A Comparison of Agricultural Farming Methods and their Impact on the Environment

A Thesis Presented as part fulfilment for the Award of Master of Science in Food Business Management and Technology by

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Declaration

I hereby certify that the material, which I now submit for assessment on the programme of study leading to the award of M.Sc in Food Business Management and Technology, is entirely my own work and has not been taken from the work of others save to the extent that such work has been cited and acknowledged within the text of my own work. No portion of work contained in this thesis has been submitted in support of an application for another degree or qualification to this or any other institution.

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Abstract

The agricultural industry faces many challenges today, with one of the primary challenges being its impact on the environment. An increasing population size combined with increasing world hunger, environmental issues, greenhouse gas emissions, reduced land and water availability are all key drivers for the development of alternative, sustainable farming solutions. Sustainable farming solutions such as advanced farming are still in relatively early stages of development, and require a lot of work to make these methods economically viable and accessible to farmers around the world. While a lot of theoretical, scientific and development work has taken place in this area, many challenges still remain in reduction production and development costs of sustainable methods of farming. This research aims to eestablish the current state of the agricultural industry in terms of farming methods used globally and to find out if the use of alternative methods of farming could reduce the environmental impact of the agricultural industry. Other aspects have also been explored, fertiliser use, pesticide usage, the use of genetic modification and how these can also impact the environment. A comparison of all farming methods used in the top agricultural producing countries was also carried out to identify the impact risk each method of farming had on the environment.

List of Abbreviations

4G	Fourth Generation
AIDS	Acquired Immune Deficiency Syndrome
BC	Before Christ
BHC	Benzenehexachloride
BSE	Bovine Spongiform Encephalopathy
CP	Coat Protein
DDT	Dichlorodiphenyltrichloroethan
DNA	Deoxyribonucleic Acid
EPSPS	5-enolpyruvylshikimate-3-phosphate
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
GHG	Greenhouse Gas
GIS	Geographical Information System
GM	Genetic Modification
GMO	Genetically Modified Organism
GPS	Global Positioning Systems
ICT	Information and Communications Technology
IOT	Internet of Things
IUCN	International Union for Conservation of Nature
K	Potassium
N	Nitrogen
NPK	Nitrogen, Phosphorus, Potassium
P	Phosphorus
RS	Remote Sensor
TUD	Technological University Dublin
UK	United Kingdom
UN	United Nations
US	United States
USA	United States of America
USDA	United States Department of Agriculture
WHO	World Health Organisation
WSN	Wireless Sensor Network

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Chapter One: Introduction

1.1 Chapter Introduction

This chapter sets out to provide the reader with a general understanding and overview of the agricultural industry, the history of farming and agriculture and farming methods and techniques used, while also taking into consideration the impact these methods of farming have on the environment.

1.1.1 Farming and Agriculture Overview

Farming and agriculture are essential for nations and countries all over the world as a source of food, materials as well as occupations (Caffaro et al., 2022). Agriculture is the cultivation of processes for producing foods, animal feed, fuel, and other goods through the systematic raising of plants and animals. It includes the production and processing of animal and plant products for consumers to use and how they are distributed to markets (Gowdy, 2020).

It is thought to have been sporadically practiced for the past 13,000 years, becoming an established practise roughly 10,000 years ago. This is a brief period of time when the long line of human history is taken into consideration. During its brief history, agriculture has radically transformed societies across the world and helped to fuel the global population that is continuing to grow at a rapid pace (Stringer and Galway-Witham, 2017).

Many people get confused between farming and agriculture and use both terms synonymously. Agriculture is a much wider and broader bracket term in comparison to farming. It includes all agriculture activities such as farming, livestock, cattle rearing, crop cultivation and horticulture and husbandry, to name a few (Epp Schmidt et al., 2022). Farming however, is the implementation of agriculture. It is in relation to the techniques and methods used in cultivating land and crops etc. Farming can be on a small scale, for cultivation only for consumption or on a larger scale, using intensive farming methods with a mechanical environment (Epp Schmidt et al., 2022).

Agriculture and farming provide majority of the food and fabric for the world. For example, material such as wool, cotton and leather are all products produced from agriculture (Brown and Caldeira, 2017). Agriculture also provides wood needed for paper and construction. The products, along with the agricultural and farming methods used, vary largely around the world (Li et al., 2020).

1.1.1.1 History of Farming and Agriculture

The development of agricultural areas and communities began when plants and animals were first domesticated by humans. This enabled families and community groups to transition from hunter-gatherer, nomadic lifestyles where they were dependant hunting for survival. Nomadic hunters did not farm for food but acquired it as they travelled. They hunted and gathered food and other resources as it became available (Cucchi and Arbuckle, 2021).

Over the years, the growth of agriculture has largely contributed to the advancement of civilisation. Before the agricultural industry became established, humans spent a lot of their lives hunting and searching for food by hunting wild animals and gathering plants. It was roughly 10,000 years ago when people started learning how to grow crops, become established and settle down to a farming-based life. Around this time, people also started breeding and herding wild animals, such as sheep and cattle. The adaption of wild plants and animals is known as domestication. The first plants to be domesticated were rice and corn, thought to be cultivated by Chinese farmers as early as 7500 BC (Abbo and Gopher, 2020). Dogs were the first animals to be domesticated and were used for aiding hunting. Goats and sheep were domesticated shortly after, followed by pigs and cattle. Many animals were originally hunted for their hides and meat. Nowadays, these animals are also sources of milk, butter and cheese. Animals such as horses and oxen were eventually domesticated too and used for ploughing, pulling and transportation (Finstad et al., 2021).

The development of agricultural industry allowed humans to produce food in surplus. This surplus of food was essential for people in those days as it could be traded for other goods or used when crops failed. This surplus food also enabled people to complete other tasks that were unrelated to farming. This change in society and how people lived is also known as the Neolithic Revolution or the first agricultural revolution. Crops and animals were being grown and reared to meet the demand for food, the worldwide population grew rapidly, from roughly five million people 10,000 years ago, to more than seven billion people today (Cucchi and Arbuckle, 2021).

The development of the agricultural industry kept previously nomadic people close to their own land, and lead to the development and establishment of permanent villages and settlements. The developments of agriculture also lead to the development of new economies and trades. In some areas, these new economies became so successful that cities grew and civilisations became fully developed (Armanda et al., 2019).

During the second agricultural revolution, there was a large increase in food productivity that helped to break many food security cycles. This evolution occurred from the late 1600's up until the end of the 1800's (Tyagi, 2016). New ideas such as selective breeding, crop rotation, land reclamation and the use of fertiliser made farming practices more efficient and intensive. Crops that produced lower yields such as rye, were replaced with crops that produced higher yields, such as wheat and barley (Guo and Lin, 2021).

New technologies were also adapted during the industrial revolution that allowed farmers to do more farm work, with less people, making the whole process of farming more efficient and less time consuming. Farms that were previously communal became privatized and many farmers moved away from substance farming. Farmers were now making much more money, and so they started to enclose farms that were once shared among the community (Bailey-Serres et al., 2019).

Agriculture underwent drastic developments in the 20th century, mainly because of the green revolution. At the beginning of the 1900's, farmers in the U.S typically produced sufficient food to provide enough food for a family of five. Today, many farmers can comfortably feed a family of five, as well as hundreds of other people. This massive leap in productivity is largely due to scientific advancements and the development of new sources of farming methods, techniques, power, machinery (Armanda at al., 2019). By the 1950's, the majority of farmers in developed countries were using resources such as electricity and gasoline to power farming machinery. Steam powered machinery and draft animals such as horses and oxen were replaced with tractors. Farmers began using machines in nearly every stage of cultivation and livestock management (Salomon and Cavagnaro, 2022).

Japan and Germany were the first countries to use electricity as a source of power on their farms. This happened in the early 1900's, by 1960, most farms in developed countries were electrified. Electricity was used to light up farm buildings and to power machinery such as machines, feeding equipment, milking machines and water pumps. Nowadays, electricity is used to control entire farming environments in livestock farmhouses and barns (Salomon and Cavagnaro, 2022). Various factors encouraged people in different regions of the world to use farming to their advantage (Guo and Lin, 2021).

