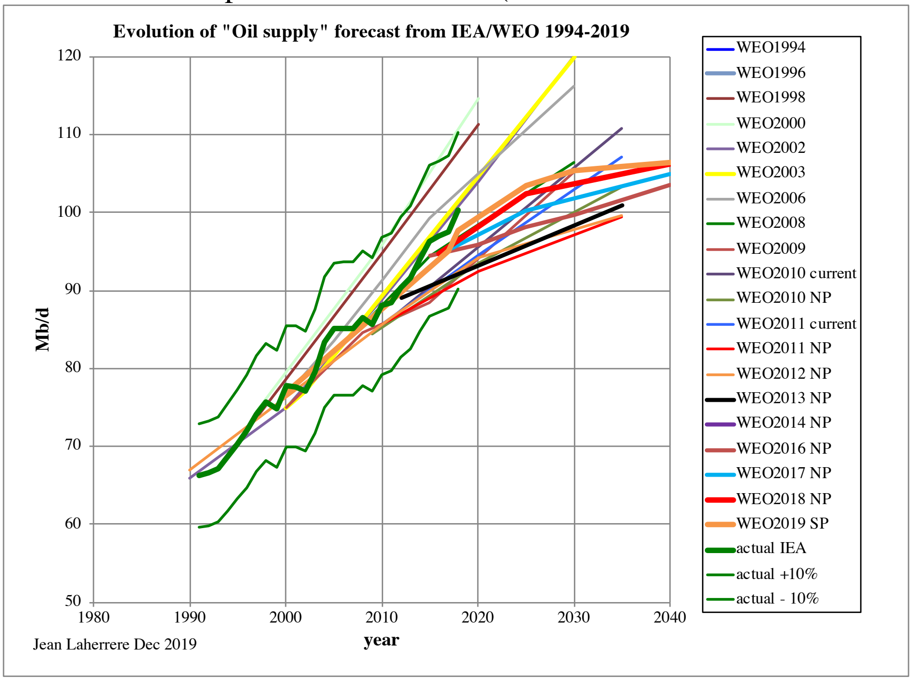
Jean Laherrère 13 January 2020

Phosphate production and reserves: doubtful inequality?
What about peak potash and peak nitrogen?

Phosphate is one of the three major nutrients (called P = phosphorus, K = potassium, N = nitrogen) required for plant growth, growth which is needed to supply future food for the world population assumed by the UN to grow until 2050.
Phosphate is also present in our cells in DNA, RNA and ATP.
US Geological Survey in its annual mineral commodity summaries report (on the web since 1996) lists them as phosphate rock, potash and nitrogen, following British Geological Survey reports since 1913 on statistical summary of the mineral industry.
Phosphate rock production peak and subsequent decline is very important for the world future.
Our consumption society is based on growth and every politician promises growth for ever: it is politically correct to deny future peak and decline. But in a finite world, perpetual growth is impossible.
But reality will prevail! Anyone, except children, knows that Santa Claus does not exist. No peak forever is a fake, like Santa Claus. But official forecast on energy is given by the IEA (International Energy Agency) where forecast energy goes up to 2040.
The evolution of IEA oil supply forecast up to 2040 is changing but always up: no peak in view before 2040 but flattening! There is some discrepancy in IEA forecast, as IEA has not the same definition for oil in past and oil in future (WEO where biofuels are missing)



Phosphate rock is produced since a long time. Production data exists by country, but incomplete and very few historical series. But contrary to oil, phosphate reserves are badly known (there is no scout company on phosphate data) and reported.
Papers have studied phosphate rock production the same way as oil, using past production to forecast future production: Déry 2007, Cordell 2009, Morrigan 2010, Hendrix 2011, Mohr & Evans 2013, Walan 2013, White http://phosphorusfutures.net/the-phosphorus-challenge/peak-phosphorus-the-sequel-to-peak-oil/.
Peak phosphorus is as known as peak oil!

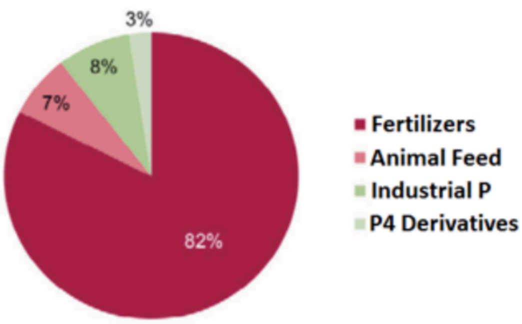
Many estimates of peak phosphorus as reported by Luke Burgess June 28, 2019
"Peak Phosphorous Isn't Really the Problem" but based on over optimistic Morocco reserves

Study	Peak year	Full Depletion	Size of Reserves [Gt]	Model type	Assumptions and methods
Herring and Fantel (1993)		40 - 169 years	12.6 – 37. 8**		Linear growth or exponential production growth at a rate of 1.04 to 3%. Stable demand after 2025, 2050 or 2100 in the most optimistic scenarios.
Steen (1998)		60 - 130 years	10– 22.4	Dynamic R/P	2-3 % yearly production growth rate, but most likely lower.
Smil (2000)		80 years	10.5– 24. 5	Static R/P	Continued constant production.
Rosemarin (2004)		130 years	18	Dynamic R/P	3 % annual production growth rate.
Déry and Anderson (2007)	1989		2	Curve-fitting	Aggregated world production data. URR is found with Hubbert linearization.
Fixen (2009)		93 years	15	Static R/P	Constant 2007-2008 production rate.
Vaccari (2009)		90 years	15	Static R/P	Continued constant production.
Udo de Haes et al. (2009)		75 years	16.8	Dynamic R/P	0.7 % yearly production growth rate
Cordell et al. (2009)	2033		16.5	Curve-fitting	Aggregated world production data. URR is found by adding cumulative production and reserve data.
Smit et al. (2009)		69 – 100	18	Dynamic R/P	0.7-2% production growth rate until 2050 and 0% increase after that
van Kauwenbergh (2010)		300 - 400 years	60	Static R/P	Continued constant production.
van Vuuren et al. (2010)		50 - 90% of the resource base still remaining in 2100	13–72.6**	System dynamics	Four different scenarios for demand. Three different resource estimations; low, medium and high.
Mórrigan (2010)	1989 – 2033		2.5– 17	Curve-fitting	Using aggregated world data. URR is found with Hubbert linearization.
Sverdrup and Ragnarsdottir (2011)	~2050	30-330 years	18 / 25 **	System dynamics	Demand-supply model, using price and recovery feedbacks to supply scarcity.
Cooper et al. (2011)		370 years*	65	Static R/P	Continued constant production.
van Enk et al. (2011)		31 – 87 years/ 61 - >200year	15 / 47 **	Dynamic R/P	Four different scenarios for the demand of food and biofuels.
Cordell et al. (2011a)	2051 – 2092		60	Curve-fitting	Aggregated world production data. URR is found by adding cumulative production and reserve data.
Mohr and Evans (2013)	2020 – 2136		6.7 – 57	Curve-fitting and System dynamics	Demand-production interaction model based on URR for regions. Three scenarios are used for different size of the URR.
Koppelaar and Weikard (2013)	~2050 – >2100	100 – >200years	15.7 – 53.9 **	System dynamics	Demand-supply model, using price feedbacks and global flow analysis. Recycling postpone depletion.

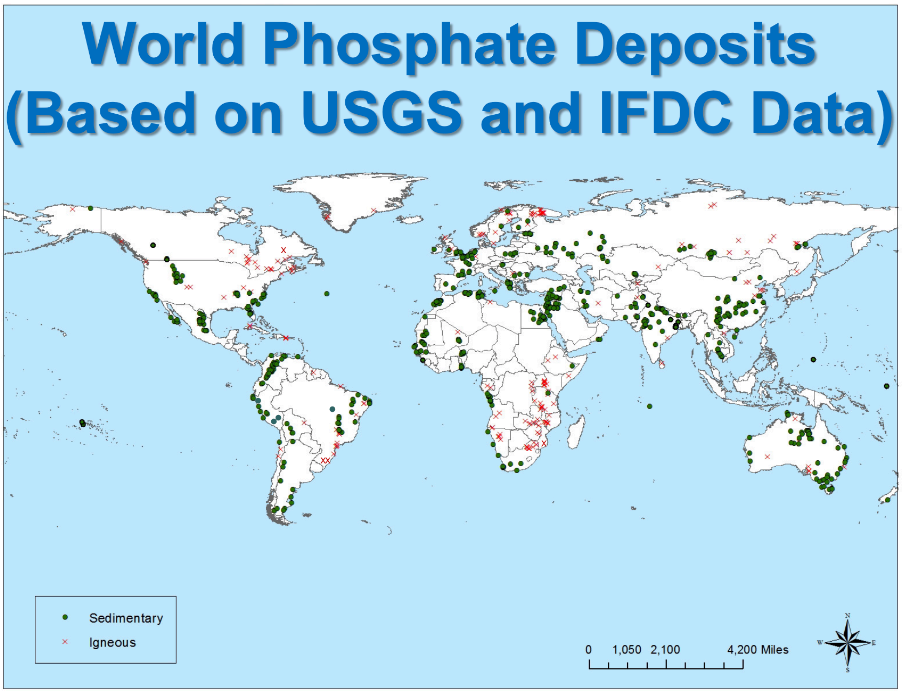
* Most countries' reserves will be depleted in less than 100 years.
** Reserve base is included in the highest reserve estimations

The range of reserves is 2 to 65 Gt! My ultimate (see below as 25 Gt) is in the middle!

Phosphate is mainly used as fertilizer (82 % in 2010)
(Prud'Homme, 2010, from Schroder et. al., 2010)



Phosphate comes from two major types: Kauwenberger IFDC 2014
-Sedimentary – carbonate apatite, 80%-90% world production
-Igneous – fire-formed (fluor-chlor-hydroxyl- apatite), 10%-20% world production



“Phosphate Mining and the Paradox of Abundance” Christian Danielewitz · September 17, 2019 · https://edgeeffects.net/phosphate-mining/
Neolithic peoples used fertilizers, but the first fertilizer produced by chemical processes was ordinary superphosphate, made early in the 19th century by treating bones with sulfuric acid. A century ago, as the environmental reporter Fred Pearce points out, much of the world’s internationally traded phosphate, a compound of phosphorus and oxygen, actually came from bones as well as guano excavated from Pacific islands where birds had been defecating phosphate for millions of years.
Bones aren’t traded much anymore, and most of the guano islands have been exhausted. But that didn’t spell the end of phosphate; in the mid-19th century the British began mining phosphate rock, and in the following decades it took over as the primary source to produce fertilizer. Today, phosphate is the key ingredient in modern agriculture. Indeed, it could be argued that phosphates make modern plantation systems possible.

There are no substitutes for phosphorus in agriculture. Fortunately, phosphorus - unlike oil - can be recycled. But phosphate is also wasted and creates pollution (green algae)!
Dana Cordell (founder of Global Phosphorus Research Initiative) stated in 2010: *currently 80% of the phosphorus mined for food production never reaches the food the world eats due to substantial inefficiencies in the entire food production and consumption system.*
Phosphorus can theoretically generate its weight 500 times in algae.

Some scientists warn phosphorus peak could come as early as 2030, while a group from the International Fertilizer Development Center (IFDC) has found that there could be enough phosphorus to last hundreds of years. But IFDC uses doubtful estimates for Morocco, as shown below.

Nedelciu et al 2019 Stockholm University “Opening access to the black box: The need for reporting on the global phosphorus supply chain”
Thus currently, P is both angel and demon: it is vital for agricultural productivity, yet it is one of the most widespread water pollutants, causing ecosystem devastation.

This study showed that when it comes to reporting on P reserves and resources, the information is not harmonized, unreliable, fragmented and non-transparent
Estimates show up to 90% phosphate loss from mine to fork. A considerable part of this loss is phosphate pollution in water, some of which creates "dead zones," areas where little or no marine life can survive.

The goal of this paper is to see from updated data if phosphate (as K and N) production can be better forecasted and to provide longer historical production data!
There are many annual reports published by government agencies (USGS, BGS, NRCan) but there is no synthesis gathering historical series; government agencies lack synthesis because it is politically incorrect to forecast peak: it is a pity, and universities should work more on the subject, asking students to gather data, but very few have the competence and the will to forecast peak.

Past data is a good tool to estimate peak and future decline. But production data for long historical period is hard to find. The tool is simple: production data displays cycles and cycles can be modelled with symmetrical curves, as Hubbert did it

-1956 Hubbert forecast on USL48 oil production
M.K. Hubbert 1956 "Nuclear energy and fossil fuels " Am. Petrol. Inst. Drilling & Production Practice, Proc. Spring Meeting San Antonio Texas p7-25 forecasted USL48 conventional oil peak in 1965 for an ultimate of 150 Gb or in 1970 for an ultimate of 200 Gb.

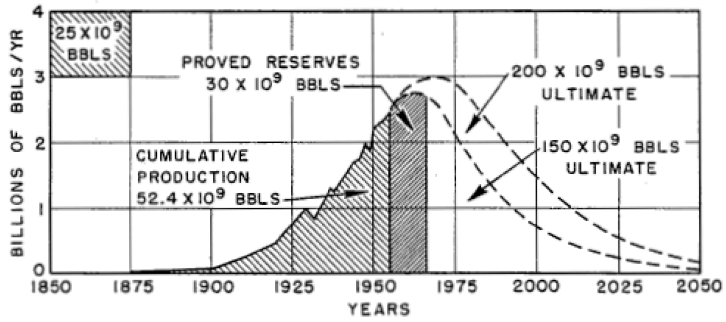
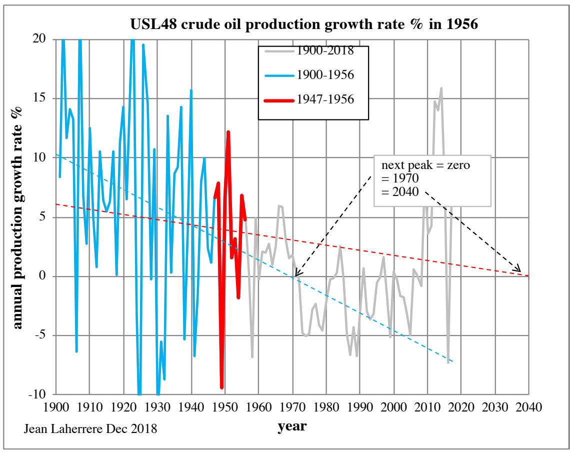
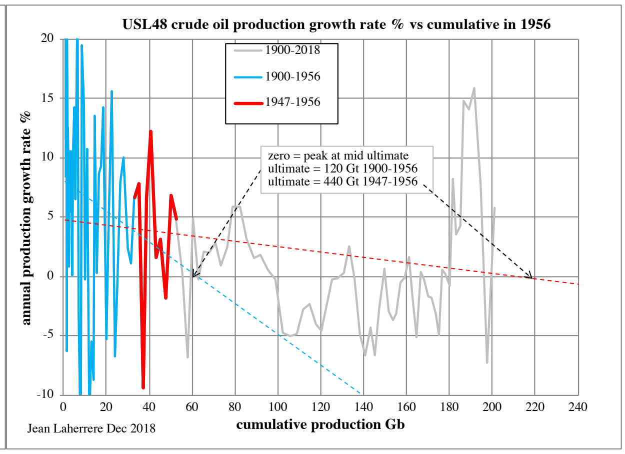


Figure 21 – Ultimate United States crude-oil production based on assumed initial reserves of 150 and 200 billion barrels.

The 150 Gb ultimate was Hubbert's estimate and the 200 Gb ultimate was Wallace Pratt's highest estimate.
In 1956, Hubbert could have forecasted the peak time using the extrapolation of oil production growth rate versus time for the period 1900-1956 cutting the zero line at 1970, which is the peak time. So, using this plot Hubbert could have selected only 1970 as the future peak, dropping 1965. But using the period 1947-1956 the peak would be in 2040





But the other extrapolation of growth rate versus cumulative production for 1900-1956 cuts the zero line at 60 Gb = mid-point, meaning that the ultimate is 120 Gb, which is too low, the grey curve which is the complete plot 1900-2018 cuts in fact the zero line further, close to 100 Gb, meaning an ultimate of 200 Gb for conventional USL48 oil. But the same plot for the period 1947-1956 gives an ultimate of 440 Gb. It appears that this extrapolation of growth rate is not reliable, as the plot is chaotic.

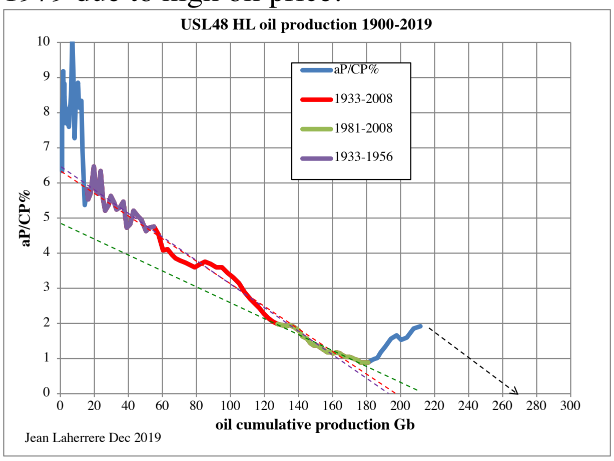
The problem is that peak occurring at mid-point works only when one cycle, but in fact there are very often several cycles.

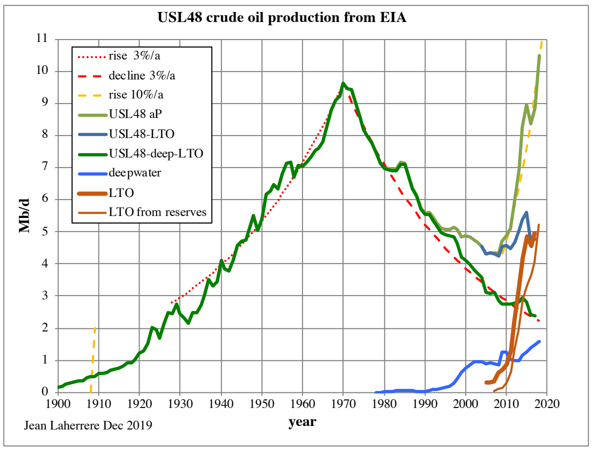
The next graph is the Hubbert linearization (HL) of the past production and the plot 1933-1956 (purple) trends towards 200 Gb, as in fact then plot 1933-2008 (red curve). On 1956 Hubbert, using HL for 1935-1956, should choose 200 Gb as ultimate and 1970 as peak.

But with the arrival of shale oil (LTO) in 2008 the plot 2008-2019 is rising. A probable future curve should be parallel trends towards an ultimate of 270 Gb.

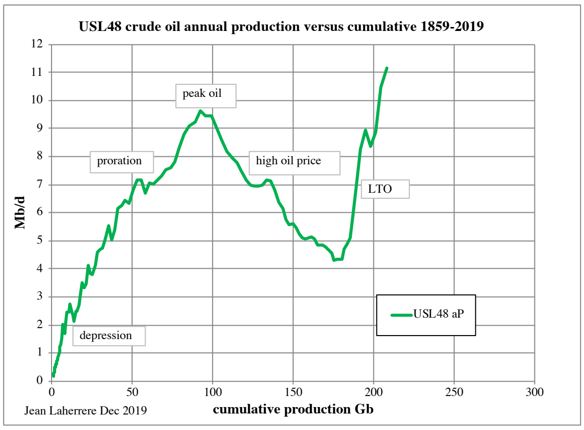
USL48 oil production is plotted with the breakdown of LTO (two plots as the production data provided with EIA reserves estimate is different from the LTO production provided by EIA in their drilling productivity report, which confuses LTO with conventional oil produced with horizontal wells (in particular in the Permian Basin).

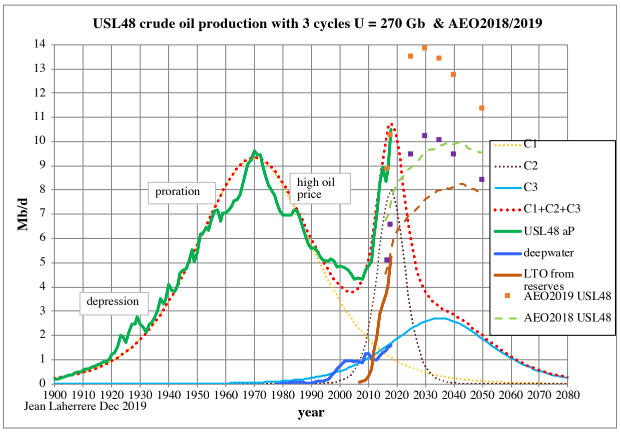
The plot of the USL48 oil less LTO and deepwater displays amazing symmetrical curves centered on 1970 with a growth rate of 3%/a from 1930 to 1970 and a decline of 3%/a from 1970 to 2019. It is amazing to find a shoulder at 7 Mb/d in 1955 due to proration and also in 1979 due to high oil price.





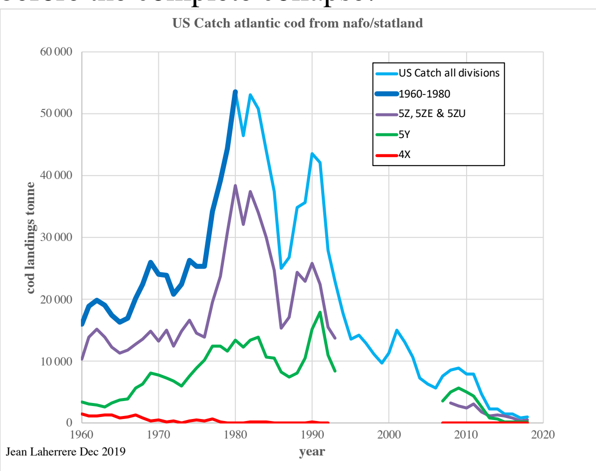
It is likely that the same symmetry will be found in LTO production and that future LTO decline will be equal to the rise of LTO for 2008-2018, which was 10% per year.

