An investigation on the factors of phosphorus demand in approximating

PEAK PHOSPHORUS

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Word count: 4000

Abstract:

Phosphorus is an element crucial for food production. Since the global population explosion from 1950 and beyond, the demand for food has grown proportionally and with it; the demand for phosphorus. While for a long time artificial fertilizer was seen upon as the ultimate problem-solver to this issue, new investigations show that the global supply of phosphate is dissipating. Soon, we are expected to hit *Peak Phosphorus*, which occurs when half of the world reserves are still in the ground. This will mark the point where food prices will soar, as phosphorus is non-renewable and without substitutes. Our option is to recognize the time-line, followed by large-scale innovation and recycling to minimize our dependency. In light of the previous, this investigation asks:
"***When, if assessing the main factors of increasing Phosphorus demand, can Peak Phosphorus be estimated to occur?"***
With a hypothesis expecting a number prior to 2040 – a number chosen with respect to several sources. The investigation identified three major aspects of phosphorus demand; the rising global population, the increase in meat consumption due to rising GDP, and the rise of biofuel productions. Using a large array of sources, and with data collected from UN, IFA, EFMA, FAO and other independent researchers and less known organizations, each of these three factors were estimated between 2008 and 2050.When all the calculations had been entered into tables, it was possible to conclude that these three factors alone allow for a *Peak Phosphorus* prediction before 2042. While this required the author to ultimately reject the original hypothesis, it was evaluated that other unaccounted-for factors such as fish and dairy demand will indeed confirm the original assumption in due course.

The investigation finally repeats the necessity of technological advances and recycling, as well as substantial societal reform, in hope of avoiding *Peak Phosphorus*.

Word count: 300

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I would like to thank my father for introducing me to this topic of extreme importance, and for giving me the correct tools and advice to undertake the task of writing an essay on it.

Thanks to my brothers, Lars and Mikhail, who helped me in performing the endless calculations required. Their assistance was essential.

I would like to thank Knut Røed from YARA in assisting me in obtaining price and consumption data for the Norwegian market in recent years, even though I eventually rewrote my research question, rendering them sub-optimal for the investigation.

I would also like to give a great thanks to Dana Cordell, whom supported me with several useful links and tips, invaluable for the essay. I hope that some of her vast knowledge on the subject is reflected in this piece of writing.

Thanks to Per Magne Eidet, my IB economics teacher, for supervising this Extended Essay, catching me whenever I began to digress in my writing.

Finally, a great thanks to Nicholas Johansson for reading my EE and critically comment on it.

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1 Introduction

"Phosphate is a crucial component of DNA, RNA, ATP, and other biologically active compounds. (…) humans cannot exist without it. (…) But resources are limited, and phosphate is being dissipated. Future generations ultimately will face problems in obtaining enough to exist."

- Philip H. Abelson, Science, 26 March, 1999

"There are no substitutes for phosphorus in agriculture."

- U.S. Geological survey, Mineral Commodity Summaries, January 2007

The above quotes illustrate the human dependency on phosphorus, one of the three basic elements in artificial (NPK) fertilizer[1], and the crucial situation modern society will face if our scarce amount of the un-renewable resource were to run out.

However, while the complete depletion of phosphorus – a crucial element in food production - is not a situation of the immediate future, the world is soon expected to hit a "production peak", which occurs when half of the resource base is still imbedded in rock. Beyond this point, production costs will sharply rise and thereby hamper global food production. Estimating the occurrence of this peak is crucial for securing and sustaining global food security.

1.1 The Situation of Phosphorus

Phosphorus is an element required for cellular growth, and subsequently the production of food is utterly dependant on it. It is a resource found in rock, whereas 90% is located in no more than five countries[2]. Since the green revolution of the 1950's the demand for mined phosphate has steeply and steadily increased due to the surge in the global population[3]. Simultaneously an increasing proportion of the world's farmers are required to utilize artificial fertilizer in order to feed us.

In the agricultural history of man, phosphorus and other minerals has been naturally recycled by a circular process of ingestion and excretion on local land. However, urbanization and modernization now sees crop and meat products sent to, and consumed in, urban centers. Here, along with the phosphorus in it, these products are now ending up on the ocean floors; the final stop of our sewage systems. For a successful crop next season, farmers will tend to regulate the lessening soil concentration by using NPK fertilizer.

The global phosphate production peak marks where demand will outpace supply, which is where the price for food will consequently steepen. The FAO estimates current low-cost rock reserves to equal 12 000 million tons[4]. In 2008, the global demand for phosphate was 140 million[5].

[1] Dêry, Patrick and Anderson, Bart. "Peak phosphorus": Energy bulletin.
[2] Elser, James and White, Stuart. "Peak phosphorus": Foreign Policy
[3] Elser, James and White, Stuart. "Peak phosphorus": Foreign Policy
[4] "Use of Phosphate Rock for Sustainable Future"; FAO.
[5] Von Horn, J., and C. Sartorius. *Impact of Supply and Demand on the Price Development of Phosphate (fertilizer)*. Publication. Fraunhofer Institute Systems and Innovation Research, 2009.

1.2 Goal

It is highly relevant to investigate if economic theory can make reasonable predictions of Peak Phosphorus. The imminent crisis facing the global society can only be avoided if our present and future consumption can be measured. The results would allow us to appreciate at what pace we must innovate and minimize dependency in order to achieve global food security.

The following research question and hypothesis has been designed to investigate if phosphorus demand can be measured in the years to come. If so it will be used to approximate Peak Phosphorus.

Research Question:

When, if assessing the main factors of increasing Phosphorus demand, can Peak Phosphorus be estimated to occur?

Hypothesis:

An investigation on the growth of Phosphorus demand will allow for a prediction of Peak Phosphorus within 2040[6].