1.1.1.2 Fertiliser Use

At the beginning of the 1800's, it was discovered by scientists that the elements nitrogen (N), potassium (K) and phosphorus (P) are most important for plant growth. This discovery later led to the manufacture of fertiliser containing these elements. The U.S and Europe were the first to manufacture this fertiliser. Today, farmers commonly use chemical fertilisers with phosphates and nitrates added because they help to massively increase the yield of crops (Chai et al., 2019). Figure 1 illustrates the mineralisation of fertiliser following application to soil.

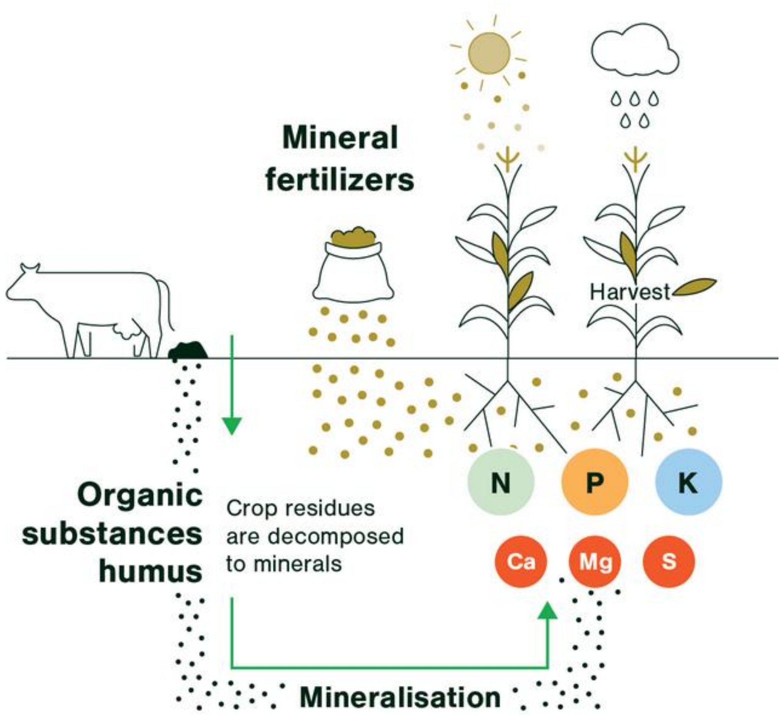

Figure 1: The mineralisation of fertiliser following application to the soil (taken from Xiao et al., 2018).

Farmers traditionally used a range of methods to protect crops from diseases, pests and weeds. Previously farmers have used natural, herb-based poisons on crops, manually picked insects off crops and used crop rotation as a method to reduce and control insects (Chai et al., 2019). Years ago, farmers had to rely on natural fertiliser made from manure, decomposing foliage, or ground bones to replenish and increase the soils nutrients. More recently, farmers rely on chemical fertilisers to control pests and weeds, especially in developed countries. The use of chemicals has resulted in less crop loss, allowing the prices of crops to fall dramatically (Heinsoo et al., 2020)

However, the use of chemical fertiliser and pesticides has given rise to another set of problems. Farmers quickly became heavily reliant on the use of chemical fertilisers, which has had a negative impact on the environment (Xiao et al., 2018). Fertilisers can also destroy helpful species and organisms, along with harmful ones. Chemicals can also pose a health risk to humans, as the runoff of fertilisers into water supplies can result in chemicals contamination (Martinho, 2021). Table 1 highlights examples of both organic/natural and inorganic/synthetic fertilisers.

Table 1: Examples of organic/natural and inorganic/synthetic fertilisers (adapted from Heinsoo et al., 2020; Xiao et al., 2018).

Type of Fertiliser	
Natural/Organic Fertiliser	· Manure · Wood ash · Ground bones · Seaweed · Guano · Compost
Synthetic/Inorganic Fertiliser	· Nitrogenous fertilisers · Potassium fertilisers · Phosphate fertilisers · Complete fertiliser – Nitrogen, Phosphate, Potassium (NPK) · Calcium, magnesium & sulphate

Agricultural scientists are researching safer and more environmentally friendly chemicals that can be used as fertilisers and pesticides. Many farmers use natural controls and do not depend on chemicals; these farmers are known as subsistence farmers. These farmers use the food produced from farming for their own use and their family. This is the opposite of commercial farmers, who grow crops primarily to sell them for profit (Ma et al., 2021)

1.1.1.3 Pesticide Use

A pesticide can be defined as a substance or mixture of substances that can be used to prevent, destroy, repel or mitigate pests such as rodents, insects, fungi, weeds, nematodes or any other type of pests (Patinha et al., 2018).

Table 2 highlights examples of pesticides and the pest they target. Pesticides have been used by humans for years. For example, during the 19th century, fungicides and arsenicals were used to protect fruit and vegetables and control pests and insects. However, these were highly toxic and were replaced with pesticides including Dichlorodiphenyltrichloroethan (DDT) and benzenehexachloride (BHC), which were widely adopted by farmers and also thought to be safe. However, in the 1960's, the potential for the bioaccumulation and toxicity of these pesticides became evident (Geissen et al., 2021).

Although the use of pesticides has led to improvements in agricultural production and reduced pests and disease, there are also problems associated with their use, including health and environmental concerns (Patinha et al., 2018).

Table 2: Examples of pesticides and their taget pests (adapted from Patinha et al., 2018; Geissen et al., 2021).

Pesticide Type	Pest Targets
Insecticide	Insects
Fungicide	Fungi
Herbicide	Plants & weeds
Rodenticide	Rodents
Nematicide	Nematodes
Molluscicide	Snails/slugs
Miticides/Acaricide	Spiders/mites
Algicide	Algae

Bactericide	Bacteria
Avicide	Birds

1.1.1.4 Genetic Modification

Inside all cells are genes, which determine the characteristics of the organism. Genetically modified organisms (GMO's) are plants, animals or microorganisms that have had their genetic traits and characteristics altered. It is also commonly known as biotechnology and genetic engineering (Oosthuizen and Howes, 2021).

In the early 1970's, scientists discovered that it was possible to rearrange genes within an organism, and add new genes, in order to promote disease resistant traits, improved productivity and other desired characteristics. Since the early 2000's, genetically modified crops and animals have been developed. Genetically modified organisms have been used widely in farming and agriculture to aid with the crop and animal development. For example, farmers can use genetically modified organisms to help protect their crops from pests, weeds and extreme dry or wet weather conditions. Genetic modification is also commonly used on crops improve crop yields and overall growth. Eenennaam (2017), states that genetically modified crops can help reduce crop diseases. Selective breeding was originally on animals to improve the characteristics of various livestock animals. Genetically modified crops use and development has evolved in recent decades. For example, genetically modified crops covers roughly of 181 million hectares in 2018, in comparison to 1.7 million hectares in 1996 (Purohit, Rana and Idrishi, 2021).

However, large controversies surrounding the use of GMO's do exist. Consumers are concerned about the possible allergenicity and toxicity of genetically modified organisms, as well as the potential increase in antimicrobial resistance (Biden et al., 2018).

Figure 1 illustrates an overview of farming and agriculture.