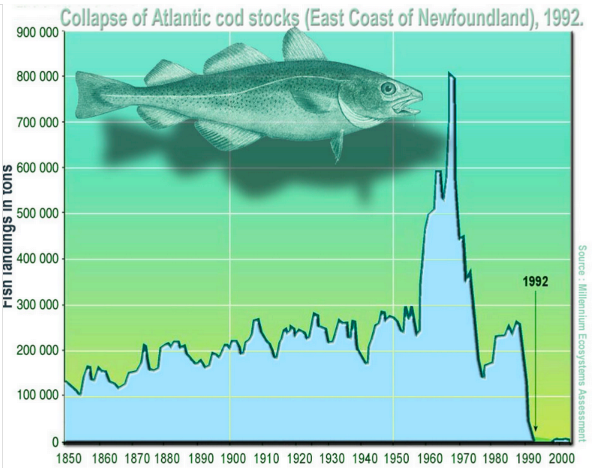




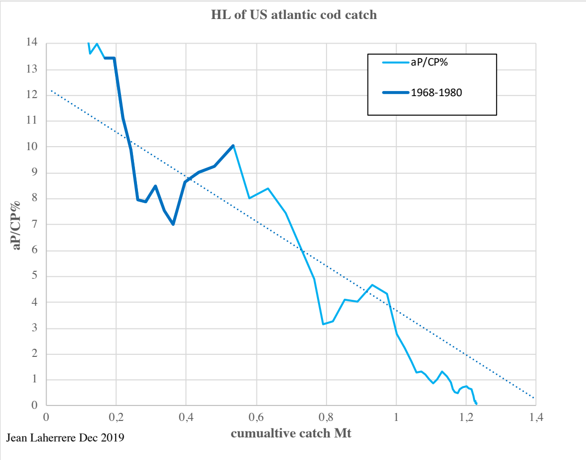
In fact, HL technique was not used by Hubbert, who mentioned the technique only in1982. HL was introduced by Ken Deffeyes in his 2001 book "Hubbert's peak" and 2005 "Beyond oil". Deffeyes worked with Hubbert. HL is based on the logistic model, given a bell shape cycle, derivative of the cumulative production with a S curve. L.F. Ivanhoe (M. King Hubbert center of petroleum supply studies) in his newsletter 1997#1 "King Hubbert -updated" did not mention HL. It is written that the term was coined by Stuart Staniford in "The oil drum"
https://www.resilience.org/stories/2007-08-13/peak-phosphorus/
John R. Boyce 2013 called the model "Hubbert-Deffeyes peak oil model" = HDPO and criticized the results but did not propose any better approach. Criticizing is easy, forecasting is difficult!

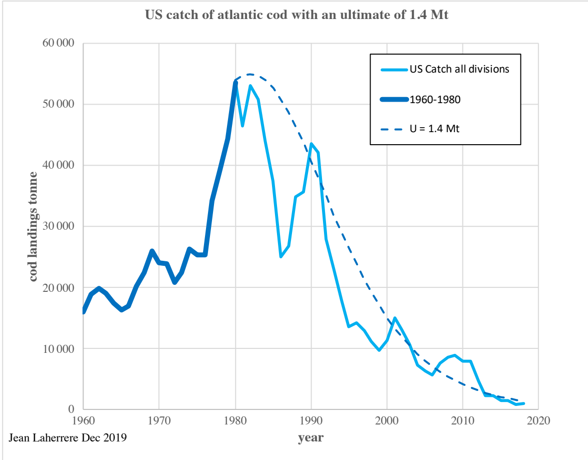
In his new book "Before the collapse" Ugo Bardi asks (page 25) how to forecast the US North Atlantic cod landings with only the sharp rise 1976-1980 (thanks to the technological progress of trawlers), where he sees a Seneca cliff 1990-1998 on the decline page 26, but in fact the decline was as sharp as the rise.
The data can be found for1960-2018 US Atlantic cod landings on
https://www.nafo.int/Data/STATLANT
Ugo Bardi asks how to extrapolate the deep blue curve 1960-1980 to the peak. This sharp rise is due to trawlers which in few years destroy completely the fishing areas and they are then obliged to go to other fishing places. The answer is to look at cod landings in other places which were destroyed sooner, as in the east coast of Newfoundland with a peak before 1970. And the answer is, after two years at the same level, to apply a sharp decline identical with the sharp rise and when down to the level of before rise, a new cycle occurs with a smaller peak, before the complete collapse.





Furthermore, the extrapolation of HL for the period 1968-1980 gives an ultimate (from 1960) of 1.4 Mt and such ultimate gives a model fitting fairly well the real data to 2018





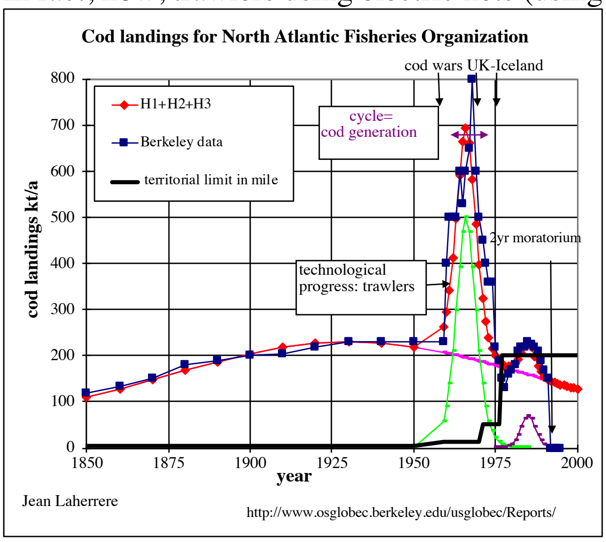
It means that in 1980 it was possible to give a fairly good forecast of the US North Atlantic cod landings. Symmetry and Hubbert linearization can deliver reliable forecasts, if well chosen!

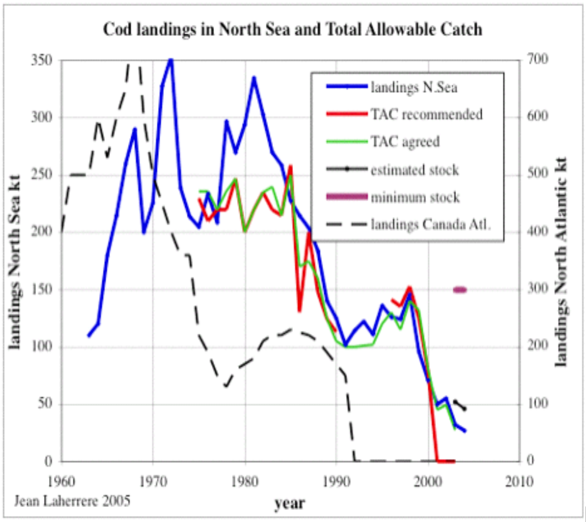
There is a connection between cod and phosphate: cods landed in Norway are send to China to be cut and injected with E451 (triphosphate STP to retain water) before sent back to Europe for sale!

In my paper Evora University 2006 “Peak oil and related peaks!” I presented two graphs on cod landings in North Atlantic and North Sea showing the two peaks and they are similar, only 10 years apart! It means that the mistakes are repeated: trawlers destroy fish and habitat, and quotas are not respected! It is amazing to see for cod landings, the parallelism of North Atlantic and North Sea: but in fact, it is the same fishermen, who have not learned: what a pity!

Politicians are also guilty, with wrong quotas and poor enforcements.

In fact, now, trawlers using electric nets (using less fuel) seem worse, but there will be a ban!





What is obvious in these examples is that sharp rise is quickly follows by a peak and a sharp decline, but a smaller peak can follow later and ending in a graveyard. Sea fishing is destroyed by the fishermen who have to catch more to pay for their expensive trawlers!

-Nauru island

The phosphate production of the small Nauru Island is a good example of one cycle peak (1974) (forgetting the second war), as the production is depleted.

In 1974 Nauru island (21 km2) had the second highest GPD per capita after Saudi Arabia!
In 2013 Petter Walan (Uppsala University) modeled Nauru island production
« Modeling of Peak Phosphorus-A Study of Bottlenecks and Implications for Future Production"   www.w-program.nu›filer›exjobb›Petter_Walan

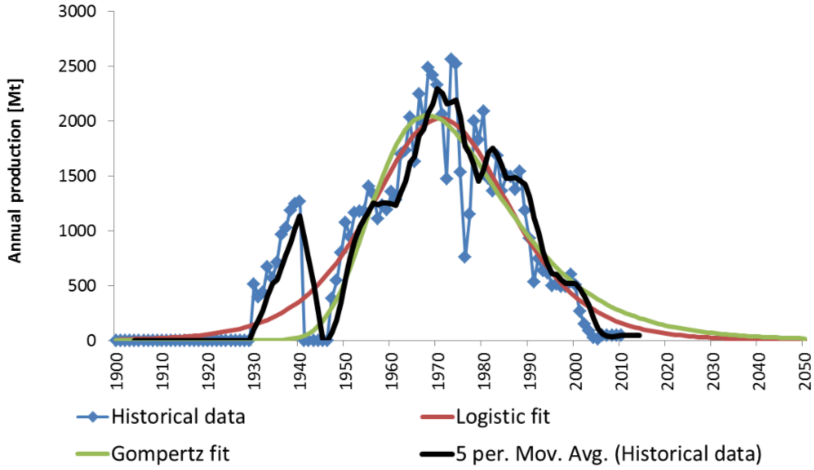
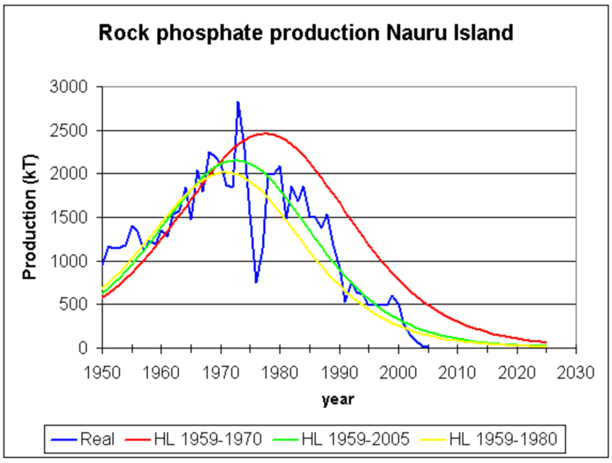
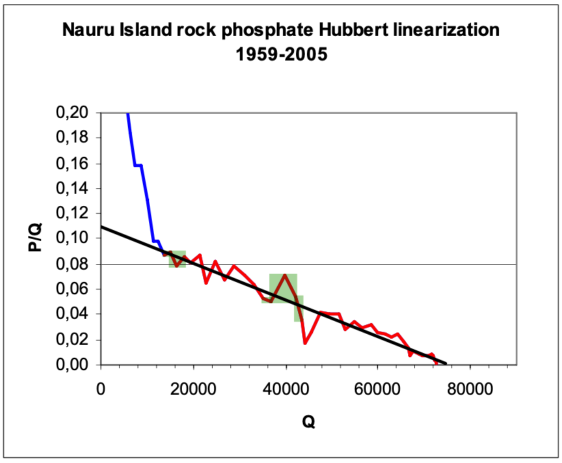
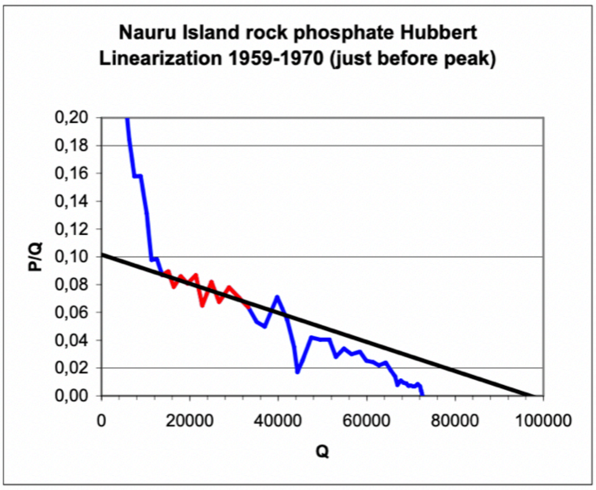


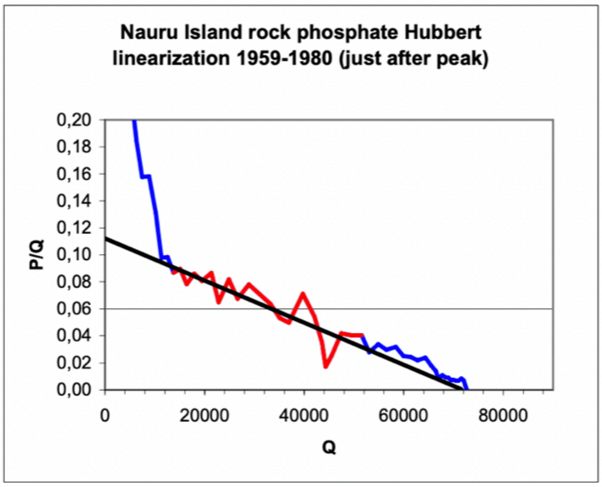
Figure 13. Curve models for Nauru.

Before, in 2007, P. Déry has estimated, using Hubbert Linearization (HL), Naurus phosphate ultimate at 97 Mt (before peak at 1978) or 72 Mt (after peak at 1971)
Déry, P., Anderson, B., 2007. Peak phosphorus.
In: Energy Bulletin www.energybulletin.net/node/33164









The best source for minerals production and reserve is the USGS with annual "Mineral commodity summaries" = mcs

mcs 2019 data in thousand metric tons (tonnes)

PHOSPHATE ROCK

World consumption of P_2O_5, contained in phosphoric acid, fertilizers, and other uses, was projected to increase to 50.5 million tons in 2022 from 47.0 million tons in 2018. Africa, India, and South America would account for about 75% of the projected growth. U.S. consumption of P_2O_5 was expected to remain at nearly 5 million tons per year.

World Mine Production and Reserves: Reserves for China, India, and Russia were updated with official Government data. Reserves for Israel and Jordan were updated with information from company reports.

	Mine production		Reserves[4]
	2017	2018[e]	
United States	27,900	27,000	1,000,000
Algeria	1,300	1,300	2,200,000
Australia	3,000	3,000	[5]1,100,000
Brazil	5,200	5,400	1,700,000
China[6]	144,000	140,000	3,200,000
Egypt	4,400	4,600	1,300,000
Finland	980	1,000	1,000,000
India	1,590	1,600	46,000
Israel	3,850	3,900	67,000
Jordan	8,690	8,800	1,000,000
Kazakhstan	1,500	1,600	260,000
Mexico	1,930	2,000	30,000
Morocco and Western Sahara	30,000	33,000	50,000,000
Peru	3,040	3,100	400,000
Russia	13,300	13,000	600,000
Saudi Arabia	5,000	5,200	1,400,000
Senegal	1,390	1,500	50,000
South Africa	2,080	2,100	1,500,000
Syria	100	100	1,800,000
Togo	825	850	30,000
Tunisia	4,420	3,300	100,000
Uzbekistan	900	900	100,000
Vietnam	3,000	3,300	30,000
Other countries	1,100	1,300	770,000
World total (rounded)	269,000	270,000	70,000,000

In this table in 2018 Morocco represents 71% of the world reserves, but only 12% of the production. Are these reserves estimates reliable?

British Geological survey reports also annual minerals production (but not reserves) with the last world Mineral Production 2013-2017.

Production of phosphate rock tonnes (metric)

Country	2013	2014	2015	2016	2017
Finland	877 189	946 234	956 564	939 531	978 613
Russia	10 500 000	10 700 000	11 500 000	12 300 000	12 500 000
Turkey	510 080	604 000	713 230	772 500	—
Algeria	1 150 000	1 417 950	1 288 900	1 274 000	* 1 300 000
Burkina Faso	1 414	1 832	* 1 000	* 1 000	* 1 000
Egypt (a)	4 500 501	4 830 918	3 427 000	* 3 000 000	* 3 000 000
Malawi	11 783	11 194	12 400	2 500	10 000
Mali	* 7 500	* 15 000	31 000	37 236	41 000
Morocco	26 400 000	27 390 000	26 264 000	26 900 000	32 800 000
Senegal	882 400	806 200	1 062 000	1 609 000	1 385 000
South Africa	2 131 854	2 011 151	1 852 348	1 696 533	2 079 294
Tanzania	23 020	* 23 000	* 23 000	23 658	* 23 000
Togo	1 213 657	1 085 546	1 150 194	850 076	732 503
Tunisia	3 283 522	3 783 969	3 228 311	3 663 613	4 422 100
Zimbabwe	17 900	6 100	6 200	6 500	* 6 500
Canada	316 000	—	—	—	—
Cuba	3 000	1 300	—	—	—
Mexico	2 217 481	1 733 479	1 929 439	3 294 266	2 307 180
USA	31 200 000	25 300 000	27 400 000	27 100 000	* 27 700 000
Brazil (b)	6 715 000	6 513 000	6 100 000	6 500 000	5 500 000
Chile					
Phosphate rock	12 041	20 142	16 141	1 604	—
Guano	2 915	2 717	3 408	4 601	4 238
Colombia	65 759	41 692	95 483	66 324	45 272
Peru	14 842 307	10 884 269	11 161 636	10 561 111	8 450 379
Venezuela	98 458	35 820	26 324	* 25 000	* 25 000
China	108 510 000	120 438 000	142 039 000	144 398 000	123 132 000
Christmas Island (a)(c)(d)	672 000	575 000	671 000	770 000	644 000
India (e)	1 453 580	1 608 145	1 571 973	1 124 440	1 534 269
Iran (f)	119 961	75 092	85 066	64 805	* 65 000
Iraq	140 000	* 140 000	* 140 000	* 140 000	* 140 000
Israel	2 539 166	2 778 715	3 427 469	3 591 200	2 637 440
Jordan	5 398 600	7 143 713	8 335 993	7 991 157	8 687 581
Kazakhstan	1 831 800	* 1 830 000	* 1 830 000	* 1 830 000	* 1 830 000
Laos					
Phosphate rock	1 325	—	—	—	—
Guano	5 000 000	—	—	181 000	435 000
Pakistan (a)	104 961	101 971	109 874	115 140	61 677
Philippines					
Phosphate rock	3 478	3 897	5 437	8 019	* 8 000
Guano	443	409	495	670	* 700
Saudi Arabia	1 820 000	1 911 000	2 002 000	5 400 000	5 670 000
Sri Lanka	49 106	62 595	52 518	38 848	42 435
Syria	897 600	1 230 000	750 000	* —	* 100 000
Thailand	350	500	* 500	* 500	* 500
Uzbekistan	700 000	* 700 000	* 700 000	* 700 000	* 700 000
Vietnam	2 656 100	2 470 900	2 923 400	3 142 500	3 238 900
Australia (a)	2 064 291	1 950 050	1 027 622	1 037 265	942 373
Nauru (c)	347 184	153 418	94 021	114 350	126 000
World total	241 000 000	241 000 000	264 000 000	271 000 000	253 000 000

The BGS first report starts in 1913

World's Production of Phosphates

(long tons).

—	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.
Egypt	102,771	70,789	81,664	122,999	113,872	30,646	28,893	
Canada ...	344	852	194	181	133	125	21	
Christmas Island	149,956	93,703	23,731	44,209†	89,889†	53,370†		
Australia ...	5,950	6,783	5,714	7,455	8,626	11,918	9,017	
New Zealand ...	11,000	10,743	—	7,600	5,050	5,000	4,000	
Ocean Island ...	215,000	158,000	126,000	105,000	101,000	70,000	53,000	
Nauru Island	133,000	72,000	92,000	97,000	98,000	83,000	60,000	
Belgium ...	402,000	292,000	83,000	254,000	197,000	229,000	179,000	
France ...	330,000	270,000		25,500				
Norway ...	745	738	1,870	2,200	1,803			
Russia ...	24,600	14,700		56,452				
Spain	3,491	8,178	8,934	13,884	27,696	42,607	24,633	
Algeria † ...	431,552	349,432	222,261	382,956	231,051	199,284	238,294	329,325
Tunis	2,038,476	1,373,171	1,151,196	1,024,466	665,726	848,632	820,000*	
Dutch West Indies†	39,000	96,000	30,805	14,235	3,524	—	18,746¶	63,915
United States	3,152,208	2,649,174	1,935,341	2,169,149	2,851,886	2,284,245	1,851,549	3,265,000‡
French Guiana	5,000							
Formosa ...	5,531	1,317	495	1,476				
Japan	18,737	37,644	56,788	112,965	119,673	189,181		
Angaur Island	88,500	59,000†	29,500	29,500				
Makatea Island	80,737	71,753	70,571	38,654	31,741	39,000*	39,000*	
New Caledonia	—	2,361	2,755	2,424	5,909			

Austrian Federal Ministry for sustainability and tourism https://www.bmnt.gv.at reports mineral production in World Mining data since 2012: world phosphate production in 2017 is for P2O5 content, as 84 Mt, against 253 Mt for rock by BGS and 269 Mt for USGS.