The goal of this investigation is to see if the above Research Question and Hypothesis holds, therefore seeing if the role of consumer demand is measurable. As the investigation will only use numbers prior to the peak, little attention will be given to global phosphate supply.

1.3 Approach

The research question will be attempted answered by assessing a range of both primary and secondary sources in order to investigate the most important determinants on phosphorus demand. As these factors are analyzed, they will be combined to gradually form a clear and coherent picture on how the finite phosphorus supply will diminish, and when.

The three major impacts on near-future demand, according to J.von Horn and C. Sartorius[7], is;

- Population growth
- GDP per capita growth
- Increased Agro-fuel production

(As a delimitation, no other factors of increasing demand will be considered. This will be commented on in section 4.2)

These factors will be analyzed from an economic perspective in section 2, and their impact investigated in section 3. A conclusion will be attempted in section 4, along with an evaluation in relation to sources of error. The investigative range is set between 2008 and 2050.

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[6] A number chosen in relation to the following source: Elser, James and White, Stuart. "Peak phosphorus": Foreign Policy – AND, in relation to unofficial conversations between the author and Dana Cordell (PhD).

[7] Von Horn, J., and C. Sartorius. *Impact of Supply and Demand on the Price Development of Phosphate (fertilizer)*. Publication. Fraunhofer Institute Systems and Innovation Research, 2009.

1.4 Assumptions of Market Situation

(a) The price mechanism will be in effect:

This investigation will assume that the increased demand of phosphorus will create an increase in price. The signal and incentive functions will be at work, allowing supply to increase and hence fulfill society's need up until *Peak Phosphorus*. This will allow us to dismiss supply as a factor of quenching global demand up until the estimated peak.

(b) No excess efficiency or innovation:

Today, much of the arable land is already used in food production[8], meaning that increased demand for food will to a large extent require increased efficiency and technological innovation. Increased use of NPK fertilizer is on many markets such an advance. This investigation will assume that such progress will take place. This investigation will though also assume that no additional innovative initiatives are taken besides those necessary for allowing demand fulfillment.

(c) Phosphorus supply is fixed:

The investigation will assume that phosphorus reserves remain at 12 000 million tons[9]. I.e; no additional low-cost phosphate sources are located, nor does any technological advances makes any additional phosphate sources low-cost up until 2050 (range of investigation).

(d) All phosphorus production is used in agriculture:

The number is ≈90%, however[10], for simplicity of calculation, it will be assumed that all phosphate production is used in fertilizer. The resulting weaknesses in measurements are discussed in section 4.2.

[8] Elam, Thomas, E."Projections of Global Meat Production Through 2050"; FarmEcon.
[9] "Use of Phosphate Rock for Sustainable Future"; FAO.
[10] "Phosphorus essential element for food production"; EFMA.

2 Economic Theory

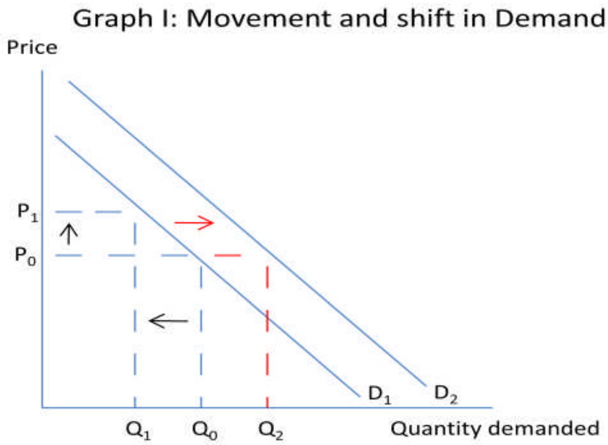
This Extended Essay will require knowledge on several aspects of the Economics curriculum. Section 2 will define demand, and from there analyze the key determinants on phosphorus demand, as mentioned in section 1.3. Below this additional key terminology will be briefly explained for the purpose of coherent understanding of the logic and approach.

2.1 Demand

Demand is a hypothetical measurement of society's willingness and ability to acquire a good at a certain price. The law of demand states that; "*Ceteris Paribus, a change in price will lead to a change in quantity demanded*"[11]. The distinctive shape of a regular demand curve exhibits the trait of having a negative correlation between price and quantity demanded. This makes intuitive sense, as an increase in price of a good will in but-all cases mean a smaller quantity demanded by the market. The opposite also holds true[12].

2.2 Determinants of Demand

While a change in price will cause a movement along the demand curve, causing a new quantity to be desired by the market, any non-price determinant of demand will cause the curve to "shift"[13]. Each of the following shift factors correspond to an aspect which is to be investigated (see section 1.3).



2.2.1 Size of the market[14]

The UN estimates a population growth of approximately 2.5 billion people within 2050 in their medium-variant projection[15]. For all humans, nutrition is the most basic requirement for survival, meaning that the demand for phosphorus will be affected strongly.

[11] McGee, Matt. "Economics – in Terms of the Good, the Bad, and the Economist"; pg. 56 (2009)
[12] Illustrated by graph: (P0,Q0) and (P1, Q1)
[13] Illustrated by graph: The shift creates curve D2. At D2, P0 = Q2.
[14] Ziogas, Constantine. "Economics for the IB diploma"; pg.9 (2008)
[15] Elam, Thomas, E."Projections of Global Meat Production Through 2050"; FarmEcon.

2.2.2 Change in consumers' income[16]

The investigation will attempt to map the effect as GDP per capita increases between modern day and 2050. There are opinions that agricultural goods are *inferior* to meat products.[17] (yED explained in section 2.3) This means that as consumer sovereignty tends to grow, farm products will be substituted in favor of meat. In precise terms; demand for meat will grow. This is highly relevant for our investigation as meat not only contains half the phosphorus of wheat[18], but it also takes three times it own weight in grain to theoretically make[19]. The result is an increase in indirect demand for phosphorus.

