the year 3000. First, **2.88%** which is the rate consistent with GDP per capita & population growth shown earlier:



Here are the numbers that can be extracted from this:

year	exact GDP (exp. 2.88%)	rough
2000	71 656 364 205 474 $	7.17×10^{13} $
2050	296 391 857 890 027 $	2.96×10^{14} $
2100	1 225 964 147 044 890 $	1.23×10^{15} $
2150	5 070 949 318 712 950 $	5.07×10^{15} $
2200	20 974 942 093 485 100 $	2.10×10^{16} $
2250	86 758 547 201 713 000 $	8.68×10^{16} $
2300	358 858 941 254 946 000 $	3.59×10^{17} $
2350	1 484 346 428 936 960 000 $	1.48×10^{18} $
2400	6 139 694 648 245 090 000 $	6.14×10^{18} $
2450	25 395 588 010 196 600 000 $	2.54×10^{19} $
2500	105 043 642 613 071 000 000 $	1.05×10^{20} $
2600	1 797 184 955 537 870 000 000 $	1.80×10^{21} $
2700	30 747 922 330 806 300 000 000 $	3.07×10^{22} $
2800	526 064 234 372 774 000 000 000 $	5.26×10^{23} $
2900	9 000 399 302 067 420 000 000 000 $	9.00×10^{24} $
3000	153 987 255 364 814 000 000 000 000 $	1.54×10^{26} $

Now again, for **2.91%** which is the rate deduced from the actual data for global total gdp gathered from Our World In Data:



Here are the numbers that can be extracted from this:

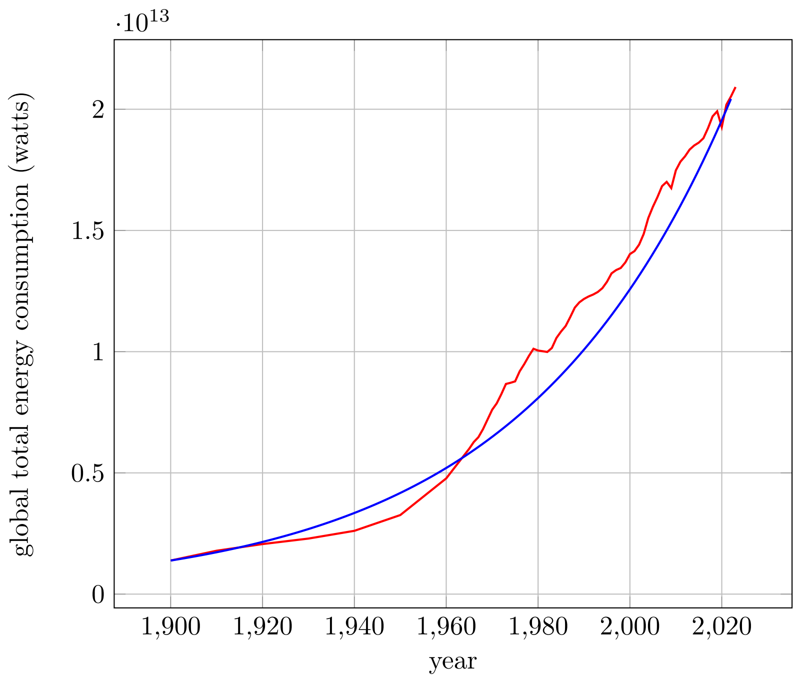
year	exact GDP (exp. 2.91%)	rough
2000	74 072 024 713 093 \$	7.41×10^{13} \$
2050	311 505 299 969 375 \$	3.12×10^{14} \$
2100	1 310 016 194 168 611 \$	1.31×10^{15} \$
2150	5 509 191 750 999 848 \$	5.51×10^{15} \$
2200	23 168 563 781 417 100 \$	2.32×10^{16} \$
2250	97 433 956 187 161 900 \$	9.74×10^{16} \$
2300	409 752 451 979 616 000 \$	4.10×10^{17} \$
2350	1 723 188 490 681 750 000 \$	1.72×10^{18} \$
2400	7 246 762 185 490 900 000 \$	7.25×10^{18} \$
2450	30 475 808 338 462 100 000 \$	3.05×10^{19} \$
2500	128 164 119 383 167 000 000 \$	1.28×10^{20} \$
2600	2 266 673 181 320 900 000 000 \$	2.27×10^{21} \$
2700	40 087 719 836 463 000 000 000 \$	4.01×10^{22} \$
2800	708 979 704 233 437 000 000 000 \$	7.09×10^{23} \$
2900	12 538 807 970 757 400 000 000 000 \$	1.25×10^{25} \$
3000	221 757 695 444 216 000 000 000 000 \$	2.22×10^{26} \$