Austrian data British data

Phosphates (P_2O_5-Content)

Country	2013 metr. t	2014 metr. t	2015 metr. t	2016 metr. t	2017 metr. t
Algeria	391 000	482 100	438 200	433 200	378 100
Australia	474 790	448 500	236 375	238 494	216 670
Brazil	2 504 000	2 521 000	2 167 000	2 012 500	1 705 000
Burkina Faso	650	0	0	0	0
Chile	4 190	6 400	5 470	1 740	1 190
China	32 553 000	36 131 400	42 611 700	43 319 400	43 332 000
Christmas Island	132 250	154 330	177 100	148 120	147 890
Colombia	16 440	10 420	23 870	20 960	13 580
Egypt	1 788 700	1 305 300	1 401 000	993 800	1 000 000
Finland	315 800	340 640	344 360	338 230	352 300
India	338 910	363 060	368 350	313 450	385 000
Iran	113 600	36 527	65 342	77 912	88 715
Iraq	63 800	25 000	0	40 000	40 000
Israel	1 109 200	1 040 700	1 192 900	1 223 600	1 032 900
Jordan	1 727 550	2 285 990	2 667 520	2 557 170	2 780 030
Kazakhstan	410 500	349 500	387 100	348 600	400 000
Korea, North	95 000	95 000	95 000	95 000	95 000
Malawi	2 000	1 900	2 110	430	1 700
Mexico	717 435	520 040	578 830	988 280	692 150
Morocco	8 441 700	8 748 400	8 388 700	8 601 000	10 490 100
Nauru	136 800	58 000	45 700	39 800	50 900
Pakistan	18 890	18 350	15 230	20 730	11 100
Peru	5 640 080	4 136 020	4 241 420	4 013 220	3 211 140
Philippines	3 887	4 340	5 930	8 690	8 600
Russia	4 095 000	4 173 000	4 485 000	4 797 000	4 875 000
Saudi Arabia	364 000	382 200	1 020 000	1 080 000	1 134 000
Senegal	342 120	309 820	589 110	886 500	841 020
South Africa	746 100	703 900	648 300	593 800	727 800
Sri Lanka	17 190	21 910	18 380	13 600	14 850
Syria	270 000	370 000	225 000	100 000	100 000
Tanzania	225 060	162 360	49 020	5 200	300
Thailand	350	500	0	0	2 400
Togo	441 164	394 600	418 100	306 600	266 260
Tunisia	952 200	1 097 400	936 200	1 062 400	1 203 600
Turkey	153 000	181 200	214 000	231 800	0
United States	8 930 000	7 110 000	7 710 000	7 615 000	7 784 000
Uzbekistan	155 000	136 510	166 800	170 000	170 000
Venezuela	29 780	10 030	7 370	5 000	5 000
Vietnam	796 830	741 270	877 020	942 750	971 670
Total	74 517 966	74 877 617	82 823 507	83 643 976	84 529 965

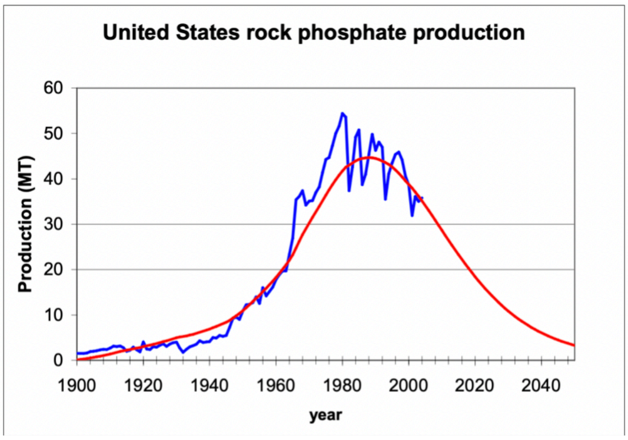
Production of phosphate rock tonnes (metric)

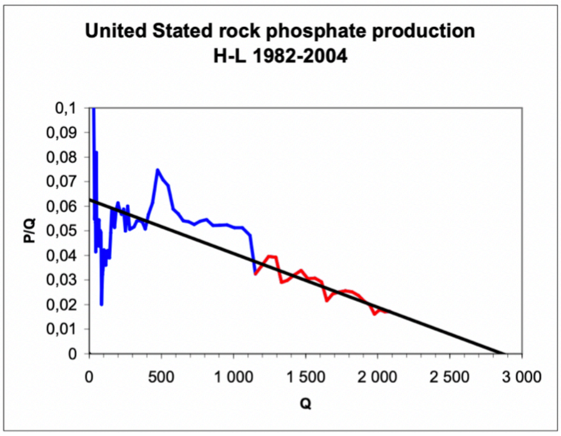
Country	2013	2014	2015	2016	2017
Finland	877 189	946 234	956 564	939 531	978 613
Russia	10 500 000	10 700 000	11 500 000	12 300 000	12 500 000
Turkey	510 080	604 000	713 230	772 500	—
Algeria	1 150 000	1 417 950	1 288 900	1 274 000	* 1 300 000
Burkina Faso	1 414	1 832	* 1 000	* 1 000	* 1 000
Egypt (a)	4 500 501	4 830 918	3 427 000	* 3 000 000	* 3 000 000
Malawi	11 783	11 194	12 400	2 500	10 000
Mali	* 7 500	* 15 000	31 000	37 236	41 000
Morocco	26 400 000	27 390 000	26 264 000	26 900 000	32 800 000
Senegal	882 400	806 200	1 062 000	1 609 000	1 385 000
South Africa	2 131 854	2 011 151	1 852 348	1 696 533	2 079 294
Tanzania	23 020	* 23 000	* 23 000	23 658	* 23 000
Togo	1 213 657	1 085 546	1 150 194	850 076	732 503
Tunisia	3 283 522	3 783 969	3 228 311	3 663 613	4 422 100
Zimbabwe	17 900	6 100	6 200	6 500	* 6 500
Canada	316 000	—	—	—	—
Cuba	3 000	1 300	—	—	—
Mexico	2 217 481	1 733 479	1 929 439	3 294 266	2 307 180
USA	31 200 000	25 300 000	27 400 000	27 100 000	* 27 700 000
Brazil (b)	6 715 000	6 513 000	6 100 000	6 500 000	5 500 000
Chile					
Phosphate rock	12 041	20 142	16 141	1 604	—
Guano	2 915	2 717	3 408	4 601	4 238
Colombia	65 759	41 692	95 483	66 324	45 272
Peru	14 842 307	10 884 269	11 161 636	10 561 111	8 450 379
Venezuela	98 458	35 820	26 324	* 25 000	* 25 000
China	108 510 000	120 438 000	142 039 000	144 398 000	123 132 000
Christmas Island (a)(c)(d)	672 000	575 000	671 000	770 000	644 000
India (e)	1 453 580	1 608 145	1 571 973	1 124 440	1 534 269
Iran (f)	119 961	75 092	85 066	64 805	* 65 000
Iraq	140 000	* 140 000	* 140 000	* 140 000	* 140 000
Israel	2 539 166	2 778 715	3 427 469	3 591 200	2 637 440
Jordan	5 398 600	7 143 713	8 335 993	7 991 157	8 687 581
Kazakhstan	1 831 800	* 1 830 000	* 1 830 000	* 1 830 000	* 1 830 000
Laos					
Phosphate rock	1 325	—	—	—	—
Guano	5 000 000	—	—	181 000	435 000
Pakistan (a)	104 961	101 971	109 874	115 140	61 677
Philippines					
Phosphate rock	3 478	3 897	5 437	8 019	* 8 000
Guano	443	409	495	670	* 700
Saudi Arabia	1 820 000	1 911 000	2 002 000	5 400 000	5 670 000
Sri Lanka	49 106	62 595	52 518	38 848	42 435
Syria	897 600	1 230 000	750 000	* —	* 100 000
Thailand	350	500	* 500	* 500	* 500
Uzbekistan	700 000	* 700 000	* 700 000	* 700 000	* 700 000
Vietnam	2 656 100	2 470 900	2 923 400	3 142 500	3 238 900
Australia (a)	2 064 291	1 950 050	1 027 622	1 037 265	942 373
Nauru (c)	347 184	153 418	94 021	114 350	126 000
World total	241 000 000	241 000 000	264 000 000	271 000 000	253 000 000

Phosphate production data are messy because this confusion between rock ore and P2O3 equivalent. As the percentage of phosphate in ore varies, the best data is in P2O3 equivalent, but this data is often missing: it is the same for oil production as the heat content varies widely between fields: in 2014 5084 kBtu/b in Sudan against 6393 in Cuba, with a world average of 5860. Oil production should be reported in volume as in toe = tonne oil equivalent

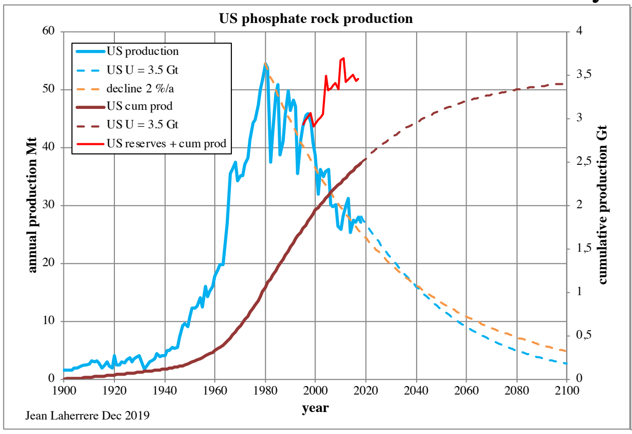
-US

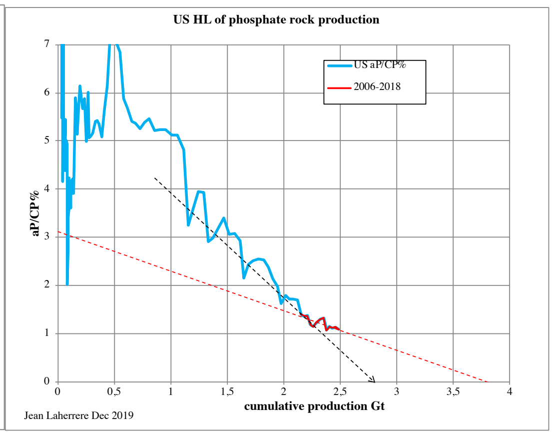
In 2007 P. Déry has modelled US & world phosphate rock production, using an ultimate of 2.9 Gt for US





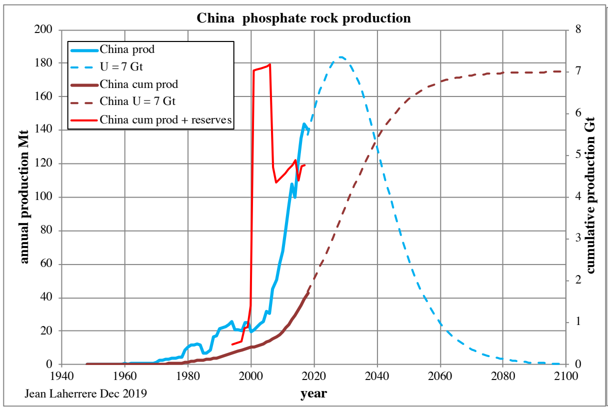
HL of past US 2006-2018 trends towards an ultimate of 3.5 Gt, which is about the value of cumulative production + USGS reserves of the past 10 years
With an ultimate of 3.5, Gt US phosphate production has peaked in 1980 and since this date its decline is about 2%/a down to 2018 and beyond to 2100

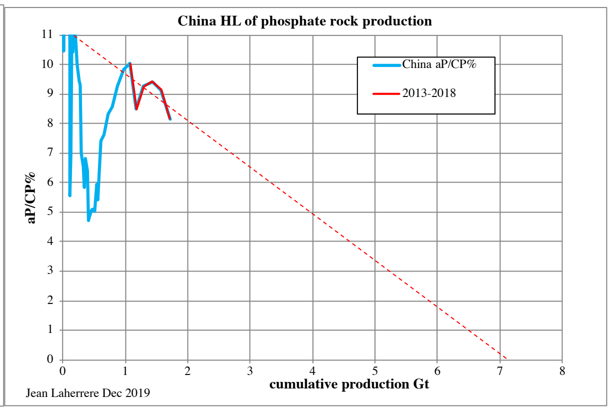




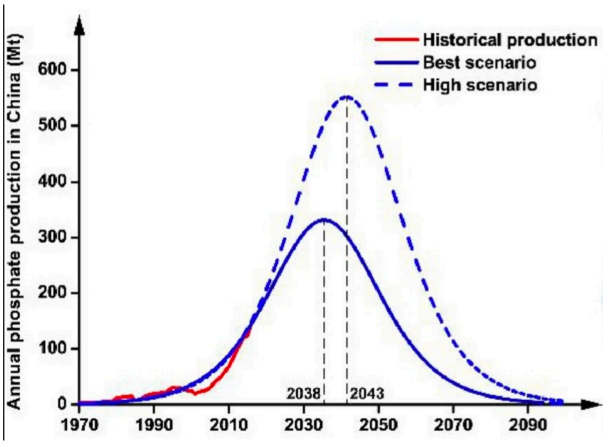
-China

China phosphate rock ultimate is estimated at 7 Gt from Hubbert linearization of 2013-2018 production, when USGS cumulative production + reserves has varied from 2000 around 7 Gt to less than 5 Gt in 2018
With such ultimate phosphate production will peak before 2030 at 180 Mt, but the peak could be sooner.

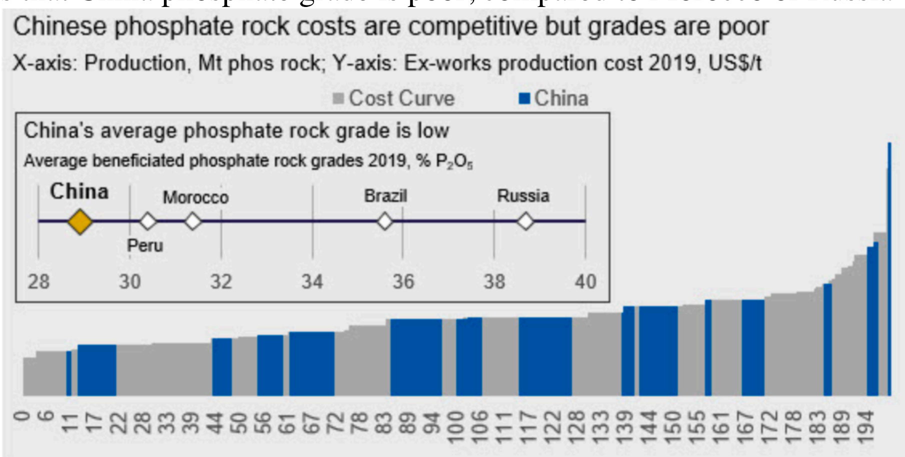




"Peak phosphorus, demand trends and implications for the sustainable management of phosphorus in China" Binlin Li, KB Bicknell, Alan Renwick July 2019
https://doi.org/10.1016/j.resconrec.201
The results indicate that China`s production of PR is likely to peak sometime between 2035 and 2045. This result was derived using Chinese data, which differs from the U.S. Geological Survey (USGS) data, upon which estimates are more commonly based.
China best estimate peak in 2038 at 320 Mt against my forecast in 2028 at 185 Mt

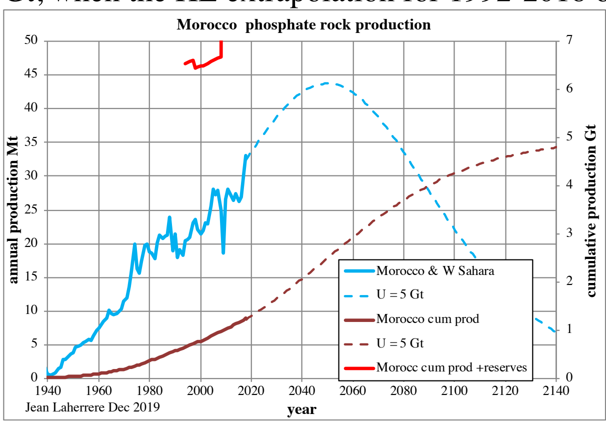


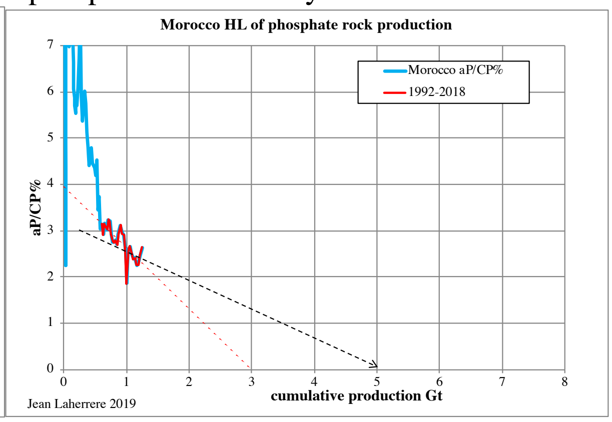
CRU reports that China phosphate grade is poor, compared to Morocco or Russia



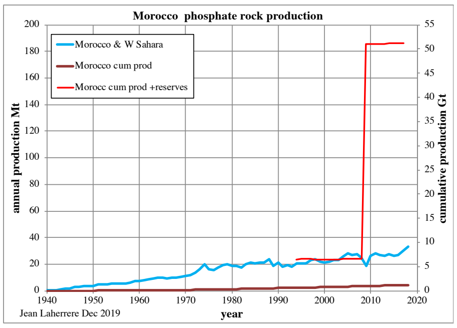
-Morocco

Morocco phosphate production will peak around 2050 at less than 45 Mt for an ultimate of 5 Gt, when the HL extrapolation for 1992-2018 of past production is only 3 Gt.





In 2009 USGS increased their reserve estimate from 6.7 Gt to 51 Gt, to follow a publication by IFDC



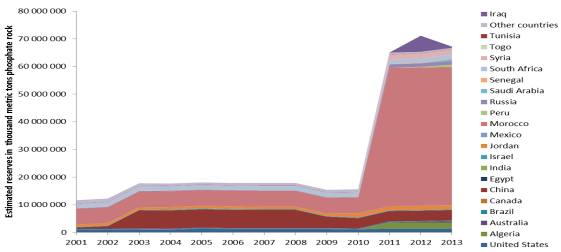


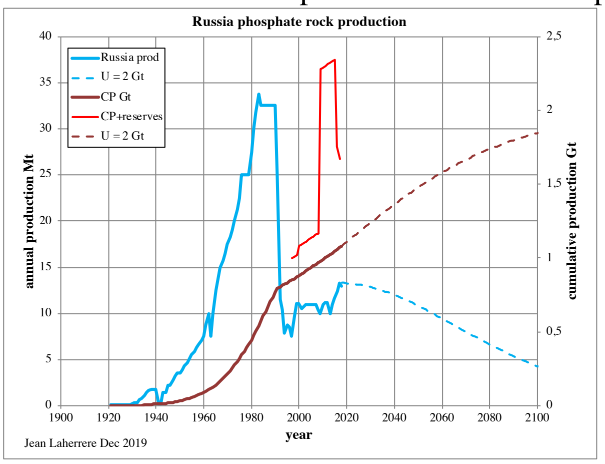
Figure 2. The size of USGS reported reserves from 2001 until 2013 in thousand metric tons of phosphate rock (data from Jasinski, 2013).

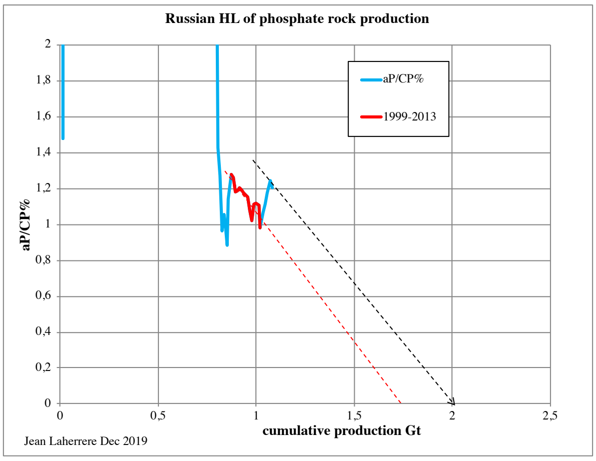
As written above, in USGS mcs 2019, Morocco represents 71% of the world reserves, but only 12% of the production. It appears, from present past production data extrapolation, that this very high estimate for Morocco is much too high: this reserve matter is discussed later.

But Morocco reserves include those of Western Sahara, claimed by the Polisario Front since 1973 after the departure of Spain. From Wikipedia, the Polisario controls about 20–25% of the Western Sahara territory (separated by a fortified wall), as the Sahrawi Arab Democratic Republic (SADR), and claim sovereignty over the entire territory of Western Sahara. A referendum was planned and never achieved.

-Russia

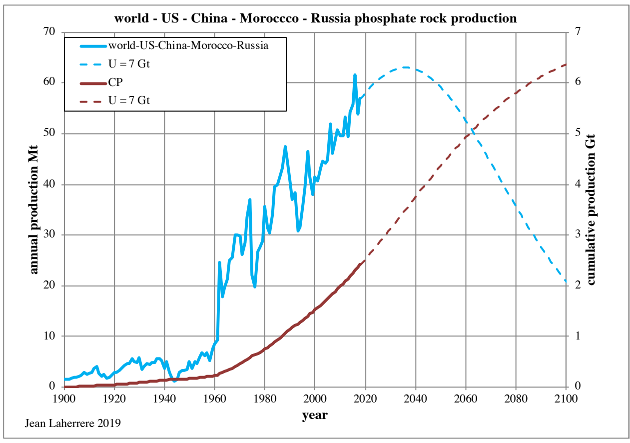
Russia phosphate production has peaked in 1983 at 34 Mt and will peak again in 2020 at 13 Mt for an ultimate of 2 Gt. Cumulative production + reserves were at 2.3 Gt in 2015, but 1.7 Gt in 2018. HL is extrapolated at the last data parallel with the trend 1999-2013.

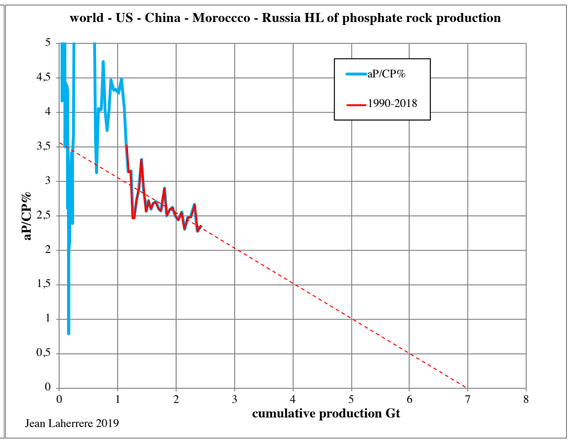




-world -US-China-Morocco-Russia

HL of phosphate production of the world excluding US, China, Morocco and Russia for the period 1990-2018 trends towards 7 Gt and the peak will be in 2035 at 63 Mt





Adding this ultimate of 7 Gt plus 2 Gt for Russia, 5 Gt for Morocco, 7 Gt for China and 3.5 Gt for US gives an ultimate of 25 Gt for the world phosphate rock production

-world

Jeremy Stroud October 9, 2019 https://bonnefield.com/2019/10/09/part-vi-an-essential-nutrient-phosphorus-shortages-and-overuse/

This graph displays the main importance of phosphate rock present production in the phosphorus production compared with guano, human excreta and manure (source Cordell 2009)

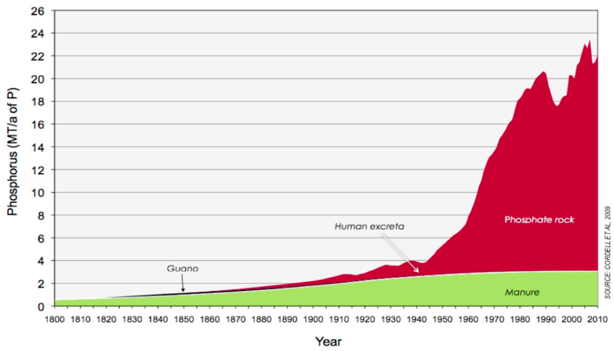
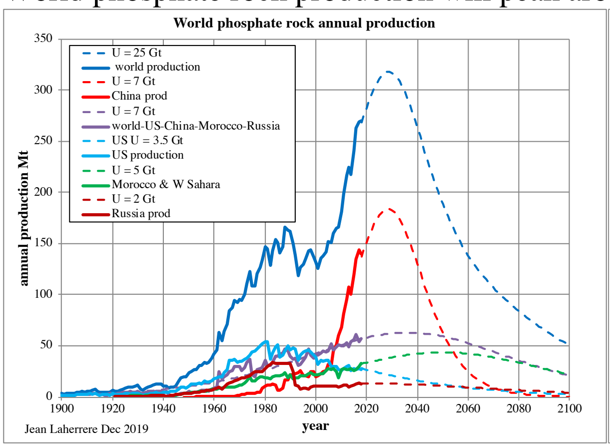
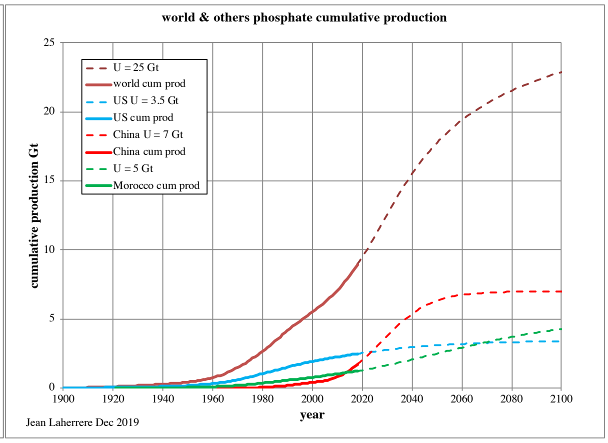


Figure 1: Historical Global Sources of Phosphorus Fertilizer, 1800 – 2010 [5]

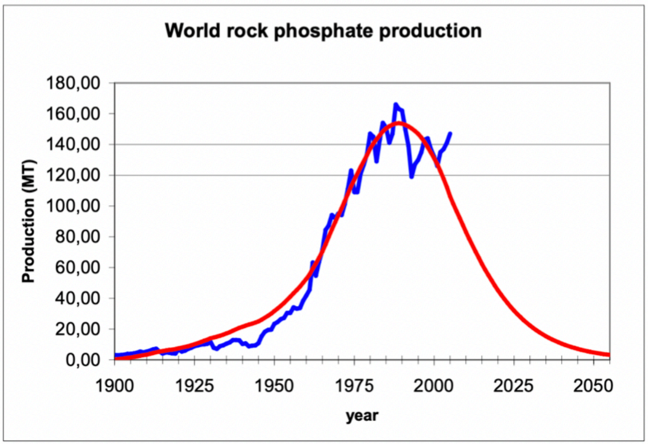
Source: Cordell et al., 2009

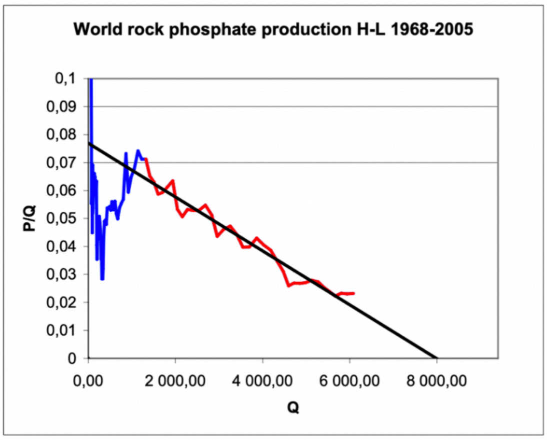
World phosphate rock production will peak around 2030 at 320 Mt for an ultimate of 25 Gt.