2.2.3 Change in preferences (tastes)[20]

The unprecedented focus on environmental issues over the last couple of years, coupled with the steady increase in the price for oil, has spawned a new way of thinking towards carbon neutrality and created a new demand for oil-substitutes. The business of bio-fuels is one such response. The production of bio-fuels not only raises ethical questions as the crops used are potential sources for food, it now also gives light to the second question if increasing amounts of phosphorus should be diverted into this new sector when scarcity is such a pressing matter.

2.3 Additional Economic terminology

Income elasticity of demand (yED)[21]*;*

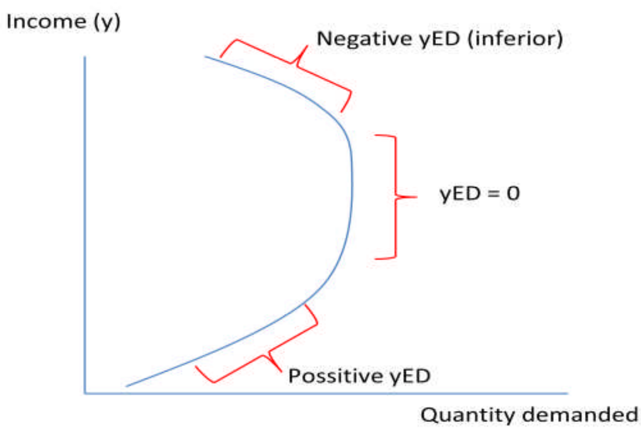
Is a measurement of the change in quantity demanded of products in relation to a change in consumer income. A good which demand is in positive correlation with income is termed a *normal* good. A good with a yED between 0 and 1 is termed income inelastic. An income elastic good has a yED more than 1. A good which demand is negatively correlated with income is deemed *inferior*.

The formula for measuring yED can be written as:

$$yED = \frac{\%\Delta \ in \ Qd}{\%\Delta \ in \ y}$$

In relation to the graph, it is suggested as individuals become richer they will first stop buying more, and ultimately buy less, grain.

Graph II: yED of inferior good (wheat)



[16] Ziogas, Constantine. "Economics for the IB diploma"; pg.9 (2008
[17] Swick, Robert A. "Supply and Demand of raw materials: Are they in balance?"; Agrenco Group.
[18] "Phosphorus essential element for food production"; EFMA
[19] "The Environmental Food Crisis"; UNEP
[20] Ziogas, Constantine. "Economics for the IB diploma"; pg.9 (2008
[21] Ziogas, Constantine. "Economics for the IB diploma"; pg.18 (2008)

Gross Domestic Product (GDP), nominal and corrected for inflation;
"Is an account of the money value of goods and services produced within an economy"[22], usually calculated on a yearly basis. GDP is a measurement of a geographical entity's (country) economic well-being, and is used among other things to rank countries according to this perceived standard of living. GDP measurements can be nominal, or real, i.e corrected for inflation; being a sustained increase in the general price level[23]. When the growth of GDP is discussed in this essay, predicted <u>nominal</u> values are presented. Therefore, true consumer sovereignty will by all predictions in truth be less, as inflation – in healthy economies – increases by a certain percentage each year.

[22] McGee, Matt. "Economics – in Terms of the Good, the Bad, and the Economist"; pg. 314 (2004)
[23] McGee, Matt. "Economics – in Terms of the Good, the Bad, and the Economist"; pg. 297 (2009)

3 Market Investigation

The execution of this investigation will be conducted in three parts, each assessing a single of the three major determinants of phosphorus demand (Section 1.3). As the effect of each individual determinant is approximated, they will be added to estimate *Peak Phosphorus*. While the amount of profitable phosphate reserves vary greatly according to different sources, this investigation will use the FAO data from 2004 stating that world reserves are at approximately 12 000 million tons[24]. For simplicity in relation to other sources, this number will be accounted as true as of 2008. This decision will be commented on in section 4.2; sources of error.

3.1 Peak Phosphorus at current consumption

In 2008, sustaining approximately 6.7 billion people[25], the world demand for phosphorus was 140 million tons[26] for one year. Using the assumptions of this essay, *Peak Phosphorus* at current consumption can be calculated by taking the world reserve's *half-life (=half of existing resources, which is the peak)* and divide by current consumption:

$$years\ until\ Peak = \frac{6000\ million\ tons}{140\ million\ {}^{tons}/_{year}}$$

$$years\ until\ Peak \approx 43$$

This means that off 2008, at current levels of consumption, *Peak Phosphorus* will occur in 2051 $(2008 + 43)$. The following investigation will include several factors into this estimation, making it a closer reality.

3.2 The effect of population growth

Two aspects are important when measuring global population growth: Firstly, by 2050, the UN estimates that there will be over 2.5 billion more mouths to feed[27]. Secondly, it is estimated that the population growth will occur in low developed countries only[28]. The increase in population in Europe and America is to happen solely due to net immigration.[29]

For the first investigative approach of this essay, it will be attempted to estimate how much more phosphate rock is necessary to produce to feed the rising population. This first attempt will assume that all additions to the world population will only be feed enough for basic food security, which EFMA (European Fertilizer Manufacturer Association) estimates as 1.6g of phosphorus a day. [30]

[24] "Use of Phosphate Rock for Sustainable Future"; FAO.
[25] UN press release. "World population to exceed 9 billion by 2050". (2009)
[26] Von Horn, J., and C. Sartorius. *Impact of Supply and Demand on the Price Development of Phosphate (fertilizer)*. Publication. Fraunhofer Institute Systems and Innovation Research, 2009.
[27] Elam, Thomas, E."Projections of Global Meat Production Through 2050"; FarmEcon.
[28] "Linking population, poverty and development", UNFPA
[29] UN press release. "World population to exceed 9 billion by 2050". (2009)
[30] "Phosphorus essential element for food production"; EFMA;

To find this number, one must multiply the amount of P necessary for basic nutrition with population increase (Δpop). This then needs to be multiplied to reflect a year contrary to a single day, and finally multiplied by 5 as the "mine to farm to fork" efficiency of phosphorus is estimated at a mere 20%.[31] Meaning; an amount X demanded will require a mining of 5X.

