Czech University of Life Sciences Prague
Faculty of Economics and Management
Department of Economics

Bachelor Thesis

Evaluation of Economic Efficiency of Plant-Based Agriculture

Daniyar Karatay
Supervisor: Jiří Mach Ph.D.

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Economics and Management

BACHELOR THESIS ASSIGNMENT

Daniyar Karatay

Business Administration

Thesis title

Evaluation of economic efficiency of plant based agriculture

Objectives of thesis

The main objective is to assess the economic efficiency of the plant-based agriculture as compared to a present-day, meat-based agricultural production system. This is to be done through analyzing its three key angles of prospective impact on the economy: production cost efficiency, environmental implication, and socio-economic consequences. The focus will be given to cost efficiency of production of plant-based and livestock produce, and their respective environmental implications.

Methodology

In the analytical part, basic cost efficiency of production of animal and crop produce is compared based on the formulas and data from the United States Department of Agriculture and then adjusted to reflect the cost of nutritional value – per kilocalorie and per protein, – and the cost of processing –farmer's share of a retail dollar. The intercorrelation of meat and grain markets is also examined through the supply and reverse demand model and elasticity analysis. The same approach as in cost efficiency calculation is then applied to environmental implications of produce, comparing the water footprint, land use, and greenhouse emission of meat-based and plant-based produce regarding their nutritional value. The final comparative analysis will showcase the input (of resources)-to-output (of nutritional value) conversion of products which is used to conclude whether the volumes of input justify the output of animal livestock as opposed to plant-based products.

The proposed extent of the thesis

40 – 60 pages

Keywords

agriculture, economic efficiency, plant-based, animal farming, livestock, vegetarianism, nutritional value, cost efficiency, environment, greenhouse gas, water footprint, deforestation

---

Recommended information sources

Clay, Jason W. World Agriculture and the Environment: a Commodity-by-Commodity Guide to Impacts and Practices. Island Press, 2004. ISBN: 9781610910156

CRAWLEY, M J. *Statistics : an introduction using R.* Chichester: John Wiley & Sons, 2005. ISBN 978-0-470-02298-6.

Jha, Raghbendra, et al. Handbook on Food: Demand, Supply, Sustainability and Security. Edward Elgar, 2014. doi : 10.1111/1745-5871.12087

Leahy, E., Lyons, S., & Tol, R. S. J. (2010). An estimate of the number of vegetarians in the world. ESRI Working Paper, No. 340.

Lusk, Jayson L., and F. Bailey Norwood. "Some Economic Benefits and Costs of Vegetarianism." Agricultural and Resource Economics Review, vol. 38, no. 02, 2009, pp. 109–124., doi:10.1017/s1068280500003142.

National Research Council of the National Academies. Toward Sustainable Agricultural Systems in the 21st Century. Washington: National Academies Press; 2010, doi:10.17226/12832.

Pimentel, David, and Marcia Pimentel. "Sustainability of Meat-Based and Plant-Based Diets and the Environment." The American Journal of Clinical Nutrition, vol. 78, no. 3, Jan. 2003, doi:10.1093/ajcn/78.3.660s.

Thompson, Susan, and Ernest Braun. "Cropping for Plant-Based Agriculture." Food Policy, vol. 3, no. 2, 1978, pp. 147–149., doi:10.1016/0306-9192(78)90082-9.

Expected date of thesis defence

2019/20 WS – FEM (February 2020)

The Bachelor Thesis Supervisor

Ing. Jiří Mach, Ph.D.

Supervising department

Department of Economics

Electronic approval: 27. 2. 2019

prof. Ing. Miroslav Svatoš, CSc.

Head of department

Electronic approval: 1. 3. 2019

Ing. Martin Pelikán, Ph.D.

Dean

Prague on 28. 11. 2019

Declaration

I declare that I have worked on my bachelor thesis titled "Evaluation of Economic Efficiency of Plant-Based Agriculture” by myself and I have used only the sources mentioned at the end of the thesis. As the author of the bachelor thesis, I declare that the thesis does not break copyrights of any their person.

In Prague on 29.11.2019 ____________________________

Acknowledgement

I’m very grateful to my supervisor Jiří Mach for constant support, knowledge and advisory provided to me during this thesis work performed.

Hodnocení ekonomické účinnosti rostlinného zemědělství

Souhrn:

Podle studie Institutu pro hospodářský a sociální výzkum (ESRI) z roku 2010 je na celém světě odhadováno 1,53 miliard lidí, kteří žijí převážně na vegetariánské stravě, z toho 1,45 miliard jsou vegetariáni z nutnosti a dalších 75 milionů je dobrovolná volba.

Nezáleží na tom, zda motivace těch, kteří volí vegetariánskou stravu před masem, má co do činění s jejich zájmem o dobré životní podmínky zvířat, životní prostředí, náboženství nebo zdraví.

Kromě toho celosvětová závislost na fosilní energii dosáhla svého vrcholu za poslední desetiletí, kdy západní země využívaly v průměru 15% fosilní energie vyrobené na planetě k výrobě potravin, spolu s až 50% celkové rozlohy půdy a 80% spotřeby sladké vody jako např. USA.

Zhoršování životního prostředí a zjevně rostoucí popularita vegetariánství vyžaduje přechod ke zcela novému socio-ekonomickému paradigmatu produkce potravin. Budoucí ekonomický účinek přechodu na rostlinné zemědělství je však nejasný kvůli nedostatečnému výzkumu tohoto tématu. Tato práce si klade za cíl analyzovat ekonomickou a environmentální účinnost přechodu na rostlinné zemědělství a řešit otázku, zda existuje vztah mezi vegetariánstvím, environmentální udržitelností a ekonomickou prosperitou. Na základě analýzy nákladové efektivnosti a srovnávací analýzy dopadů na životní prostředí tato bakalářská práce cílí na prokázání celkové nezbytnosti přechodu na rostlinné zemědělství.

Klíčová slova: zemědělství, ekonomická účinnost, rostlinná výroba, chov zvířat, hospodářská zvířata, vegetariánství, nutriční hodnota, nákladová efektivnost, životní prostředí, skleníkový plyn, vodní stopa, odlesňování.

Evaluation of Economic Efficiency of Plant-Based Agriculture

Summary:

According to the Economic and Social Research Institute (ESRI) study from 2010, there are an estimated of 1.53 billion people worldwide living primarily on a vegetarian diet, 1.45 billion of which are vegetarians of necessity and another 75 million are those of choice. Some studies suggest a much higher number of the latter, and the trend holds—regardless of whether the motivation of those choosing a vegetarian diet over a meat-based one has to do with their concern for animal welfare, environment, religion or health, the increased acceptance of vegetarianism as a lifestyle choice is undeniable. In addition, global dependency on fossil energy has reached its all-time peak over the past decade, with Western, first-world countries using an average of 15% of the fossil energy produced in a country for food production, along with as much as 50% of the total land area and 80% of fresh water as in the example with the U.S. Researchers' concern of environmental degradation and the apparent rising popularity of vegetarianism call for a transition to an entirely new socio-economic paradigm of food production. However, the prospective economic effect of switching to a plant-based agriculture is unclear due to lack of research on the topic. The following thesis aims to analyze the economic and environmental efficiency of transitioning to a plant-based agriculture and addresses a question of whether there is an intercorrelation among vegetarianism, environmental sustainability, and economic prosperity. Based on the analysis of cost efficiency and comparative analysis of environmental implications this thesis aims to prove overall necessity for transitioning to a plant-based agriculture.

Key words: agriculture, economic efficiency, plant-based, animal farming, livestock, vegetarianism, nutritional value, cost efficiency, environment, greenhouse gas, water footprint, deforestation.

Table of Contents

Table of Figures and Tables

1. Introduction

According to the Economic and Social Research Institute (ESRI) study from 2010 (Leahy et.al, 2010), there are an estimated of 1.53 billion people worldwide living primarily on a vegetarian diet, 1.45 billion of which are vegetarians of necessity and another 75 million are those of choice. Some studies suggest a much higher number of the latter, and the trend holds regardless of whether the motivation of those choosing a vegetarian diet over a meat-based one has to do with their concern for animal welfare, environment, religion or health, the increased acceptance of vegetarianism as a lifestyle choice is undeniable. In addition, global dependency on fossil energy has reached its all-time peak over the past decade, with Western, first-world countries using an average of 15% of the fossil energy produced in a country for food production (Pimentel, 2003), along with as much as 50% of the total land area and 80% of fresh water as in the example with the U.S. (Pimentel, 2003).

As the global population continues to boom, especially over the last hundred years, and rising incomes and persisting industrialization suggests that demand for animal products will likely rise because of a number or reasons, among cultural habits and cheap consumer prices. Yet it is undeniable that animal farming costs billions and billions in external costs and has a potential to be replaced with a much more cost-efficient alternative, even if not entirely plant-based. Researchers' concern of environmental degradation and the apparent rising popularity of vegetarianism call for a transition to an entirely new socio-economic paradigm of food production. The literature review of the thesis highlights the importance of having a conversation about the economic efficiency (where the environmental implications are a future cost to be paid, whether monetary or in-kind) of the common agricultural systems we currently have in place. Existing studies that raise a concern about fossil fuel use, production and processing expenses, greenhouse emissions, land degradation and water use are presented and discussed, all to formulate hypotheses for the theoretical part.

While it is difficult to picture a full transition to a plant-based agriculture and to accurately assess the implications of it, a number of studies have proposed approaches to that estimation. For the purpose of this thesis, one of the main omnivorous arguments is taken and implemented into the calculations, that is, that nutritional value of meat produce justifies the resources allocated to its production, both direct (e.g. cost of production) and indirect (e.g. labour involvement and environmental footprint). By accounting for the nutrition – protein and kilocalorie value – a debate on whether a plant-based agriculture is more efficient than the alternatives becomes more multidimensional and less black and white.

2. Objectives

The main objective is to assess the economic efficiency of the plant-based agriculture as compared to a present-day, meat-based agricultural production system. This is to be done through analysing its three key angles of prospective impact on the economy: production cost efficiency, environmental implication, and socio-economic consequences. The focus will be given to cost efficiency of production of plant-based and livestock produce, and their respective environmental implications.

3. Literature review

3.1. Contemporary agriculture

As defined by the National Institute of Food and Agriculture (NIFA), agriculture is a process of producing food from growing crops and breeding animal livestock. In a broader sense, it also includes production of fuels and raw materials associated with agriculture, but this research solely focuses on food sources as per the NIFA definition. While the definition itself has not changed over the existence of human civilization, the ways in which people go about agriculture have undergone major changes. The industrialization, introduction of agrochemicals, and situational resource allocation, among the few, are huge drivers behind the agricultural revolution that began in Britain in mid-17th century. Trends in agriculture and food production change predominantly according to the available resources (availability of land, water, labour, capital) and market demand.

Over the last couple decades, agriculture has come to be characterized by increased productivity, partially because of intensive farming, where input of materials and effort is increased in order to reach maximum yield. That has become possible because of shift from subsistence farming, where cultivation and breeding are intended for family or local consumption only, to a larger, mostly corporate scope in developed countries.

Another often discussed topic related to conventional agriculture is its negative environmental footprint. The European Union was among the first institutions that raised a concern about contemporary agriculture being inconsiderate of the environmental effect that it imposes. In 1991, the EU first introduced organic certification for foods and later in 2005 amended its Common Agricultural Policy (CAP) to be encouraging of organic and sustainable agriculture (European Commission).

Three main conclusions can be derived from the above, 1) agriculture is among the key industries ensuring survival of humankind, 2) most yielded crops and livestock come from intensive corporate farming, 3) agriculture has a direct impact on the environment and imposes potential external costs associated with its damage. Today’s call for sustainable agriculture is based, among many, on the above three points. Since agriculture, being a huge industry largely regulated by governments and corporations as opposed to local communities, it is essential for human survival and has a direct impact on environment which quality also has direct influence on human survival, it is necessary to ensure that contemporary agriculture strives to be as sustainable as possible.

Now, sustainability, according to Cambridge Dictionary and as it will be used in this thesis, is a quality of causing little to no damage to something and fostering that something to efficiently run over a long period of time. The definition also applies to environment and economics. One of the most heated debates of the 21st century concerning sustainable agriculture is sustainability of meat-based and plant-based approaches. With the rise of veganism as a movement, especially environmental veganism, activists prompted scholars to conduct research on whether abstaining from animal products has a positive effect on environment (Linzey, 2013). Furthermore, the question posed is whether plant-based agriculture is sustainable in the long run for global economy like it is claimed to be for the environment.

3.1.1. Animal Farming and Economics of Meat Consumption

According to the Food and Agriculture Organization of the United Nations, as much as 40% of worldwide agricultural output represent livestock (UN, 2017), which is an estimated 330.51 million metric tons of global meat production (Statista, 2019).

Animal farming practices widely differ from country to country, but in most developed countries it is usually characterized by factory farming, which came to replace traditional family farming. Instead of locally-sourced mixed farms, while those still exist, the majority factory farms came into the market with a vision of the industrial revolution—minimizing the costs and maximizing the profit (United States Department of Agriculture, 2017). This led to a change in animal breeding, mostly keeping cattle inside and feeding it gran to ensure fast growth. To illustrate it, as compared to data from 1925, the average amount of days of life of a farm chicken has reduced from 112 to 48, while its average market weight almost tripled from 1 kg to 2.8 kg (CIWF, 2013). Same goes for pigs, cattle, and other animals. As the industry finds more efficient methods to make animal farming a lucrative field, the demand for it grows accordingly.

Yet, the cultural habit of eating meat has long been questioned in its sustainability and ethics. For example, according to the United States Department of Agriculture, more than 90% of the whole grain produced in the U.S. is used to feed livestock and poultry: cows, pigs, sheep, and chickens (Lappe, 1991). The use of grain for animal feeding does seem as a waste of resources considering other statistics released by the United States Department of Agriculture, which suggests that it takes 16 kilograms of grain to be fed to cattle to get one kilogram of meat (Lappe, 1991). In her book *Diet for a Small Planet*, Frans Lappe suggests that we imagine that we are sitting in front of a plate with a big steak. Now imagine that there are fifty people sitting in the same room as you, each has an empty plate. The grain spent to prepare one steak would be enough to fill the plates of all fifty people sitting in the room with porridge (Lappe, 1991). Moreover, in highly developed countries (e.g. Western Europe) livestock is fed not only with their grain, but also with protein-rich products, e.g. peanut crops that are about as rich in protein as meat itself, purchased from poor countries, especially countries in Africa (Borgstrom, 1980). Such statements even suggest that the problem of world hunger is artificially created. Speculatively speaking, todays food produce should be more than enough to feed the population of Earth given its production and resource potential. Nutritionist and Harvard University professor Jean Mayer estimated that if people worldwide reduced meat production by 10%, it would leave us with enough grains to feed 60 million people (PETA, 2013).

Another price to pay for meat production is pollution. Drainage of wastewater and the discharge of waste from meat processing plants and fattening farms into rivers and reservoirs is one of the main causes of their pollution. It is no news that the sources of clean drinking water on our planet are not only polluted, but also gradually depleted, and it is the meat industry that is especially wasteful (Lappe, 1991). Georg Borgstrom claims that wastewater from cattle farms pollutes the environment ten times more than urban sewage and three times more than industrial sewage (Borgstrom, 1980). American biologists and professors at Stanford University, Paul and Anna Ehrlich, in their book *Population, Resources, and Environment* also concluded that it takes only 60 litres of water to grow one kilogram of wheat, while it takes 1250-3000 litres to produce one kilogram of meat. (Ehrlich, 1970).