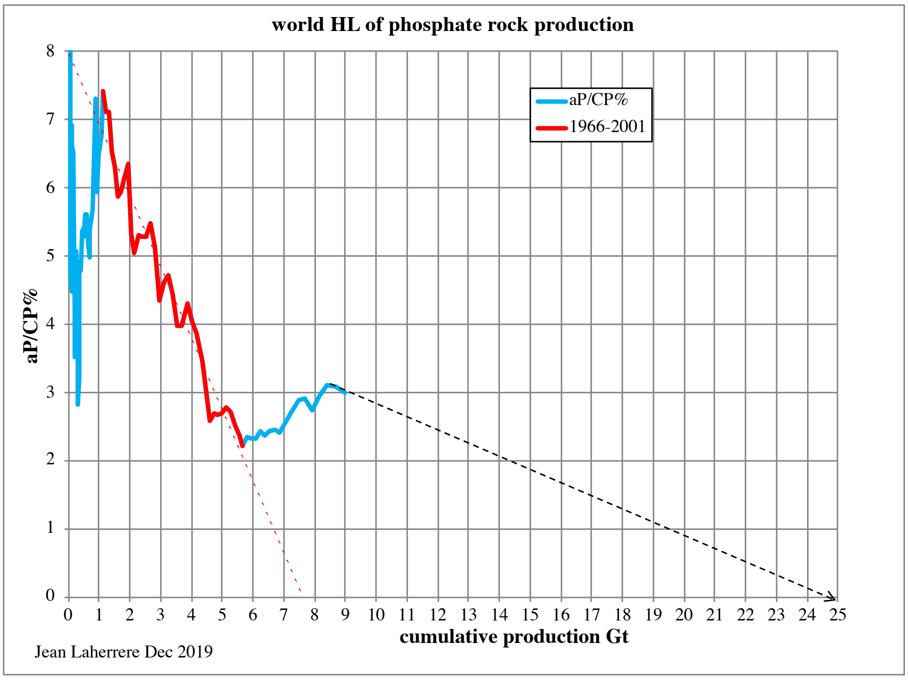


It is far from the 2007 Déry's forecast with an ultimate of 8 Gt, which is the ultimate for the HL of 1966-2001





A HL ultimate of 25 Gt is hard to guess only on the world data: it comes from the study of the main producers, but the dash line from 2018 data to 25 Gt is about symmetrical of the data 2002-2018



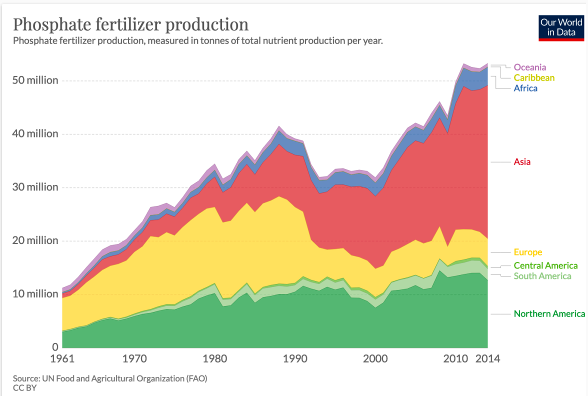
HL technique is full of surprise, but it is still the best approach, when reliable geological studies are missing (or confidential).

-Phosphate production and consumption

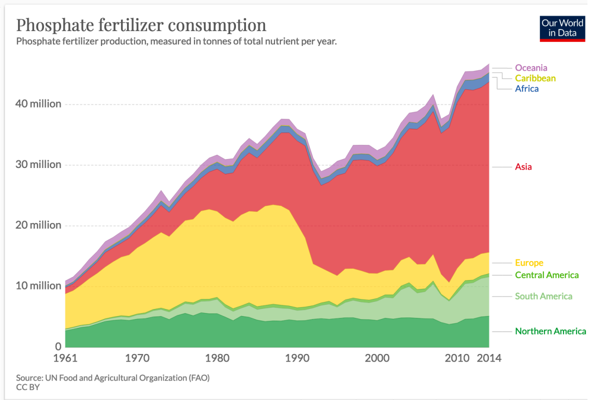
Graphs from our world in data display phosphate fertilizer production and consumption for the period 1961-2014.

Presently Asia is the great consumer and producer. Northern America produces more than it consumes.

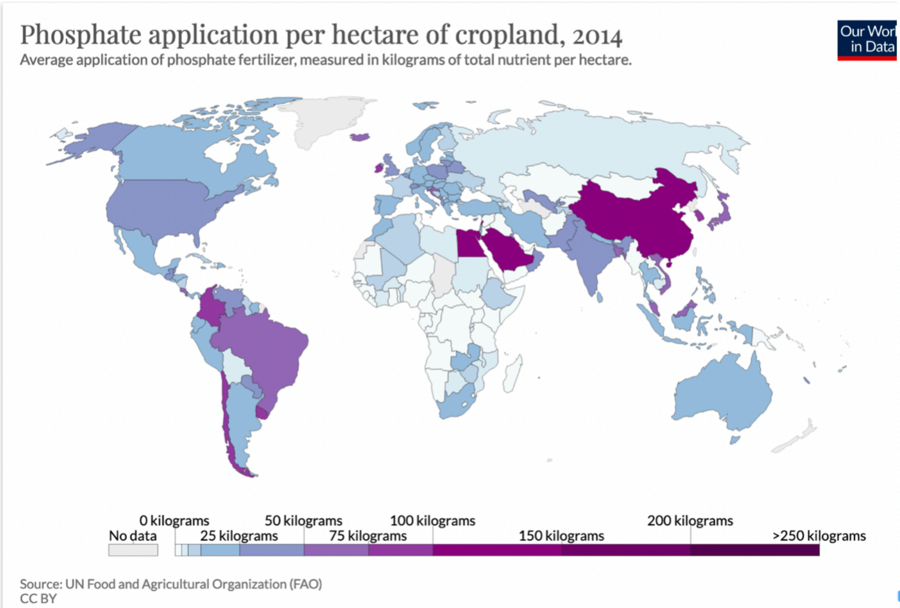
Phosphate fertilizer production



Phosphate fertilizer consumption



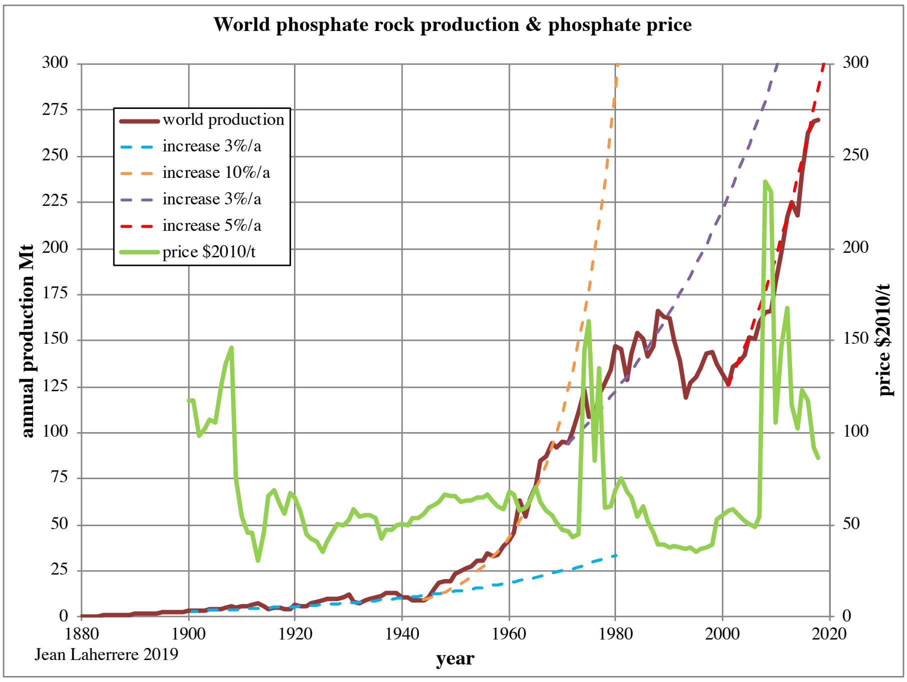
For 2014, the consumption of phosphate per hectare of crop varies with countries: the highest being China and Saudi Arabia



-Phosphate rock production & price

World phosphate rock production displays a growth rate of 3 %/a for 1900-1945, 10 %/a for 1945-1970, 3 %/a for 1970-1990 and 5 %/a for 2001-2018.

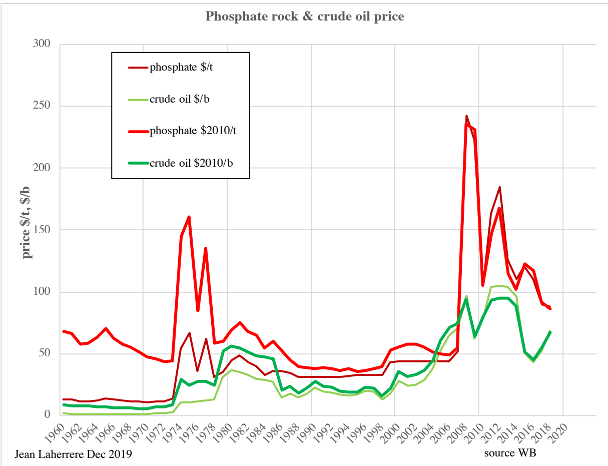
Phosphate price displays sharp peaks in 1908, 1975 and 2008. But most of the time price was around 50 $2010/t. In 2018 phosphate price was around 85 $2010/t and in 2019 price is on decline

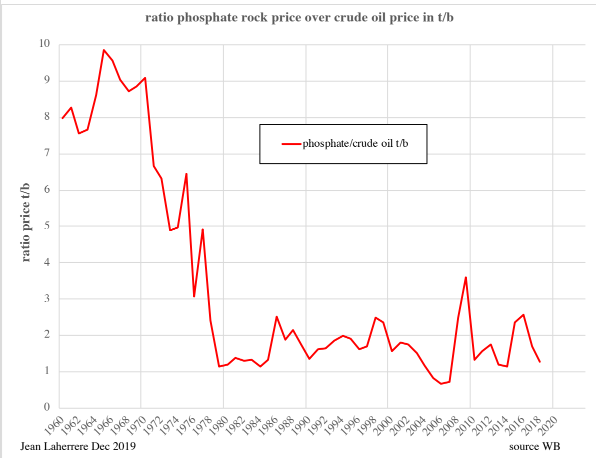


-Phosphate and oil price

Phosphate rock extraction needs energy and the price of phosphate varies as the oil price. On the period 1960-2018, phosphate price displays bursts as oil, as in 1973 and 2008

The ratio phosphate rock price over oil price was in t/b around 9 in the 1960s and since 1980 around 2.





-USGS reserves data

USGS commodity reports production and reserves since 1994

From 1994 to 2008 they reported two values: reserves and reserve base, with the following definition:

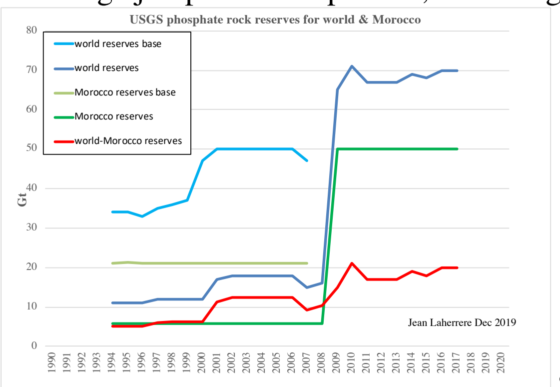
***Reserve Base**. —That part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth. The reserve base is the in- place demonstrated (measured plus indicated) resource from which reserves are estimated. It may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. The reserve base includes those resources that are currently economic (reserves),*

marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources). The term "geologic reserve" has been applied by others generally to the reserve-base category, but it also may include the inferred-reserve-base category; it is not a part of this classification system.
Reserves.*—That part of the reserve base which could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative. Reserves include only recoverable materials; thus, terms such as "extractable reserves" and "recoverable reserves" are redundant and are not a part of this classification system.*
But USGS dropped reporting reserve base. From 2009 to 2019 USGS reports only reserves and in 2009 world phosphate rock reserves jumped from 16 Gt to 65 Gt, only because Morocco reserves jumped from 5.7 Gt (in 2008) to 51 Gt
The main reason for Morocco reserves increase was an estimate by IFDC (International Fertilizer Development Center World phosphate rock reserves 2010 S.J Van Lauwenbergh

Table 7. USGS Phosphate Rock and Mineral Commodity Summary, January 2010, Mine Production (2008, 2009) Reserves. IFDC Reserve and Resource Estimate

Country	Mine Production 2008	Mine Production 2009[d]	USGS 2010 Reserves[a]	IFDC Reserves[b] (Product)	IFDC Resources[c]
			(mmt)		
United States	30.20	27.20	1,100	1,800	49,000
Australia	2.80	2.50	82	82	3,500
Brazil	6.20	6.00	260	400	2,800
Canada	0.95	0.90	15	5	130
China	50.70	55.00	3,700	3,700	16,800
Egypt	3.00	3.30	100	51	3,400
Israel	3.09	3.00	180	220	1,600
Jordan	6.27	6.00	1,500	900	1,800
Morocco	25.00	24.00	5,700	51,000	170,000[e]
Russia	10.40	9.00	200	500	4,300
Senegal	0.70	0.00	80	50	250
South Africa	2.29	2.30	1,500	230	7,700
Syria	3.22	3.00	100	250	2,000
Togo	0.80	0.80	60	34	1,000
Tunisia	8.00	7.00	100	85	1,200
Other countries	7.44	7.00	950	600[f]	22,000[g]
World total (rounded)	161.00	158.00	16,000	60,000	290,000

This huge jump looks suspicious, confusing reserves and resources



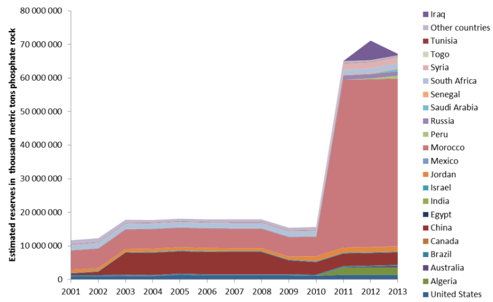
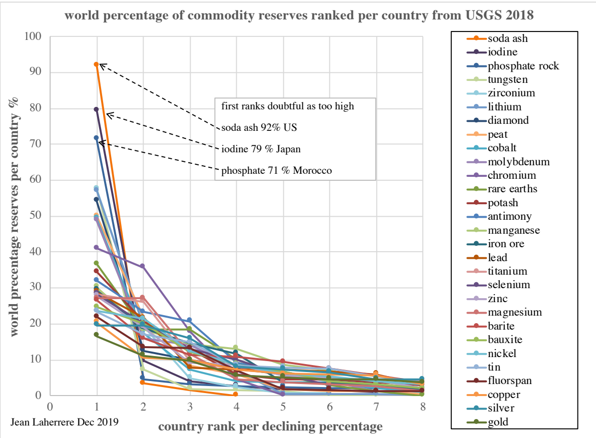
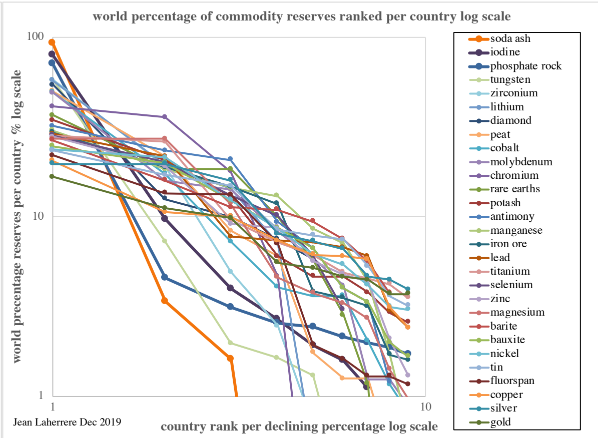


Figure 2. The size of USGS reported reserves from 2001 until 2013 in thousand metric tons of phosphate rock (data from Jasinski, 2013).

In 2014 Edixhoven criticized this Morocco increase "Recent revisions of phosphate rock reserves and resources: a critique" stating that
-IFDC used a simplified resource terminology which does not use the underlying thresholds for reserves and resources used in the USGS classification.
-The difference between PR ore and PR concentrate is barely noted in the literature, causing pervasive confusion and a significant degree of error in many assessments.
But in 2016 Scholz was less critical, arguing that exploration is incomplete, asking anyway for better definition between ore and marketable product.
It is amazing that this huge increase occurs not from new data but from different definitions of past data.
It is obvious that the distinction between reserves and reserve base was flawed and it was dropped by USGS.

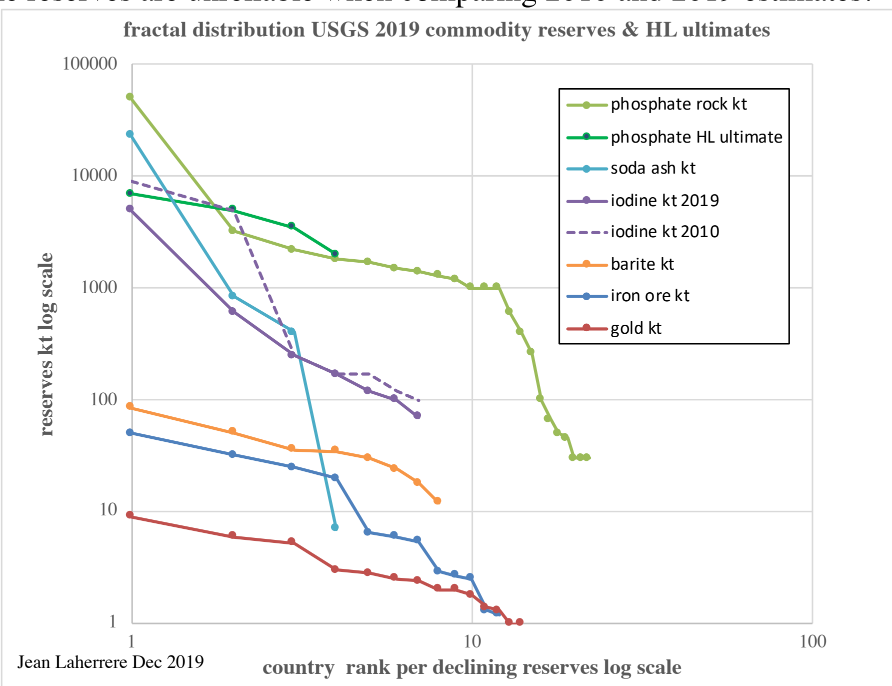
Now it appears from present past production data that this very high estimate for Morocco is not justified. Furthermore, such concentration in one country (>70%) is not seen for other mineral, except for soda ash and iodine.
From the USGS mineral commodity summaries 2019 the percentage of country commodity reserves versus world reserves is computed for each country where USGS reports the main reserves holder, as the others. But it appears that USGS reserves data is incomplete for many countries
USGS 2018 commodity reserves displayed as world percentage versus rank in decimal and in log log scale, shows that soda ash, iodine and phosphate behave differently from another mineral





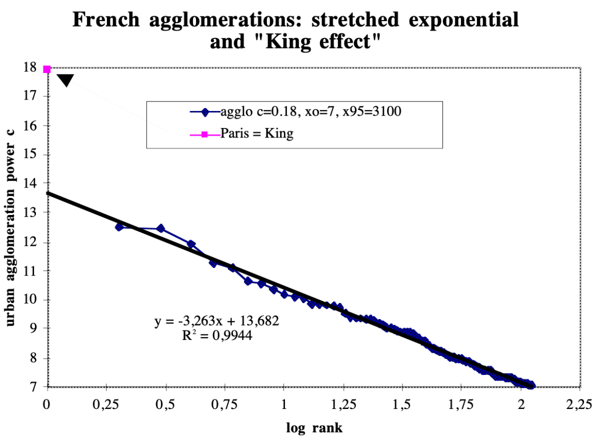
The first rank is for the highest reserves country and the values ranged from 18% (gold) to 92 % (soda ash). The normal distribution in nature is a parabolic fractal.

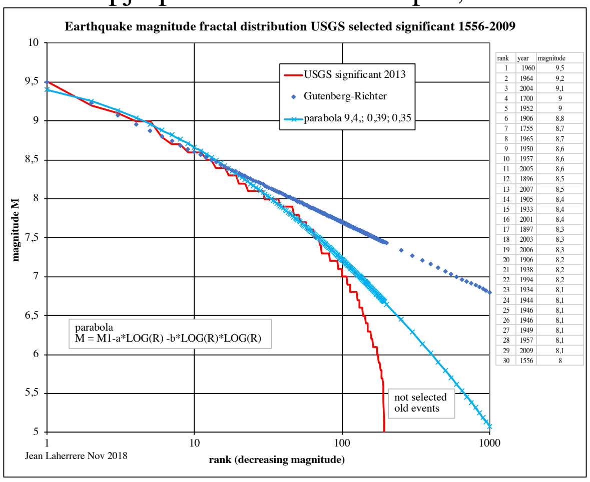
HL (Hubbert linearization) phosphate ultimate for the four largest (China 7000, Morocco 5000, US 3500 & Russia 2000) are plotted fitting the USGS reserves data.
The slopes of the first ten ranks look parallel for gold, iron, barite and the phosphate without the first Morocco. It is why I am convinced that the high value for Morocco phosphate reserve is wrong (as the first rank for iodine and soda ash)
USGS iodine reserves are unreliable when comparing 2010 and 2019 estimates!