The formula:

$$Additional\ phosphate\ rock\ required\ for\ year\ X\ (Mt) = \frac{(1.6g \times\ \Delta pop \times 365 \times 5)}{10^6}$$

When this is added to the amount already produced that year, we get the total production. By adding total productions from year 2008 until 2050, we can estimate the minimal increase in phosphate production necessary for sustaining the global production. By creating a table, it can be verified if the hypothesis holds. For the full table, please see Appendix A.

Table 1: Increasing population's effect on phosphorus (basic food security)

Year	Population (mill)	P mined for existing pop (Mt)	Population growth (mill)	P mined for additional pop (Mt)	P mined for total pop (Mt)	Total P mined since base year (2008) (Mt)
2008	6680	139 790	72.0	210,2	140 000	140 000
2009	6752	140 000	71.2	207,9	140 208	280 208
2010	6824	140 208	70.8	206,7	140 415	420 623
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2046	8940	146 389	42.5	124,1	146 513	5 598 268
2047	8983	146 513	41.5	121,2	146 635	5 744 902
2048	9024	146 635	40.5	118,3	146 753	5 891 655
2049	9065	146 753	39.5	115,3	146 868	6 038 523
2050	9104	146 868	38.5	112,4	146 981	6 185 504

This investigation assumes that there exist 12 000 billion tons of profitable phosphate rock[32]. *Peak Phosphorus* occurs when half of the resource is still un-mined. Therefore, by locating the year where production has exceeded 6 000 million tons, we will have our peak (colored in table).

By using the table above, it is suggested that *Peak Phosphorus* will occur between 2048 and 2049. This means that under the current assumptions, the hypothesis does not hold as *Peak Phosphorus* will not appear prior to 2040.

[31] "Scarcity of Phosphorus Threat to Global Food Production"; Sciencedaily.
[32] "Use of Phosphate Rock for Sustainable Future"; FAO.

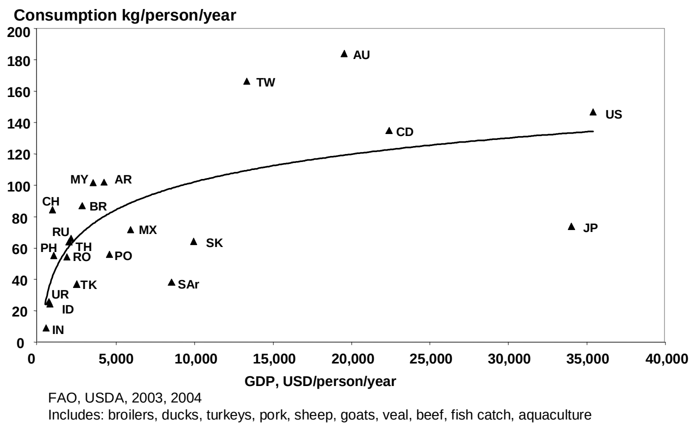
3.3 The effect of increasing meat consumption

GDP per capita is estimated to have an explosive growth in the following decades[33]. The effect of such a growth in GDP will be investigated below. The noteworthy point when assessing the importance of increased consumer sovereignty with the depletion of phosphorus is that it is primarily not because we will eat more; but rather what we will eat. The human stomach's capacity is fixed, but depending on what ends up in it, the demand of phosphorus will vary immensely [34]. As written in section 2.2.3, meat products are expected to substitute wheat and other agricultural good as income increases, making them inferior. Entering the consumption numbers presented by Dr. Thomas E. Elam[35] into the yED formula, it can be assessed how a 1% increase in GDP per capita affects meat consumption as a global average.
Formula:

$$yED = \frac{\%\Delta \text{ in } Qd}{\%\Delta \text{ in } y} = \frac{0{,}76\%}{1\%} = 0{,}76$$

0,76 means that globally, meat is consumer inelastic. However, the fact that it is a global average makes a point of interest. Quoting Matt McGee; "*Quite naturally, income elasticities will vary (…) between high and low income countries."*[36] Robert A. Swick created a graph using data from FAO illustrating how meat consumption changes with income. [37]

Figure 1. Meat and Fish Consumption by Per Capita GDP



The graph shows that at lower levels of initial income, increase in meat consumption due to an increase in income will be greater. At a high level of GDP per capita, meat consumption becomes increasingly inelastic to change. This essay will therefore conclude that the global yED average does not make for an intuitive obvious understanding. Instead, it will be stated that the income elasticity of meat varies almost from infinity (vertical) to 0 (horizontal) as suggested by the graph, and that there therefore will be a high correlation between meat's elasticity and the country is question, primarily if it is deemed a LDC or a MDC.

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[33] Elam, Thomas, E."Projections of Global Meat Production Through 2050"; FarmEcon.
[34] Elam, Thomas, E."Projections of Global Meat Production Through 2050"; FarmEcon.
[35] Elam, Thomas, E."Projections of Global Meat Production Through 2050"; FarmEcon.
[36] McGee, Matt. "Economics – in Terms of the Good, the Bad, and the Economist"; pg. 118 (2009)
[37] Swick, Robert A. "Supply and Demand of raw materials: Are they in balance?"; Agrenco Group.