Moreover, the report *Livestock's Long Shadow* published by the Food and Agriculture Organization (FAO) of the United Nations in 2006 reads that the livestock breeding is a huge stressor on a number of ecosystems and has an overall negative impact on our planet's environment, being one of the largest sources of greenhouse gases and other noxious gases and one of the largest drivers behind loss of biodiversity and water pollution (Steinfeld, 2006).

In July of 2018, academic journal *Science Magazine* published a peer study stating that the increase in human population will inevitably cause carbon emission and degradation of biodiversity, partially to an increased meat consumption if the trend persists (Godfray, 2018). This, among other things, prompted more than 15,000 scientists, researchers, and scholars worldwide to sign a so-called Warning to Humanity, urging, in addition to other things, to decrease per capita meat consumption (Kayal, 2018).

3.2. The case of Veganism and Vegetarianism

In the United States alone, there has been a 20% increase in sales of plant-based foods over the period of one year between 2017 and 2018 (Fleming, 2018). From a glance of the European number, the growth is more distinct—approximately 450% in between 2014 and 2018 (Fleming, 2018).

Abstaining from meat, once being a circumstantial (out of necessity), religious, or health related decision, is rapidly becoming mainstream in the 21st century. There are many reasons as to why one would decide to go vegetarian—abstaining from meat—or vegan—abstaining from meat and all by-products of farm slaughter, such as dairy, eggs, leather products, animal tested products, etc., —ranging from personal philosophy and ethics to political agenda, yet environmentalism remains one of the most common reasons for people to cut meat off their diets. A recently popularized terms *environmental vegetarianism* and *economic vegetarianism* both refer to a philosophy of one's conscious decision to give up meat (exception being people for whom meat is a luxury product, thus those who are practicing vegetarianism out of necessity). Environmental vegetarianism refers to a practice of sustaining a plant-based diet due to its unsustainability for the Earth and unfavorability for the animals (Bittman, 2008). Economic vegetarianism is a practice of sustaining a meat-free diet as a part of an anti-consumerism agenda since meat is expensive not only when it comes to individual consumption but also to the economy in general as explained in previous chapter (Landes, 2004).

According to Oxford University scientist Joseph Poore, as per his research, for an individual to stick to a vegetarian and even more so to a vegan diet is the most powerful step towards an environmental and economic change (Poore, 2018). Yet, it is almost impossible to estimate an actual effect of a global shift towards a plant-based consumption and thus agriculture. Given the above concerns about unsustainability of meat-based agriculture and animal farming, the following chapters will closely examine existing research on economic and environmental implications of plant-based agriculture.

3.3. Plant-based vs. meat-based agriculture

Meat and fish industries, together with all their by-products, are economically efficient for the producers since they normally do not pay the external costs of the production. Moreover, these sectors are heavily subsidized in developed countries and thus are quite lucrative (Poore, 2018). Transitioning from an omnivore-oriented production would mean a whole range of environmental, socio-agricultural, and production changes. The highlights of existing research in regard to it are presented below, all to collect evidence about global economic efficiency of plant-based agriculture as opposed to a meat-based one.

3.3.1. Production cost efficiency

Below are some excerpts from existing research about the production costs of animal and plant protein, but a more detailed breakdown of production cost of animal and plant sources will be presented in the theoretical part.

In the United States alone, more than ⅔ of all fossil fuels and raw materials are used in animal farming, with beef production having a higher water consumption than that of country's total fruit and vegetable harvest (Springmann, 2016). John Robbins in his book *The Food Revolution* calculated that not eating a pound of beef saves more water than not showering for a year (Robbins, 2001). According to Pimentel in his studies of 1996 and 1997, while it takes 500 L of water to harvest 1 kg of potatoes and 2,000 L to produce 1 kg of soy, producing 1 kg of beef requires 100,000 L of water (Pimentel 1996; 1997). Speaking of fossil fuels, producing 1 kcal of protein from plant sources takes only 2 kcal of fossil fuels, but to produce 1 kcal of protein from meat sources takes anywhere from 4 to 57 kcal of fuels (Pimentel, 2003). Similarly, a person not eating meat saves more than an acre of trees per a year as opposed to someone who does eat meat (Robbins, 2001).

3.3.2. Environmental implication

3.3.2.1. Noxious gas emission

In 2016, the Oxford Martin Program on the Future of Food published a research conducted by Marco Springmann and some of his colleagues from the National Academy of Sciences of the United States (PNAS) which is considered to be the first ever forecasting research which took into consideration existing patterns of dietary changes and their effect on climate change (Springmann et al., 2016). They then modelled how such patterns can change the climate by 2050. The study shows that food-related noxious gas emissions are expected to represent half of the increase in overall noxious gas increase. This correlates with the United Nations research that states that animal agriculture is already responsible for over 50% of gas emission worldwide (Simon, 2013). Another interesting research contributing to the above argument was conducted by Dr. Oppenlander in his book *Comfortably Unaware*, where he claimed that even if the whole population stopped using fuels, natural gas, and oil, we would still go above the maximum recommended greenhouse gas emission (which is 565 Gt) by 2030 because animal agriculture causes a large portion of it (Oppenlander, 2011). For an individual, eating one kilogram of beef contributes more to climate change with respect to carbon emission than a three-hour drive while leaving all the lights on back at home (Ogino et al, 2007).

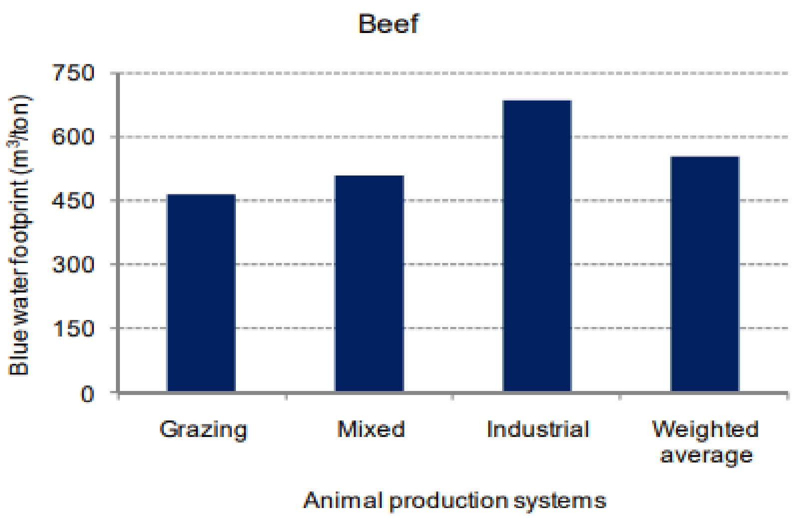
Following on the individual effort, switching to a vegetarian diet decreases carbon footprint by 1.5 t, which is almost the same as if one switched from driving a sports utility vehicle (SUV) to a hybrid vehicle (Eshel et al., 2006). Following consumption recommendations—that is, consuming at least half as less meat as one normally would and thus driving the demand down which is consequently expected to cause the supply and production go down—is projected to decrease global noxious gas emission by 29%. Following a vegetarian and vegan diet is expected to cut 63% and 70% of said emission respectively, that is accounting not only for carbon and methane footprint, but also for greenhouse gases emitted as a result of crop and forage cultivation that is used to feed livestock (Springmann, 2016).

3.3.2.2. Land, water, and waste

Animal agriculture contributes more to climate change than just with its carbon emission footprint. It also makes up 30% of global water consumption, 45% of global use of land, 91% of destruction of Amazon and is a main driver behind ocean degradation, territory destruction and species extinction.

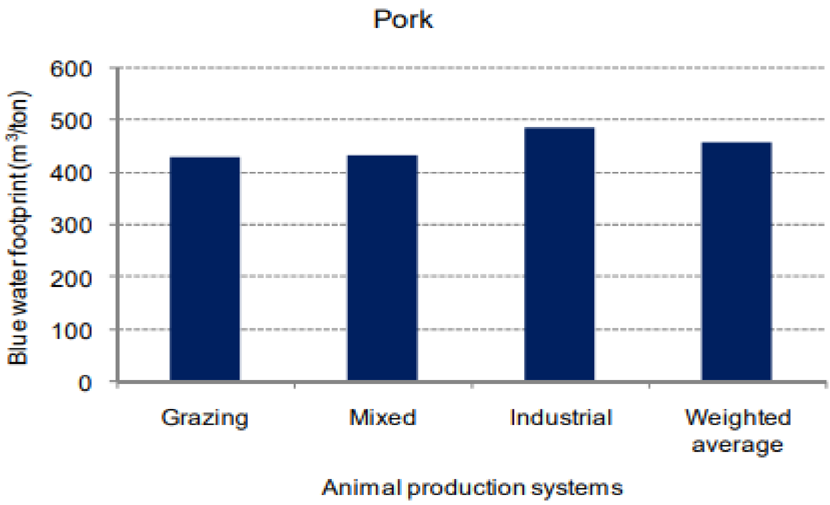
As per the water use, a Water Footprint Network published extreme numbers in their 2010 report, stating that while vegetables have a footprint around 322 L/kg, meat came to an average (among chicken, pork, sheep, and beef) of 8,622 L/kg (Mekonnen, 2011). The bluewater—open sea—footprint of meat and related products is also immense as per Graphs 1-4. As our planet continues to experience increasing water constraints and agriculture accounting for using approximately 92% of available freshwater—more than half of which is related to animal production—it is clear that our current global agriculture strategy does not seem to be sustainable (Gerbens-Leenes, 2013).

Figure 1:The water footprint of beef



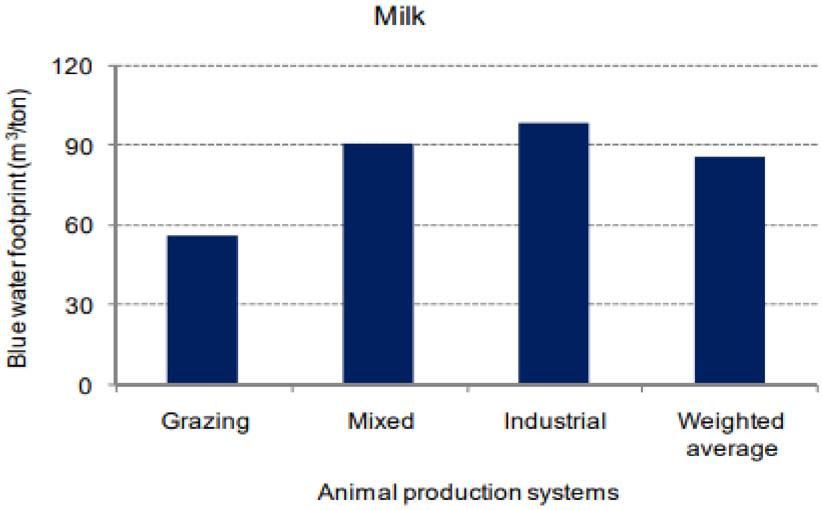
Source: The Green, Blue and Grey water footprint of farm animals and animal products, Mekonnen et al., 2019.

Figure 2: The water footprint of pork



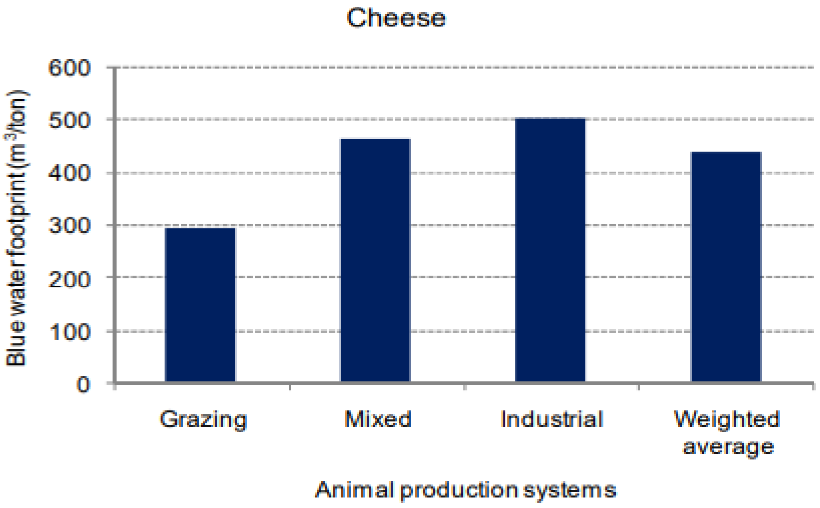
Source: The Green, Blue and Grey water footprint of farm animals and animal products, Mekonnen et al., 2019.

Figure 3: The water footprint of milk



Source: The Green, Blue and Grey water footprint of farm animals and animal products, Mekonnen et al., 2019.

Figure 4: The water footprint of cheese



Source: The Green, Blue and Grey water footprint of farm animals and animal products, Mekonnen et al., 2019.

In 1996 the Environmental Protection Agency (EPA) raised a concern as to energy-extensive industrial farms that run livestock farming in the United States. The reason was, EPA noticed that those were responsible for producing 1.5 billion tons of animal waste — an absolute maximum in comparison with the previous years (Innes, 2000). In 1995, New River hog spilled 25 million of excrement and urine into the waters of North Carolina, which resulted in an estimated of 12 million fish to die and over 300,000 acres of shellfish beds to close (Halverson, 2000).

Meat production is also notorious for contributing to erosion of billions of acres of farmland and deforestation. Cattle farming, for example, is the main reason of Amazon deforestation: as much as 80% of deforested land is used as grassland for pasturage (Greenpeace, 2009). Interestingly, deforestation associated with soy production, which is not only a meat substitute but also a product used for animal feeding—is also among main concerns of Greenpeace (Greenpeace, 2009).

3.3.2.3. Economic imprint of environmental changes

In his book *Meatonomics*, David Simon calculated financial costs of external costs of animal agriculture and came up with an extreme number—$414 billion U.S. dollars globally which is, if to be included in the price tag, would make animal products to cost almost three times their current prices (Simon, 2013). Yet, the economy of scale and close ties of agricultural sector to politics and governmental lobbying suggests that the internalization of such costs by the producers is unlikely and that animal production largely profits off the environmental resources without paying the price for its destruction.

3.4. Socioeconomic consequences

Animal farming is among the largest economic sectors in the whole world, employing as much as 26% of all workers worldwide, that is not including workers involved in meet supply chains, such as, for example, retailers and chefs (Zee, 2018). Given the above, eliminating animal farming as an industry would have a devastating impact on labour force unless executed gradually with account for workforce replacement and re-training.

Animal agriculture is often claimed to contribute to global inequality gap, since developing countries produce the majority of livestock food that is then exported to more wealthy countries, being ahead of local livestock production (Springmann, 2016). As it was previously mentioned, on average 15% (most of the sources suggest a higher number) more of protein can be obtained from plant-based sources than from meat given that the area of land is the same (Springmann, 2016). That also suggests that food shortage and starvation can be reduced if only the resources put into animal farming are redirected to plant-based agriculture.

Another economic cost associated with the transition towards a plant-based agriculture is that of healthcare and societal costs. While those are quite relative and difficult to estimate, an influential study of Ghent University suggests that the British government could save as much as 5 billion British pounds on hospital admissions and medical staff bills if only 10% of the country's population would stick to a plant-based diet (Schepers, 2018). Health consequences of a vegetarian and/or vegans are relative and difficult to estimate, but Schepers and Lieven quantified it in quality adjusted life years (QALY), with abstaining from omnivorous diet bringing as much as 100-159 yield of QALY, which is not only beneficial for one’s health but is also cost-efficient for a society (Schepers, 2018).

3.5. Criticism of plant-based agriculture

Obviously, the transition to plant-based agriculture and even its expanding popularity carries risks, and respective concerns, some already mentioned throughout the above chapters, make it questionable whether the advantages of plant-based economy outweigh its disadvantages, even though most of the studies suggest the first.