5 exponential total energy consumption

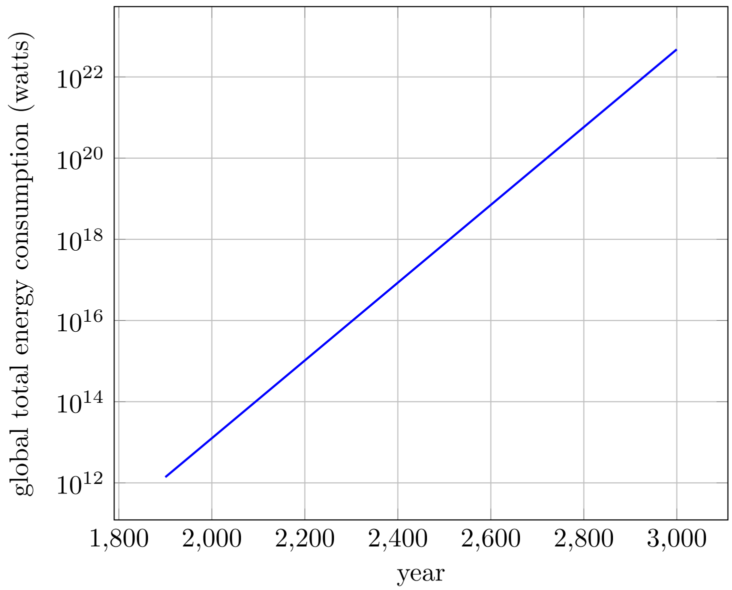
Below in red I've ploted the global energy consumption between years 1900 and 2023 according to Our World In Data (converted from terawatt-hours per year to watts), and in blue an exponential function:

$$y = 1384842719178.08 \times 1.022318254^{x-1900}$$

Which represents a starting point at year 1900 with 2700 international-$, and growth of roughly 2.91% per year.



Let's again stretch this out to the year 3000:



Here are some exact numbers that can be extracted from this:

year	exact	rough	kardashev level
2000	12 589 601 767 577 W	1.26E+13 W	0.71
2050	37 959 262 246 954 W	3.80E+13 W	0.76
2100	114 452 038 828 097 W	1.14E+14 W	0.81
2150	345 087 560 097 656 W	3.45E+14 W	0.85
2200	1 040 483 204 611 280 W	1.04E+15 W	0.90
2250	3 137 190 163 481 378 W	3.14E+15 W	0.95
2300	9 459 030 264 233 090 W	9.46E+15 W	1.00
2350	28 520 188 090 985 200 W	2.85E+16 W	1.05
2400	85 992 020 960 208 200 W	8.60E+16 W	1.09
2450	259 276 960 068 794 000 W	2.59E+17 W	1.14
2500	781 753 251 893 250 000 W	7.82E+17 W	1.19
2600	7 106 916 897 888 330 000 W	7.11E+18 W	1.29
2700	64 608 964 108 776 900 000 W	6.46E+19 W	1.38
2800	587 359 934 439 298 000 000 W	5.87E+20 W	1.48
2900	5 339 687 725 122 810 000 000 W	5.34E+21 W	1.57
3000	48 543 088 028 374 600 000 000 W	4.85E+22 W	1.67

6 Energy consumption per person

Our World In Data does not have data on energy usage per capita from before the year 1965, so I will be extrapolating from data on total global energy use and total population, but regardless the data is still presented on the chart below in red. All converted from kilowatt-hours per year to watts.

In green, an exponential function extrapolated from population and global energy trends:

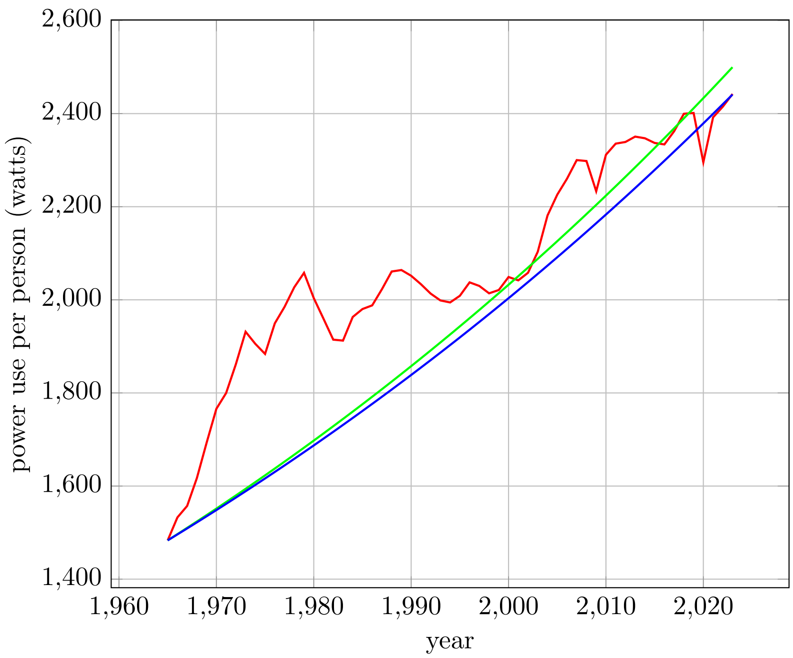
$$y = 1483.29691780822 \times 1.00904943^{x-1965}$$