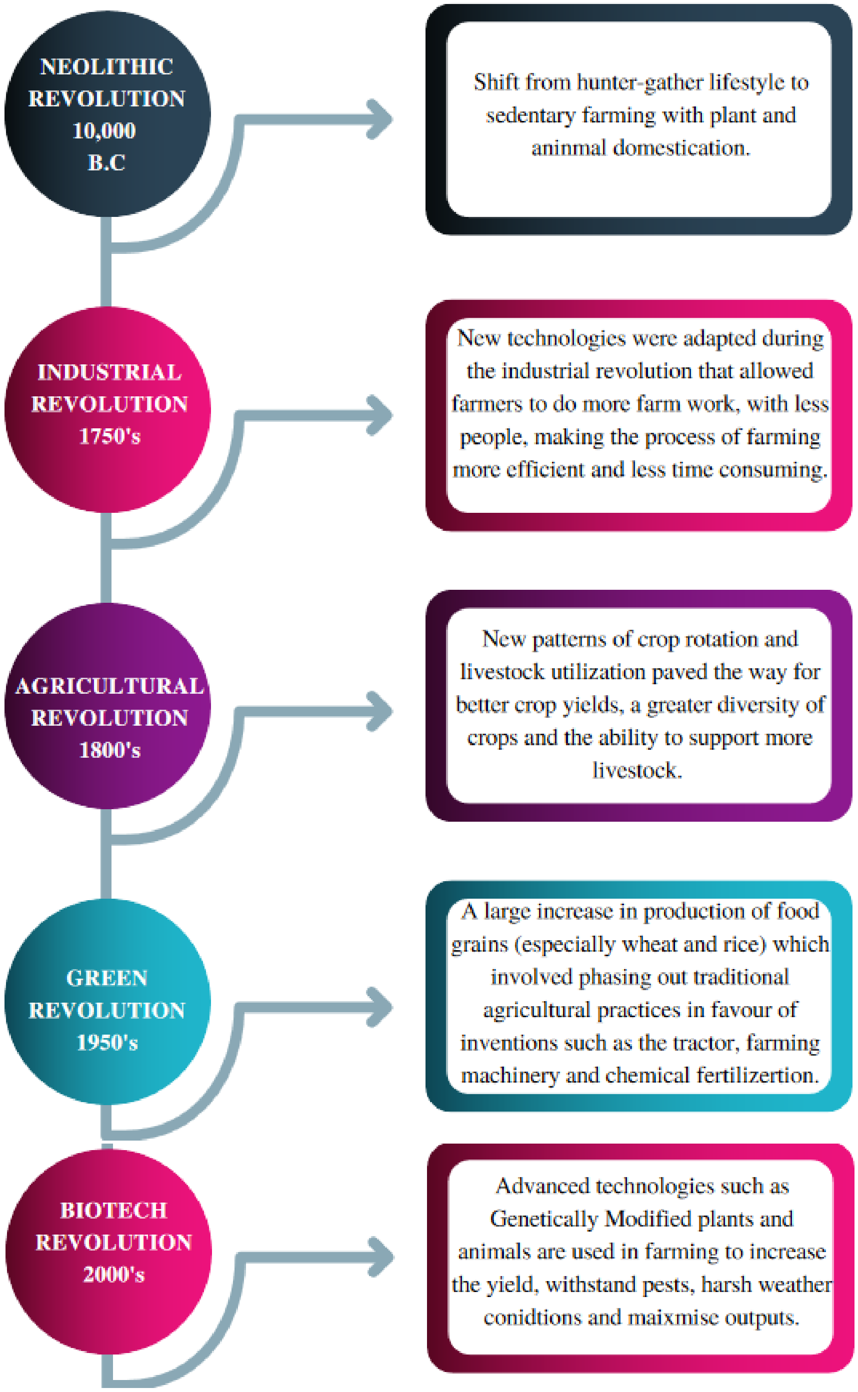

Figure 2: History of farming and agriculture (adapted from Cucchi et al., 2021; Finstad et al., 2021).

1.1.2 Environmental Impact

1.1.2.1 Population Growth

In the coming decades, population dynamics will cause massive changes to global demographics (Vermunt et al., 2020). The estimated growth of the global population is expected to be largely in south Asia, Africa and cities all over the world. By 2050, it is estimated that, two-thirds of the world will live in urban areas. Additionally, by the end of the century, it is projected that the combined population of Africa and Asia will be 9 billion people, out of the projected 11 billion people that will live on Earth (Pigford et al., 2018).

A major global concern is whether today's food and agriculture production systems will be able to meet the nutritional needs of people worldwide (Runhaar, 2017). Production needs to increase to meet this demand, which is a worrying statistic because of the large pressures on the land and water resources. This increase in production will intensify the negative impacts of climate change even more (Naber et al., 2017). It is thought that the current production systems in place are currently able to produce sufficient food, but doing this in a sustainable manner will require drastic transformations (Patterson et al., 2017).

This increased demand for food production has led to many other problems. Many people are concerned with negative environmental impacts of large-scale cultivation and intensive farming practices such air pollution from burning fossil fuels needed for farm machinery, the loss of ecosystems and land and water pollution from the use of fertilizer (Aibar-Guzmán et al., 2022). Another concern is that the price of biofuels is continuously growing, which is also causing the price of agricultural products to rise considerably (Ansell et al., 2016).

The main global challenge is to produce enough food globally in a sustainably manner. However, this raises additional questions. Is the agricultural industry capable of meeting the unprecedented global demand for food in a sustainable way that ensures the use natural resources is minimized, while also minimizing greenhouse gas emissions? (Hebinck et al., 2021).

Can sufficient food worldwide be secured, particularly in low-income and developing countries, where the population growth is often most rapid? Can the agricultural industry and rural economies be changed to allow for improved employment opportunities for all, especially children and woman to help avoid mass immigration to cities that have a limited labour-absorptive capacity. Can the massive problem of food waste and loss be addressed and tackled? It is estimated that nearly one third of the total food production ends up wasted (Ansell et al., 2016).

Public policies need to be enforced to address the ‘triple burden of malnutrition’ through the promotion and enforcement of food production systems that gives access to food for all socio-economic classes, reducing deficiencies, excesses, and imbalances in human food intake. The ‘triple burden of malnutrition’ refers to under nutrition, obesity and being overweight and micronutrient deficiencies (Smith et al., 2020).

1.1.2.2 Greenhouse Gases Emissions

Greenhouse gases (GHG) confine heat within the air and heats Earth. A greenhouse gas can be naturally occurring and include carbon dioxide, nitrous oxide, methane, and water vapour. Synthetic greenhouse gases also exist and include fluorinated gases. Each greenhouse gas is eliminated from the air via different process over time. For example, carbon dioxide is removed via plants, soil and the ocean (Niloofar et al., 2021).

The influence of each greenhouse gas has on global warming is dependent on the amount of the gas exists and how long it remains in the atmospheres and how effective the gas is at trapping heat (Ouatahar et al., 2021).

Carbon dioxide (CO_2) is emitted into the air through fossil fuel combustion. Burning other materials such as trees, solid waste and other biological matters also release carbon dioxide into the atmosphere (Kipling et al., 2018). Methane (CH_4) emissions occur during oil, coal and natural gas production and transportation. They also happen because of agricultural processes, the use of land and the decomposition of organic waste in landfills. Nitrous oxide (N_2O) is also released during agricultural and farming processes. Burning fossil fuels and solid waste also emits nitrous oxide, as well as wastewater treatment. Fluorinated gases are also potent greenhouse gases that are released during industrial processes. Examples of fluorinated gases include perfluorocarbons, hydrofluorocarbons, sulfur hexafluoride, and nitrogen trifluoride (Warner et al., 2017).

A carbon footprint is the total greenhouse gases released as result of human activities all over the world. Carbon footprints are the emission of these gases related to activities such as transport, power generation, construction, industrial processed and agriculture (Litskaset al., 2020). Offsetting the carbon footprint is completed through the reducing, removing or avoiding the emission of greenhouse. Offset systems play a crucial role in reducing greenhouse gases (Ouatahar et al., 2021).

Greenhouse gas emissions arise either directly or indirectly at every point during the life of a product. Direct emissions include emissions from animals, fertiliser application or through fuel use. Indirect emissions can occur through electricity generation. Each greenhouse gas can increase atmospheric temperatures (Niloofar et al., 2021).

1.1.2.3 Global Warming and Greenhouse Gases

In the last century alone, massive progress and developments have been made globally in improving the welfare of humans. Developments in technology and machinery in production systems have led to a radical change in societies all over the world (El Bilali, 2019). However, a lot of this progress for humanity has come with a large environmental cost. The heavy impacts of global warming and climate change are being felt today and will continue to intensify massively soon if left unabated (Hebinck et al., 2021).