Between 2006 and 2050, the world's GDP is expected to more than triple[38]. During the same period of time, world average GDP per capita is expected to double.[39] However, it is by far the developing world which will witness the strongest growth. The growth will open up entirely new markets for meat and dairy products, and it is also worth mentioning that some of the nations with the strongest expected growth are the countries with the world's highest population, amplifying the situation. The following table illustrates the extreme projected GDP growth in a selection of countries:

Table 2: GDP per capita (nominal) [2006-2050][40] – selected countries

Country	*2006*	*2010*	*2015*	*2020*	*2025*	*2030*	*2030*	*2040*	*2045*	*2050*
China	2,041	3,463	5,837	8,829	12,688	17,522	23,511	30,951	39,719	49,650
India	817	1,061	1,492	2,091	2,979	4,36	6,524	9,802	14,446	20,836
Vietnam	655	1,001	1,707	2,834	4,583	7,245	11,148	16,623	23,932	33,472
Bangladesh	427	510	627	790	1,027	1,384	1,917	2,698	3,767	5,235

Swick estimates that at $10 000 GDP per Capita, the average citizen will consume 100kg of meat in a year[41]. If one takes the GDP data from table 2 and investigate its intercept in figure 1, India will show a 500% increase in meat consumption by 2050. Vietnam will do the same. Due to the inefficiency of producing meat in terms of land, water and phosphorus, it seems logical that such an increase will have a relevant impact on the world's phosphate supply.

When creating a table to estimate meat's effect on Peak Phosphorus, the investigation will use data with five-year gaps. These gaps will be filled in with the assumption that the increase from each year within each five year period is constant. The meat-phosphorus relationship will look as such:

$$Phosphate\ mined\ due\ to\ \Delta meat\ (Mt) = \frac{(\Delta meat \times 3 \times 7.8 \times 5)}{10^6}$$

Any increased meat production (in million kg) is multiplied by 3 to convey its weight in wheat[42]. Then it is multiplied by 7.8 to be converted to the amount of phosphorus in this amount of grain (in grams)[43]. Then, the mine-farm-fork deficiency of a factor 5 must be included. It is divided to display a value in million tons. For the full table, please see Appendix B. Note that the existing phosphorus demand for each year reflects results from the previous table.

[38] "Sustainable consumption: Facts and Trends"; *World Business Council for Sustainable Development.*
[39] Elam, Thomas, E."Projections of Global Meat Production Through 2050"; FarmEcon.
[40] Wilson, Dominic and Stupnytska, Anna. "The N-11: More than an acronym" [table by Wikipedia – source: 5.6]
[41] Swick, Robert A. "Supply and Demand of raw materials: Are they in balance?"; Agrenco Group.
[42] The Environmental Food Crisis"; UNEP
[43] "Phosphorus essential element for food production"; EFMA.

Table 3: Increased meat consumption due to rise in GDP (2008-2050)

Year	GDP per capita in $ (2000)	Extra meat produced compared to 2008(Mt)	P mined for extra meat (Mt)	Existing P mined that year (Mt)	Total mined that year (Mt)	Total mined since base year (2008) (Mt)
2008	5923	0	0	140 000	140 000	140 000
2009	6013	4	468	140 208	140 676	280 676
2010	6103	16,2	1 895	140 415	142 310	422 986
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2040	9654	253,2	29 624	145 734	175 359	5 192 802
2041	9807	262,2	30 677	145 871	176 548	5 369 349
2042	9960	271,3	31 742	146 004	177 746	5 547 095
2043	10117	280,3	32 795	146 135	178 930	5 726 025
2044	10267	289,4	33 860	146 263	180 123	5 906 148
2045	10420	298,4	34 913	146 389	181 302	6 087 450
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The effect of increased meat consumption will draw *Peak Phosphorus* closer with approximately 5 years. However, even though the peak is now estimated in the period of 2044/45, the hypothesis still does not hold. The factors of demand are still not severe enough to pull *Peak Phosphorus* into the 2030's.

3.4 The effect of increased demand for agro-fuel

Today, the ethanol + biodiesel business comprises 40 million liters a year.[44] By 2030, the business is expected to see an explosive growth, reaching 300 million[45]. For simplicity, the annual growth will be assumed constant (see section 4.2). From 2030 to 2050, no official projections were found; therefore the investigation will assume that the growth will continue at this level. If this assumption is unrealistic will be commented on in section 4.2

IFA's consumption data[46] shows a relationship between phosphate and fertilizer at 24%. However, by comparing data between IFA's phosphate consumption and numbers on phosphate production, we can identify a deficiency of 3.51 (mine-farm). As a result, any amount of NPK must be multiplied by 0.8424 (0.24x3.51) to display the parallel phosphorus demand.

[44] Msangi, Siwa, Timothy Sulser, Mark Rosegrant, Rowena Valmonte-Santos, and Claudia Ringler.*Global Scenarios for Biofuels: Impacts and Implications*. Publication. International Food Policy Research Institute.
[45] Von Horn, J. and C. Sartorius. *Impact of Supply and Demand on the Price Development of Phosphate (fertilizer)*. Publication. Fraunhofer Institute Systems and Innovation Research, 2009.
[46] IFA: P_2O_5 consumption/production data: http://www.fertilizer.org/ifa/ifadata/results {accessed May 5th/ 10}

The demand in 2030 and the consumption since 2008 (assuming the other previous parts of the investigation as present) will have the relevant aspects displayed next. For the full table, please see Appendix C and D. Following, the demand up until 2050 and its impact on phosphorus supply will be illustrated.