But it should be noticed that a natural distribution (as rank and size of fields) displays parabolic fractal curves, but the distribution of a commodity size by country is not a natural one as the boundary of a country is not natural but political.

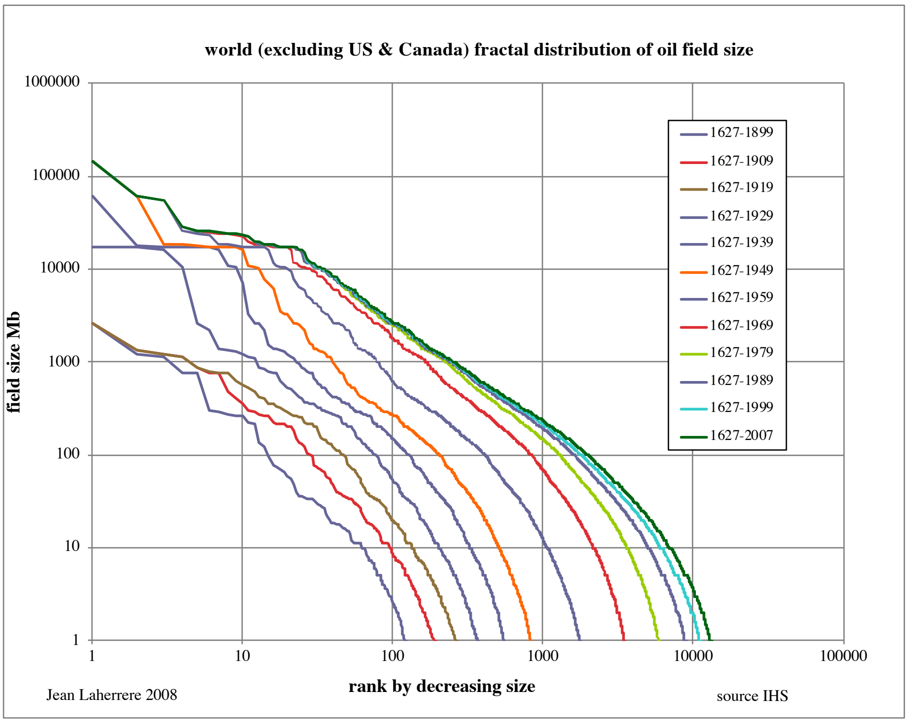
I have described in my paper to the French sciences academy that most natural distributions follow a parabolic fractal distribution = galaxies, earthquakes, urban agglomerations, oil reserves: Laherrère J.H. 1996 “Distributions de type fractal parabolique dans la Nature”- Comptes Rendus de l’Académie des Sciences- T.322 -Série IIa n°7-4 Avril p535-541
http://www.oilcrisis.com/laherrere/fractal.htm
But in some distributions the first rank is above the parabolic model (compared to rank 2 and beyond): it is that I call the King effect in -Laherrère J.H., Sornette 1998 " Stretched exponential distributions in nature and economy: fat tails» with characteristic scales" European Physical Journal B 2, April II, p525-539 : http://xxx.lanl.gov/abs/cond-mat/9801293 or http://www.edpsciences.com/articles/epjb/pdf/1998/08/b8019.pdf,





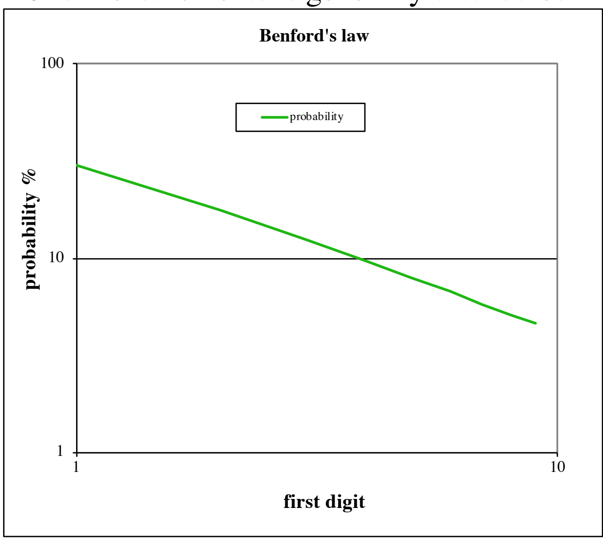
In urban agglomeration parabolic fractal distributions, Paris is a King, as London or Moscow but New York is not a king.
Is Morocco phosphate a King? It is possible, but the difference between rank 1 and rank 2 is usually much lower for a King. The sudden jump in 2010 looks queer. And no change in production data justifies such high value. I did not find any scientific paper on Morocco phosphate reserves. OCP (Morocco producer) annual report just report USGS reserves data.

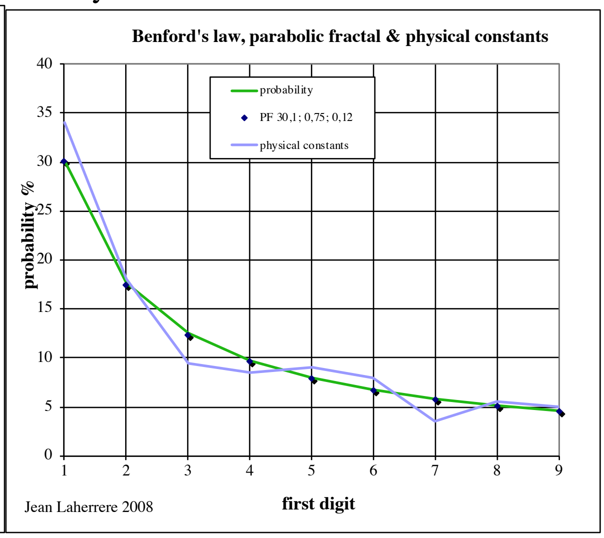
Most of so-called laws, as the Richter Gutenberg law, are a “linear fractal law” or a power law: the size of rank n is equal to the size of rank one power n or $Sn = So^n$, when in fact a “parabolic fractal law” is much better.
Nothing is linear in nature but curved by the matter.
The evolution of the size of oil discoveries (1637-2010) in the world excluding US and Canada onshore from Petroconsultants database by decade displays a curve keeping the same shape.



An interesting fractal distribution is the Benford law, observed by the degree of degradation of the pages of log tables of students studying the size of natural lakes

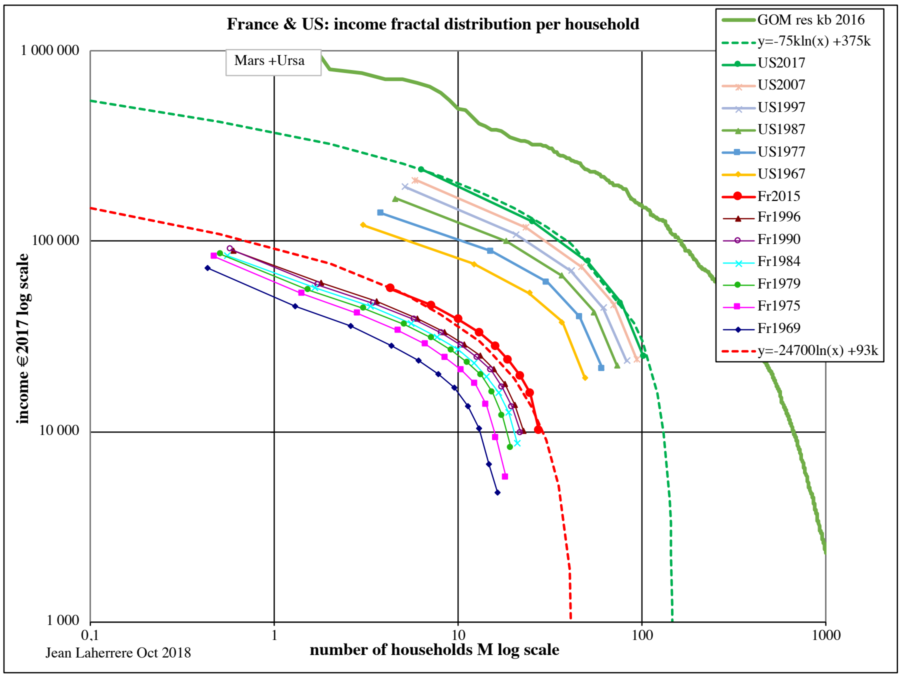
Benford's law, also called the first-digit law, states that in lists of numbers from many real-life sources of data, the leading digit is distributed in a specific, non-uniform way. According to Benford's law, the first digit is 1 almost one third of the time, and larger numbers occur as the leading digit with less and less frequency as they grow in magnitude, to the point that 9 is the first digit less than one time in twenty. This is based on the observation that real-world measurements are generally distributed logarithmically, thus the logarithm of a set of real-world measurements is generally distributed uniformly.





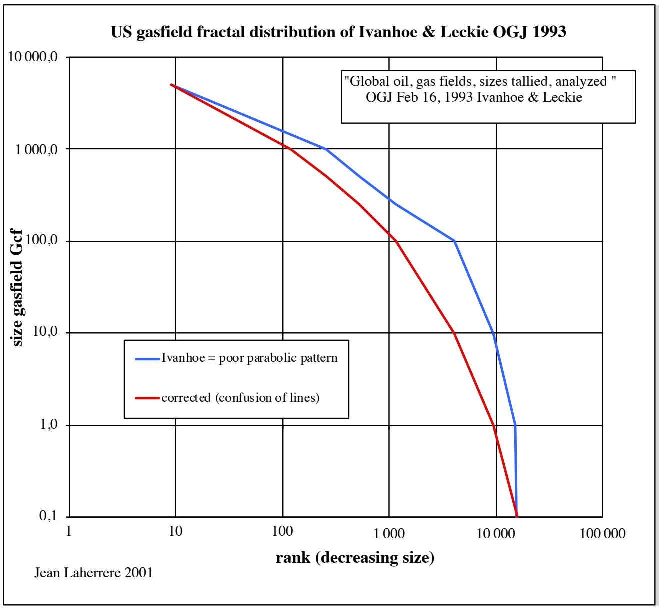
Benford’s law is used by some (in particular in tax reports) to distinguish fake reports with a constant percentage for the first digit.

This fractal parabolic display works well for individual incomes in the US and France with time. The parallelism of income distribution per household with time on France and in the US is striking as with the oil reserves in the Gulf of Mexico distribution



This income parabolic fractal shows clearly that the poverty distribution does not change much with time (50 years) and with country (US & France), despite the statements of many economists, in particular Piketty who seems to ignore this kind of plot. If France had the same number of households as US, the French richest man will be as rich as the richest US.

But the best example of parabolic fractal distribution is the US natural gas field distribution by Ivanhoe and Leckie OGJ « Global oil, gas fields, sizes tallied, analyzed » Feb 1993. When I plotted the data form this paper the display in blue was queer, and I asked Leckie in London if the data was right. He answered that Ivanhoe (already fairly old) has missed one line when reporting data and he sent me the right data, which is in red, displaying a beautiful parabolic curve



	Ivanhoe =	corrected
size Tcf	poor parabolic patterr	confusion of lines
9	5000	
261	1000	
531	500	
1142	250	
4069	100	
9367	10	
15214	1	
15673	0,1	
9		5000
121		1000
261		500
531		250
1142		100
4069		10
9367		1
15878		0,1

This OGJ 1993 wrong paper was never corrected and it is the only paper giving the oil and NG US field size distribution as this date and up to now. EIA published in 1990, as open file, this report: USDOE/EIA-0534 1990 "US oil and gas reserves by year of field discovery»
It was assumed to be the first one of a series, in fact now it is not anymore available, and it was never updated! In fact, this 534 report was censured, as being too realistic! EIA prefers to

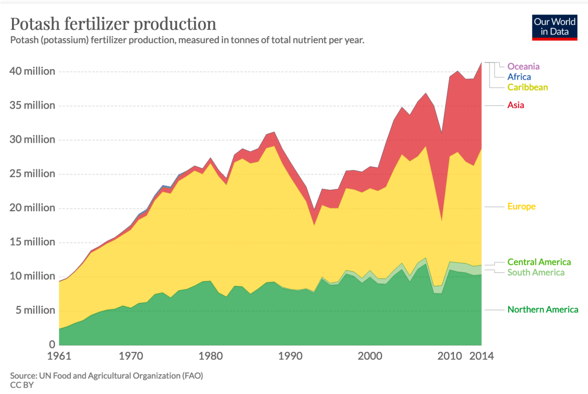
show the proven reserve growth as real, when it is the result of a poor practice of reporting only the so-called proven reserve, prescribed by the SEC. Discovery should be reported as backdated, which is the today estimate, posted for the year of discovery. Discovery reserves were reported backdated in Canada by CAPP (Canadian Association of Petroleum Producers See my paper -Laherrère J.H. 2011 «Backdating is the key » ASPO 9 Brussels 27 April http://www.aspo9.be/assets/ASPO9_Wed_27_April_Laherrere.pdf, http://aspofrance.viabloga.com/files/JL_ASPO2011.pdf, but after this paper CAPP stopped reporting backdated discoveries: truth is bad when oil reserve growth is said to be the way to grow when in fact it is bad practice.

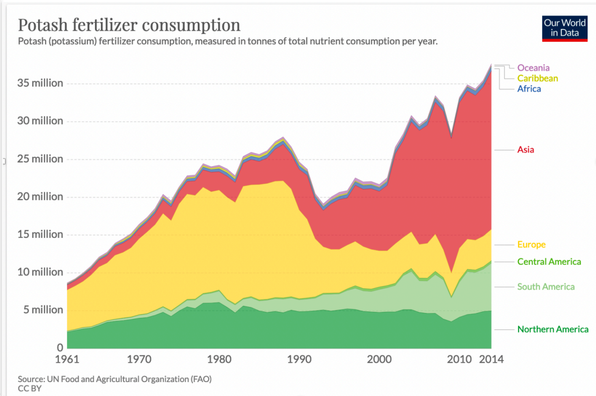
To conclude on reserves, it appears that present USGS Morocco phosphate reserves, as rank one, are too high compared with the rank one of other mineral distributions and not justified by any geological study. Such correction changes widely phosphate future production.

After the study of phosphate, it is necessary to investigate potash and nitrogen production

-Potash production

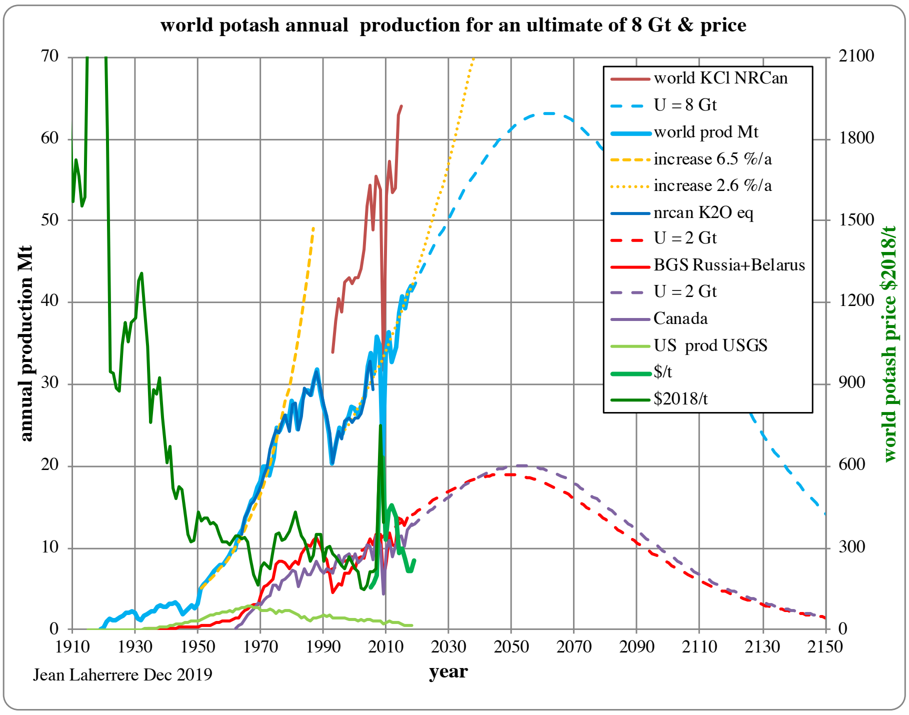
Potash fertilizer production & consumption per continent is displayed for 1961-2014 by our world in data: Asia (red) consumes more than it produces, in contrary with Europe (yellow).



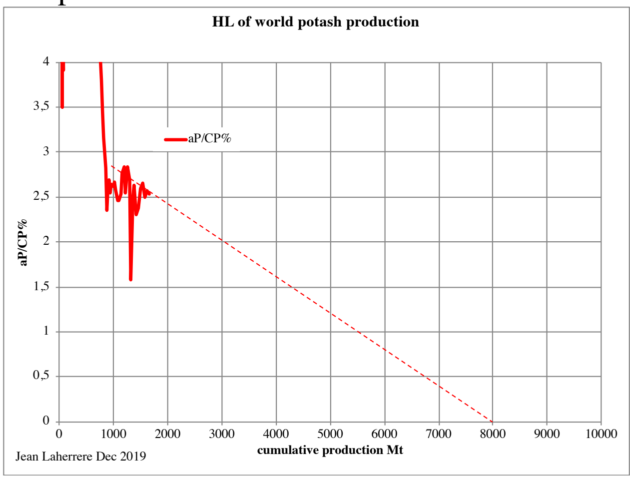


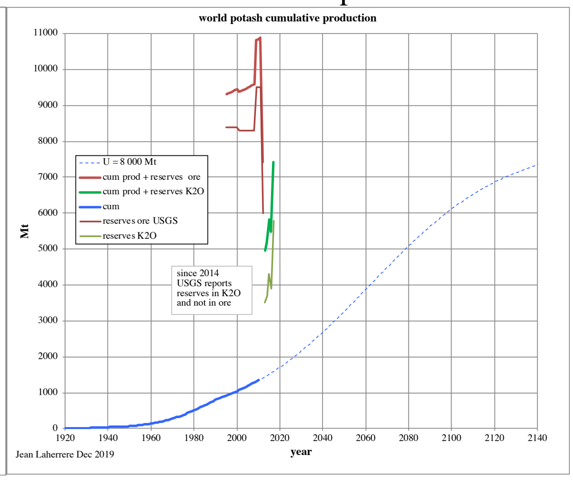
World Potash production displays since 1993 a rate growth of 2.6 %/a

My forecast for world potash production is a peak around 2060 at 62 Mt/a for an ultimate of 8 Gt



HL of world past potash production is hard to be extrapolated and 8 Gt was chosen as a compromise between USGS reserves and to obtain a curve in line with the past.





USGS mcs varies widely and reserves are reported both as recoverable ore and as in K2O equivalent. But USGS annual reports displays erratic changes

Mcs 2018

World Mine Production and Reserves: Reserves for Brazil, Russia, Spain, the United Kingdom, and the United States were revised with information contained in individual company reports.

	Mine production		Reserves[5]	
	2016	2017[e]	Recoverable ore	K_2O equivalent
United States[1]	500	480	1,000,000	210,000
Belarus	6,180	6,400	3,300,000	750,000
Brazil	301	300	310,000	24,000
Canada	10,800	12,000	4,200,000	1,000,000
Chile	1,200	1,200	NA	150,000
China	6,200	6,200	NA	360,000
Germany	2,800	2,900	NA	150,000
Israel	2,050	2,200	NA	[6]270,000
Jordan	1,200	1,300	NA	[6]270,000
Russia	6,480	7,200	3,000,000	500,000
Spain	670	680	NA	44,000
United Kingdom	450	450	NA	40,000
Other countries	480	500	250,000	90,000
World total (rounded)	39,300	42,000	NA	3,900,000

Mcs2019 increases other countries ore reserves from 250 Mt to 1500 Mt and Russia K2O reserves are multiplied by 4, becoming the first rank (recoverable ore reserves data is missing). But it appears that there is some confusion between data in ore and data in K2O equivalent

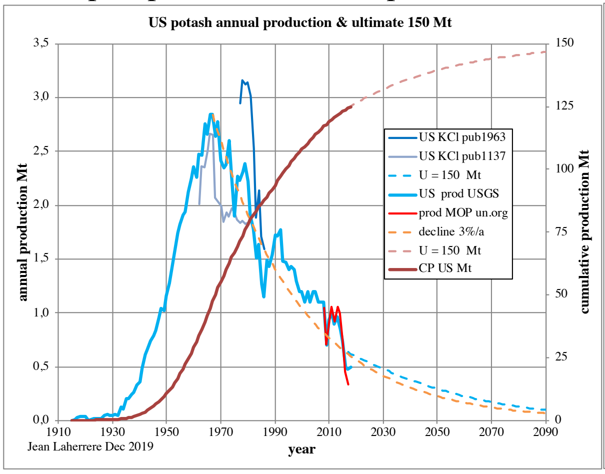
World Mine Production and Reserves: Reserves for the United States, Canada, Chile, China, Spain, and the United Kingdom were revised with information contained in individual company reports. Reserves for Russia were revised based on official Government data.