According to some estimations, the number of vegans worldwide has increased 160 percent over the last decade, that is not accounting for vegetarians (Henderson, 2018). To support a proportional increase in demand, fruits and vegetables, especially rather exotic ones, have been imported from countries with their production potential, for example mangoes from India, goji berries from China, beans from Latin America, lentils from Canada, etc. For economies importing fruits and vegetables—that is almost every economy around the globe since only few have capacity to produce all ranges of harvest given the differences in climate conditions—the transportation cost involved makes the importing cost inefficient as opposed to local crop production (Henderson, 2018). In his book *How Bad Are Bananas?* Mike Berners-Lee warned that some of the trendy vegan products, such as avocados, quinoa, and asparagus, among many, are so heavy in air mileage (transportation cost) and respective packaging costs that their environmental benefit actually undoes itself and causes more harm than good. Asparagus, because it is being transported by air, has a carbon-dioxide footprint of 8.9 kg per each kilogram, which is seven times more than the transportation cost of avocados which can be shipped by sea, even though avocados are already considered to be cost not efficient as to their transportation and harvesting (Berners-Lee, 2011). Yet, Berners-Lee also states that in comparison with meat products, the above footprint of trendy foods is still very small.

The cost of harvesting and importing and its consequent effect on local communities is another concern here. Take quinoa, for example, being rich in protein and a popular substitute to meat as a source of protein, or even avocados, the price of which was so jacked by the Western demand that their country of origin and producing communities have become unable to afford these foods (Martinko, 2018). Kenya has already banned exporting avocados due to its low supply and Australian authorities are ringing the bells because the prices of their greens have become impossibly unaffordable for the locals because, as in example with avocados, Australia was supplying when the production in Mexico went down (Martinko, 2018). In 2013, the price of quinoa in Latin America—the region which supplies the majority of quinoa worldwide—has also reached its all times high and became too expensive for the locals, reaching $7 U.S. dollars per a kilogram which is higher than the price of one kilogram of chicken in the same region (Henderson, 2018).

The above counter arguments to plant-based agriculture, however, do not suggest that meat-based agriculture is better, but merely lessen the magnitude of plant-based agriculture's advantages. The ongoing changes in food industry still suggest that people are aware of the environmental and subsequent economic cost of animal farming, yet, as per the counter arguments, the idea of shifting towards a 100% plant-oriented agriculture, to be equally beneficial for the whole planet and not its selective, more privileged regions, needs to be better studied and implemented with consideration of all the residuals and external costs that it carries.

3.6. Conclusions from existing literature

After examining data from 570 existing researches that covered almost 40,000 farms, assessing land and water use, noxious gas emissions, waste, potential problems with ground- and freshwaters, Poore and his fellow scholars still could not find a single animal product or by-product that would be more environmentally friendly as its plant-based alternative (Poore, 2018).

The global population continues to boom, especially over the last hundred years, and rising incomes and persisting industrialization suggests that demand for animal products will likely rise because of a number or reasons, among cultural habits and cheap consumer prices. Yet it is undeniable that animal farming costs billions and billions in external costs and has a potential to be replaced with a much more cost-efficient alternative, even if not entirely plant-based. As Springmann said before he himself went vegan, it is unrealistic to expect the whole world to decide to abstain from meat overnight—that raises its own concerns—but adopting a more environmentally sustainable diet, that is, less meat-oriented, is a huge step towards a more sustainable global economy (Springmann, 2016).

4. Methodology

The analytical part of the thesis is of explanatory nature, aiming to reject or support already existing hypothesis regarding the economic efficiency of plant-based agriculture. Two key factors are chosen for the analysis: cost efficiency and environmental implications, as they can be quantified and there is data available for comparison and examination. There is a widespread pro-omnivorous diet argument that meat is more nutritious than grains and that it justifies its production and respective selling prices. For that reason, when calculating and comparing both environmental and economic impact of agriculture in this thesis, the calculations will be adjusted for the nutritional value for respective meats and grains. That is to be done by rewriting the formulas for energy measures: kcal energy and protein count.

To calculate and compare the cost efficiency of meat and plant-based agriculture, typical commodities from each will be closely observed—hogs and cattle (chosen because of global production volume), and then corn, soybeans, and wheat (chosen because of data availability), respectively. For both livestock and grains, the production cost estimation was comprised from the formula pattern of the United States Department of Agriculture (elaborated in Chapter 4.1.2.). Using the reports of USDA on Commodity Costs and Returns, the calculations as per above-mentioned formulas are comprised for the averaged values of 2017-2018 data to compensate for the lags (see Appendix). At the moment of writing this thesis, 2019 reports are not yet available. There are also no shock values indicated in the 2017-2018 reports which makes the data suitable for estimation. Such cost estimations, however, do not include the cost of processing the product, e.g. slaughtering and butchering, in case with meat, or milling, in case with wheat, and only represent the cost of production at the farm level and not final retail, since no processing or transportation costs were considered. These differ largely from company to company, retailer to retailer, and commodity to commodity which makes it difficult to calculate just how much production costs. To account for it, an approximation technique to adjust calculations for retail level proposed by Lusk and Bailey will be used (Lusk et al., 2009). They proposed to incorporate a farmer's share of the retail dollar for each of selected commodities in order to account for the differences (Lusk et al, 2009). By separating farmer's share of a retail dollar, it is possible to calculate the proportion of farm contribution as opposed to retail contribution (meaning, post processing and transportation). Another factor of cost efficiency to consider is the interrelationship for the grain and meat markets. Based on the studies of JM Marsh (2007) and Lusk and Bailey (2009), a supply and inverse demand matrix is to be interpreted to for the purpose of this research. Also, income elasticity is to be considered to understand whether beef (the most environmentally unfriendly commodity) is a luxurious food and if people will be willing to substitute it with other kinds of meat.

Same approach with calculating per protein and per calorie footprint is applied to environmental implication comparison, that is, green, blue, and grey water footprint, land use (with a share of grassland), and carbon emissions.

Put together, per energy measures of cost efficiency and environmental impact are to be compared, analysed, and aligned with the theoretical findings, all to conclude whether the hypotheses stand to the evidence. The final comparative analysis will showcase the input (of resources)-to-output (of nutritional value) conversion of products which is used to conclude whether the volumes of input justify the output of animal livestock as opposed to plant-based products.

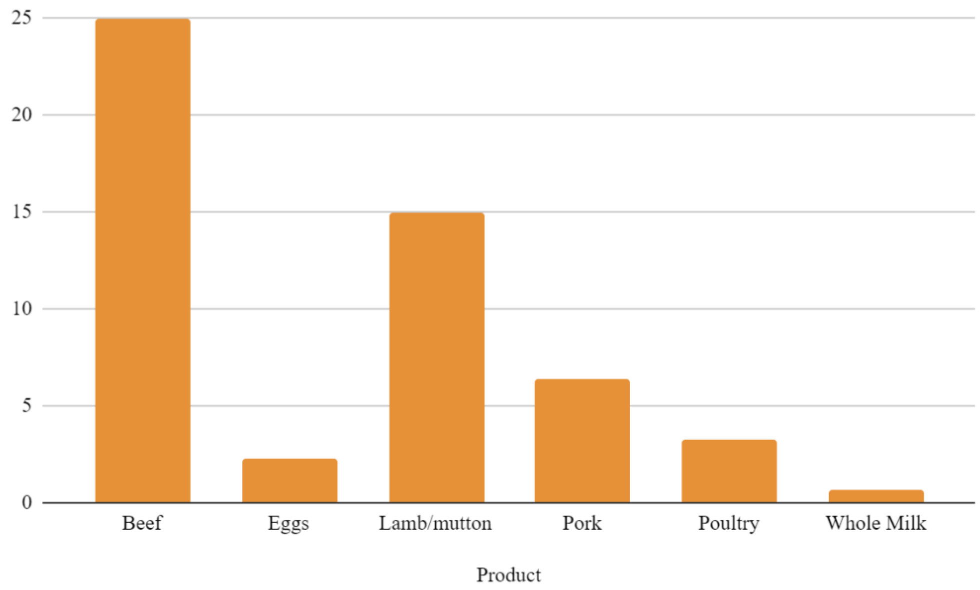
4.1. Cost efficiency

The economic factor of agriculture is mostly concerned with per unit cost of production because agriculture is an industrialized sphere with an objective to minimize the production cost and to maximize the profit. Production cost estimation is very complex and varies from one commodity to another, which is why for the sake of comparison the same measure units will be used.

Another thing to consider is interrelation of grain and meat markets. In a discourse of meat-based versus plant-based agricultures those two categories of products become more of substitutes instead of complementary products as today and thus are expected to have an inverse relationship with one another (e.g. an increase of prices of one should cause an increase in demand of another). Also, in case with meat and grains there is also some simultaneous effect of one on another, since grain is also used as feed grain for livestock (Figure 5). Last, but not least, it is important to understand that comparing grains and meats in weight measures, such as kg, is slightly misleading since they have different protein and calorie counts, meaning that an energy derivation from one kg of meat does not necessarily equal that of one kg of grain. This is also to be considered for further calculations.

All the data used for estimation will be from the U.S. sources to make it standardized for comparison, but the theoretical findings are expected to reflect the pattern for all industrialized countries with some residuals. Respectively, cost values will be reflected in USD. All measures (acres, pounds, kilograms, etc.) will be specified in each case.

Figure 5: Feeding grain needed to produce one kg of meat and dairy, y-axis in kg



Source: Human Appropriation of Land for Food, Peter Alexander, et al., 2016

4.1.1. Hypothesis formulation

Drawing on the derivations from the theoretical part, the hypothesis for cost efficiency of meat-based versus plant-based agriculture is as follows: the plant-based food system is more cost effective in terms of production. The hypothesis is to be supported or rejected post cost estimation below.

4.1.2. Basic comparison of costs of production

To provide a better overview of meat and grain production, three typical commodities from each will be closely observed—hogs and cattle (chosen because of global production volume), and then corn, soybeans, and wheat (chosen because of data availability), respectively. For both livestock and grains, the cost estimation was comprised from the pattern of the United States Department of Agriculture, which is below.

Livestock:

Operating costs =

Total feed costs (Purchased feed + Homegrown harvested feed + Grazed feed)

+ Miscellaneous costs ((Feeder pigs + Nursery pigs) or Cattle for backgrounding

+ Veterinary and medicine + Bedding and litter

+ Fuel, lube, and electricity + Repairs)

Allocated overhead =

Hired labour + Opportunity cost of unpaid labour

+ Capital recovery of machinery and equipment

+ Opportunity cost of land (rental rate)

+ Taxes and insurance

+ General farm overhead.

Grains:

Operating costs =

Seed + Fertilizer (commercial fertilizers, soil conditioners, and manure)

+ Chemicals

+ Custom services (custom operations, technical services, and commercial drying)

+ Fuel, lube, and electricity

+ Repairs

+ Purchased irrigation water

+ Interest on operating capital.

Allocated overhead =

Hired labour

+ Opportunity cost of unpaid labour

+ Capital recovery of machinery and equipment

+ Opportunity cost of land

+ Taxes and insurance

+ General farm overhead.

The formulas mentioned are going to be used below under the Results section to perform a comparative analysis of costs of production for the given commodities.

4.1.3. Cost of producing nutrients

The reason the basic cost of production overview in previous Chapter cannot efficiently reflect the production costs of meat and grain comes back to a widespread pro-omnivorous diet argument that meat is more nutritious than grains and that it justifies its production and respective selling prices. For this reason, the below calculations account for energy measures, such as kcal energy and protein count.

Cost of Energy = Unit cost / Energy (USD/kcal)

Cost of Protein = Unit cost / Protein (USD/gram of protein)

The weight measures that will be used in calculations are in pounds (lb) because they are taken from the USDA and are in traditional U.S. imperial system. Pounds, however, cancel out in the final calculations of cost of energy and cost of protein and thus were not converted to metric system (kilograms).

Table 1: Cost of production of selected commodities and their nutritious values

	Production cost			**Nutrient content**	
	Cost of Production (USD)	**Yield**	**Cost (USD/lb)**	**Energy (kcal/lb)**	**Protein (grams/lb)**
Hogs (Pork)	**65.965** per cwt live weight gain	**75** lbs of meat per live cwt	0.879	82.953	3.069
Cattle (Beef)	**1.342.325** per head live weight	**1150** lbs per head; **0.65** lbs of meat per live lb	1.796	64.2	3.821
Corn	**687.045** per acre	**189** bushels per acre, **56** lbs per bushel	0.065	80.526	2.078
Soybeans	**443.48** per acre	**50.5** bushels per acre, **60** lbs per bushel	0.146	98.397	8.05
Wheat	**301.7** per acre	**46** bushels per acre, **60** lbs per bushel	0.109	72.143	2.782

Source: USDA (Production cost) and Clark (2017) (nutrient content)

4.1.4. Processing cost

Still, the above estimations only represent the cost of production at the farm level and not final retail, since no processing or transportation costs were considered. These differ largely from company to company, retailer to retailer, and commodity to commodity which makes it difficult to calculate just how much production costs. As opposed to basic cost valuation, where formulas are available, the overall cost is a variable on many levels. Lusk and Bailey, however, came up with an approximation technique to adjust calculations for retail level (Lusk et al., 2009). They propose to incorporate a farmer's share of the retail dollar for each of selected commodities in order to account for the differences (Lusk et al., 2009). The formulas of Costs of Energy and Protein are then to be rewritten as follows:

Adjusted Cost of Energy = Cost of Energy / Farmer's share of Retail USD

Adjusted Cost of Protein = Cost of Protein / Farmer's share of Retail USD

Where the results are still in USD/kcal and USD/gram, respectively.

By separating farmer's share of a retail dollar, we can calculate the proportion of farm contribution as opposed to retail contribution (meaning, post processing and transportation). Farmer's share of Retail dollar is expected to be much higher for meat commodities which are often being prepared for transportation and processing by already bleeding and sometimes butchering, while the grains are normally only being harvested. The values for farmer's share of retail dollar are 2017 percentage values taken from the report of the National Farmers Union, an accredited union by the United States Department of Labour and United States Department of Agriculture (National Farmers Union, 2018).

4.1.5. Interrelationship of markets

As it was explained in the theoretical part of the thesis, an idea of a shift towards vegetarianism is mostly fueled by people's ethical decisions, but such a change on a global level would raise far more questions than just about morality. The above two sections where basic production costs were calculated and then adjusted for overall production cost including processing, greatly support the claim that, in a limited sense, production of grains is more cost-efficient.

Nevertheless, those calculations and comparisons only reflect today's reality, Now, if people worldwide would suddenly stop consuming meat altogether, that would call for re-calculation of all done above. Being intercorrelated by nature, that is being markets of food, meat and grain markets are expected to have a great influence on one another. That is why it is important to consider how the prices of grains would react to a massive global increase in their demand as an alternative to meat products.

Now, it is fairly impossible to calculate the impact of disappearing supply of meat on demand and consequent prices of grains because we would have to assume a ceteris paribus situations where all factors would stay constant as to now, since this is the only data that is available, but some approximation can be done by applying the basic cross-elasticity approach. To do that, let us select corn as a representative commodity from grain market and focus on their interrelationship to meats. Since corn is a close substitute to wheat and soybean, the decision on grain selection does not matter much. For meat market we will take both hogs and beef to cover as much of meat market as possible, and also add chicken (broilers) for more accurate representation of meat market. Up to this step, chicken was ignored in production cost estimation due to limited availability of data for it on all aspects (e.g. basic and adjusted production costs) and USDA databases do not contain statistics about chicken farms due to their huge amount on local farm level.