Despite improvements in human welfare, hunger and malnutrition is still extremely prevalent all over the world. Amid plenty, billions across the world still live in poverty and face gross inequalities, disease and deprivation (Pigford et al., 2018). Many difficulties have been resolved in recent years, but new difficulties have also emerged. Challenges remain in relation to regulations and the need to steer these processes towards more sustainable and equitable ones (Patterson et al., 2017).

It is imperative to reduce the greenhouse gas emissions from agriculture. All sectors within the agricultural industry must make rapid efforts on a large scale to lower their emissions to meet the

Paris Agreement’s climate targets (Mulder et al., 2021). The Paris Agreement is an international accord that was adopted in 2015 by almost every nation to address the pressing issues and impacts of climate change (Glanemann et al., 2020). The Paris Agreement aims to lower emissions of greenhouse gases substantially to address, reduce and mitigate the worldwide rising temperature in this century. All major countries that have high greenhouse gas emissions have committed to this agreement to reduce their pollution status over time (Mulder et al., 2021). This agreement provides a pathway for developed countries to aid developing countries with their own climate targets. It will also create a framework and guideline for monitoring and reporting of countries individual and collective climate goals (Glanemann et al., 2020). An insufficient reduction of agricultural emissions will potentially compromise the mitigation and prevention of global warming. At the minute, the emissions from current food systems in place threaten this target alone (Cherry et al., 2021).

There are many steps involved in successfully reducing agricultural greenhouse gas emissions. Firstly, the major source of these emissions must be identified. The farms and farming methods used that produce the most greenhouse gases need to be identified. What countries are using these methods of farming? Appropriate mitigation options for these farms and farming methods must be identified and executed. The most cost-effective options should be selected to keep the cost of the final product as low as possible for the consumer (Soteriades et al., 2020). Sustainable agriculture needs direct and immediate action to preserve Earth’s remaining natural resources. To achieve this, good governance is essential, and policies must be put in place (Hannus, et al., 2020).

To allow people and communities to adjust to the rapid change and increased uncertainty, sustainability and climate change should be viewed as a process rather than an end point. However, this requires the development of policy, technical, financing and governance strategies that support the agricultural industry in the dynamic process of innovation (Soteriades et al., 2020).

1.1.2.4 Biodiversity Risk

Biodiversity is the term used to describe the variation of life on earth (Cepic et al., 2022). Biodiversity includes every living thing on Earth, from humans, plants, animals, and bacteria. It is estimated by scientists that there are nearly 9 million species on plants and animals on Earth, with just over 1 million species that are identified, majority of which are insects/ this means that there are millions of other living organisms that have not yet been found (Kremen and Merenlender, 2018).

All species on Earth are interlinked and work together to maintain their ecosystems. For instance, grass-fed livestock animals such as cattle, which produce manure that is used to return nutrients to the soil, which in turn helps more grass grow. Manure is commonly used for fertilising crops. Many species on Earth are very beneficial for humas, as they provide food, shelter, clothing, and medicine (Isbell et al., 2017).

Biodiversity on Earth is at risk to human activities that have disturbed and destroyed ecosystems (Isbell et al., 2017). Climate change, pollution, greenhouse gas emissions and growth in population all threaten biodiversity massively. This has led to a rise in the extinction of many species. Scientists predict that roughly half of Earth's species will be extinct over the next 100 years (Lartey, 2015). Scientists from all over the world are calling for alternative methods and approaches to traditional intensification of agriculture that enhance ecosystem services that are provided by biodiversity (Kremen and Merenlender, 2018).

1.1.3 Methods of Farming

Farming and agriculture are essential in every country and nation worldwide. Many people's livelihoods all over the world are dependent on farming as an occupation. Many experts think that farming has changed the course of human life, which led to the shift from nomadic hunting-gathering to the establishment of permanent settlements (Epp Schmidt et al., 2022).

Cattle, sheep and pigs were the first animals to be reared and farmed and wheat, barely were the first crops to be cultivated. Crop rotation, selective breeding and land reclamation were common practices and techniques used in ancient days across Europe and Egypt. As the agricultural revolution progressed across continents, newer and more modern techniques were being used (Abbo and Gopher, 2020).

The agricultural methods used widely vary all over the world. The methods used are dependent on climate, culture, traditions, and the technology of the country. For example, minimal technology farming usually involves permanent crops where the crops grown are not replanted annually after each harvest. Examples of permanent crops include coffee plants and citrus trees. High technology farming usually involves methods such as crop rotation, which involves knowledge of what land is farmable. Farmers plant crops in line with the season, soil type and the amount of water that is needed. Farming techniques such as crop rotation and irrigation are usually used (Finstad et al., 2021).

1.1.3.1 Conventional Farming Methods

Conventional farming is also commonly known as traditional or industrial farming. This type of farming includes the use of chemical fertilisers and pesticides, intense tillage and heavy use of irrigation and farm machinery. It is usually very environmentally demanding and requires the high use of resources and energy. Although conventional farming is highly efficient and productive, it is not very sustainable. The methods of farming highlighted below are all examples of traditional farming methods (Schärer et al., 2022).

1.1.3.1.1 Arable Farming

Arable farming refers to the systematic use of land to grow crops. It is one of the most common types of farming methods used globally. Arable farming is an appropriate method to use in warmer climates and is commonly used around Europe and the United Kingdom (U.K). Arable farming is popular in areas that are mostly flat, fertile and moist. Arable farming usually involves growing crops such as wheat, barley, maize and rice (Peltoniemi et al., 2021).

This farming process involves cultivating crops in fields that have been ploughed before planting. Slightly sloping land with fertile soil that is not too wet or dry and a warm climate will support the growth of arable crops. It only involves crop cultivation and does not include animal rearing. It is mainly used on small scale, commercial and large agricultural farms (Peltoniemi et al., 2021).

1.1.3.1.2 Pastoral Farming

Pastoral farming is a method of farming used solely for rearing animals and not for growing crops. This method of farming is ideal for rearing livestock such as sheep, beef cattle and dairy cattle. Pastoral farming is ideal in cold and wet climates as opposed to hot and dry climates (Feng et al., 2021).

1.1.3.1.3 Mixed Farming

The method of mixed farming incorporates crop cultivation and livestock on a single farm. A single piece of land is used to support both arable and pastoral farming. This can be advantageous for farmers as the overall farm yield is increased, providing two livelihood options with a single piece of land. The animal manure can also be used to assist in soil fertility during arable farming (Sneessens et al., 2019).

1.1.3.1.4 Subsistence Farming

Subsistence farming is a method of farming where majority of the crops and livestock raised are used for the farmer’s personal use and not for commercial use. It is usually a very small-scale practice of cultivating and growing crops and raising animals, usually no more than a few acres in size. This method of farming usually doesn’t require the use of heavy machinery and technology. This is a common type of traditional farming (Saridakis et al., 2021).

1.1.3.1.5 Commercial Farming

Unlike subsistence farming, commercial farming is a method of farming that is used for profit making and commercial use. Commercial farming is usually a large-scale practice as the final product will be sold in the market for profits (Finstad et al., 2021). This method of farming involves growing crops and rearing animals and livestock for meat, dairy and eggs. Machinery and technology are commonly used in commercial farming but it usually dependent on the scale of the farm in question. Machinery and farm technology are usually required on commercial farms, because they are usually producing on a larger scale. Commercial farms also usually only grow a single type of cash crop, rather than several kinds at once (Glover and Jones, 2019).

1 .1.3.1.6 Extensive Farming

According to Nemecek et al (2020), extensive farming is a farming method that used limited inputs such as labour, capital, insecticides, fertilisers, machinery and technology in comparison to the land being cultivated.

The overall objective of extensive farming is to increase the land tillage to improve the final output. This method of farming uses more traditional farming methods. Productivity is more reliant on the natural fertility of the soil and the climate of the area. Extensive farming practices are usually practiced on larger farms to produce a higher yield and more profit. The total amount of crops produced is high due to the large amount of land cultivated, but low in terms of unit per production. Because extensive farming used fewer chemicals, fertilisers, pesticides and insecticides, it is a more environmentally friendly method of farming (Bertolozzi-Caredio et al., 2020).