Table 4: Increased agro-fuel demand (2008-2030)

Year	Increased demand for agrofuel (MT)	NPK necessary for increased agrofuel demand (Mt)	Phosphorus necessary for NPK demand (Mt)	Existing P demand (table 2) (Mt)	Total P demand that year (Mt)	Total P consumption since base year (Mt)
2008	0	0	0	140000	140000	140000
2009	11820	941,8	793	140676	141469	281469
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2029	248220	19777,8	16653	162703	179356	3510537
2030	260040	20719,6	17446	163817	181263	3691800

Table 5: Continuous growth in agro-fuel demand (2030-2050)

Year	Increased demand for agrofuel (since 2030) (Mt)	Increased demand for agrofuel (since 2008) (Mt)	NPK necessary for increased agrofuel demand (Mt)	Phosphorus necessary for NPK demand (Mt)	Existing P demand (table 2) (Mt)	Total P demand that year (Mt)	Total P demand since base year (2008) (Mt)
2030	0	260 040	20 720	17 455	163 817	181 263	3 691 800
2031	11 820	271 860	21 662	18 248	164 966	183 214	3 875 014
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2041	130 020	390 060	31 080	26 182	176 548	202 730	5 814 341
2042	141 840	401 880	32 022	26 975	177 746	204 721	6 019 062
…………….	…………….	…………….	…………….	…………….	…………….	…………….	…………….
…………….	…………….	…………….	…………….	…………….	…………….	…………….	…………….
2049	224 580	484 620	38 614	32 529	186 098	218 627	7 507 664
2050	236 400	496 440	39 556	33 322	187 287	220 609	7 728 273

Even with a continuous increase in agro-fuel demand beyond 2030, *Peak Phosphorus* is not estimated prior to 2040, disproving the hypothesis.

4 Evaluation

The investigation has assessed and estimated three determinants for phosphorus demand and their impact on the world phosphorus supply. Using the results, it will be verified if the hypothesis holds.

4.1 Conclusion

This essay set out to investigate if the demand for phosphorus could be estimated over time using three key determinants. The research question, asking if *Peak Phosphorus* could be estimated has been answered and it has been measured to occur in 2041/42. Since *Peak Phosphorus* is not estimated to occur prior to 2040, the hypothesis must be rejected. However, the essay has revealed that compared to present day consumption, total Phosphorus demand will (theoretically) increase by approximately 80 million tons a year by 2050; an increase more than 50%.

The investigation has shown that the increased meat consumption is the greatest obstacle to food security. Also, reviewing these results, it must not be forgotten the amazing meat consumption present worldwide already in 2008, which will amplify its effect over agro-fuel as a factor of *Peak Phosphorus*. In fact, a major source of error to this investigation is the lack of data collected on fish and dairy products. If such factors were included in the investigation, the estimated peak would probably have been pushed forward by several years.

Phosphorus needs to be recycled or the world's food security will be greatly threatened before mid-century. The first part of the investigation shows that a consumption pattern necessary for basic-food security will have a relatively mild impact on demand. In fact, only 6 million tons extra phosphate is required each year. This contrasts to the heavy impact of increased meat consumption, which will require approximately 33 million tons in the same time period. The developed world needs to see a substantial change in dietary behavior. Only if meat consumption were to decrease can long term food security be achieved through recycling. This essay will also conclude that the agro-fuel business should not see the growth which is projected for 2030, nor the growth personally projected by the author for 2050. Substitute goods such as electrical, hydrogen and hybrid technologies should be prioritized. Also, R&D by the public and private sector alike is crucial for improving technology and recycling strategies.

4.2 Sources of Error

The investigation has substantial areas of possible error and uncertainties, some of which will be discussed below. Approximately 90% of Phosphorus is used in fertilizer; however this essay has assumed this number at 100 (section 1.4(d)). This, along with the assumption of the mine-farm-fork deficiency at exactly 80%, will tamper with phosphorus production values. The phosphate necessary to be mined for any weight of meat was estimated by the author using a range of sources in compilation. The accuracy of this estimate is not proven.

Also, the world supply is assumed as constant (12 000 million tons), and the same goes for technology (section 1.4(b), which will most probably/hopefully prove wrong. The global supply is tampered with, as the global supply is assumed correct as of 2008; a deviation of four years. While this may mildly degrade the authenticity of the results, the weight of the individual factors will still reflect the same relative to each other.

It is noteworthy that neither fish nor dairy products have been included in the investigation. The impact of increased consumption in these sectors remains unknown. As mentioned in the conclusion, if we appreciate the massive consumption in such fields, it is factors which greatly underestimate the investigations estimation of *Peak Phosphorus*.

The author has decided to allow agro-fuel to see a continuous growth beyond 2030, a claim not backed up by any source. Also, the business in question would hardly see any continuous growth at all; more probably an increase in the form of an exponential function. This would make a steady increase beyond 2030 at the assumed level unrealistic. On the other hand, the rapid depletion of Phosphorus might just, and probably will, remove the tag of agro-fuels being a renewable resource, as its elementary ingredient is not.[47] This would diminish the odds of agro-fuel's ever reaching the estimated level of consumption.

4.3 Possible sources of improvements and extensions

The investigation can be improved in a number of ways. Most of the improvements mentioned will relate to the identified sources of error in the previous section.

The phosphate necessary for NPK fertilizer, for meat compared to wheat/grain production, and the losses of any mining, should be (and can be if one purchase memberships in relevant organizations) accurately calculated as this will have a major impact on the conclusive elements.

Other determinants of demand should be included in the investigation. As mentioned, fish and dairy has been left out due to lack of available data.

The price development of fertilizer due to decreasing supply may have a relevant impact in SR demand; a possible extension of this investigation. A notable starting point could be the 800% price shock which occurred in 06/08[48]. From this PED could be calculated (theoretically).