4.1.5.1. Supply and reverse demand

To analyse the supply and demand correlation, we will refer back to study of JM Marsh (2007) and further discussion on it of Lusk and Bailey (2009). Marsh conducted estimation of supply-demand relationship among corn and meat commodities (beef, pork, and chicken), while Lusk and Bailey applied econometric calculation to explain demand shocks—which is exactly what is needed to be examined in this thesis since an instant disappearance of demand of a meat commodity would be considered a shock.

The breakdown Marsh's calculations can be found in Appendix 6. Marsh calculated supply and inverse demand for corn and then expressed it for other variables (beef, pork, and chicken). Then, Lusk simplified the equations and adjusted then for long-term perspective. He then took all eight adjusted Marsh's equations (Appendix 6) and put them in a matrix form, expressing eight endogenous variables: supply and inverse demand for each of four selected commodities. The final AX=B matrix is below, with X containing endogenous variables and where A and B — constant values:

Equation 1: Supply and inverse demand matrix

$$\begin{bmatrix} 0.469 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ -1 & 0.440 & 0.127 & 0.454 & -0.371 & 0 & 0 & 0 \\ -0.278 & 0.817 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & -0.565 & 0 & 0 \\ -0.710 & 0 & 1.555 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & -0.641 & 0 \\ -0.344 & 0 & 0 & 0.695 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & -1 & 0 & 0 & 0 & -0.133 \end{bmatrix} \begin{bmatrix} \hat{P}_{CN} \\ \hat{P}_B \\ \hat{P}_P \\ \hat{P}_{CK} \\ \hat{Q}_{CN} \\ \hat{Q}_B \\ \hat{Q}_P \\ \hat{Q}_{CK} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ -S_B \\ 0 \\ -S_P \\ 0 \\ -S_{CK} \end{bmatrix}$$

Source: Lusk, Jayson L., and F. Bailey Norwood (2009)

After Lusk and Bailey solved the above matrix for corn (CN) and came up with the following equations:

(2) $P_{CN} = 0.280S_B + 0.059S_P + 0.385S_{CK}$

(3) $Q_{CN} = 0.131S_B + 0.028S_P + 0.181S_{CK}$

Equation 2: Price of corn and willingness-to-pay equations from matrix in Equation 1

Equation 3: Quantity produced of corn and WTP from matrix in Equation 1

Where equation (2) reflects the price of corn and equation (3) its quantity produced, and S of pork, beef and chicken are respective willingness-to-pay (WTP).

4.1.5.2. Income elasticity

In addition to demand analysis in the previous chapter we can calculate income elasticity for the three most consumed types of meat – beef, pork and chicken, in order to understand whether beef can be substituted with a cheaper type of meat. This is because beef has the most negative environmental impact among all the other types, which will be discussed in further chapters.

To calculate income elasticity, we will find a logarithmic function based on consumption of mentioned goods and household income (Appendix 7 and Appendix 8).

$$y = a * \ln(x) + b$$

Equation 4: Logarithmic function

With the following function we are able to calculate a theoretical value of product consumption, which then is be used in income elasticity formula. It calculates how change in consumer's income affects the demand of a specific product.

$$E_i = \frac{\partial y_i}{\partial x_k} \frac{x_k}{y_i}$$

y_i = demand for i^{th} product
x_k = disposable income

Equation 5: Income elasticity formula

4.2. Environmental implication

Whether sustainable or not, both crop agriculture and animal farming carry implications on the environment. Global agriculture feeds over seven billion people, but it also, as discussed in practical part, is the leading cause of environmental deterioration. The deterioration is mostly driven by increased indicators of such factors as water use, land use and deforestation, and greenhouse gas (GHG) emissions (Steinfeld, H., 2006).

Environmental footprint, especially nowadays, is a cost on its own. Because of contemporary policies, tax and jurisdiction requirements, it is also included in a price of a product, a higher value compensating for the efforts of a producer to make it as environmentally-friendly as possible. Moreover, environmental degradation is a future cost to be paid, which is why it is important to consider the footprint that meat-based and plant-based agriculture entail and quantify it to make it comparable.

4.2.1. Hypothesis formulation

The hypothesis derived from the theoretical part is as follows: the meat-based food system requires more energy (and thus produces more GHG), land, and water resources than the vegetarian diet. In this limited sense, the vegetarian diet is more sustainable than meat-based diet and therefore is more favourable for the economy. To reject or accept, we need to compare quantifiable values which will be examined below.

4.2.2. Water footprint impact

According to the literature review, animal products have a greater land use related impact than plant-based ones. To showcase the quantitative distortion, the values of water footprint of produce will be taken from the research of Mekonnen (2011) and paired with nutritional values as in Table 1 (but now in kilograms since the metrics units will not cancel out in calculation as in Table 1), all to calculate the water footprint per calorie and protein. In the table, green water is water from precipitation, blue water is freshwaters, both surface and groundwaters, and grey water is polluted water which is reused after being a product of domestic activities (Mekonnen, 2011).

Table 2: Water footprint per ton for selected commodities

	Water footprint per ton (m3/ton)			
	Green	**Blue**	**Grey**	**Total**
Beef	14414	550	451	15415
Pork	4907	459	622	5988
Dairy	863	86	72	1021
Poultry	3545	313	467	4325
Eggs	2592	244	429	3265
Rice	7016	1367	680	9063
Wheat	1232	228	184	1644
Maize	2023	220	121	2364
Pulses	3180	141	734	4055

Source: The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products, Mekonnen, M. M. et al, Hydrology and Earth System Sciences, vol. 15, 2011, pp. 1577–1600.

4.2.3. Land use impact

Due to the heterogeneity of both animal farming and crop agriculture, calculating land use per a unit on nutritional value is virtually ineffective. Instead, we can compare the land use of rich in protein products in regard to their life cycle, since land is, in a sense, a highly reusable asset, in contrast to freshwaters. Below is the breakdown of land use, including grassland use, of most of the rich in protein food. The protein content is denoted in parentheses in relation to the overall nutritional value of each product. The outcomes are denoted not as single values, but as value ranges, which reflects different categories of products within a category (e.g. extensive industrial farming, extensive pastoral farming, meadow systems, etc.), or different types of products within a category (e.g. wheat, rice, maize, etc. under an umbrella category *Grains and crops*).

Table 3: Land use of foods rich in protein per a kilogram of produce

Produce	Land use (m2/kg)	Of which grassland (m2/kg)
Beef (20%)	7–420	2–420
Mutton (20%)	20–33	18–30
Pork (20%)	33–158	N/A
Poultry (20%)	5–8	N/A
Eggs (13%)	4–7	N/A
Milk (3.5%)	1–2	1
Aquaculture and Fishery (16–20%)	2–6	N/A
Meat substitutes containing dairy (15–20%)	1–3	0–2
Grains and crops (10-16%)	2–3	N/A
Pulses (20–36%)	3–8	N/A

Source: The Price of Protein, Nijdam, Durk, 2012, pp. 760-770,

4.2.4. Carbon emissions

With a global increase of temperature, greenhouse gas emission should be an important issue to address worldwide. Food production, together with its land use, currently contribute to a quarter of all GHG emissions that contribute to climate change. Meat and dairy industries have the largest share among those above mentioned 25%, damaging the environment tremendously. To give a perspective, currently livestock farming alone is responsible for 14% of total GHG emissions, which is equivalent to the entire transportation sector (Greenpeace International, 2018). Note that around another 10% among the food industry sector is reserved to palm oil cultivation alone, which leaves 1-2% of contribution to all other foods (Donnellan, 2016). To showcase the drastic difference between meat and dairy produce as opposed to plant-based food alternatives, below two tables and respective charts display the quantified values of GHG emission per units of protein and calories.

Table 4: Greenhouse gas emission per gram of protein

Produce	g CO2 per gram protein
Beef and Mutton	221.6325178
Dairy	35.07044163
Eggs	24.37099383
Maize	4.422307692
Aquaculture and Fishery	81.10457143
Pork	36.33007692
Poultry	31.74791932
Pulses	0.577692308
Rice	21.1625
Wheat	4.623513514

Source: Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice, Clark and Tilman, 2017

Table 5: Greenhouse gas emission per kilocalorie

Produce	g CO2 per kcal
Beef and Mutton	22.01128
Aquaculture and Fishery	16.132
Pork	3.514826
Dairy	1.823336
Poultry	3.729167
Eggs	2.140921
Rice	0.454167
Wheat	0.215946
Maize	0.113846
Pulses	0.046154

Source: Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice, Clark and Tilman, 2017, adjusted for kcal

5. Results

5.1. Calculating cost efficiency

Using the reports of USDA on Commodity Costs and Returns, the calculations as per formulas from Chapter 4.1.2 were comprised and can be seen in Table 6. The most recent values for taken, for 2017-2018 and averaged to provide a better overview and compensate for lags. At the moment of writing this thesis, 2019 reports are not yet available. There were also no shock values indicated in the 2017-2018 reports which makes the data suitable for estimation. These cost estimations, however, do not include the cost of processing the product, e.g. slaughtering and butchering, in case with meat, or milling, in case with wheat. Those costs will be further discussed. For now, the basic comparison covers the production cost up until its processing.

Table 6: Cost and Returns of production of selected commodities

	Pigs (per cwt live weight gain)	**Cattle (per head live weight)**	**Corn (per acre)**	**Soybeans (per acre)**	**Wheat (per acre)**
Gross value of production	52.875	660.6	620.145	473.32	205.895
Operating costs	41.52	557.835	340.27	159.195	107.945
Allocated overhead	24.445	784.49	346.775	284.285	193.755
Total, costs listed	65.965	1342.325	687.045	443.48	301.7

Source: Summary of Appendices 1-6 based on USDA, Economic Research Service.

From the above table, it is clear that even before processing the products meat comes out as the most expensive per unit of production. Grains are as much as twice, in case with corn, or four times, in case with wheat, cost effective. As it was concluded in the theoretical part, processing cost of meats tends to be much higher in comparison with grains because of its high reliability on water and fossil fuels, which will be later discussed in Environmental Implication chapter.

5.1.1. Calculating cost of producing nutrients

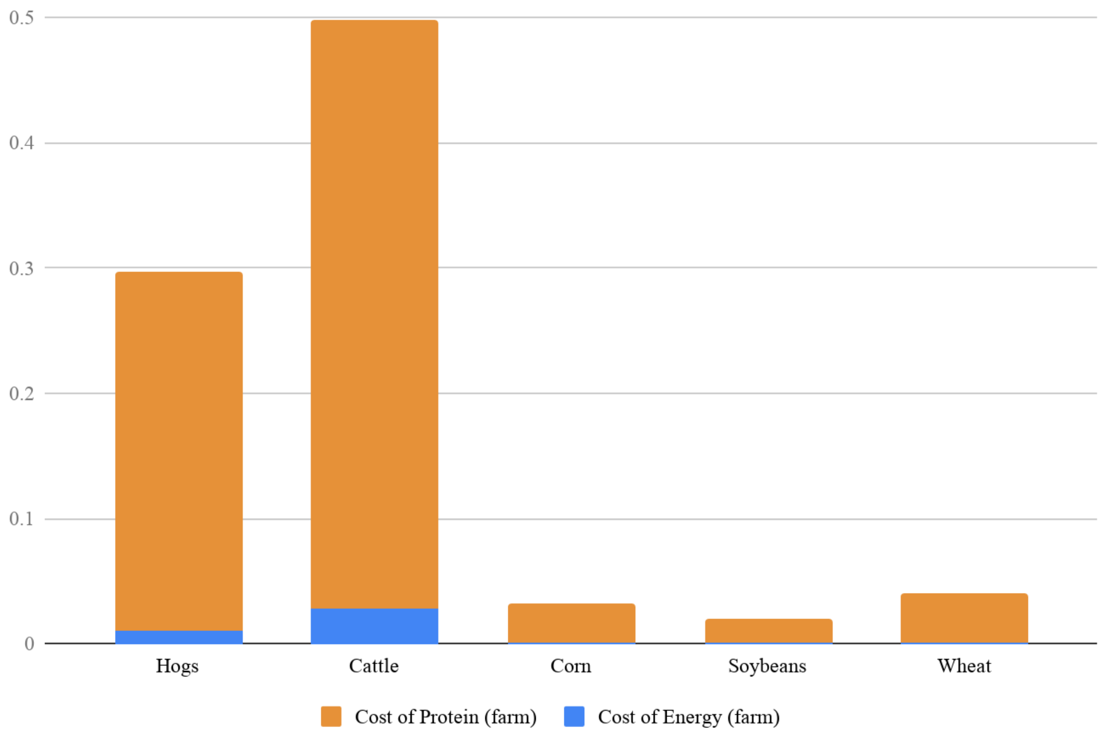
Table 7: Cost of production of selected commodities accounting for nutritious value

Production cost	**Nutrient content**		**Unit cost**	
Cost (USD/lb)	**Energy (kcal/lb)**	**Protein (grams/lb)**	**Cost of Energy (USD/kcal)**	**Cost of Protein (USD/gram)**
0.879	82.953	3.069	0.0106	0.2864
1.796	64.2	3.821	0.0281	0.4700
0.065	80.526	2.078	0.0008	0.0313
0.146	98.397	8.05	0.0015	0.0181
0.109	72.143	2.782	0.0015	0.0392

Source: Own calculations of unit cost based on USDA (production cost), Clark (2017) (nutrient content)

To show the above calculations in a perspective, on the below graph it is visible that not only per unit (here it is gram and kcal) cost of production of both meats is greater than that of all three grains, it is also drastically larger. Cost of energy of grains is so small that it is barely seen on the graph, indicating that not only overall basic production cost of selected grains is much less than of meats, but that it also stands when the nutritious value is taken into consideration.

Figure 6: Cost of production of selected commodities at farm level accounting for nutritious value per a gram (in case with protein) and per kcal (in case with energy), vertical axis in USD



Source: Self-made from calculations in Table 7

5.1.2. Calculating processing cost

Table 8: Cost of production of selected commodities at retail level, accounting for nutritious value

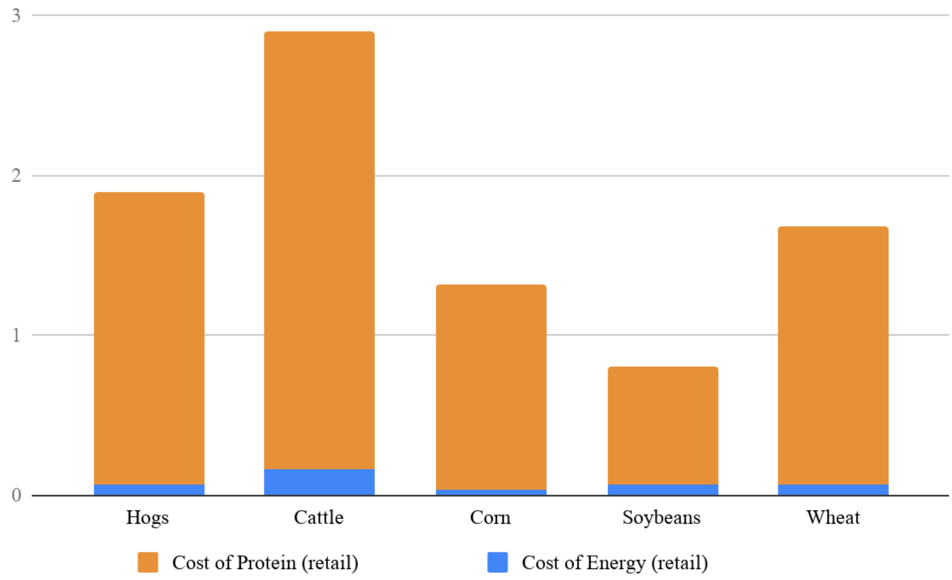
	Cost of Energy (farm) (USD/kcal)	Cost of Protein (farm) (USD/gram)	Farmer's share of retail USD	Cost of Energy (retail) (USD/kcal)	Cost of Protein (retail) (USD/gram)
Hogs	0.0106	0.2864	0.157	0.0675	1.8242
Cattle	0.0281	0.47	0.172	0.1634	2.732
Corn	0.0008	0.0313	0.0243	0.0331	1.2881
Soybeans	0.0015	0.0181	0.0243	0.0617	0.7449
Wheat	0.0015	0.0392	0.0243	0.0617	1.6132

Source: Self-made, Table 7 adjusted for farmer's share of a retail dollar

Cattle and hogs have a larger portion of farmer's share, and wheat, soybeans and corn fall under the same category of grains and cereals and have the same low share. Now that we can calculate the final production cost accounting for nutritious value. Below are adjusted calculations with Farmer's contribution to retail price, to compare the costs more precisely.