1. 1.3.1.7 Intensive Farming

Intensive farming refers to the intensification and mechanization of farming, with the main aim of increasing the productivity of the land being used. This is completed through the use of inputs such as labour, capital, machinery, technology, fertilisers and pesticides, resulting in an increase crop yield. In this method of farming, the use of inputs is comparatively higher than the area of land being cultivated. More than one crop is commonly attempted to cultivate in the same area or field (Yang, 2018).

Intensive farming can also be applied to the rearing of animals and livestock, where a large number of livestock are reared in a small area. Inputs such as animal feed and medication can also be used to increase animal productivity and yield. Intensive farming relies on inputs and the use of chemicals to improve the growth of animals and the yield of crops (Burton and Fischer, 2015).

1.1.3.1.8 Nomadic Farming

Nomadic farming is a method of farming where the farmers and cultivators do not stick to one area permanently, but instead keep moving in search of land, pasture and waste. It can also be movement away from pests and infections and adverse weather conditions. For example, the Fulani nomadic farmers move their livestock from the north of Nigeria to the south of Nigeria during the dry season, when the land and pasture in Northern Nigeria have dried up. This method of farming is used in countries where there is little rainfall and usually involves animals such as camels, sheep, goats, cattle, horses and donkeys (Sattler et al., 2021).

1.1.3.1.9 Sedentary Farming

Sedentary farming is a farming method where the same piece of land is farmed annually. The land here is used to permanently grow and cultivate crops or rear animals. This is the opposite to nomadic farming, where new areas of land are farmed because the soil becomes loses nutrients from extensive planting, extremely dry or wet weather and shifting cultivations. Sedentary farming is one of the oldest methods of farming used globally (Mansard et al., 2018).

1.1.3.2 Sustainable Farming Methods

Sustainable farming methods ultimately aim to promote the use of more sustainable methods of farming that are also profitable for farmers and safe for consumers. Common practices of sustainable farming include methods to promote the health of the soil, minimize the use of water, fertilisers, pesticides, heavy machinery and lower the pollution levels and carbon footprint of the farm (Verburg et al., 2022).

1.1.3.2.1 Organic Farming

Organic farming is a method of farming where artificial inputs such as artificial pesticides, insecticides and fertilisers are removed from farming activities. Instead, ecological based pest controls and biological fertilisers derived from animal manure and plant waste are used to protect crops and increase their yield and quality. Modern organic farming was developed in response to environmental concerns associated with the use of chemical fertilisers, pesticides and insecticides in conventional agriculture (Verburg et al., 2022).

1.1.3.2.2 Advanced Farming Systems

The agricultural industry has undergone a technological revolution in recent years with the introduction of new and advanced farming systems, which is a new way for farmers to use technological advancements to increase productivity and efficiency on the farm while also reducing costs and the environmental damage of the agricultural industry. This evolution and digitization of agriculture has lead to new concepts and farming systems to emerge in recent years (Durai and Shamili, 2022).

1.1.3.2.3 Precision Farming

Precision farming is an integrated crop management system that used remote sensor technology (RS), Global Positioning Systems (GPS) and geographical information system (GIS) to monitor the land and crops at ground level. The soil properties and differences within the field are recorded, which can then be analysed by the farmer. Precision farming uses various types of technology to gather this information including drones, sensors, robotics and automated hardware and software (Aquilani et al., 2022). The aim of precision farming is to enable farming practices to become more accurate, controlled and optimized when rearing livestock and growing crops. For example, farmers can use precision farming to measure the soil variations of their land and adapting the fertiliser strategy accordingly, as opposed to applying an equal amount of fertiliser to all the land. This ensures the fertiliser is used optimally, and not wasted on land that does not necessarily need it, while also reducing costs and recuing the environmental impact of the fertiliser used (Aquilani et al., 2022).

Precision farming principles have become more common over the last decade, which is primarily due to the rapid advancements in technology overall. For example, the adoption of mobile phones and devices, high speed internet, reliable satellite communications and improved farm equipment have all helped in the development of precision farming (Zhang et al., 2021).

1.1.3.2.4 Smart Farming

Smart farming involves the application of the data gathered in order to optimize the complex farming systems. Smart farming focuses primarily on access and application of this data and how this information can be collected and used in a ‘smart’ way. Technology used in smart farming techniques include the internet of things (IoT), drones and robotics for tracking, monitoring and analyzing data. With these tools, farmers are able to monitor and make farming decisions without going to the field, saving time and improving efficiency (Podder et al., 2021).

The main focus of smart farming is how farmers can use the collected data in a smart or intelligent manner. The overall aim involves improving the agricultural product produced and enhancing labour processes. Smart farming techniques are adaptable and can be used on small farms, organic farms and large agricultural farms (Skobelev et al., 2019). Smart farming is primarily managed through the use of software and monitoring sensors. Smart farming practices can reduce the overall prices, improve the yield overall and increase the quality and availability of the product overall. The use of automation and technology in farming has led to large improvements in production, efficiency, quality and sustainability (Skobelev et al., 2019).

1.1.3.2.5 Digital Farming

The purpose of digit farming is to create value from the data gathered. Digital farming involves integrating both smart farming and precision farming techniques consistently. Digital farming gives farmers the opportunity to improve the overall production of the farm, save costs, eliminate risks and reduce the environmental impact of the agricultural industry overtime (Shang et al., 2021).

1.2 Rationale

The introduction has outlined the history, background and development of farming and the agricultural industry as a whole. Environmental issues associated with the agricultural industry were also outlined. There are many farming methods available for use, all of which benefit farmers in of different financial backgrounds and in various areas of the world. However, many of these farming methods have huge environmental impacts and therefore more sustainable methods must be research and developed. Studies have also outlined massive concerns associated with the rising global population, world hunger, and food waste worldwide. Whilst the development of more sustainable advanced farming systems has been quite successful, more needs to be done to make these methods available to farmers worldwide.

1.3 Aims and Research Questions

Ultimately this research question asks whether alternative methods of farming can be used to reduce the carbon footprint of the agricultural industry. Thus, the following aims have been outlined:

Aims:

- Establish the current state of the agricultural industry in terms of farming methods used globally
- To find out if the use of alternative methods of farming could positively impact the carbon footprint of the agricultural industry
- To find out if alternative/more sustainable methods of farming are cost effective
- To find out if alternative/more sustainable methods of farming will impact the agricultural yield.
- Identify the impact these methods will have on the food industry overall
- Carry out a comparison with traditional/conventional methods of farming and sustainable methods of farming in relation to their impact on the environment.

1.4 Chapter Conclusion

Chapter one provides a summary of the background and history of farming and agriculture, as well as an insight into the use of fertilisers, pesticides and genetically modified organisms within the agricultural industry. The following chapters will outline and further detail the methods of farming currently used globally, as well as more sustainable farming methods and practices.

Chapter Two: Methodology

2.1 Chapter Introduction

The theoretical and academic background underpinning this study was established in Chapter One, the methodology of the research conducted shall now be outlined. Prior to the commencement of the study, ethical approval was granted by Technological University Dublin (TUD). There was no primary research associated with this study.

2.2 Methods: Study Design

This section outlines the methods used to compare farming methods used globally and their impact on the environment. This is a desk based study of peer reviewed, published research papers, along with data and information from both government and non-government sources. This methods section shows results on current, conventional methods of farming and their environmental impact as well as more sustainable farming methods and techniques. It further highlights the methods used to search databases for relevant studies and papers on farming methods and the background into each.

2.3 Scope

The scope of this research question focuses on the comparison of agricultural farming methods and how they impact the environment. This research establishes where the agricultural industry is currently at in terms of global warming impact and greenhouse gas emissions and how this can be reduced across the industry. Focus will be placed on the environmental impact of each method, with various methods of farming and farming techniques being explored. The scope of this research is to highlight areas of concern and aspects of the agricultural industry that are doing the most environmental damage. This research will use current literature to highlight farming methods that could reduce the environmental impact of agriculture, establish if they are cost effective and if they will affect the yield of product produced.

Some key areas that this research focuses on because of frequent reporting in the literature include traditional farming methods, advanced farming methods, fertiliser use, pesticide use, genetic modification, greenhouse gases and land use in agriculture.