Recycling and technological advances could be simulated to investigate at what level and when our dependency may be deemed acceptable for global food security. This is a highly relevant continuation onto existing research.

[47] Lewis, Leo. "Scientists warn of lack of vital phosphorus as biofuels raise demand"; the times.
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5 Bibliography

The following works are in alphabetic order with respect to the information available – all sources except those found in 5.6 (Other sources) are formatted according to MLA standards. The dissertation (5.4) was used for background knowledge only and is not directly quoted in this essay.

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6 Appendices

Here are the full tables of primary interpreted data, in chronological order relative to their appearance in the main essay.

6.1 Appendix A: *Population increase as a factor of phosphorus demand.*

Year	Population (mill)	Phosphate mined for existing pop. (in thousand tons)	population growth (mill)	Phosphate mined for additional pop. (in thousand tons)	Phosphate mined for total population (in thousand tons)	Total phoshate mined since base year (2008)
2008	6680	139 790	72.0	210,2	140 000	140 000
2009	6752	140 000	71.2	207,9	140 208	280 208
2010	6824	140 208	70.8	206,7	140 415	420 623
2011	6894	140 415	70.6	206,2	140 621	561 243
2012	6965	140 621	70.5	205,8	140 827	702 070
2013	7036	140 827	70.2	205	141 032	843 102
2014	7106	141 032	69.9	204,1	141 236	984 337
2015	7176	141 236	69.6	203,2	141 439	1 125 776
2016	7245	141 439	69.2	202	141 641	1 267 417
2017	7314	141 641	68.5	200	141 841	1 409 258
2018	7383	141 841	67.9	198,3	142 039	1 551 297
2019	7451	142 039	67.1	195,9	142 235	1 693 532
2020	7518	142 235	66.4	193,9	142 429	1 835 961
2021	7584	142 429	65.5	191,3	142 620	1 978 582
2022	7650	142 620	64.6.	188,6	142 809	2 121 390
2023	7714	142 809	63.6	185,7	142 995	2 264 385
2024	7778	142 995	62.6	182,8	143 177	2 407 562
2025	7841	143 177	61.7	180,2	143 358	2 550 920
2026	7902	143 358	60.9	177,8	143 535	2 694 455
2027	7963	143 535	60.0	175,2	143 711	2 838 166
2028	8023	143 711	59.1	172,6	143 883	2 982 049
2029	8082	143 883	58.1	169,7	144 053	3 126 102
2030	8140	144 053	57.2	167	144 220	3 270 322
2031	8198	144 220	56.3	165,4	144 385	3 414 707
2032	8254	144 385	55.3	161,5	144 547	3 559 254
2033	8309	144 547	54.3	158,6	144 705	3 703 960
2034	8363	144 705	53.2	155,3	144 861	3 848 820
2035	8417	144 861	52.3	152,7	145 013	3 993 834
2036	8469	145 013	51.4	150,1	145 164	4 138 997
2037	8520	145 164	50.4	147,2	145 311	4 284 308
2038	8571	145 311	49.3	144	145 455	4 429 763
2039	8620	145 455	48.3	141	145 596	4 575 358
2040	8668	145 596	47.5	138,7	145 734	4 721 093
2041	8716	145 734	46.6	136,1	145 871	4 866 963
2042	8763	145 871	45.7	133,4	146 004	5 012 967
2043	8808	146 004	44.8	130,8	146 135	5 159 102
2044	8853	146 135	44.0	128,5	146 263	5 305 365
2045	8897	146 263	43.2	126,1	146 389	5 451 754
2046	8940	146 389	42.5	124,1	146 513	5 598 268
2047	8983	146 513	41.5	121,2	146 635	5 744 902
2048	9024	146 635	40.5	118,3	146 753	5 891 655
2049	9065	146 753	39.5	115,3	146 868	6 038 523
2050	9104	146 868	38.5	112,4	146 981	6 185 504

6.2 Appendix B: *Increased meat consumption as a factor of phosphorus demand.*

Year	GDP per capita in $ (2000)	Extra meat produed compared to base year; (2008) (1000 tons)	Phosphorus mined for extra meat (1000 tons)	Existing phosphorus mined that year (1000 tons)	Total mined that year (1000 tons)	Total mined since base year
2008	5923	0	0	140 000	140 000	140 000
2009	6013	4	468	140 208	140 676	280 676
2010	6103	16,2	1 895	140 415	142 310	422 986
2011	6200	23,2	2 714	140 621	143 335	566 321
2012	6297	30,2	3 533	140 827	144 360	710 681
2013	6394	37,1	4 341	141 032	145 372	856 053
2014	6491	44,1	5 160	141 236	146 395	1 002 449
2015	6588	51,1	5 979	141 439	147 418	1 149 866
2016	6693	58,5	6 845	141 641	148 485	1 298 352
2017	6797	66	7 722	141 841	149 563	1 447 915
2018	6902	73,4	8 588	142 039	150 627	1 598 542
2019	7006	80,9	9 465	142 235	151 700	1 750 242
2020	7111	88,3	10 331	142 429	152 760	1 903 002
2021	7224	96,1	11 244	142 620	153 864	2 056 866
2022	7337	103,8	12 145	142 809	154 954	2 211 820
2023	7450	111,6	13 057	142 995	156 052	2 367 872
2024	7563	119,3	13 958	143 177	157 136	2 525 007
2025	7676	127,1	14 871	143 358	158 228	2 683 235
2026	7798	135,2	15 818	143 535	159 354	2 842 589
2027	7920	143,3	16 766	143 711	160 477	3 003 066
2028	8042	151,3	17 702	143 883	161 585	3 164 651
2029	8164	159,4	18 650	144 053	162 703	3 327 354
2030	8286	167,5	19 598	144 220	163 817	3 491 171
2031	8417	175,9	20 580	144 385	164 966	3 656 137
2032	8549	184,3	21 563	144 547	166 110	3 822 247
2033	8680	192,7	22 546	144 705	167 251	3 989 498
2034	8812	201,1	23 529	144 861	168 389	4 157 887
2035	8943	209,5	24 512	145 013	169 525	4 327 412
2036	9085	218,4	25 553	145 164	170 716	4 498 129
2037	9227	227,4	26 606	145 311	171 917	4 670 045
2038	9370	236,3	27 647	145 455	173 102	4 843 147
2039	9512	245,3	28 700	145 596	174 296	5 017 443
2040	9654	253,2	29 624	145 734	175 359	5 192 802
2041	9807	262,2	30 677	145 871	176 548	5 369 349
2042	9960	271,3	31 742	146 004	177 746	5 547 095
2043	10117	280,3	32 795	146 135	178 930	5 726 025
2044	10267	289,4	33 860	146 263	180 123	5 906 148
2045	10420	298,4	34 913	146 389	181 302	6 087 450
2046	10586	307,6	35 989	146 513	182 503	6 269 953
2047	10751	316,8	37 066	146 635	183 700	6 453 653
2048	10917	326,1	38 154	146 753	184 907	6 638 560
2049	11082	335,3	39 230	146 868	186 098	6 824 658
2050	11248	344,5	40 307	146 981	187 287	7 011 945