To illustrate the change Figure 7 follows the same structure as Figure 6 but now with adjusted to retail values.

Figure 7: Cost of production of selected commodities at retail level accounting for nutritious value per a gram (in case with protein) and per kcal (in case with energy), vertical axis in USD



Source: Self-made from calculations in Table 8

From the graph above we can see that the overall trend stands: meat production is more expensive post processing than production of selected grains, yet the difference in comparison with Figure 6 is not nearly as drastic. That is because, as it was mentioned before, meat is usually readier for processing on farm level then grains which require more processing before they appear on the shelves.

5.1.3. Interpretation of elasticities

Getting back to the Chapter 4.1.5.1, we would want to interpret the equations.

(1) $$P_{CN} = 0.280S_B + 0.059S_P + 0.385S_{CK}$$

(2) $$Q_{CN} = 0.131S_B + 0.028S_P + 0.181S_{CK}$$

Now, simulating absolute shock scenarios from these equations would be irrational since they only reflect the data set used by Marsh, but we can understand the pattern of changes by interpreting the final equations. If we look at price equation (1), the following are the result derivations:

1. If willingness-to-pay for beef (cattle) goes down by 1%, corn prices will also go down by 0.28% because we would incorporate a -1 S (WTP) of beef, and the other way around.
2. If willingness-to-pay for hogs (pork) goes down by 1%, corn prices will also go down by 0.059%.
3. If willingness-to-pay for chickens (broilers) goes down by 1%, corn prices will also go down by 0.385%.

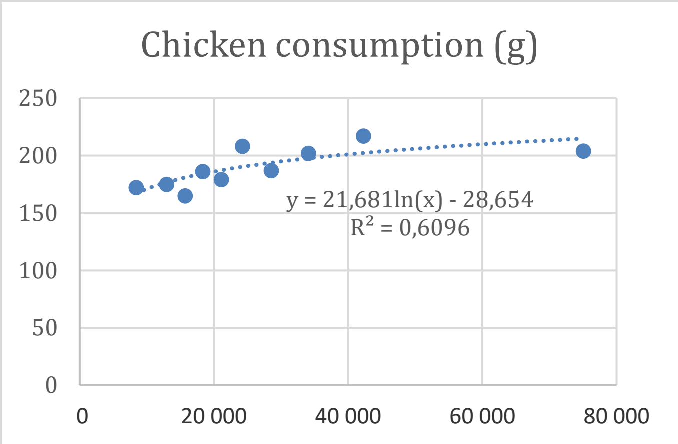
Equation (2) can be interpreted in a similar way:

1. If willingness-to-pay for beef (cattle) goes down by 1%, corn quantity produced will also go down by 0.131%.
2. If willingness-to-pay for pork (hogs) goes down by 1%, corn quantity produced will also go down by 0.028%.
3. If willingness-to-pay for chicken (broilers) goes down by 1%, corn quantity produced will also go down by 0.181%.

Given the above six conclusions, we can finally conclude that even as little as a 1% change in meat consumption would drive down both the price and quantity produced of corn. Interestingly, there is an inverse relationship here as well — lower prices of corn cause prices of meat to go down, too, which means that not only a shift away from omnivorous diets would make a vegetarian diet cheaper, it would also make a regular non-vegetarian diet cheaper.

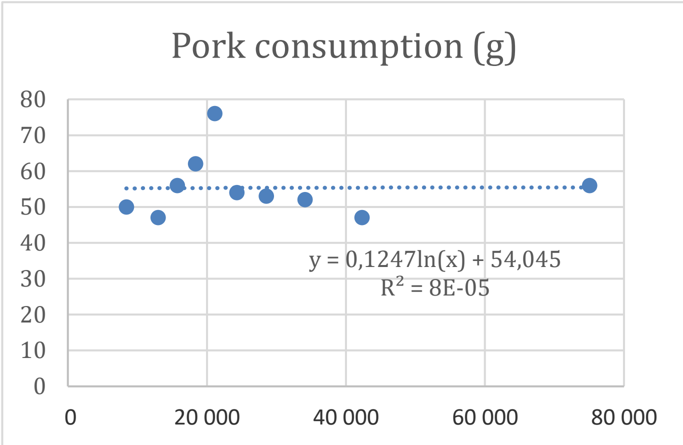
5.1.4. Income elasticity analysis

Figure 9: Logarithmic function graph for chicken consumption, vertical axis – quantity in g, horizontal axis – net money income



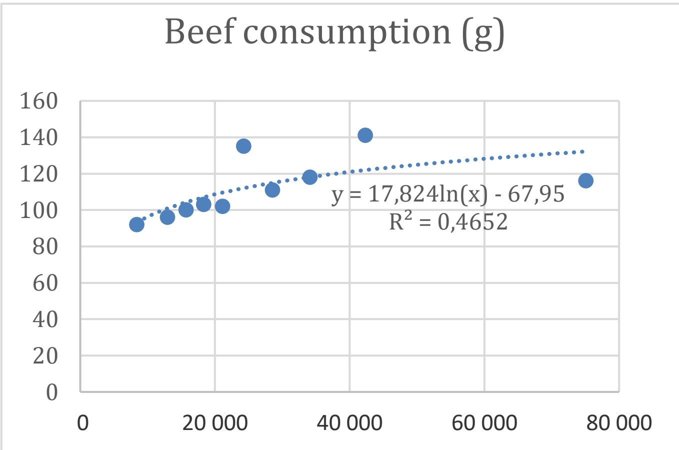
With the income increase consumption tend to raise

Figure 8: Logarithmic function graph for pork consumption, vertical axis – quantity in g, horizontal axis – net money income



Consumption stays on the same level with the income

Figure 10: Logarithmic function graph for beef consumption, vertical axis – quantity in g, horizontal axis – net money income



Apparent raise in consumption with income raise, confirms that the good tends to be luxurious

Figure 8 – 10: Source - Living Costs and Food Survey, UK Data Service, 2011

At first, we proceed with creating graphs to identify logarithmic function coefficients and use them in further calculations of theoretical values of goods consumption. Using Equation 5, we are able to get income elasticity values, see Table 9. Mean is calculated to be able to compare the results.

Table 9: Income elasticity of chosen commodities

Income elasticity	Deciles										
	1	2	3	4	5	6	7	8	9	10	**Mean**
Beef	0,191	0,177	0,171	0,167	0,163	0,159	0,155	0,151	0,146	0,135	0,1614
Pork	0,0023	0,0023	0,0023	0,0023	0,0023	0,0023	0,0023	0,0023	0,0023	0,0022	0,0023
Chicken	0,130	0,123	0,120	0,118	0,116	0,114	0,112	0,110	0,107	0,101	0,1149

Source: Own calculations of income elasticity

As per the results we can see that beef has the highest elasticity, meaning that it is closer to luxurious goods. Given that, we can substitute beef with other types of meat, as beef in this case is purchased by customer not because of necessity, but because of choice of superior good.

5.2. Calculating environmental implication

5.2.1. Quantification of water footprint

Table 10: Water footprint per calorie and protein, by commodity

	Water footprint per ton (m3/ton)	**Nutritional value**		**Water footprint per unit of nutritional value**	
	Total	**Calorie (kcal/kg)**	**Protein (g/kg)**	**Calorie (litre/kcal)**	**Protein (litre/g protein)**
Beef	15415	1513	138	10.19	111.7
Pork	5988	2786	105	2.15	57.028
Dairy	1021	560	33	1.82	30.94
Poultry	4325	1440	127	3.01	34.05
Eggs	3265	1425	111	2.29	29.4
Rice	9063	1290	266	7.03	34.07
Wheat	1644	3208	80	0.51	20.55
Maize	2364	2908	146	0.81	16.19
Pulses	4055	3412	215	1.19	18.86

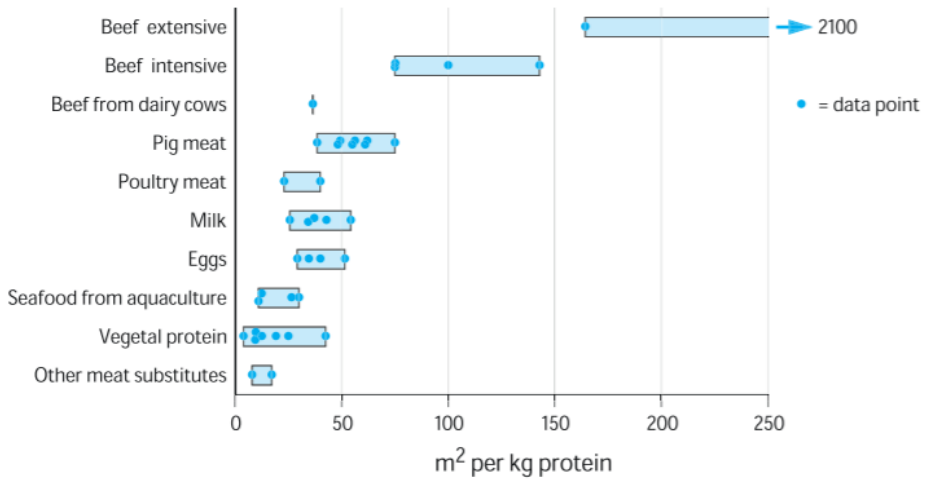
Source: Self-made calculations of calorie and protein per litre, The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products, Mekonnen, M. M. et al, Hydrology and Earth System Sciences, vol. 15, 2011, pp. 1577–1600.

Based on the results, it is visible that animal produce requires on average three times the amount of water in its production than plant-based produce, both in the case with calories and protein. Beef, as expected, is the most water-consuming produce out of meats, and rice is the most water-consuming out of grains and crops due to its specific nature of irrigation. Wheat, maize, and pulses, however, are considerably less water-extensive than meats and animal-based products. It is important to note that different products in Table 10 contain different types of proteins, but for this research that is neglected.

Moreover, as concluded by Mekonnen (2011), replacing 50% of all animal produce by equally nutritious (i.e. rich in calories and protein) crops, such as pulses, would result in a 30% decrease of water footprint related to food production. Freshwater is usually the subject of concern in regard to the environment due to its necessity and scarcity. The conclusion here is that in terms of freshwater consumption, it is more efficient to obtain protein from plant-based products.

5.2.2. Quantification of land use

Figure 11: Land use of foods rich in protein per a kilogram of produce (see Table 3)

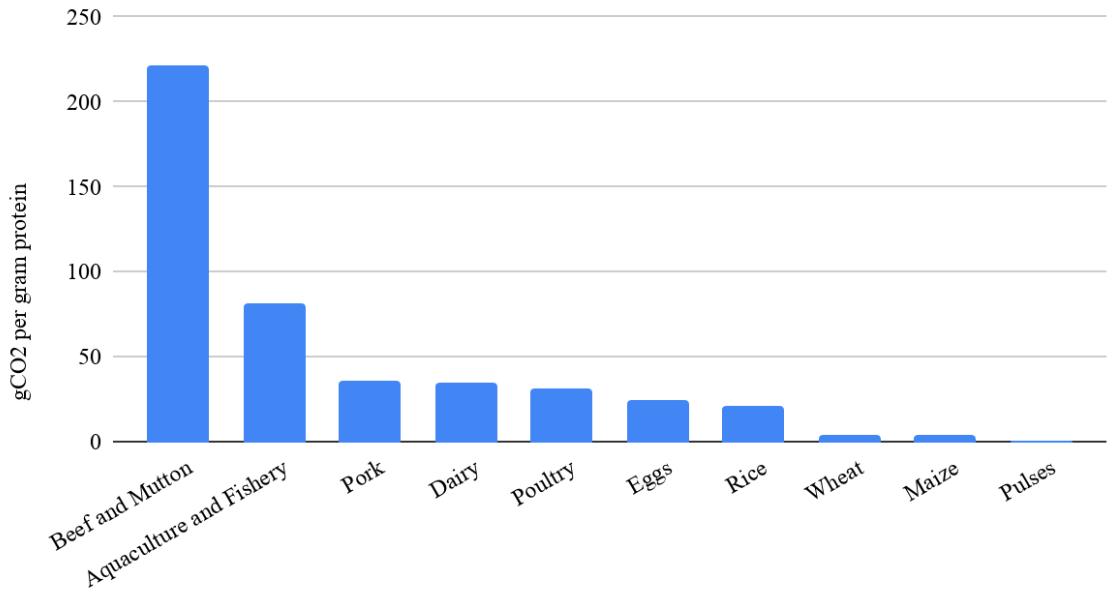


Source: The Price of Protein, Nijdam, Durk, 2012, pp. 760-770,

As expected, beef protein requires the most amount of land as it is being extensively produced, as opposed to such meats as pork and poultry, which are largely demanding of arable land, that also take up a lot of space in comparison with grains and crops. Land occupation of beef, that is as rich in protein as pulses, is in some cases a hundred times over that of pulses, which yet again proves that extracting protein from plant-based produce is much efficient in regards to scarce resource use. It is important to note that excessive land use (e.g. extensive grazing) leads to deforestation, which also indirectly contributes to the greenhouse footprint and adds on the environmental residual of a product (Swain, 2018). That happens because soil and plant materials, such as leaves and wood, store carbon which is released when deforestation takes place. Thus, not only deforestation disrupts the ecological system, it also adds onto the GHG emission which is discussed in the following section.

5.2.3. Quantification of carbon emission

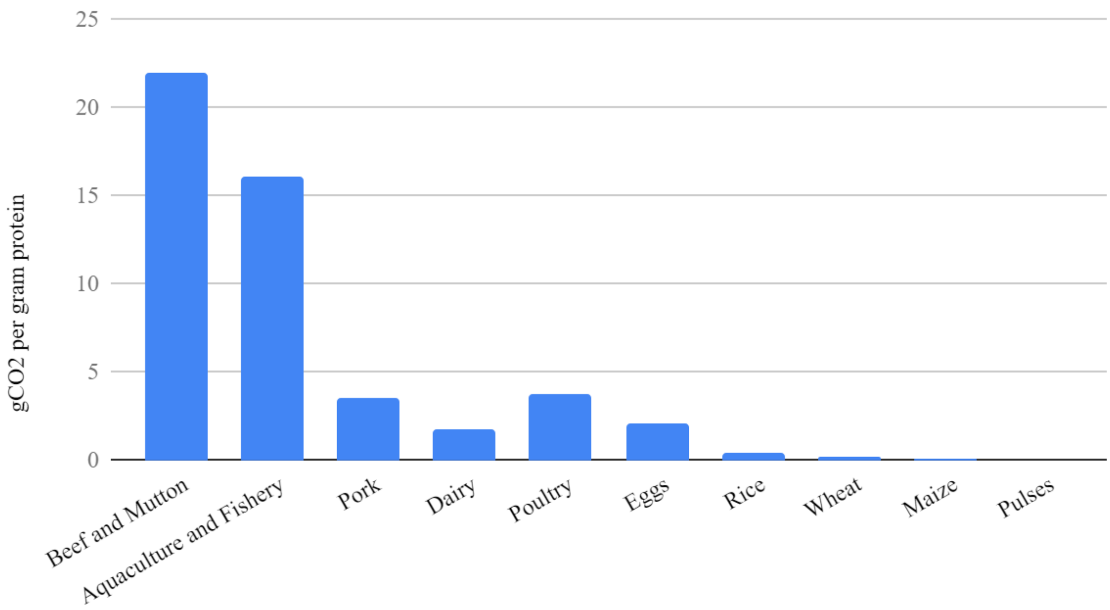
Figure 12: GHG emission per gram of protein, by food



Source: Interpreted from Table 4

Beef is yet again the largest contributor, similarly to cases with water- and land-use. This time, however, the difference is in absolutes—hundreds the times of GHG emission of grains. Rice, being not that rich in protein, has the GHG footprint nearly equivalent to eggs and poultry. That distortion is mitigated when carbon footprint is calculated per kilocalorie.