2.4 Literature Search Methods

Various databases that present reputable, peer reviewed papers and published literature were used to search for literature including Science direct, Web of Science and the TUD Online library.

Sources of grey literature sources were also searched such as, the World Health Organisation (WHO) and The Food and Agriculture Organization of the United Nations (FAO). Grey literature and publications from these types of reputable organisations were deemed acceptable for use in this research study. Other databases such as websites and publications on the World Wide Web were avoided completely as they are deemed as unreliable sources of information. This includes websites such as Wikipedia. Key words related to the subject area, along with the aims of this research study were used in order to identify and select relevant and appropriate papers. These key words included the following:

- Types of farming, farming methods, advanced farming methods, farming in developed countries, farming in developing countries, traditional farming methods, farming techniques, agricultural techniques and environmental impact of farming.

More specific terms were also searched including:

- Farming methods by country, farming in developed countries, farming in developing countries, challenges in the agricultural industry, genetic modification, fertiliser use, pesticide use and environmental challenges of agriculture

The word "AND" was used in the search phrases to narrow down from the initial search terms. The use of the word "AND" limited the search criteria. By using the word "AND", literature including information on both terms was returned when searched on the database. For example:

- Farming 'AND' developing countries, agriculture 'AND' environmental issues etc.

Likewise, if the specific terms used did not return a substantial number of papers in the database being used, the word "OR" was used to increase the number of papers returned. By using the word "OR", literature for both search terms was returned. For example:

- Farming methods 'OR' agricultural techniques, challenges of farming 'OR' barriers to agriculture etc.

The use of inverted commas was also used in order to limit the search. For example:

- "Farming methods" and "developed countries", "farming methods" and "developing countries"

Figure 3 highlights how the papers were searched, screened and selected for review.

2.4.1 Inclusion Criteria

In order for articles to be included in this literature review, it was important to meet the following criteria:

- Published in the last 5 years
- Had the full text available
- Written in the English language
- Relevant, high quality data in the papers
- Material was relevant to the research question and aims

The articles chosen had to be relevant to the title of the review and contribute to information on the following:

- The current state of the agricultural industry in terms of farming methods used globally
- If the use of alternative methods of farming could positively impact the carbon footprint of the agricultural industry
- If alternative/more sustainable methods of farming are cost effective
- If alternative/more sustainable methods of farming will impact the agricultural yield.
- Identify the impact these methods will have on the environment overall

After conducting the search, various methods were applied in order to narrow down and select the relevant papers. To begin, the title of each paper under each search was scanned and read. If thought to be relevant, the abstract was also then analysed in order to determine the suitability of the paper. If the literature in the papers was relevant to the research question and aims, then the papers were kept and used. Any data included and kept was predominantly published within the last five years. Any data used that was older than five years, has only been used if the data is still current and relevant, or if no new data has been generated in that area.

2.4.2 Exclusion Criteria

Any data that was not peer reviewed has been excluded for review data. Any unsubstantiated data has also been excluded from the review.

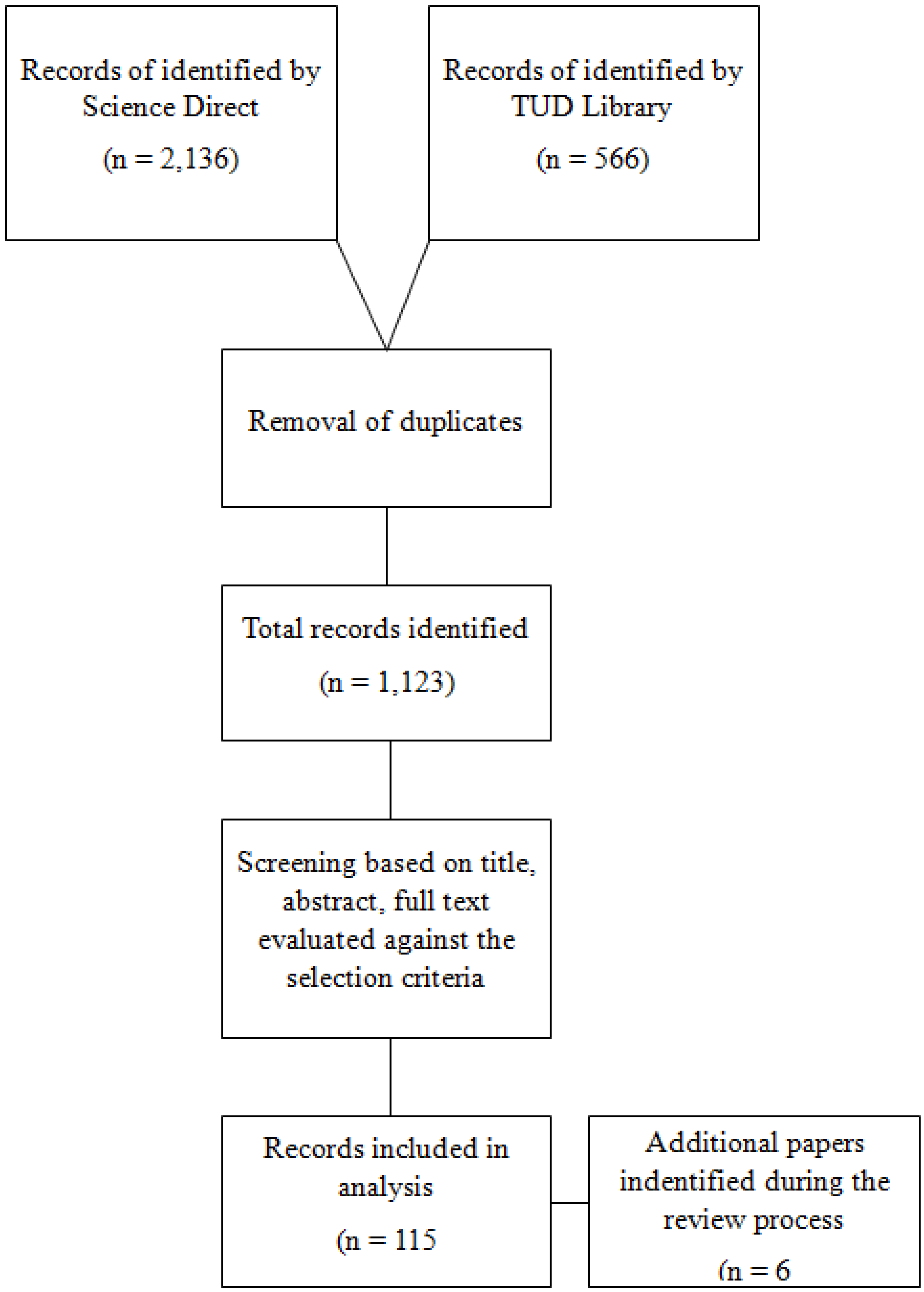

Figure 3: Selection of papers picked for review.

Chapter 3: Results

3.1 Global Land Use for Agriculture

Figure 4 illustrates that the world is covered by roughly 71% ocean and 29% land. Global land was mostly wilderness, grassland, shrubbery and forests for a lot of human history. Over the centuries, this has dramatically changed; many wild habitats are now removed and have been replaced by agricultural land. It is estimated that 1000 years ago, less than 4% of the worlds land was used for farming and agriculture which is roughly 4 million square kilometres (Kastner et al., 2021).

Figure 4 shows a breakdown of today's global land area. Barren land accounts for 19% of the global land area including deserts, beaches, sand dunes, dry salt flats and exposed rocks. Glaciers cover 10% of the world, leaving the remaining 71% of land on Earth as habitable land. Studies show that 50% of the habitable land on Earth is used for agricultural purposes. Once agricultural land is accounted for, only 37% of the land left is forests, 11% as grassland areas and 1% as freshwater coverage. The remaining 1% of land on Earth accounts for built up urban areas including cities, towns and villages, as well as roads and other infrastructures (Balima et al., 2020).