6.3 Appendix C: *Increased bio-fuel production as a factor of phosphorus demand (08-30).*

Year	Increased demand for agrofuel (1000 tons)	NPK necessary for increased agrofuel demand (1000 tons)	Phosphorus necessary for NPK demand (1000 tons)	Existing phosphorus demand (table 2) (1000 tons)	Total P demand that year (1000 tons)	Total P consumption since base year (1000 tons)
2008	0	0	0	140 000	140 000	140 000
2009	11 820	942	793	140 676	141 469	281 469
2010	23 640	1 884	1 586	142 310	143 896	425 365
2011	35 460	2 825	2 379	143 335	145 714	571 079
2012	47 280	3 767	3 172	144 360	147 532	718 611
2013	59 100	4 709	3 965	145 372	149 337	867 948
2014	70 920	5 651	4 758	146 395	151 153	1 019 102
2015	82 740	6 593	5 551	147 418	152 969	1 172 070
2016	94 560	7 534	6 344	148 485	154 829	1 326 900
2017	106 380	8 476	7 137	149 563	156 700	1 483 600
2018	118 200	9 418	7 930	150 627	158 557	1 642 157
2019	130 020	10 360	8 723	151 700	160 423	1 802 580
2020	141 840	11 302	9 516	152 760	162 276	1 964 856
2021	153 660	12 243	10 309	153 864	164 173	2 129 029
2022	165 480	13 185	11 102	154 954	166 056	2 295 085
2023	177 300	14 127	11 895	156 052	167 947	2 463 032
2024	189 120	15 069	12 688	157 136	169 824	2 632 855
2025	200 940	16 011	13 481	158 228	171 709	2 804 564
2026	212 760	16 952	14 274	159 354	173 628	2 978 192
2027	224 580	17 894	15 067	160 477	175 544	3 153 736
2028	236 400	18 836	15 860	161 585	177 445	3 331 181
2029	248 220	19 778	16 653	162 703	179 356	3 510 537
2030	260 040	20 720	17 446	163 817	181 263	3 691 800

6.4 Appendix D: *Increased bio-fuel production as a factor of phosphorus demand (30-50)*

Year	Increased demand for agrofuel (2030) (1000 tons)	Increased demand for agrofuel (2008) (1000 tons)	NPK necessary for increased agrofuel demand (1000 tons)	Phosphorus necessary for NPK demand (1000 tons)	Existing phosphorus demand (app. 5.3) (1000 tons)	Total P demand that year (1000 tons)	Total P consumption since base year (2008) (1000 tons)
2030	0	260 040	20 720	17 455	163 817	181 263	3 691 800
2031	11 820	271 860	21 662	18 248	164 966	183 214	3 875 014
2032	23 640	283 680	22 604	19 041	166 110	185 151	4 060 165
2033	35 460	295 500	23 545	19 835	167 251	187 086	4 247 251
2034	47 280	307 320	24 487	20 628	168 389	189 017	4 436 268
2035	59 100	319 140	25 429	21 421	169 525	190 946	4 627 215
2036	70 920	330 960	26 371	22 215	170 716	192 931	4 820 146
2037	82 740	342 780	27 313	23 008	171 917	194 925	5 015 070
2038	94 560	354 600	28 254	23 802	173 102	196 903	5 211 974
2039	106 380	366 420	29 196	24 595	174 296	198 891	5 410 864
2040	118 200	378 240	30 138	25 388	175 359	200 747	5 611 611
2041	130 020	390 060	31 080	26 182	176 548	202 730	5 814 341
2042	141 840	401 880	32 022	26 975	177 746	204 721	6 019 062
2043	153 660	413 700	32 963	27 768	178 930	206 698	6 225 760
2044	165 480	425 520	33 905	28 562	180 123	208 685	6 434 445
2045	177 300	437 340	34 847	29 355	181 302	210 657	6 645 102
2046	189 120	449 160	35 789	30 148	182 503	212 651	6 857 753
2047	200 940	460 980	36 731	30 942	183 700	214 642	7 072 395
2048	212 760	472 800	37 672	31 735	184 907	216 642	7 289 037
2049	224 580	484 620	38 614	32 529	186 098	218 627	7 507 664
2050	236 400	496 440	39 556	33 322	187 287	220 609	7 728 273