Figure 13: GHG emission per kilocalorie of production, by food



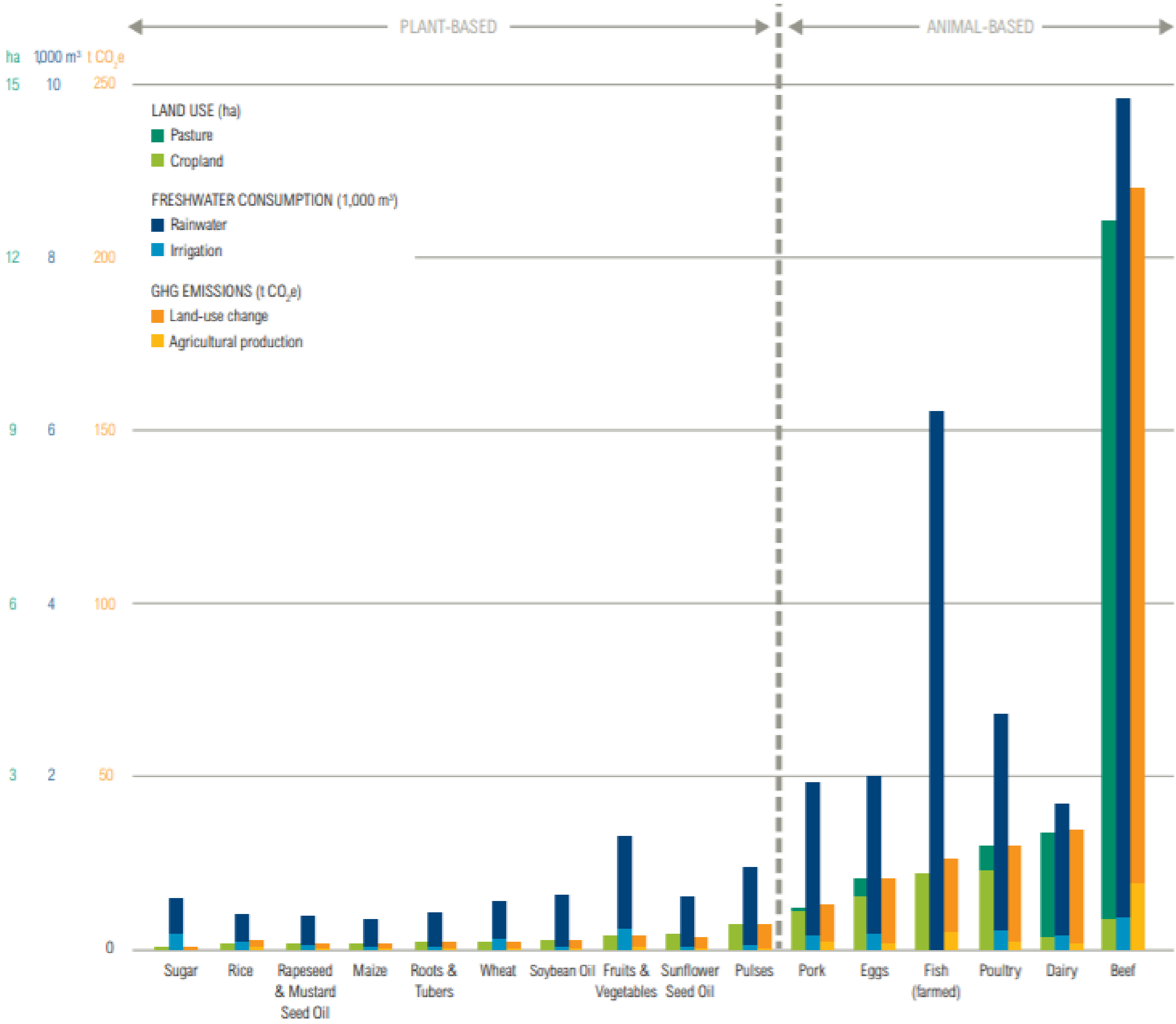
Source: Interpreted from Table 5

Accounting for kilocalories shows a clear difference in GHG emission levels between meat- and dairy-based products and plant-based products. To conclude this section, in the grand scheme of things, plant-based foods are not only more sustainable when it comes to carbon emission, but also have the only footprint acceptable in the framework of keeping the global temperature increase under 1.5 C, which is outlined in Paris Climate Agreement (Greenpeace International, 2018).

5.2.4. Overview of environmental impact

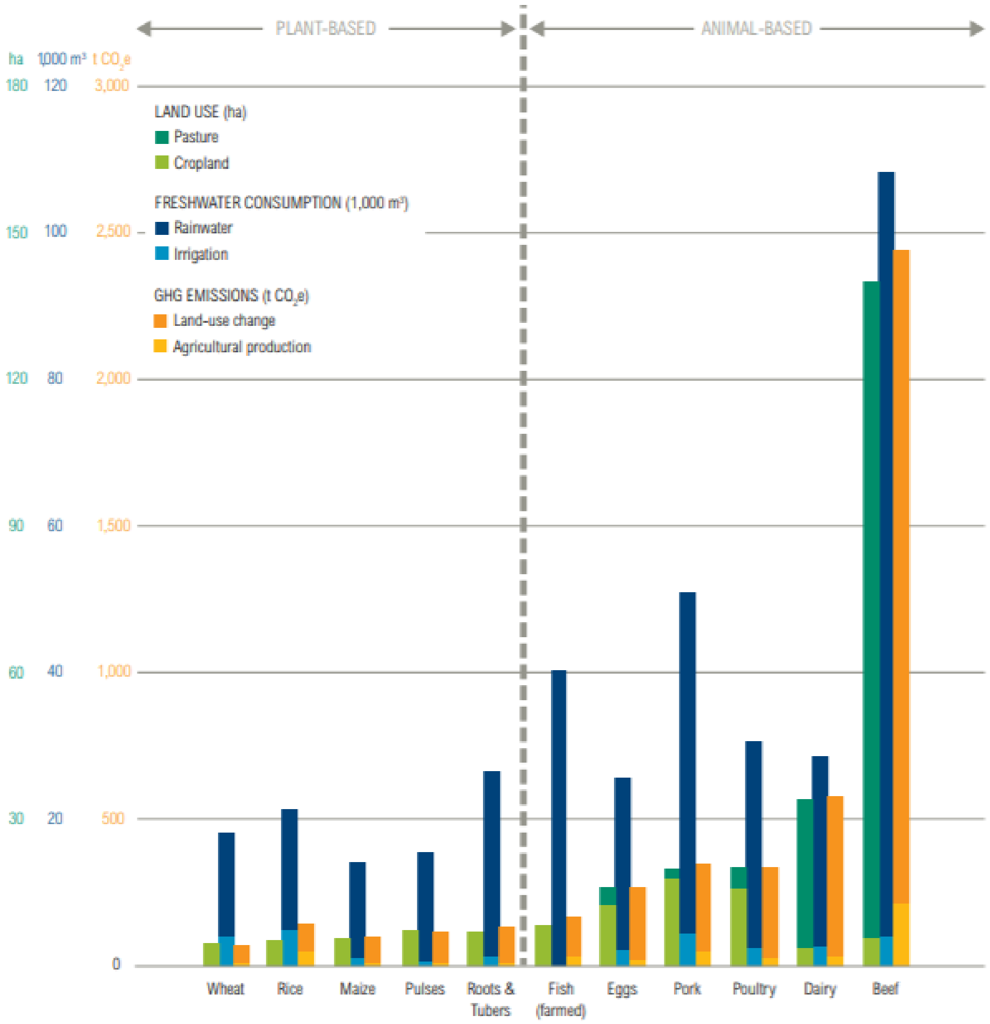
Drawing on quantitative results of water footprint, land use, and greenhouse emission that were discussed in this chapter, livestock has the largest share of all three. The compounded overview of everything previously discussed can be seen on Tables 4 and 5, accounting for kilocalorie and protein output, respectively.

Figure 14:Environmental implication per a million kilocalories consumed



Sources: Ranganathan, et al.(2016) (land use and greenhouse gas emissions), calculations from Mekonnen and Hoekstra (2011) (freshwater consumption), and Waite et al. (2014) (farmed fish freshwater consumption)

Figure 15: Environmental implication per a ton of protein consumed



Sources: Ranganathan, et al. (2016) (land use and greenhouse gas emissions), calculations from Mekonnen and Hoekstra (2011) (freshwater consumption), and Waite et al. (2014) (farmed fish freshwater consumption)

Beef is an obvious leader in all categories, which makes it the least efficient food to produce from a perspective of input to nutritional value output. This low efficiency of input-to-output conversion inevitably causes large volumes of greenhouse emission and land and water use as opposed to any other rich in protein food. At a global level, beef cattle is a huge driver of scarce resource use among the other agricultural produce. ¼ of Earth land is used for pasture, and beef also makes for ⅓ of water consumption from entire animal production industry. In terms of landmass use, the emerging production often calls for clearing forests and savannas, which is commonly known as deforestation, which in its turn also contributes to carbon emission. That makes beef to be responsible for more than half of GHG emission from the entire agricultural production. While beef is an obvious extreme, the rest of the meats are close runners-up in the comparison models. Pork, poultry, fish and dairy are by all categories more environmentally unfriendly than plant-based alternatives, causing in most cases more than double the harm.

6. Discussion

According to the United States Department of Agriculture, more than 90% of the whole grain produced in the U.S. is used to feed livestock and poultry: cows, pigs, sheep, and chickens (Lappe, 1991). The use of grain for animal feeding does seem as a waste of resources considering other statistics released by the United States Department of Agriculture, which suggests that it takes 16 kilograms of grain to be fed to cattle to get one kilogram of meat (Lappe, 1991). In the United States alone, more than ⅔ of all fossil fuels and raw materials are used in animal farming (Springmann, 2016). Drawing on the derivations from the theoretical part, including most recent studies of Kayal, 2018 and Poore, 2018, the hypothesis for cost efficiency of meat-based versus plant-based agriculture was that the plant-based food system is more cost effective in terms of production. While it is clear from the theory that producing and processing meat is more expensive and energy-consumptive than for grains, none of the studies listed above took into consideration the nutritional value of the products, and thus it is speculative to conclude that it is better for people to switch to a plant-based diet as it might require an unexpectedly large increase in grain production volume due to nutritional shortage.

As per the data collection in the practical part, before processing the products, meat comes out as the most expensive per unit of production (1342.325 USD for cattle per head live weight). Grains are as much as twice, in case with corn (687.045 USD per acre), or four times, in case with wheat (301.7 USD), cost effective. Once again, that is the metrics as it is usually compared in related studies (including Springmann, 2016 and Kayal, 2018). To showcase the actual production cost of nutrients, it was adjusted to reflect the cost of energy (USD/kcal) and cost of protein (USD/gram of protein). Cost of energy of grains turned out to be very small (USD 0.028/kcal and USD 0.4700/ gram of protein for cattle, in contrast to USD 0.0008/kcal and USD 0.0313/ gram of protein for corm and USD 0.0015/kcal and USD 0.0392/gram of protein for wheat), indicating that not only overall basic production cost of selected grains is much less than of meats, but that it also stands when the nutritious value is taken into consideration. Still, the above estimations only represent the cost of production at the farm level and not final retail, since no processing or transportation costs were considered. By separating farmer's share of the retail dollar, the proportion of farm contribution as opposed to retail contribution (meaning, post processing and transportation) was calculated. The overall hypothesis stood true: meat production turned out to be more expensive post processing (USD 0.1634/kcal and USD 2.732/ gram of protein for cattle) than production of selected grains (USD 0.0331/kcal and USD 1.2881/ gram of protein for corn and USD 0.0331/kcal and USD 1.2881/ gram of protein for corn and USD 0.0617/kcal and USD 1.6132/ gram of protein for wheat), yet the difference in comparison with previous calculations was not nearly as drastic. That is because meat is usually readier for processing on farm level then grains which require more processing before they appear on the shelves, which means more costs involved. In addition, after analysing the supply and demand correlations explained in study of JM Marsh (2007) and further discussion on it of Lusk and Bailey (2009), it was concluded that even as little as a 1% change in meat consumption would drive down both the price and quantity produced of corn. Interestingly, there is an inverse relationship here as well — lower prices of corn cause prices of meat to go down, too, which means that not only a shift away from omnivorous diets would make a vegetarian diet cheaper, it would also make a regular non-vegetarian diet cheaper.

There is a plethora of studies related to environmental footprint of agriculture, yet none of them among those listed throughout this thesis take into consideration the nutritional value of products. For the same reason, while the hypothesis derived from the theoretical part is quite straightforward, it needs further justification for the nutrition argument. According to Springmann, beef production in the U.S. has a higher water consumption than that of the country's total fruit and vegetable harvest (Springmann, 2016). Drainage of wastewater and the discharge of waste from meat processing plants and fattening farms into rivers and reservoirs is one of the main causes of their pollution. Georg Borgstrom claimed that wastewater from cattle farms pollutes the environment ten times more than urban sewage and three times more than industrial sewage (Borgstrom, 1980). American biologists and professors at Stanford University, Paul and Anna Ehrlich, in their book *Population, Resources, and Environment* also concluded that it takes only 60 litres of water to grow one kilogram of wheat, while it takes 1250-3000 litres to produce one kilogram of meat. (Ehrlich, 1970). Meat production is also notorious for contributing to erosion of billions of acres of farmland and deforestation. Cattle farming, for example, is the main reason of Amazon deforestation: as much as 80% of deforested land is used as grassland for pasturage (Greenpeace, 2009). Interestingly, deforestation associated with soy production, which is not only a meat substitute but also a product used for animal feeding—is also among main concerns of Greenpeace (Greenpeace, 2009).

The hypothesis that was derived from the theoretical part was as follows: the meat-based food system requires more energy (and thus produces more GHG), land, and water resources than the vegetarian diet. In this limited sense, the vegetarian diet is more sustainable than meat-based diet and therefore is more favourable for the economy. Using the same nutritional metrics, the comparative tables were adjusted to reflect the footprint per calorie and gram of protein. Based on the results, it was concluded that animal produce requires on average three times the amount of water in its production (10.19 L/kcal and 111.7 L/gram of protein for beef) than plant-based produce (0.51 L/kcal and 20.55 L/gram of protein for wheat and 7.03 L/kcal and 34.07 L/gram of protein for rice), both in the case with calories and protein. Beef, as expected, is the most water-consuming produce out of meats, and rice is the most water-consuming out of grains and crops due to its specific nature of irrigation. Wheat, maize, and pulses, however, are considerably less water-extensive than meat and animal-based products.