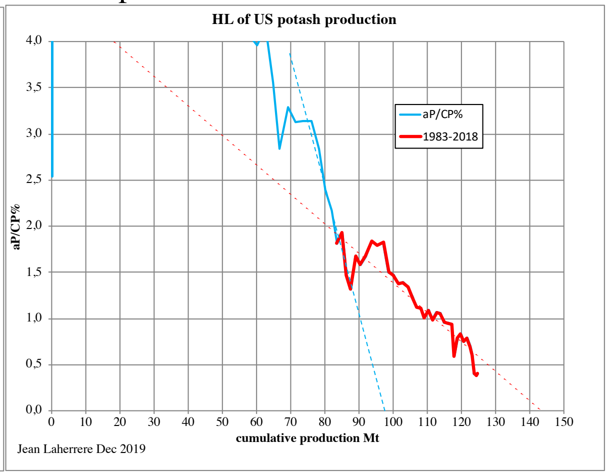
	Mine production		Reserves[5]	
	2017	2018[e]	Recoverable ore	K_2O equivalent
United States[1]	480	500	970,000	220,000
Belarus	7,100	7,100	3,300,000	750,000
Brazil	290	300	310,000	24,000
Canada	12,200	12,000	4,900,000	1,200,000
Chile	1,100	1,000	NA	100,000
China	5,510	5,500	NA	350,000
Germany	2,700	2,900	NA	150,000
Israel	2,000	2,000	NA	[6]270,000
Jordan	1,390	1,400	NA	[6]270,000
Russia	7,300	7,500	NA	2,000,000
Spain	610	560	NA	41,000
United Kingdom	250	190	NA	170,000
Other countries	500	600	1,500,000	280,000
World total (rounded)	41,400	42,000	NA	5,800,000

-US

US potash production has peaked in 1967 and since this peak the decline was about 3%/a down to now and beyond for an ultimate of 150 Mt

HL of past production for the period 1983-2018 is extrapolated towards an ultimate of 150 Mt

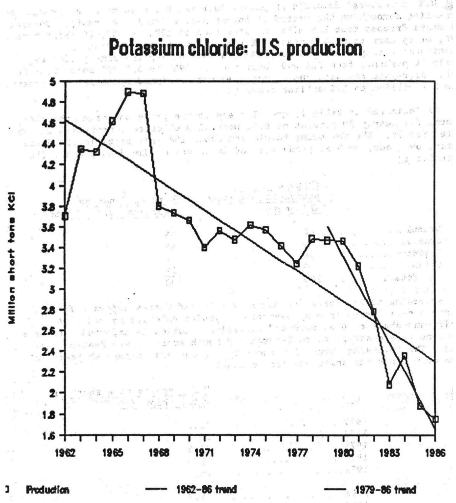




Old production data are for potassium chloride = KCl = muriate of potash = MOP

USITC pub1137 in 1981 & USITC pub1963 in 1987 report quite different MOP data (dark blue curves in the above graph)!

Figure 3.--U.S. production of potassium chloride, 1962-86



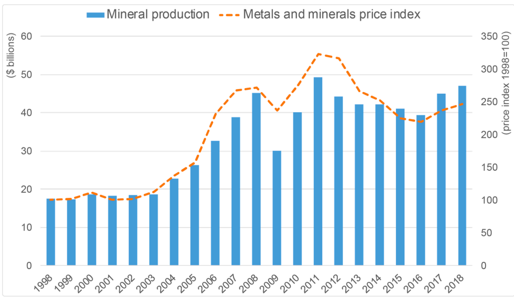
UN.org reports MOP production 2006-2017 (red curve) similar with USGS data

-Canada

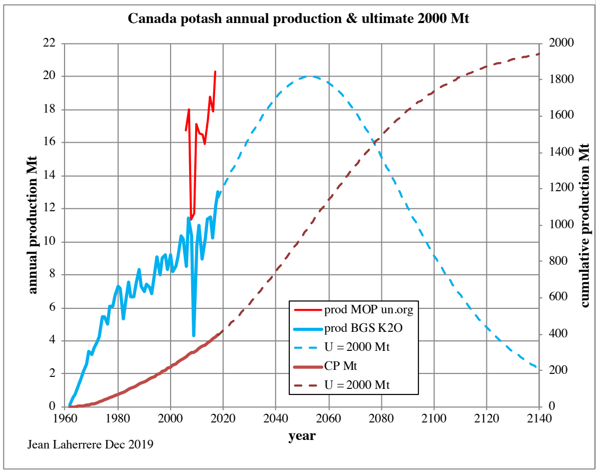
Potash is rank 3 for Canada minerals production in value, with a large growth in 2018

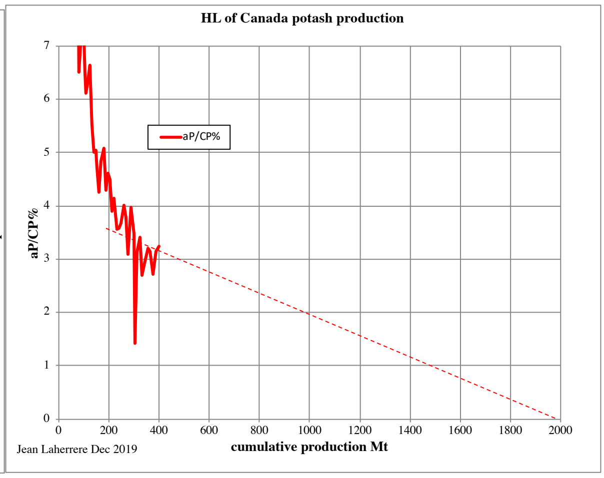
Rank	Mineral products	2017 $ billions	2018 $ billions		Change (%)
1	Gold	8.8	9.6	▲	9
2	Coal	6.3	6.4	▲	2
3	Potash (K_2O)	4.4	5.5	▲	26
4	Iron ore	4.7	4.8	▲	2
5	Copper	4.6	4.5	▼	-3
6	Nickel	2.8	3.0	▲	7
7	Diamonds	2.7	2.7	▲	2
8	Sand and gravel	2.1	1.9	▼	-7
9	Stone	1.7	1.7	▼	-2
10	Platinum group	1.0	1.2	▲	19

Figure 2: Mineral production with respect to the metals and minerals price index, 1998–2018



Canada is the first producer of potash with 13 Mt/a in 2018 and will peak around 2050 at 20 Mt/a

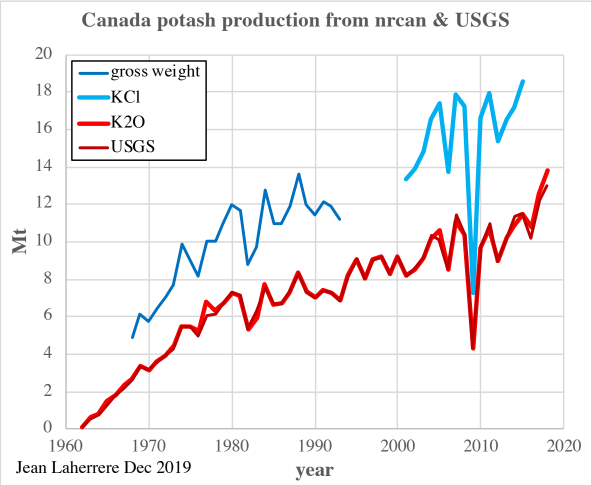


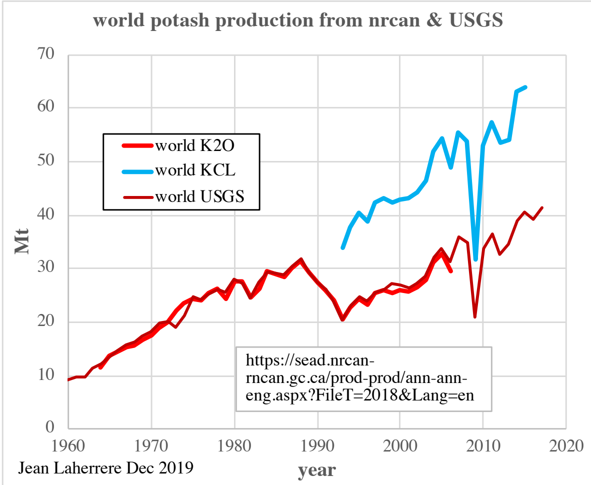


HL is hard to be extrapolated and USGS reserves are poor. It is a pity that the Canadian government does not publish any potash reserves data despite being the first producer and exporter. Potash was found in Saskatchewan oil wells in 1943.
Nutrien https://www.nutrien.com/what-we-do/our-business/potash is the world's largest potash producer with over 20 million tonnes of potash capacity at our six lower-cost potash mines in Saskatchewan. Nutrien is the merger in 2018 of Potash Corp and Agrium
Old data (Stanford Research Institute) is for potassium chloride KCl but given in K2O and similar with BGS data. It appears that the use of this term potassium chloride (or muriate of potash MOH, which is a fertilizer) is not used by USGS production data! Fertilizer could be also SOP = sulfate of potash = K2SO4.
But UN.org reports (see red curve above) Canada MOP production (being a fertilizer), data being over 50% larger than BGS potash production given in K2O equivalent
It appears that potash production can be different: ore or K2O or MOP
Amazon https://www.amazon.com/Potassium-Chloride-Fertilizer-Greenway-Biotech/dp/B01GF4S952 sells MOP 0-0-60 14.75 $/5 lb. and SOP 0-0-53 25 $/5 lb.
Natural Resources Canada reports minerals yearbook since 1962 giving Canada and world productions https://www.nrcan.gc.ca/maps-tools-publications/publications/minerals-mining-publications/18733
Many data are reported on potash but there is a mess between short tons and metric, production and capacity, mining data and fertilizer data, gross weight and K20 equivalent, KCl and K2O.

KCl is used to measure the production tonnage, when K2O is used to measure the fertilizer content in KCl

NRCan gross weight production (in blue) is about 164% more than K2O equivalent production and is similar with KCl data: USGS data corresponds to K2O equivalent





But NRCan confuses US production data in K20 and KCl

In the first table 2 US production for 1998 is 1454 kt in KCl and 872 kt in K2O, but in the second table 6 for 1998 it is 1300 kt in K2O: something wrong!

TABLE 2. WORLD POTASH PRODUCTION, 1998-2006

	1998	1999	2000	2001	2002	2003	2004	2005	2006 (p)
					(000 tonnes)				
POTASSIUM CHLORIDE (KCl) (1)									
Canada	15 051	13 564	15 056	13 357	13 911	14 924	16 557	17 370	13 705
United States	1 454	1 511	1 368	1 348	1 438	1 166	1 499	1 363	1 215
Belarus	5 752	6 022	5 620	6 145	6 318	7 048	7 687	8 213	7 676
Russia	5 768	6 750	6 193	7 096	7 386	7 756	9 332	10 443	9 540
France	695	519	535	407	213	–	–	–	–
Germany	5 970	5 908	5 682	5 918	5 752	5 942	6 044	6 108	6 026
Spain	828	915	870	785	678	844	922	824	728
United Kingdom	1 014	825	1 001	887	900	1 036	899	732	716
Israel	2 780	2 836	2 913	2 957	3 197	3 264	3 563	3 707	3 539
Jordan	1 527	1 800	1 936	1 963	1 956	1 960	1 929	1 829	1 699
Brazil	526	561	567	575	606	636	617	620	707
Chile	467	520	550	650	682	733	717	718	623
China	280	363	458	658	717	1 033	1 880	2 417	2 620
Total	42 112	42 094	42 749	42 746	43 754	46 342	51 646	54 344	48 794
POTASSIUM OXIDE (K_2O) (1)									
Canada	9 201	8 304	9 205	8 181	8 515	9 104	10 100	10 596	8 360
United States	872	907	821	809	863	711	914	832	741
Belarus	3 451	3 613	3 372	3 687	3 791	4 229	4 612	4 928	4 605
Russia	3 461	4 050	3 716	4 258	4 432	4 653	5 599	6 266	5 724
France	665	417	321	244	128	–	–	–	–
Germany	3 582	3 545	3 451	3 551	3 451	3 565	3 626	3 665	3 616
Spain	497	549	522	471	407	506	553	494	437
United Kingdom	608	495	600	532	540	621	540	439	430
Israel	1 668	1 702	1 748	1 774	1 918	1 958	2 138	2 224	2 123
Jordan	916	1 080	1 162	1 177	1 174	1 176	1 157	1 098	1 020
Brazil	327	337	340	345	364	382	370	372	424
Chile	280	312	330	390	409	440	430	431	374
China	168	218	275	395	430	620	1 128	1 450	1 572
Total	25 696	25 529	25 863	25 814	26 422	27 965	31 167	32 794	29 426

Sources: Natural Resources Canada; International Fertilizer Industry Association.
– Nil; (p) Preliminary.
(1) Potassium chloride (KCl) is used in the measurement of production tonnage, while potassium oxide (K_2O) is used to measure fertilizer content in KCl.
Notes: Statistics show potassium chloride (KCl) only, excluding other forms of potash. One tonne of KCl contains 60-62% K_2O.

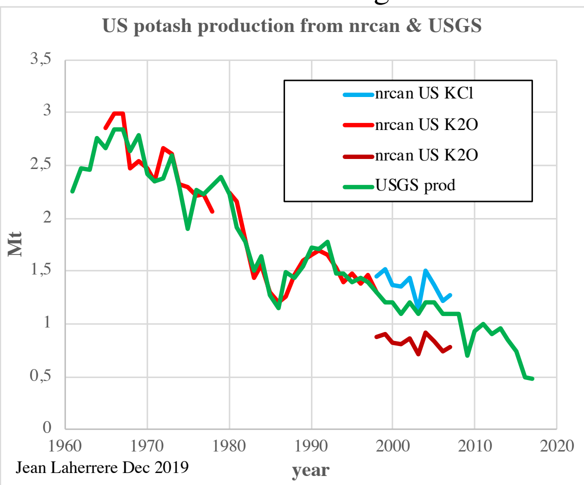
It is said that one tonne of KCl contains 60-62 % of K2O

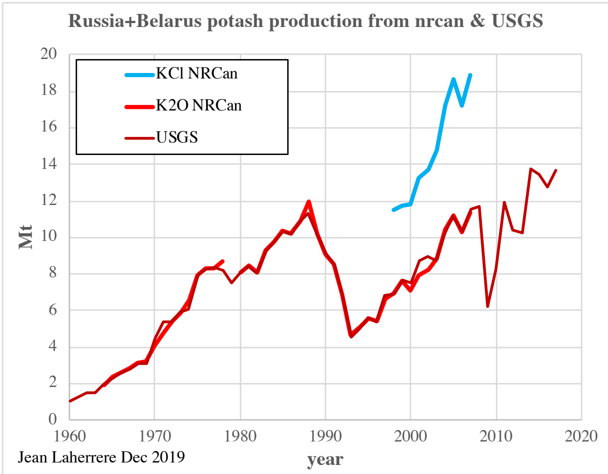
TABLE 6. WORLD POTASH PRODUCTION, 1993-99

	1993	1994	1995	1996	1997	1998r	1999e
				(000 tonnes K_2O)			
Brazil	173	242	223	234	280	327	335
Canada	6 850	8 182	9 065	8 044	9 029	9 195	8 230
Chile	35	52	52	179	235	280	315
China	60	90	171	150	186	168	250
C.I.S.[1]	4 667	5 112	5 605	5 395	6 650	6 912	7 665
France	890	870	802	751	665	417	310
Germany	2 860	3 286	3 278	3 334	3 423	3 582	3 545
Israel	1 309	1 259	1 326	1 500	1 488	1 668	1 700
Italy	–	–	–	–	–	–	–
Jordan	822	930	1 068	1 059	849	916	1 080
Spain	661	684	650	680	640	497	550
United Kingdom	555	580	582	618	565	608	495
United States	1 525	1 400	1 480	1 387	1 465	1 300	1 300
Total	20 407	22 687	24 302	23 331	25 475	25 870	25 775

Sources: Natural Resources Canada; International Fertilizer Association; company interviews.
– Nil; e estimated; r Revised.
1 Russia and Belarus.

For US, NRCan K2 agrees with USGS up to 1998 and disagrees beyond, but for Russia+Belarus USGS data agrees with NRCAN K2O





It appears that NRCan potash US data is wrong since 1998, as they have confused rock production (extraction) and fertilizer production (making).

NRCan & USGS data are similar for Russia+Belarus

The grade of the potash production varies from 1 to 25 % in K2O in 1963: the best is in Canada, Utah and Ethiopia.

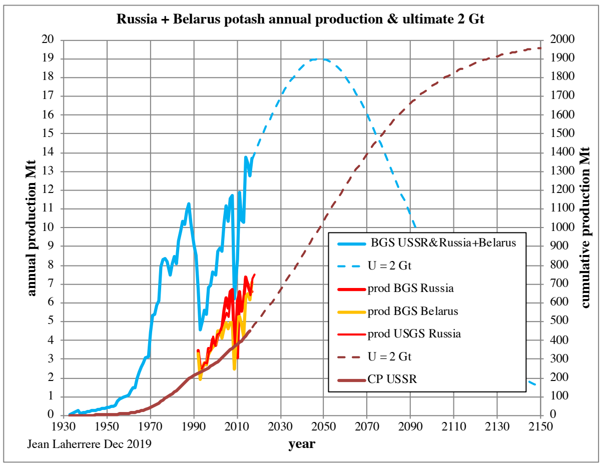
TABLE 5
World Potash Resources

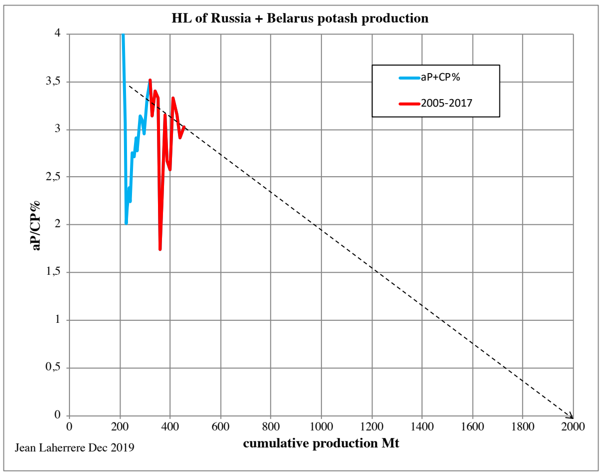
Country	Estimated Reserves in Millions of Metric tons	Estimated Grade in Per cent K_2O	Estimated Production 1963 Millions of Metric Tons K_2O
United States,	400		
New Mexico		18	2.524
Utah		25	under construction
West Germany	2-20,000	12	1.948
East Germany	9,000	20	na
France	300-400	18	1.697
U.S.S.R.	17,600-20,300	10	na
Spain	270-500	16	.272
Italy	155	12	na
Canada	50,000	25	.630
Israel } in Dead Sea	2,000	3	.186
Jordon } brines			under construction
Poland	165	8	na
Ethiopia	50	25	under construction
Gabon	40	na	under construction
Britain			
England	350	16	under investigation
Scotland (shales)	100	10	under investigation
Chile (KNO_3)	na	1	na
Peru (in brines)	na	na	under investigation
Morocco	na	12	under investigation
Libya	9	na	under investigation
Total	103,000	15	na

Sources: U.S. Bureau of Mines, *Phosphorus and Potassium* and others.
Note: 1000 kilograms = 1 metric ton = 1.1023 short tons.
Symbol: na Not available.

-Russia, Belarus & former USSR

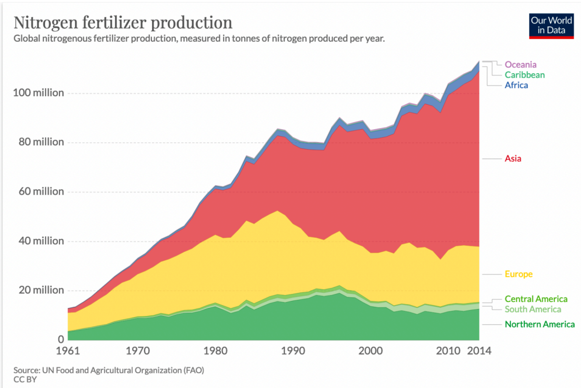
Potash in former USSR was only in Russia and Belarus and their production since 1990 is similar. HL for Russia+Belarus 2004-2017 trends towards 2 Gt.
Production will peak around 2050 at 19 Mt

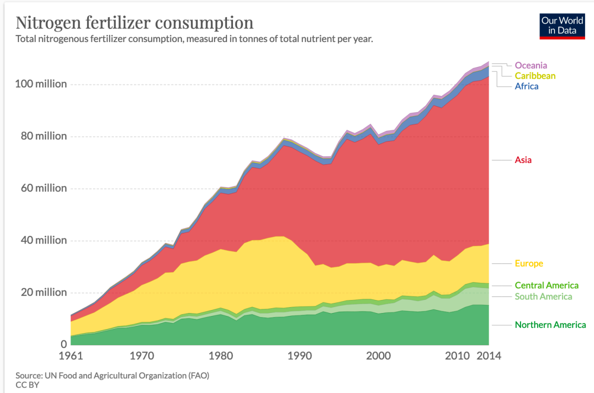




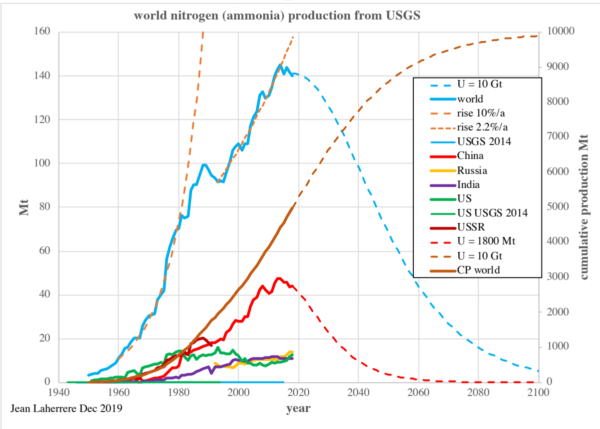
-Nitrogen (ammonia)

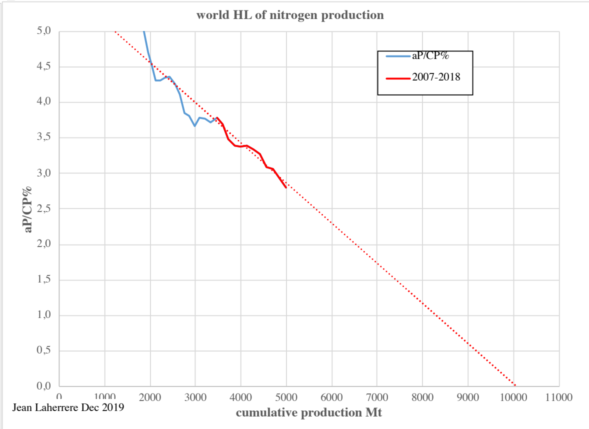
Nitrogen N is abundant in the atmosphere but cannot be absorbed by the plant, as CO2.
N has to be transformed in ammonia (NH3) to be used by plants.
Ammonia is produced (97%) from natural gas
Nitrogen (ammonia) is mainly produced and used in Asia. Europe produces more nitrogen than it uses.



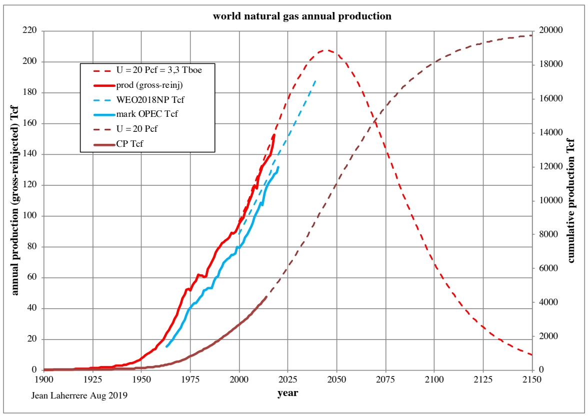


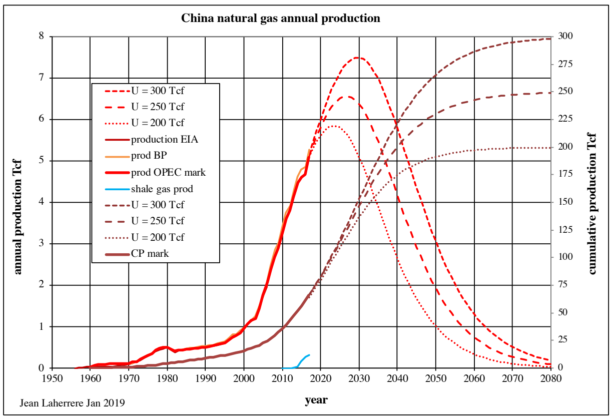
World nitrogen displayed a growth rate of 10 %/a from 1960 to 1960 and of 2.2% from 1992 to 2015, presently flat. It will decline after 2020 if the ultimate is 10 Gt.
HL of world nitrogen production trends for the period 2007-2018 towards 10 Gt.