In relation to habitable land use, land distribution between the growth of crops for humans and livestock is very unequal. When the pastures and land used for animal grazing is combined with the land that is used for growing feed for animals, livestock uses around 77% of total land used for farming globally. Therefore, livestock accounts for a large proportion of global agricultural land. Despite this, only 18% of the total calories worldwide is produced from livestock and 37% of the world's protein overall (Kastner et al., 2021).

It was found that, out of the 28,000 species on The International Union for Conservation of Nature's (IUCN), agriculture is a threat for roughly 24,000 of the species listed. The IUCN Red List indicates the current status and health of biodiversity worldwide. The red list illustrates the species that are currently under threat (Matej et al., 2021).

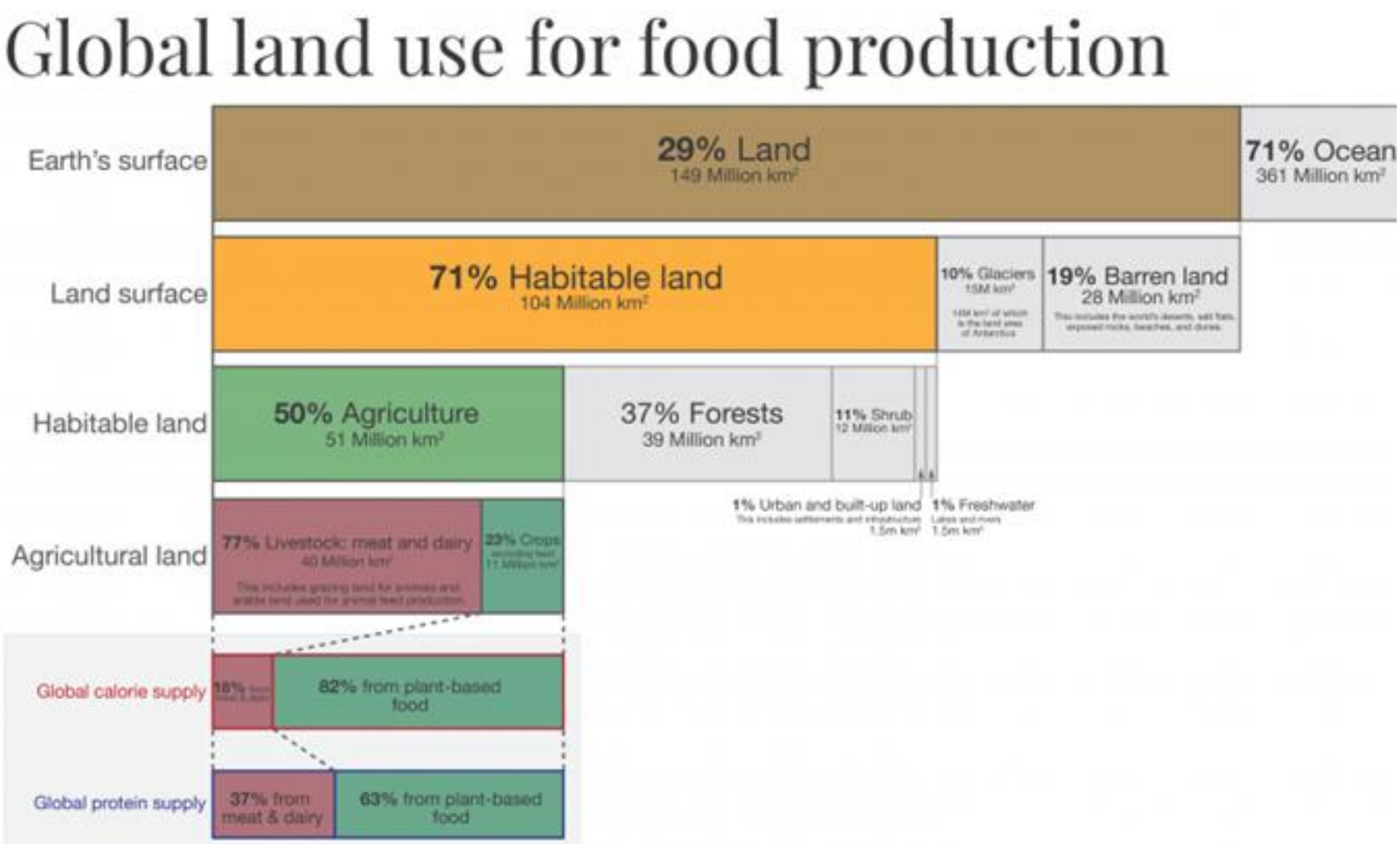

Figure 4: Global land use for food production (taken from Our World in Data, 2022).

Figure 5 illustrates the total land used for agriculture (measured in hectares) and how it has increased over the centuries. The land used for agriculture stayed roughly the same throughout the 17th, 18th and for the first half of the 19th century. The land used for agriculture began to rapidly increase around the 1850's, which, as mentioned in chapter one, is around the time when the agricultural revolution began. There was another rapid increase in agricultural land use around the 1950's, which was around the time of the green revolution, where traditional methods of farming were phased out and replaced with farming machinery, tractors and the use of fertilisers (Matej et al., 2021).

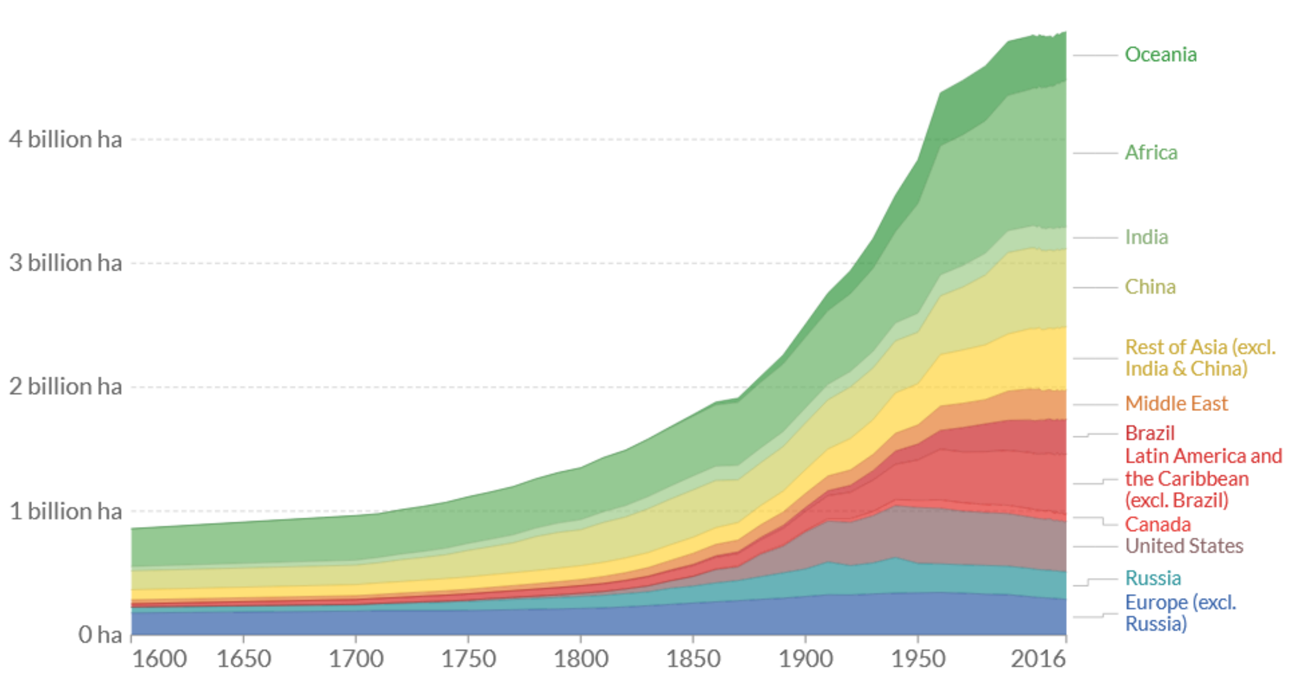

Figure 5: The development of land use for agriculture (taken from Our World in Data, 2022).