Similarly, after comparing produce rich in protein, beef protein turned out to require the most amount of land (7–420 m2/kg) as it is being extensively produced, as opposed to such meats as pork (33–158 m2/kg) and poultry (5–8 m2/kg), which are largely demanding of arable land, that also take up a lot of space in comparison with grains and crops (2-3 m2/kg). Land occupation of beef, that is as rich in protein as pulses (3-8 m2/kg), is in some cases a hundred times over that of pulses, which yet again proves that extracting protein from plant-based produce is much efficient in regards to scarce resource use. It is important to note that excessive land use (e.g. extensive grazing) leads to deforestation, which also indirectly contributes to the greenhouse footprint and adds on the environmental residual of a product (Swain, 2018). That happens because soil and plant materials, such as leaves and wood, store carbon which is released when deforestation takes place. Thus, not only deforestation disrupts the ecological system, it also adds onto the GHG emission.

When it comes to greenhouse emissions, beef yet again turned out to be the largest contributor (221.63 g CO2 per gram of protein), similarly to cases with water- and land-use. This time, however, the difference is in absolutes—hundreds of times of GHG emission of grains. Rice, being not that rich in protein, has the GHG footprint (21.16 g CO2 per gram of protein) nearly equivalent to eggs (24.37 g CO2 per gram of protein) and poultry (31.74 g CO2 per gram of protein). That distortion is mitigated when carbon footprint is calculated per kilocalorie: beef -- 22.01128 g CO2 per kcal, rice -- 0.454167 g CO2 per kcal, poultry -

- 3.729167 g CO_2 per kcal. Accounting for kilocalories yet again shows a clear difference in GHG emission levels between meat- and dairy-based products and plant-based products.

Drawing on quantitative results of water footprint, land use, and greenhouse emission that were discussed in this chapter, livestock has the largest share of all three. Beef is an obvious leader in all categories, which makes it the least efficient food to produce from a perspective of input to nutritional value output. This low efficiency of input-to-output conversion inevitably causes large volumes of greenhouse emission and land and water use as opposed to any other rich in protein food. At a global level, beef cattle is a huge driver of scarce resource use among the other agricultural produce. ¼ of Earth land is used for pasture, and beef also makes for ⅓ of water consumption from entire animal production industry. In terms of landmass use, the emerging production often calls for clearing forests and savannas, which is commonly known as deforestation, which in its turn also contributes to carbon emission. That makes beef to be responsible for more than half of GHG emission from the entire agricultural production. While beef is an obvious extreme, the rest of the meats are close runners-up in the comparison models. Pork, poultry, fish and dairy are by all categories more environmentally unfriendly than plant-based alternatives, causing in most cases more than double the harm.

Summing up the above, the adjustments for the nutritional values do not skew the hypothesis assumptions -- both hypotheses from the literature review stand to the empirical evidence, however, it is important to emphasize the extent of them. Overall, when converting conventional metrics to per gram of protein and per calorie, the distortion between meat- and plant-based products becomes smaller. Thus, while the conclusions from the theoretical part are supported by the evidence in the practical part, they are somewhat overestimated in existing research and, considering the nutritional value of meat protein, its production costs, both internal (cost efficiency) and external (environmental residuals) can be argued to be justified.

7. Conclusion

This thesis aimed to assess the economic efficiency of the plant-based agriculture as compared to a present-day, meat-based agricultural production system through analysing its three key angles of prospective impact on the economy: production cost efficiency, environmental implications, and agro-economic consequences.

From literature review, the assumptions about meat-based agriculture were derived, stating that livestock accounts for a large share of environmental damage and does not justify its basic production costs. As far as socioeconomic factor is concerned, animal farming is among the largest economic sectors in the whole world and eliminating animal farming as an industry would have a devastating impact on labour force unless executed gradually with account for workforce replacement and re-training. Multiple research also shows that animal farming contributes to global inequality gap, since developing countries produce the majority of livestock food that is then exported to more wealthy countries, being ahead of local livestock production. That also suggests that food shortage and starvation can be reduced if only the resources put into animal farming are redirected to plant-based agriculture. Health and societal costs were briefly discussed but are only used as a framework for further assumptions rather than an argument, since its quantification is out of scope of this thesis. Health consequences of a vegetarian and/or vegans are relative and difficult to estimate, but research discussed in Chapter 3.4 quantified it in quality adjusted life years (QALY), with abstaining from omnivorous diet bringing as much as 100-159 yield of QALY, which is not only beneficial for one's health but is also cost-efficient for a society in terms of social welfare and healthcare in particular.

In the practical part, the production cost and environmental implication were calculated with account to nutritional value of products. The reason the basic cost of production overview in Chapter 4.1.2 cannot efficiently reflect the production costs of meat and grain comes back to a widespread pro-omnivorous diet argument that meat is more nutritious than grains and that it justifies its production and respective selling prices. In Chapter 4.1.4, basic cost of production per unit of output was calculated based on the formulas and data from United States Department of Agriculture (the breakdown of calculation is in Appendix 1). That values were then adjusted to cost of producing nutrients and then to farmer's share of a retail dollar to calculate the cost of processing. Before processing, meat comes out as the most expensive per unit of production. Grains are as much as twice, in case with corn, or four times, in case with wheat, cost effective. When accounting for cost of kilocalorie of protein, the difference from meat products becomes more drastic (Figure 7). When accounted for processing cost, the overall trend stands: meat production is more expensive post processing than production of selected grains, yet the difference in comparison with Figure 7 is not nearly as drastic. That is because meat is usually readier for processing on farm level then grains which require more processing before they appear on retail.

Above mentioned calculations and comparisons only reflect today's reality, Now, if people worldwide would suddenly stop consuming meat altogether, that would call for re-calculation of all above. Being intercorrelated by nature, that is being markets of food, meat and grain markets are expected to have a great influence on one another. After analysing the supply and demand correlation of meats and grains, the conclusion is that even as little as a 1% change in meat consumption would drive down both the price and quantity produced of corn. Interestingly, there is an inverse relationship here as well — lower prices of corn cause prices of meat to go down, too, which means that not only a shift away from omnivorous diets would make a vegetarian diet cheaper, it would also make a regular non-vegetarian diet cheaper.

For environmental implication, a similar approach was chosen — impact was adjusted to per kilocalorie and per protein of output, where possible. The conclusion is that meat and dairy products have a much larger contribution to water footprint (consumption), greenhouse (carbon) emissions, and land use (including deforestation and respective GHG emissions associated with it). The low efficiency of input (of resources)-to-output (of nutritional value) conversion inevitably causes large volumes of greenhouse emission and land and water use as opposed to any other rich in protein food. That not only shows the grassroot inefficiency of animal agriculture in respect to the environment, but also indicates that the cost of such environmental externalities are not being paid in full when the produce reaches the shelves, or else it would have hit through the ceiling by now. Not to mention that the basic cost of production of grains and crops, even with account of their nutritional levels, is much more economically efficient than that of livestock farming.

The global population continues to boom, especially over the last hundred years, and rising incomes and persisting industrialization suggests that demand for animal products will likely rise because of a number or reasons, among cultural habits and cheap consumer prices. Yet it is undeniable that animal farming costs billions and billions in external costs and has the potential to be replaced with a much more cost-efficient alternative, even if not entirely plant-based. It is unrealistic to expect the whole world to decide to abstain from meat overnight—that raises its own concerns—but adopting a more environmentally sustainable diet, that is, less meat-oriented, is a huge step towards a more sustainable global economy. Adopting a more plant-based oriented agriculture and consumption would also align with the goals of the United Nations Sustainable Development, such as eliminating hunger, efficient water management, controlled climate change (limiting the global temperature rise to 1.5 to 2 degrees Celsius, also outlined in Paris Climate Agreement), developed terrestrial ecosystem, and improved living standards.

8. Bibliography

1. Alexander, Peter, et al. "Human Appropriation of Land for Food: The Role of Diet." *Global Environmental Change*, vol. 41, 2016, pp. 88–98., doi: 10.1016/j.gloenvcha.2016.09.005.

2. Berners-Lee, Mike. *How Bad Are Bananas?: the Carbon Footprint of Everything*. Greystone Books, 2011.

3. Bittman, Mark. "Rethinking the Meat-Guzzler." *The New York Times*, The New York Times, 27 Jan. 2008, www.nytimes.com/2008/01/27/weekinreview/27bittman.html.

4. Borgstrom, G. *The need for appropriate animal production systems for the tropics*, Animal production systems for the tropics. Publication No. 8. International Foundation for Science, 1980, Stockholm.

5. Cambridge Dictionary, SUSTAINABILITY | Meaning in the Cambridge English Dictionary." *Cambridge Dictionary*, dictionary.cambridge.org/dictionary/english/sustainability.

6. CIWF, *The Life of Broiler Chickens*, 2013, Compassion in World Farming, www.ciwf.org.uk/media.

7. Clark, Michael, and David Tilman. "Comparative Analysis of Environmental Impacts of Agricultural Production Systems, Agricultural Input Efficiency, and Food Choice." *Environmental Research Letters*, vol. 12, no. 6, 2017, p. 064016., doi:10.1088/1748-9326/aa6cd5.

8. Clay, Jason W. *World Agriculture and the Environment: a Commodity-by-Commodity Guide to Impacts and Practices*. Island Press, 2004.

9. Colbert, Francis T., et al. "Population, Resources, Environment." *Journal of Range Management*, vol. 23, no. 4, 1970, p. 304., doi:10.2307/3896229.

10. Donnellan, Douglas, et al. "Whatâ™s the True Cost of Food?" *Food Tank*, 13 Nov. 2016, foodtank.com/news/2015/09/conventional-agriculture-isnt-cheap/.

11. Ehrlich, Paul R., and Anne H. Ehrlich. *Population, Resources, Environment: Issues in Human Ecology*. Freeman, 1975.

12. Eshel G., Martin P.A., *Diet, energy, and global warming*. 2006, *Earth Interact*, vol. 10, pp. 1–17

13. European Commission, *The Common Agricultural Policy at a Glance*, 28 May 2019, ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/cap-glance_en.

14. Fleming, Sean. *Ever Ordered a Vegan Meal? You Will Soon. This Is Why*, World Economic Forum, www.weforum.org/agenda/2018/11/the-vegan-economy-is-booming-and-big-food-wants-a-slice-of-it/.

15. Gerbens-Leenes, P.w., et al. "The Water Footprint of Poultry, Pork and Beef: A Comparative Study in Different Countries and Production Systems." *Water Resources and Industry*, vol. 1-2, 2013, pp. 25–36., doi: 10.1016/j.wri.2013.03.001.

16. Godfray, H. Charles J., et al. "Meat Consumption, Health, and the Environment." *Science*, vol. 361, no. 6399, 2018, doi:10.1126/science.aam5324.

17. Greenpeace International. "Less Is More." *Greenpeace International*, www.greenpeace.org/international/publication/15093/less-is-more/.

18. Halverson, Marlene. *The Price We Pay for Corporate Hogs*. Institute for Agriculture and Trade Policy, 2000.

19. Henderson, Emma. "Why Being Vegan Isn't as Environmentally Friendly as You Might Think." *The Independent*, Independent Digital News and Media, 29 Jan. 2018, www.independent.co.uk/life-style/food-and-drink/veganism-environment-veganuary-friendly-food-diet-damage-hodmedods-protein-crops-jack-monroe-a8177541.html.

20. Innes, Robert. "The Economics of Livestock Waste and Its Regulation." *American Journal of Agricultural Economics*, vol. 82, no. 1, 2000, pp. 97–117., doi:10.1111/0002-9092.00009.

21. Jha, Raghbendra, et al. *Handbook on Food: Demand, Supply, Sustainability and Security*. Edward Elgar Publishing, 2015.

22. Kayal, Mohsen, et al. "Humanity and the 21st Century's Resource Gauntlet: a Commentary on Ripple Et Al.'s Article 'World Scientists' Warning to Humanity: a Second Notice.'" 2018, doi: 10.7287/peerj.preprints.27276v1.

23. Landes, Maurice R. "Indian Agriculture and Policy in Transition." *Food for Policy*, pp. 19–67., doi:10.1017/upo9788175968462.003.

24. Lappe, Frances Moore. *Diet for a Small Planet*. Ballantine Books, 1991.

25. Leahy, Eimear; Lyons, Seán; Tol, Richard S. J. (2010) : National determinants of vegetarianism, ESRI Working Paper, No. 341, The Economic and Social Research Institute (ESRI), Dublin

26. Linzey, Andrew, and Desmond Tutu. *The Global Guide to Animal Protection*. University of Illinois Press, 2013.

27. Lusk, Jayson, *Farmer's Share of the Retail Dollar - Enough Already*, jaysonlusk.com/blog/2018/7/23/farmers-share-of-the-retail-dollar-enough-already.

28. Lusk, Jayson L., and F. Bailey Norwood. “Some Economic Benefits and Costs of Vegetarianism.” *Agricultural and Resource Economics Review*, vol. 38, no. 02, 2009, pp. 109–124., doi:10.1017/s1068280500003142.

29. M., John. “Cross-Sector Relationships Between the Corn Feed Grains and Livestock and Poultry Economies.” *AgEcon Search*, 1 Jan. 1970, ageconsearch.umn.edu/record/8595?ln=en.

30. Martinko, Katherine. “Ordinary Mexicans Struggle to Afford Avocados.” *TreeHugger*, Treehugger, 11 Oct. 2018, www.treehugger.com/green-food/mexico-might-have-import-avocados-feed-locals.html.

31. Mekonnen, M. M., and A. Y. Hoekstra. “The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products.” *Hydrology and Earth System Sciences*, vol. 15, no. 5, 2011, pp. 1577–1600., doi:10.5194/hess-15-1577-2011.

32. National Farmers Union, *Farmer's Share of Retail Food Dollar Hits New Low*, 4 May 2018, nfu.org/2018/05/04/farmers-share-of-retail-food-dollar-hits-new-low/.

33. National Institute of Food and Agriculture (NIFA), *Spurring Innovation in Food and Agriculture: a Review of the USDA Agriculture and Food Research Initiative Program*. National Academies Press, 2014

34. National Research Council. *Toward Sustainable Agriculture Systems in the 21st Century*. Washington, DC: National Academies Press; 2010. doi:10.17226/12832.

35. Nijdam, Durk, et al. “The Price of Protein: Review of Land Use and Carbon Footprints from Life Cycle Assessments of Animal Food Products and Their Substitutes.” *Food Policy*, vol. 37, no. 6, 2012, pp. 760–770., doi: 10.1016/j.foodpol.2012.08.002.

36. Ogino, Akifumi, et al. “Evaluating Environmental Impacts of the Japanese Beef Cow?Calf System by the Life Cycle Assessment Method.” *Animal Science Journal*, vol. 78, no. 4, 2007, pp. 424–432., doi:10.1111/j.1740-0929.2007.00457.x.

37. Oppenlander, Richard A. *Comfortably Unaware: Global Depletion and Food Responsibility ... What You Choose to Eat Is Killing Our Planet.* Langdon Street Press, 2011.

38. PETA, *Vegans: We Do Care About Humans!* 22 Nov. 2013, www.peta.org/living/food/vegans-care-humans/.

39. Pimentel, David. “Agriculture and Environmental Change.” *Ecological Economics*, vol. 19, no. 2, 1996, pp. 189–191., doi:10.1016/0921-8009(96)84163-2.

40. Pimentel, David, and Marcia Pimentel. “Sustainability of Meat-Based and Plant-Based Diets and the Environment.” *The American Journal of Clinical Nutrition*, vol. 78, no. 3, 2003, doi:10.1093/ajcn/78.3.660s.