As ammonia is produced from natural gas, peak ammonia depends on world peak natural gas, forecasted to occur around 2040 for an ultimate of 20 Pcf.

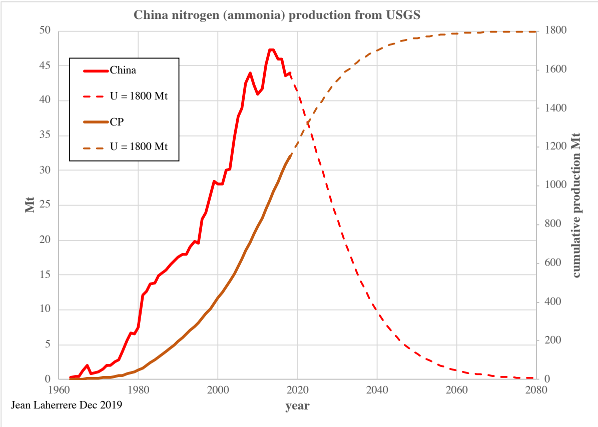


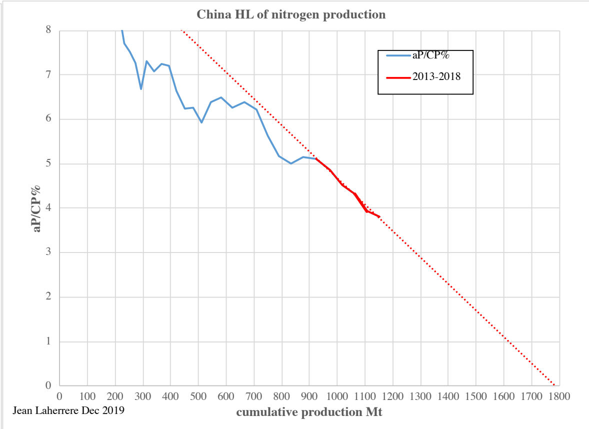


Peak ammonia could be around 2040 if growth returns (depending mainly from China?)
China NG production will peak in 2024-2030 for a range of ultimates 200-300 Tcf

-China

China nitrogen production has peaked in 2014 and will continue to decline for an ultimate of 1800 Mt, being the extrapolation of HL for the period 2013-2018. Further it is seen that the decline is due to a bad use of nitrogen and also a decline in real GDP growth. But growth can return and China N peak later, as China NG peak?





European Union Network for the Implementation and Enforcement of Environmental Law had a project 2014-2016 for Good Practice for Tackling Nitrate Pollution from Farms and Farmsteads, but there is little effect on the green algae in Brittany!

-Fertilizer

All references relating to fertilizers are in terms of the three primary plant nutrients as follows:

» nitrogen (N)
» phosphorus (P), expressed as phosphate (P2O5)
» potassium (K), expressed as potash (K2O)

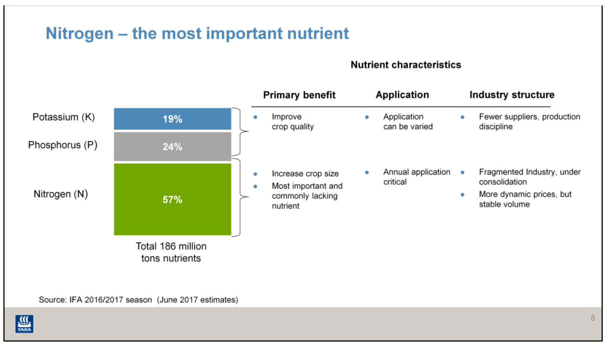
Potash comes from "pot ash", meaning the ash from wood burned in a big iron pot

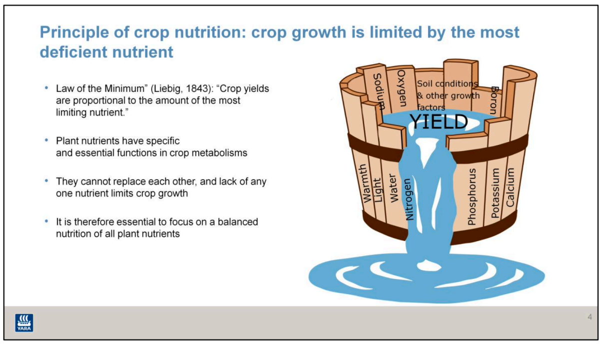
Three main nutrients: Nitrogen, Phosphorus and Potassium

• Nitrogen (N), the main constituent of proteins, is essential for growth and development in plants. Supply of nitrogen determines a plant's growth, vigor, color and yield

• Phosphorus (P) is vital for adequate root development and helps the plant resist drought. Phosphorus is also important for plant growth and development, such as the ripening of seed and fruit

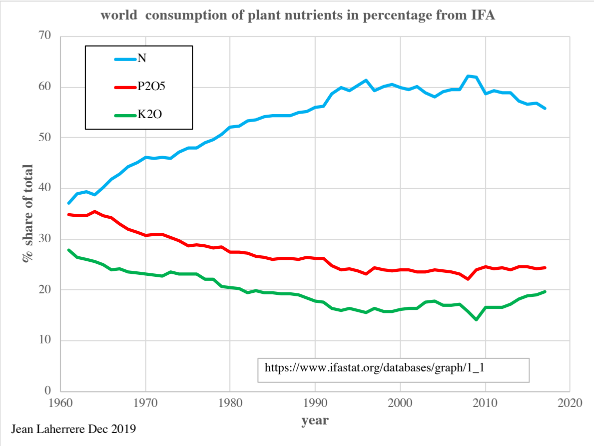
• Potassium (K) is central to the photosynthesis of crops. Potassium helps improve crop quality and crop resistance to lodging, disease and drought.

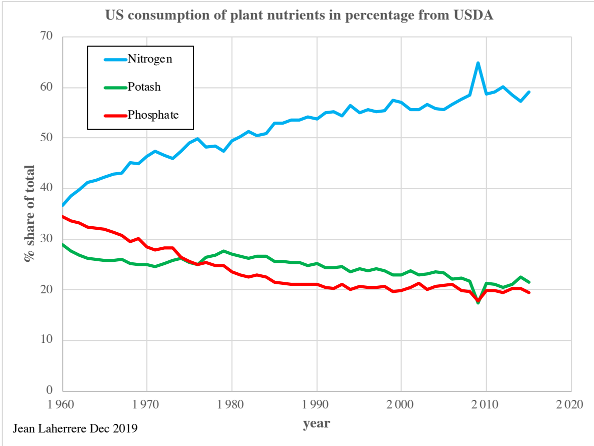




But it is important to keep the crop nutrition in balance between the three products, as crop growth is limited by the most deficient nutrient and other nutrients are wasted

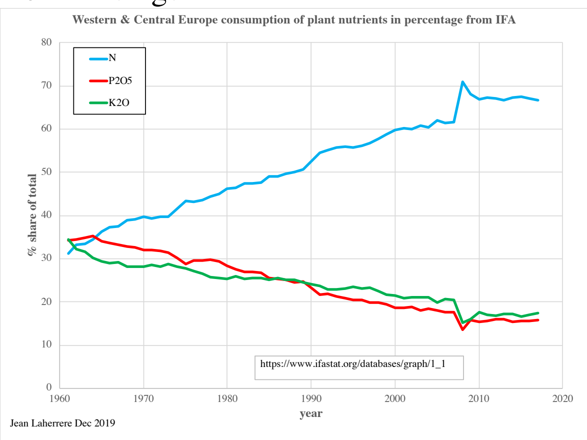
Fertilizer can be wasted if badly consumed between the three nutrients.
The evolution of the percentage of the three nutrients from 1960 to 2017 displays a stabilization since 1990 for the world at 18 % for P2O5, 24 % for K2O and 58% for N

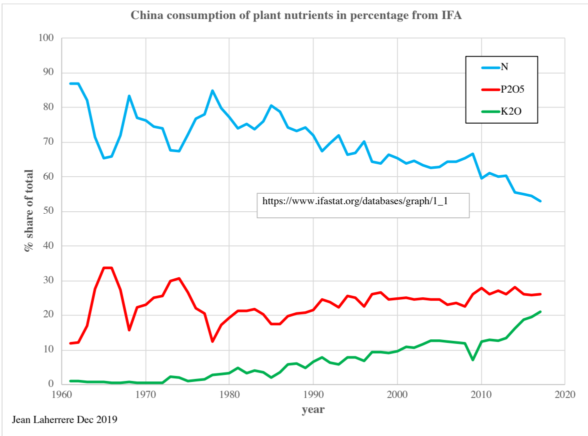




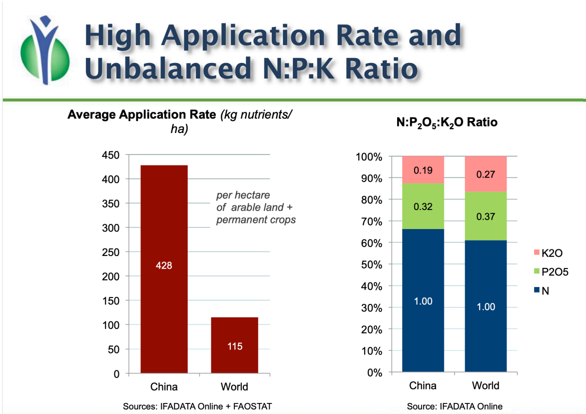
For US it is about 20% for P2O5 & K2O and 60 % for N. In 1960 the percentage was about the same for the three about 33%.

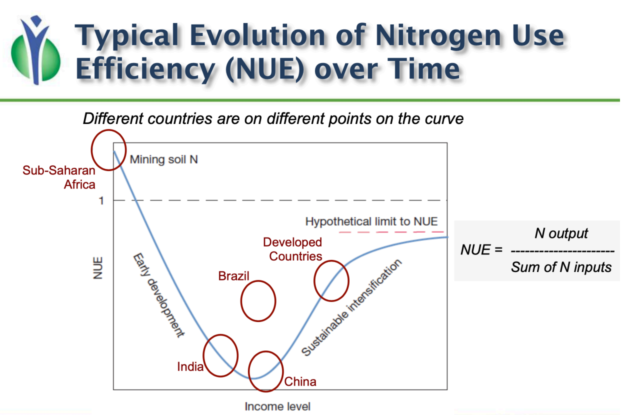
For Europe it is about 17% for P2O5 & K2O and 66 % for N. China was consuming too much nitrogen in 1960 (and not enough potash) and now its percentage of the 3 nutrients is about world average



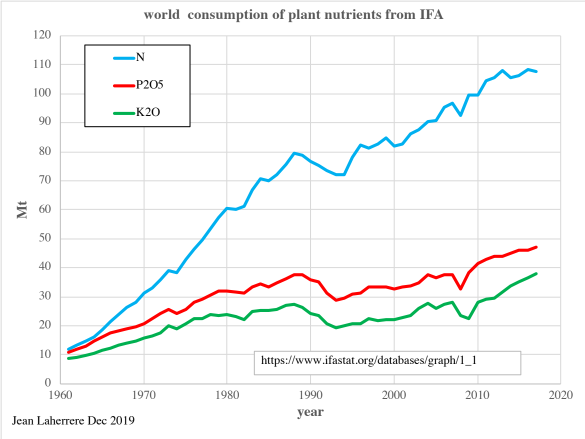


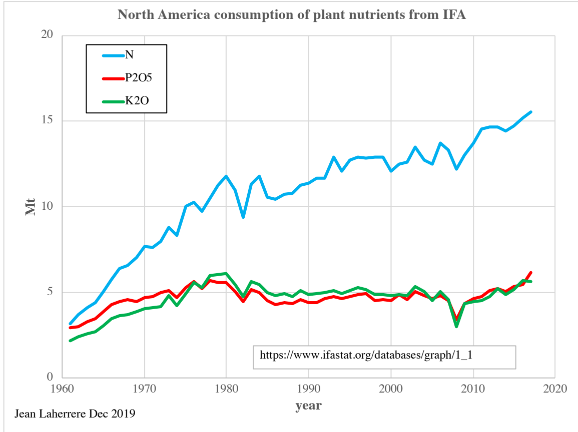
IFA states that China apply 428 kg/ha of nutrients against 114 for the world and that nitrogen use varies with income level



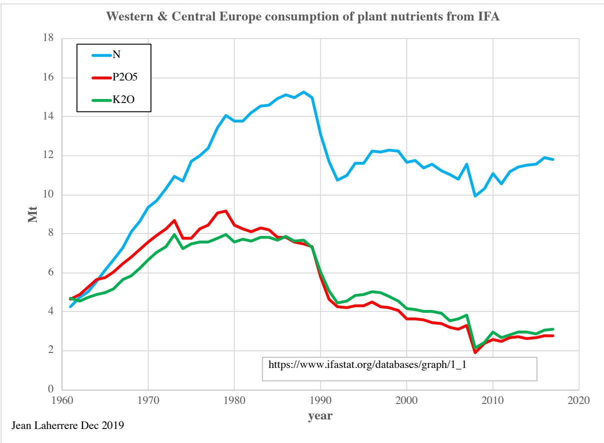


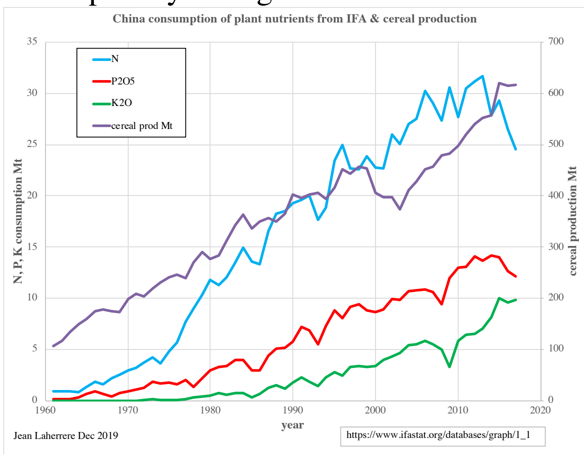
The consumption in Mt of the 3 nutrients displays for the world a peak in 1988 and since 1995 a lower growth. There is also a change in consumption in North America in 1980



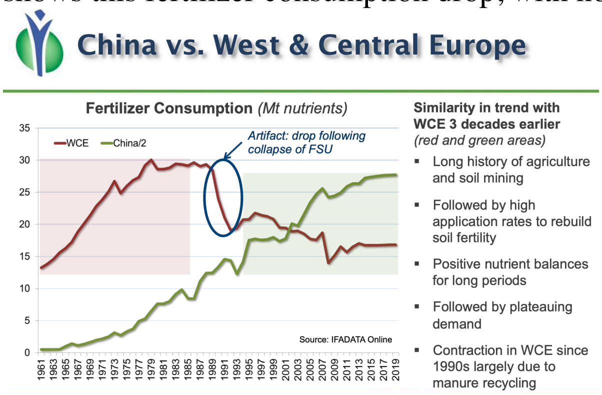


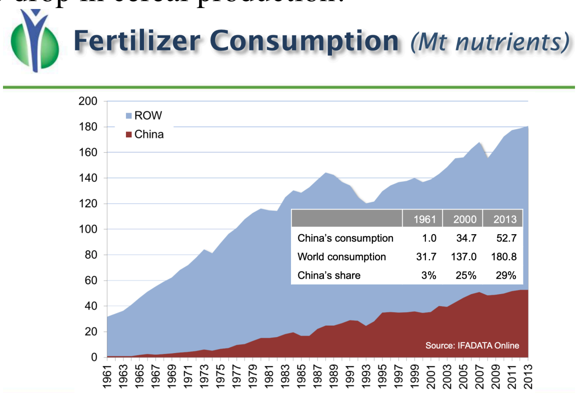
Western and Central Europe consumption dropped sharply in 1990 and after flat for N and small decline for P2O5 and K2O.
China increased nutrient consumption up to 2014 and declined after.
China is presently making the correction made in Europe 20 years ago



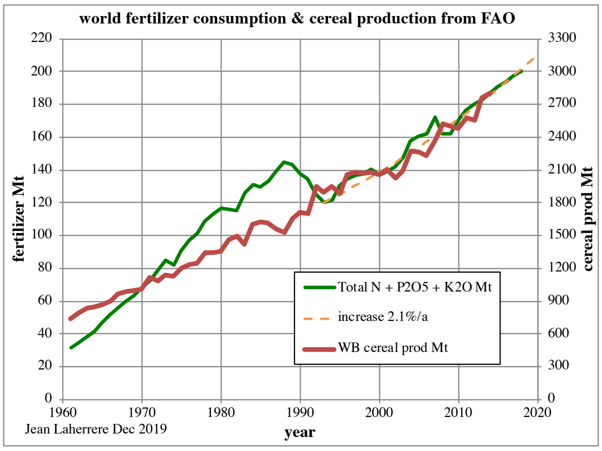


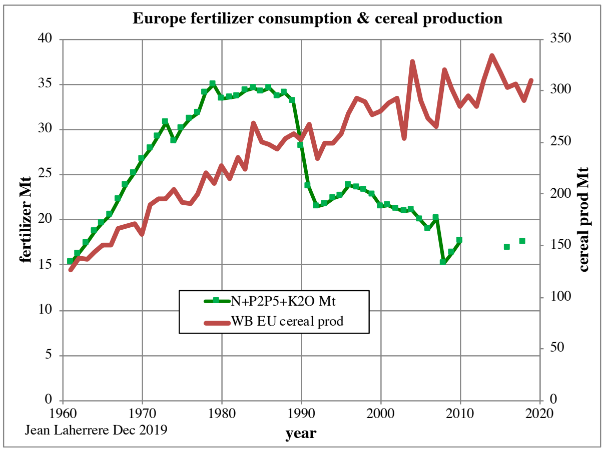
IFIA claims that the drop in central Europe is due to the collapse of FSU, but EU production shows this fertilizer consumption drop, with no drop in cereal production!





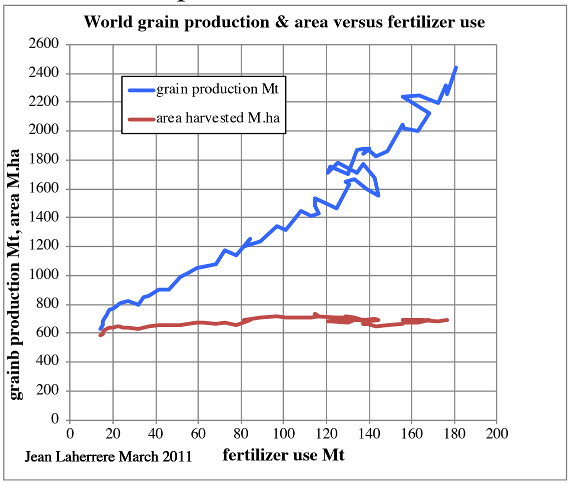
From FAO data, world fertilizer consumption is compared with cereal production.

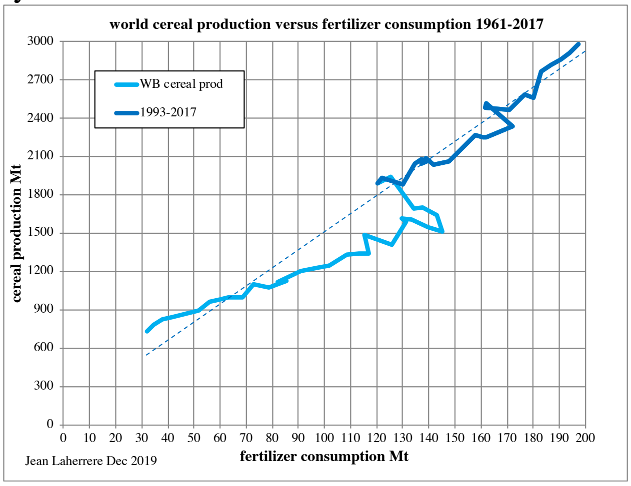




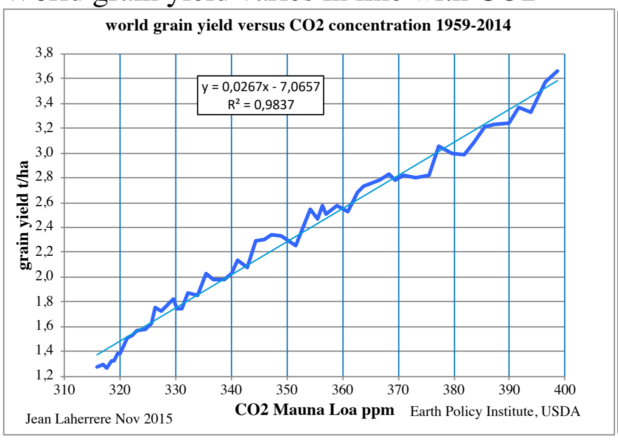
World cereal production increased on a linear growth from 1961 to 2017, when world fertilizer consumption was growing too fast from 1961 to 1988: it was a waste of fertilizer.
Fertilizer consumption since 1993 has increased by 2%/a, as world cereal production
Europe cereal production has increased from 1960 to 2014 and presently flat when Europe fertilizer consumption has sharply dropped in 1992 and is almost flat.
It is obvious that in the past fertilizer were partly wasted.