Which represents a starting point at year 1965 with 1483.29691780822 watts per person, and growth of roughly 0.905% per year.

In blue shown is an exponential function calculated from data between years 1965 and 2023:

$$y = 1483.29691780822 \times 1.008634196^{x-1965}$$

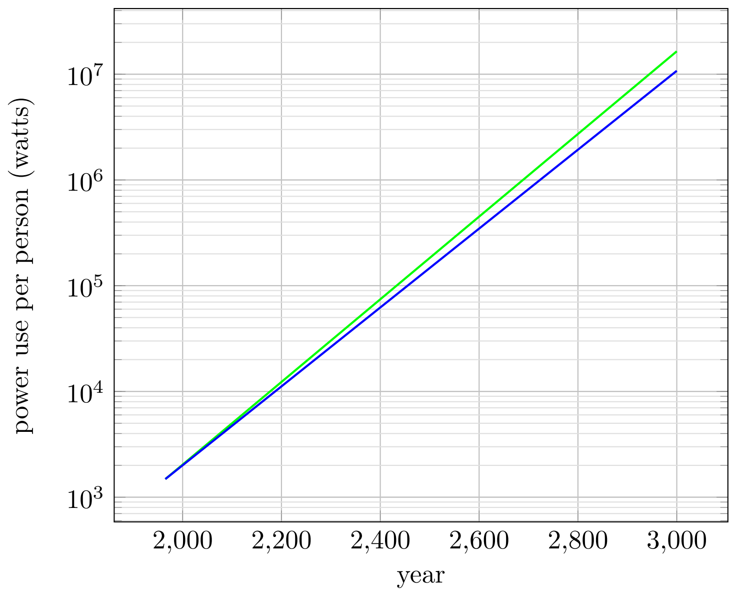
Which represents a starting point at year 1965 with 1483.29691780822 watts per person, and growth of roughly 0.863% per year.



It's noticeable that the real data shows growth, but it is not clear of what kind, personally from eyeballing it I would say maybe even logarhythmic rather than exponential, but this document focusses on exponential growth.

It is important to note though that 0.905% growth is more consistent with the growth I presented earlier for global energy use and total population size.

Extending the growth trend all the way to the year 3000, again 0.905% in green & 0.863% in blue:



Here are some exact numbers to be extracted from this:

0.905% annual growth

year	exact	rough
2000	2033 W	2.03×10^3 W
2050	3190 W	3.19×10^3 W
2100	5005 W	5.01×10^3 W
2150	7853 W	7.85×10^3 W
2200	12321 W	1.23×10^4 W
2250	19332 W	1.93×10^4 W
2300	30332 W	3.03×10^4 W
2350	47590 W	4.76×10^4 W
2400	74669 W	7.47×10^4 W
2450	117155 W	1.17×10^5 W
2500	183816 W	1.84×10^5 W
2600	452510 W	4.53×10^5 W
2700	1113968 W	1.11×10^6 W
2800	2742311 W	2.74×10^6 W
2900	6750887 W	6.75×10^6 W
3000	16619003 W	1.66×10^7 W

0.863% annual growth

year	exact	rough
2000	2004 W	2.00×10^3 W
2050	3080 W	3.08×10^3 W
2100	4735 W	4.73×10^3 W
2150	7277 W	7.28×10^3 W
2200	11185 W	1.12×10^4 W
2250	17192 W	1.72×10^4 W
2300	26425 W	2.64×10^4 W
2350	40616 W	4.06×10^4 W
2400	62428 W	6.24×10^4 W
2450	95955 W	9.60×10^4 W
2500	147486 W	1.47×10^5 W
2600	348434 W	3.48×10^5 W
2700	823169 W	8.23×10^5 W
2800	1944722 W	1.94×10^6 W
2900	4594375 W	4.59×10^6 W
3000	10854136 W	1.09×10^7 W