41. Pimentel, David, and Marcia Pimentel. “Too Many People for Food Resources and the Environment.” *Politics and the Life Sciences*, vol. 16, no. 02, 1997, pp. 217–219., doi:10.1017/s0730938400024643.

42. Poore, J., and T. Nemecek. “Reducing Food’s Environmental Impacts through Producers and Consumers.” *Science*, vol. 360, no. 6392, 2018, pp. 987–992., doi:10.1126/science.aaq0216.

43. Ranganathan, Janet & Vennard, Daniel & Waite, Richard & Searchinger, Tim & Dumas, Patrice & Lipinski, Brian. *Shifting Diets: Towards a Sustainable Food Future*, 2016

44. Robbins, John. *The Food Revolution: How Your Diet Can Help Save Your Life and Our World*. Conari, 2001.

45. Schepers, Janne, and Lieven Annemans. “The Potential Health and Economic Effects of Plant-Based Food Patterns in Belgium and the United Kingdom.” *Nutrition*, vol. 48, 2018, pp. 24–32., doi: 10.1016/j.nut.2017.11.028.

46. Simon, David Robinson. *Meatonomics: How the Rigged Economics of Meat and Dairy Make You Consume Too Much-and How to Eat Better, Live Longer, and Spend Smarter*. Conari Press, 2013.

47. Springmann, Marco, et al. “Analysis and Valuation of the Health and Climate Change Cobenefits of Dietary Change.” *Proceedings of the National Academy of Sciences*, vol. 113, no. 15, 2016, pp. 4146–4151., doi:10.1073/pnas.1523119113.

48. Statista, *Meat Production Worldwide*, 2016-2018 | Statistic.” www.statista.com/statistics/237644/global-meat-production-since-1990/

49. Steinfeld, Henning. *Livestock's Long Shadow: Environmental Issues and Options*. FAO, 2006.

50. Steinfeld, Jeffrey I. “Energy Futures and Green Chemistry: Competing for Carbon.” *Sustainability Science*, vol. 1, no. 1, 2006, pp. 123–126., doi:10.1007/s11625-006-0004-7.

51. Swain, Marian, et al. "Reducing the Environmental Impact of Global Diets." *Science of The Total Environment*, vol. 610-611, 2018, pp. 1207–1209., doi: 10.1016/j.scitotenv.2017.08.125.

52. UN, FAO: Food and Agriculture Organization of the United Nations - Office of the Secretary-General's Envoy on Youth, United Nations, www.un.org/youthenvoy/2013/09/fao-food-and-agriculture-organization-of-the-united-nations/

53. USDA, Jones, Keithly, and Mildred Haley. "Livestock, Dairy, and Poultry Outlook: April 2017." *USDA ERS*, www.ers.usda.gov/publications/pub-details/?pubid=83250.

54. USDA, "Livestock, Meat & Grains Domestic *USDA ERS - Domestic Data*, www.ers.usda.gov/data-products/livestock-meat-domestic-data/.

55. Waite, et al. "Improving Productivity and Environmental Performance of Aquaculture: Creating a Sustainable Food Future, Installment Five." *Community List*, World Resources Institute, 1 June 2014, cgspace.cgiar.org/handle/10568/56966.

56. Zee, Bibi van der. "What Is the True Cost of Eating Meat?" *The Guardian*, Guardian News and Media, 7 May 2018, www.theguardian.com/news/2018/may/07/true-cost-of-eating-meat-environment-health-animal-welfare.

9. Appendices

Data in Appendices 1-5 is from USDA, “Livestock, Meat & Grains Domestic Data.” *USDA ERS - Domestic Data*

Appendix 1: Cost and Returns of Hogs, U.S. average 2017-2018

	2018	**2017**	**AV**
Gross value of production			
Market hogs	54.78	50.91	52.845
Feeder pigs	0.21	0.19	0.2
Nursery pigs	0.02	0.02	0.02
Cull stock	1.27	1.17	1.22
Breeding stock	0.34	0.32	0.33
Inventory change	0.83	0.87	0.85
Other income 2/	3.27	3.55	3.41
Total, gross value of production	60.72	57.03	58.875
Operating costs			
Feed --			
Purchased feed	26.28	28.25	27.265
Homegrown harvested feed	6.02	6.19	6.105
Total feed cost	32.3	34.44	33.37
Other --			
Feeder pigs	0.49	0.44	0.465
Nursery pigs	0.18	0.16	0.17
Veterinary and medicine	3.07	3.15	3.11
Bedding and litter	0.04	0.05	0.045
Marketing	0.22	0.22	0.22
Custom services	0.76	0.79	0.775

Fuel, lube, and electricity	1.92	1.68	1.8
Repairs	1.43	1.39	1.41
Interest on operating capital	0.21	0.1	0.155
Total, operating costs	40.62	42.42	41.52
Allocated overhead			
Hired labor	4.33	4.28	4.305
Opportunity cost of unpaid labor	4.91	4.66	4.785
Capital recovery of machinery and equipment 3/	13.54	13.23	13.385
Opportunity cost of land (rental rate)	0.07	0.07	0.07
Taxes and insurance	0.63	0.64	0.635
General farm overhead	1.28	1.25	1.265
Total, allocated overhead	24.76	24.13	24.445
Total costs listed	65.38	66.55	65.965
Value of production less total costs listed	-4.66	-9.52	-7.09
Value of production less operating costs	20.1	14.61	17.355
Supporting information			
Production arrangement (percent of production)			
Independent	100	100	100
Under contract	0	0	0
Size of operation (head sold/removed)			
Market hogs	3,159	3,179	3169
Feeder pigs	36	37	36.5
Nursery pigs	9	10	9.5

Appendix 2: Cost and Returns of Cattle, U.S. average 2017-2018

	2018	**2017**	**AV**
Gross value of production:			
Calves	460.27	438.35	449.31
Stockers and Yearlings	96.83	97.64	97.235
Other cattle 2/	109.67	118.44	114.055
Total, gross value of production	666.77	654.43	660.6
Operating costs			
Feed--			
Purchased feed	93.47	100.26	96.865
Homegrown harvested feed	176.12	172.66	174.39
Grazed feed	117.28	119.43	118.355
Total, feed costs	386.87	392.35	389.61
Other--			
Cattle for backgrounding	53.18	50.65	51.915
Veterinary and medicine	24.49	25.28	24.885
Bedding and litter	0.48	0.5	0.49
Marketing	12.02	12.41	12.215
Custom services	11	11.36	11.18
Fuel, lube, and electricity	28.88	26.09	27.485
Repairs	38.39	37.53	37.96
Interest on operating capital	2.91	1.28	2.095
Total, operating cost	558.22	557.45	557.835
Allocated overhead			
Hired labour	38.7	37.8	38.25
Opportunity cost of unpaid labour	434.2	423.98	429.09

Capital recovery of machinery and equipment 3/	263.44	257.5	260.47
Opportunity cost of land (rental rate)	0.2	0.2	0.2
Taxes and insurance	21.73	22.43	22.08
General farm overhead	34.69	34.11	34.4
Total, allocated overhead	792.96	776.02	784.49
Total costs listed	1,351.18	1,333.47	1342.325
Value of production less total costs listed	-684.41	-679.04	-681.725
Value of production less operating costs	108.55	96.98	102.765
Supporting information			
Beef cows on farm or ranch (head per farm/ranch)	100	100	100
Cows and heifers calving (head per farm/ranch)	86	86	86
Calves weaned (head per farm/ranch)	72	72	72
Calf weaning weight (pounds per head)	500	500	500
Calves sold (head per farm/ranch)	54	54	54
Stockers and Yearlings sold (head per farm/ranch)	10	10	10

Appendix 3: Cost and Returns of Corn, U.S. average 2017-2018

	2018	**2017**	**AV**
Gross value of production			
Primary product grain	617.97	618.42	618.195
Secondary product silage	2.09	1.81	1.95

Total, gross value of production	620.06	620.23	620.145
Operating costs			
Seed	98.84	100.1	99.47
Fertilizer (commercial fertilizers, soil conditioners, and manure)	115.51	128.68	122.095
Chemicals	35.25	36.16	35.705
Custom services (custom operations, technical services, and commercial drying)	23.15	23.84	23.495
Fuel, lube, and electricity	27	23.78	25.39
Repairs	32.89	32.3	32.595
Purchased irrigation water	0.25	0.25	0.25
Interest on operating capital	1.75	0.79	1.27
Total, operating costs	334.64	345.9	340.27
Allocated overhead			
Hired labour	4.11	4.01	4.06
Opportunity cost of unpaid labour	22.17	21.63	21.9
Capital recovery of machinery and equipment	120.96	118.87	119.915
Opportunity cost of land	169.92	171.82	170.87
Taxes and insurance	11.87	11.74	11.805
General farm overhead	18.37	18.08	18.225
Total, allocated overhead	347.4	346.15	346.775
Costs listed			
Total, costs listed	682.04	692.05	687.045
Net			

Value of production less total costs listed	-61.98	-71.82	-66.9
Value of production less operating costs	285.42	274.33	279.875
Supporting information			
Yield (bushels/acre)	190	188	189
Price (USD/bushel at harvest)	3.26	3.29	3.275
Enterprise size (planted acres)	268	268	268
Production practices			
Dryland (% of acres)	89	89	89
Irrigated (% of acres)	11	11	11

Appendix 4: Cost and Returns of Soybeans, U.S. average 2017-2018

	2018	**2017**	**AV**
Gross value of production			
Primary product soybeans	454.72	491.92	473.32
Total, gross value of production	454.72	491.92	473.32
Operating costs			
Seed	58.07	58.79	58.43
Fertilizer [a]	25.06	28.14	26.6
Chemicals	26.83	27.64	27.235
Custom services	10.32	10.6	10.46
Fuel, lube, and electricity	13.57	11.89	12.73
Repairs	23.34	22.82	23.08
Purchased irrigation water	0.06	0.06	0.06
Interest on operating capital	0.83	0.37	0.6

Total, operating costs	158.08	160.31	159.195
Allocated overhead			
Hired labor	3.26	3.19	3.225
Opportunity cost of unpaid labour	19.4	18.9	19.15
Capital recovery of machinery and equipment	90.99	88.84	89.915
Opportunity cost of land	142.86	143.72	143.29
Taxes and insurance	10.66	10.52	10.59
General farm overhead	18.25	17.98	18.115
Total, allocated overhead	285.42	283.15	284.285
Costs listed			
Total, costs listed	443.5	443.46	443.48
Net			
Value of production less total costs listed	11.22	48.46	29.84
Value of production less operating costs	296.64	331.61	314.125
Supporting information			
Yield (bushels per planted acre)	49	52	50.5
Price (dollars per bushel at harvest)	9.28	9.46	9.37
Enterprise size (planted acres)	273	273	273
Production practices			
Dryland (% of acres)	90	90	90
Irrigated (% of acres)	10	10	10

Appendix 5: Cost and Returns of Wheat, U.S. average 2017-2018

	2018	2017	AV
Gross value of production			
Primary product grain	194.46	199.64	197.05
Secondary product silage/straw/grazing	8.87	8.82	8.845
Total, gross value of production	203.33	208.46	205.895
Operating costs			
Seed	14.75	15.26	15.005
Fertilizer (commercial fertilizers, soil conditioners, and manure)	30.66	34.18	32.42
Chemicals	14.56	14.89	14.725
Custom services	11.35	11.08	11.215
Fuel, lube, and electricity	12.47	10.9	11.685
Repairs	22.04	21.55	21.795
Other variable expenses (purchased irrigation water and straw baling)	0.7	0.69	0.695
Interest on operating inputs	0.56	0.25	0.405
Total, operating costs	107.09	108.8	107.945
Allocated overhead			
Hired labour	2.5	2.39	2.445
Opportunity cost of unpaid labour	19.42	18.86	19.14
Capital recovery of machinery and equipment	91.43	89.39	90.41
Opportunity cost of land	63.07	62.89	62.98
Taxes and insurance	7.36	7.24	7.3
General farm overhead	11.59	11.37	11.48

Total, allocated overhead	195.37	192.14	193.755
Costs listed			
Total, costs listed	302.46	300.94	301.7
Net			
Value of production less total costs listed	-99.13	-92.48	-95.805
Value of production less operating costs	96.24	99.66	97.95
Supporting information			
Yield (bushels per planted acre)	41	51	46
Price (dollars per bushel at harvest)	4.72	3.93	4.325
Enterprise size (planted acres)	443	443	443
Production practices			
Winter wheat (percent of acres)	69	69	69
Spring wheat (percent of acres)	26	26	26
Durum wheat (percent of acres)	4	4	4
Dryland (percent of acres)	95	95	95
Irrigated (percent of acres)	5	5	5

Appendix 6: Excerpt from Marsh’s *Cross-Sector Relationships Between the Corn Feed Grains and Livestock and Poultry Economies* on 3SLS Regression results of Livestock and Corn Model and respective formulas

$$\begin{aligned} \hat{Q}_{CN} &= 4.126 + 0.469\hat{P}_{CN(-1)} + 0.212\hat{P}_{LN} \\ &- 0.484\hat{P}_{FT} - 0.412\hat{P}_{SY} + 0.151D_{P} \\ &+ 0.011T \end{aligned}$$

$$\begin{aligned} \hat{P}_{CN} &= -3.387 - 0.371\hat{Q}_{CN} + 0.191\hat{P}_{E} \\ &+ 0.440\hat{P}_{B(-1)} + 0.127\hat{P}_{P(-1)} \\ &+ 0.454\hat{P}_{CK}, \end{aligned}$$

$$\hat{Q}_B = 1.518 + 0.188\hat{P}_{B(-1)} - 0.061\hat{P}_{CW(-1)} - 0.064\hat{P}_{CN(-1)} - 0.260\hat{P}_F - 0.004T + 0.770\hat{Q}_{B(-1)}$$

$$\hat{P}_B = 1.304 - 0.565\hat{Q}_B + 0.754\hat{P}_{BX} + 0.113\hat{P}_{BV} + 0.194\hat{P}_L - 0.001T,$$

$$\hat{Q}_P = -0.457 + 0.241\hat{P}_{P(-1)} - 0.110\hat{P}_{CN(-1)} + 0.008T + 0.845\hat{Q}_{P(-1)}$$

$$\hat{P}_P = 4.000 - 0.641\hat{Q}_P + 0.412\hat{P}_{PX} + 0.225\hat{P}_{PV} - 0.027\hat{P}_L - 0.008T,$$

$$\hat{Q}_{CK} = 0.167 + 0.091\hat{P}_{CK(-1)} - 0.045\hat{P}_{CN} - 0.055\hat{P}_{BL} + 0.006T + 0.869\hat{Q}_{CK(-1)}$$

$$\hat{P}_{CK} = -0.723 - 0.133\hat{Q}_{CK} + 1.045\hat{P}_{BR} + 0.045\hat{P}_{BX} - 0.003\hat{P}_{PX} + 0.043\hat{P}_L,$$

Appendix 7: Living Costs and Food Survey, UK Data Service, 2011

	Deciles									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Beef consumption (g)	92	96	100	103	102	135	111	118	141	116
Pork consumption (g)	50	47	56	62	76	54	53	52	47	56
Chicken consumption (g)	172	175	165	186	179	208	187	202	217	204
Expenditures on beef (p)	51	59	62	62	67	77	77	82	94	85
Expenditures on pork (p)	24	25	27	29	37	27	28	28	27	32
Expenditures on chicken(p)	62	63	62	72	74	82	85	92	104	107

Appendix 8: Average incomes, taxes and benefits by decile groups of ALL households, 2010/11, Office for national statistics, UK

	Deciles									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Equivalised disposable income	8410	12 975	15 733	18 345	21 123	24 287	28 561	34 109	42 319	75 061