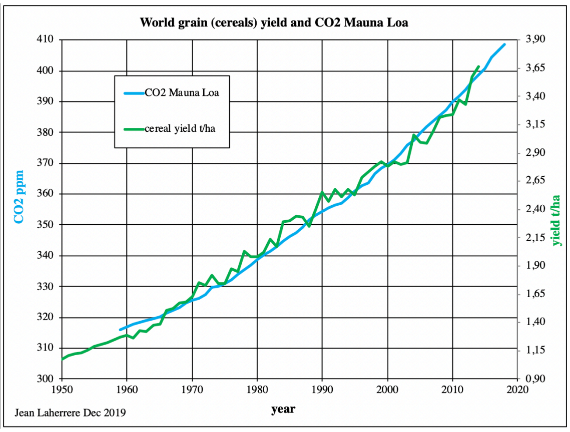
Now fertilizer use is better balanced between the three nutrients with nitrogen being two thirds and potash and phosphate being one sixth.
World grain production was plotted versus fertilizer use in 2011 and 2019
World cereal production has increased linearly with fertilizer use since 1993 to 2017



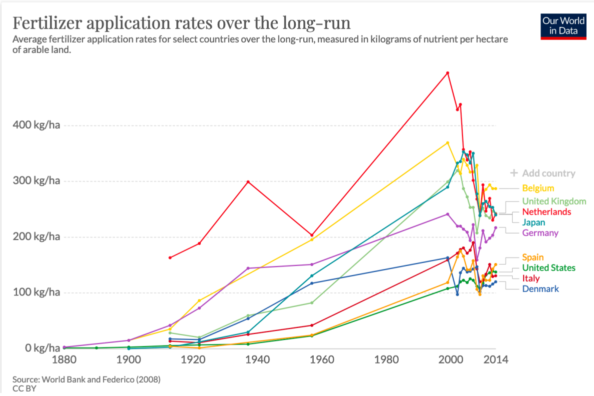


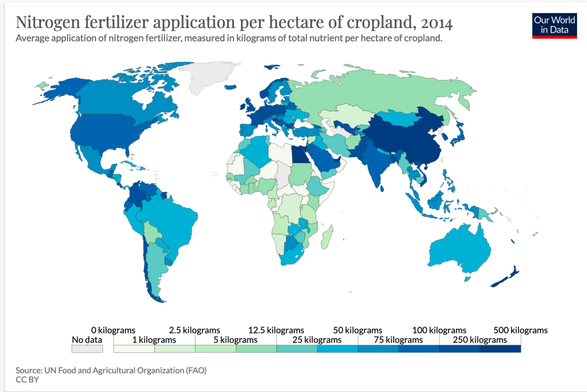
World grain yield varies in line with CO2



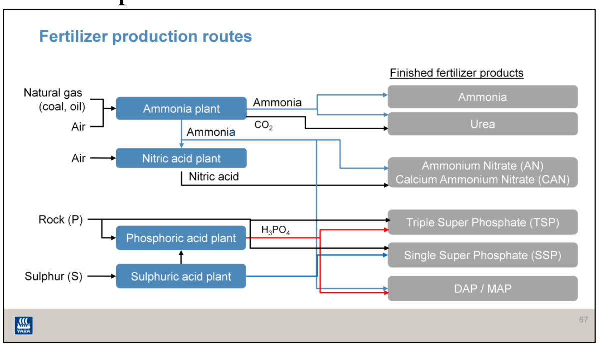


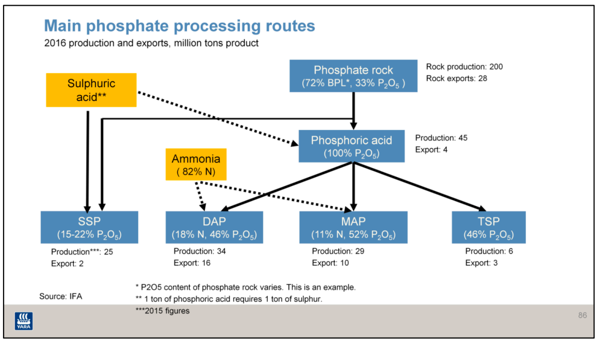
Fertilizer application per hectare has sharply increased in Europe up to 2000 and declined beyond and the range is large.
In 2014 N fertilizer per hectare was the highest in China
https://ourworldindata.org/fertilizer

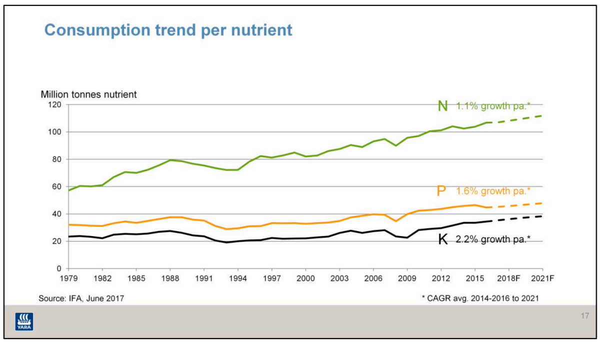


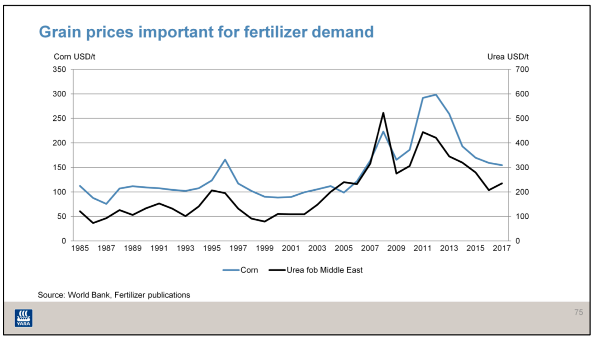


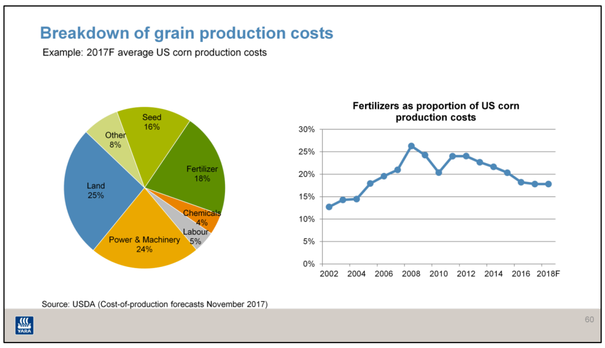
Yara fertilizer industry handbook oct 2018 describes the way from production to finished fertilizer products.

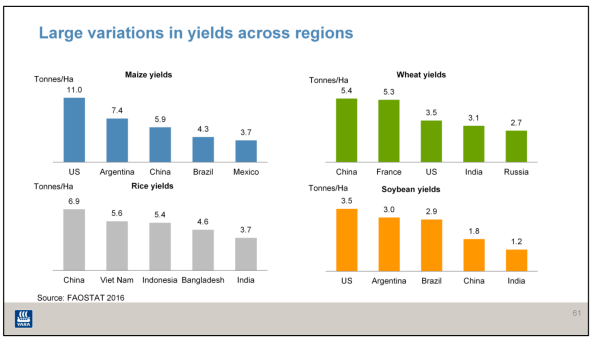




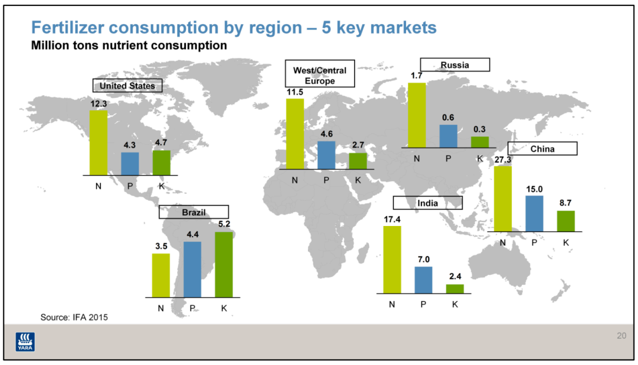


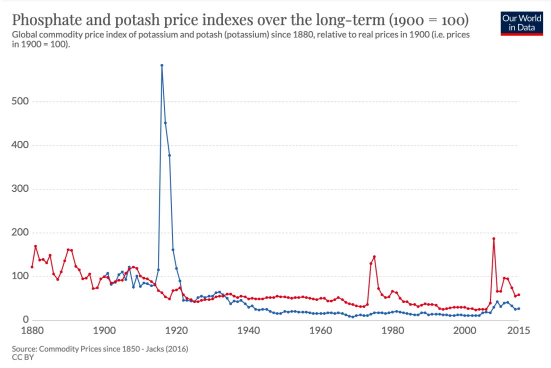


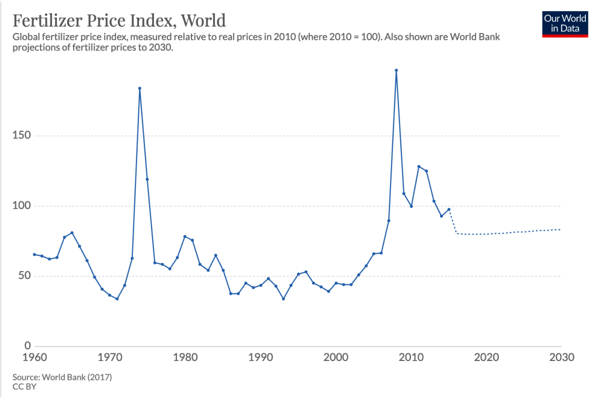


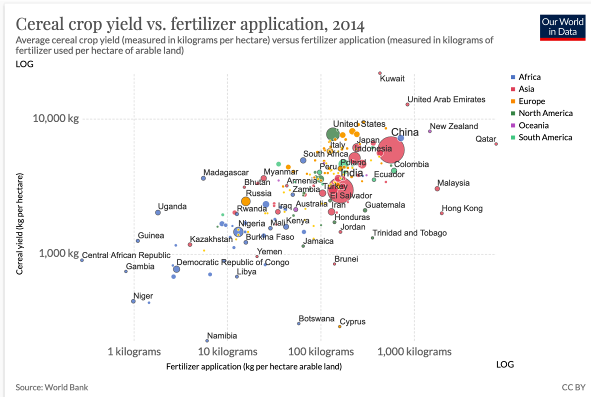


Fertilizer consumption is different between the 5 key markets: N should be about twice P and K. Brazil is too short in N and India in K

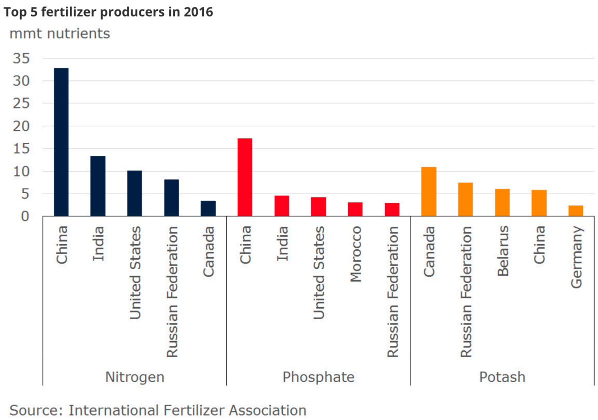


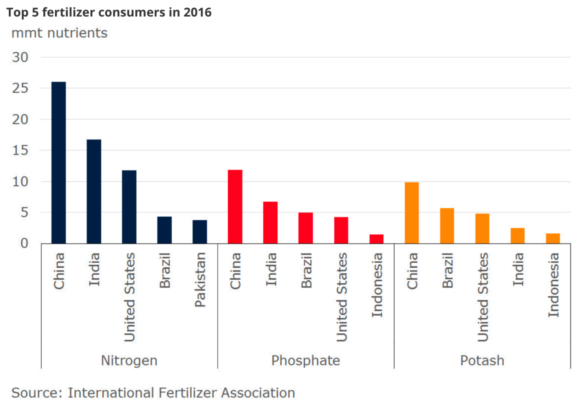






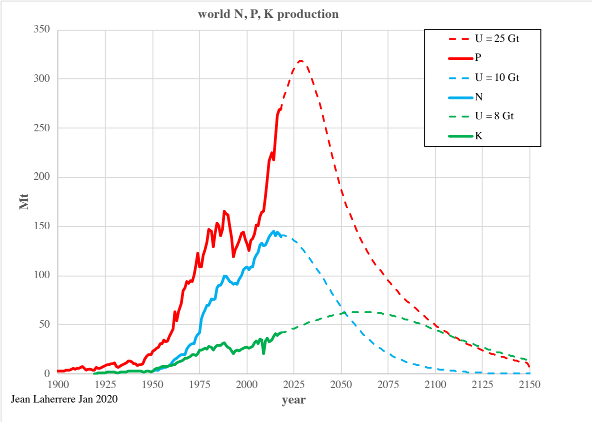
World Bank reports for 2015 the top 5 producers and consumers
https://blogs.worldbank.org/developmenttalk/fertilizer-prices-rise-2019-supportive-fundamentals

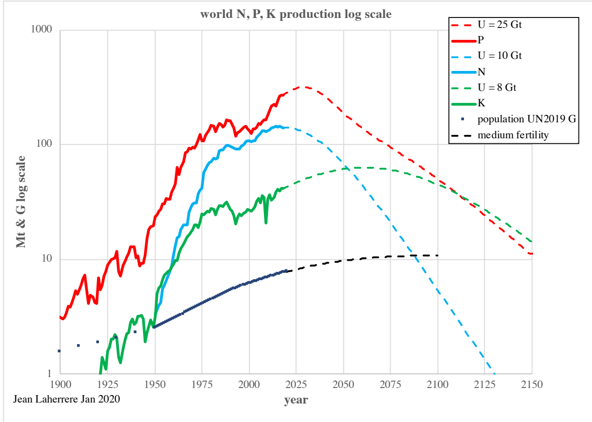




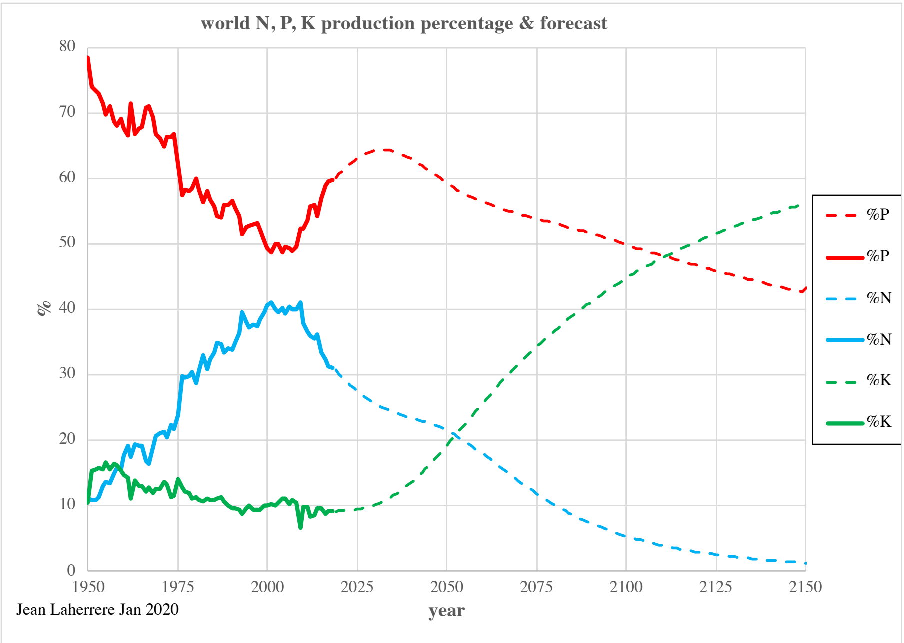
-N, P, K production synthesis

The synthesis of above phosphate, potash and nitrogen Mt productions is plotted in the same graph with their forecast. A plot in log scale, together with UN2019 population forecast, shows that since 1990 P, N, K have similar growth as population, but P since 2007 has higher growth.



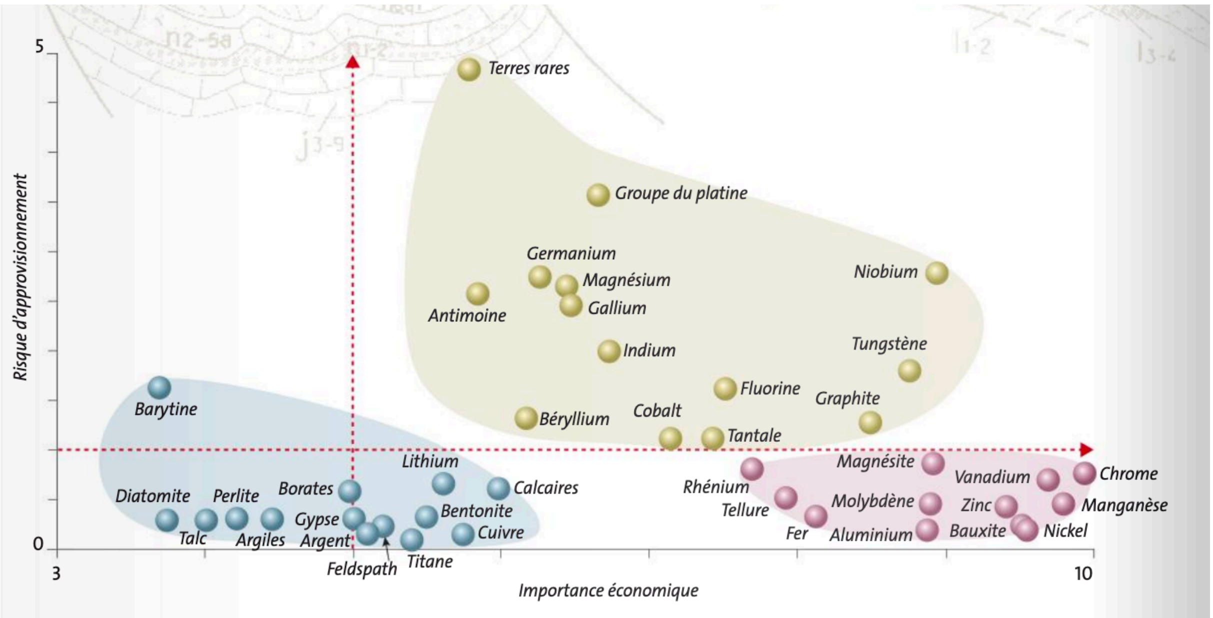


The plot in percentage shows that K is flat since 1980, when from 1950 to 2000 P declines and K increases and since 2010 it is the contrary.
The forecast with the estimated ultimates extends past trends up to 2030, beyond it diverges when the need for fertilizer should display stable percentage: it means that either our estimated ultimates are wrong or that there will be problems in balancing fertilizers!



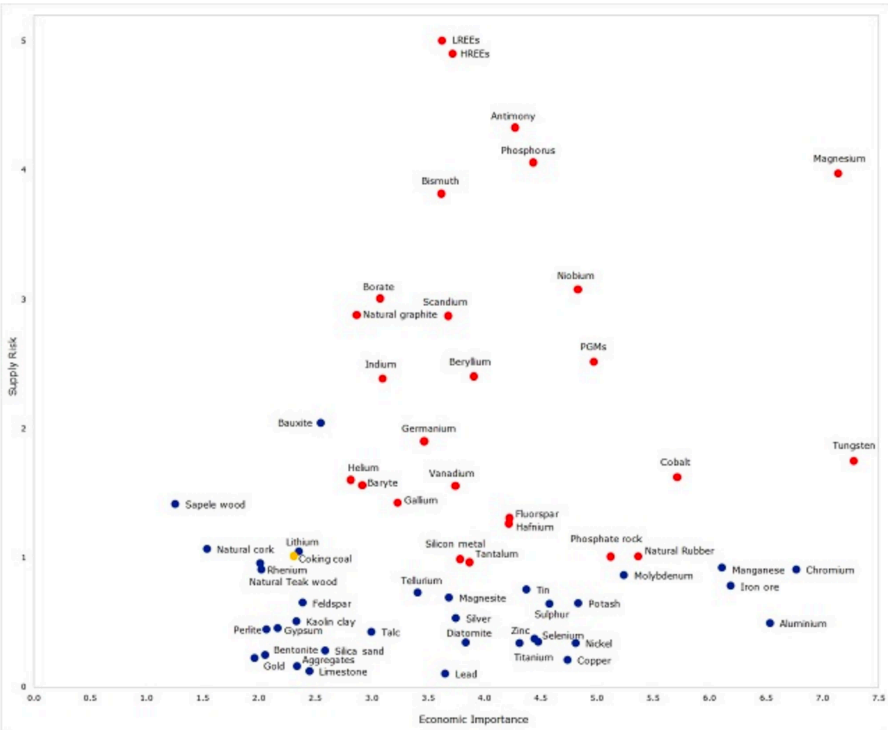
These percentages of mineral production differ from the percentages in fertilizer nutrients use, which are about 60 % N and 20% P & K, but the unit is not the same.

For the BRGM (Géosciences N°125-2012) mineral raw materials, which are critical for the EU economy, do not include N, P, K!



But the European Commission published in 2017 the list of critical raw materials = CRM = Antimony, Beryllium, Borates, Cobalt, (Coking Coal), Fluorspar, Gallium, Germanium, Indium, Magnesium, Natural Graphite, Niobium, Phosphate Rock, Silicon Metal, Tungsten, Platinum Group Metals, Light Rare Earths and Heavy Rare Earths, Baryte, Bismuth, Hafnium, Helium, Natural Rubber, Phosphorus, Scandium, Tantalum, and Vanadium.

Raw materials	**Main global producers (average 2010-2014)**	**Main importers to the EU (average 2010-2014)**	**Sources of EU supply (average 2010-2014)**	**Import reliance rate***	**Substitution indexes EI/SR****	**End-of-life recycling input rate*****
Phosphate rock	China (44%) Morocco (13%) United States (13%)	Morocco (31%) Russia (18%) Syria (12%) Algeria (12%)	Morocco (28%) Russia (16%) Syria (11%) Algeria (10%) EU – Finland (12%)	88%	1.0 / 1.0	17%
Phosphorus	China (58%) Vietnam (19%) Kazakhstan (13%) United States (11%)	Kazakhstan (77%) China (14%) Vietnam (8%)	Kazakhstan (77%) China (14%) Vietnam (8%)	100%	0.91 / 0.91	0%



-Conclusion

As world population is assumed to increase up to 2050, the need for more food is essential and more food needs more fertilizer. The production forecast for the three nutrients N, P, K is very important.
But it appears that N, P, K historical production data are incomplete and unreliable (confusing rock and equivalent, mineral and product).
Available production data on the web are USGS, BGS and NRCan annual reports, but no historical synthesis.
As for reserves, only USGS offers annual estimates since 1996, but confusing reserves and reserve base. A huge jump (about 10 times) on Morocco phosphate reserves is doubtful and not justified by past production data and comparison with other mineral distributions by country.

There are many confusions between nitrogen, phosphate and potash mineral production (extraction) and nitrogen, phosphate and potash fertilizer production (making).
World agencies and universities should spend more time and budget on the subject.
It is a shame to find confused and incomplete past data and few forecast syntheses.

In the past fertilizers were badly used, leading to pollution (green algae in the seas). The situation has improved, but the ratio of the three nutrients varies with regions, when it should be more stable per hectare.

It is hard to assess N, P, K ultimates, but Hubbert linearization appears to be a good tool as to assess fossil fuels ultimates, as there are no published reliable geological studies.
National geological surveys are not carrying their duties!

My estimates of N, P, K ultimates are from HL of past production data, but there are questionable, and the future production leads to problems beyond 2030.

I will appreciate receiving comments on my work, and I hope that more universities will try to do the same, as I doubt that any official agency in the present politically correct funding will work on peak nitrogen, peak phosphorus and peak potash.
Wikipedia has a "peak phosphorous" site, because several studies were carried out on peak phosphorus, but none on "peak potassium" or "peak nitrogen"
These peaks will occur, but when?
That is the question!
And there is no answer on the web!
What are the university students doing?
What are the university professors planning?

NB: sorry for my broken English