As mentioned oreviously, roughly 50% of the habitable land on Earth is used for agriculture and farming. Figure 6 illustrates how much non-habitable and habitable land is in use for agricultural purposes (Balima et al., 2020).

It is clear from figure 6 that there is large variation across the world, in the share of land that countries use for agriculture. The allocation of land ranges from 10% across countries such in the Scandinavian countries and Sub-Saharan Africa, to almost 80% in many regions and countries across Europe, South Africa, Saudi Arabia and Nigeria (Balima et al., 2020).

Figure 6 shows the percentage of land used for agriculture overall. The term ‘agricultural land’ refers to the proportion of land that is arable, is used permanent pastures and for permanent crops. This metric therefore includes the use of land for crop production, as well as pasture land for grazing. As a result, a large share of land is consumed by agriculture, even in areas that are extremely dry, arid or semi-arid (Bhan et al., 2021)

The proportion of land used globally for agriculture has changed over the years, and has varied in different regions of the world. Across most regions in the world, the allocation of land used for agriculture has increased in the last few decades. However, it was also found that the land used across Central Asia, North America and parts of Europe has been declining in recent years (Bhan et al., 2021).

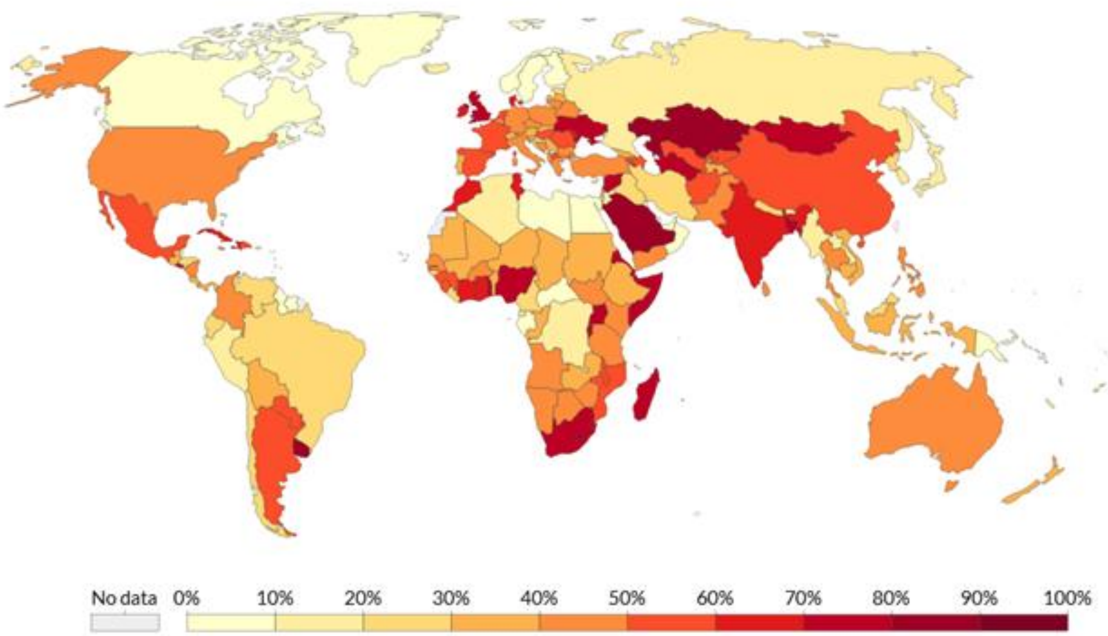

Figure 6: The share of land used for agriculture in 2018 (taken from Our World in Data, 2022).

3.1.1 Land Area used for Arable Farming

Arable farming is one of the most common types of farming used globally. As mentioned in Chapter One, arable farming is the systematic use of land to grow crops. Figure 7 shows how land is used for arable farming globally. The land used for cropland and arable farming is usually below 20-30% for most countries throughout the world, including China, the USA and Argentina. Many countries such as Brazil, Russia and South Africa use less than 10% of land for arable farming. However, South Asia as well as many countries in Europe use a significant proportion of land for arable farming, around 50-80%. In 2015, it was found that countries such as Denmark, Ukraine, India and Bangladesh all allocated more than half of the total land area available to arable farming (Matej et al., 2021).

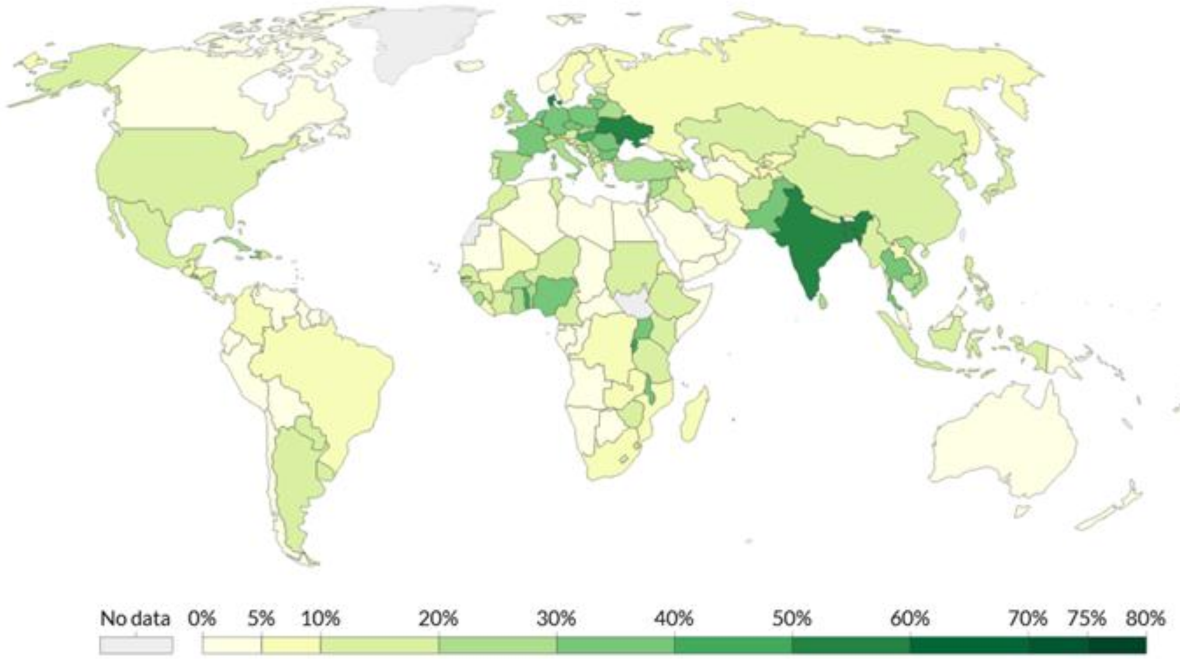

Figure 7: Share of land used for arable agriculture (taken from Our World in Data, 2022).

3.1.2 Land Area used for Pastoral Farming

Pastoral farming is another common method of farming used all over the world. As mentioned in Chapter One, pastoral farming is a method of farming used solely for rearing animals and not for growing crops. Pastureland refers to permanent meadows and pasture which is used for rearing livestock such as sheep, beef cattle and dairy cattle. Pastoral farming is ideal in cold and wet climates as opposed to hot and dry climates (Feng et al., 2021).

Figure 8 shows the majority of countries worldwide, a large proportion of agricultural land are used for pastureland and the rearing livestock. Figure 8 highlights the proportion of pastureland as a percentage of total area of land overall.

In comparison to arable farming, land use in regions such as South Asia and Europe for pastoral farming is less than 20%, compared to 50-80% used in arable farming. It is clear however, that most continental regions have countries where nearly half the total land area is allocated to pastoral farming. This can also reach up to 70% in some regions, such as Central Asia, also including Kazakhstan and Mongolia. Pastoral and livestock farming is more versatile in comparison to arable farming, as this type of farming can take place across various climatic and environmental regions, and withstand harsher weather conditions. For example, the rearing of sheep can take place in hilly and semi-arid areas; whereas arable farming could not. Therefore pastoral farming is not as constrained geographically in comparison to arable farming (Ye and Fang, 2012).

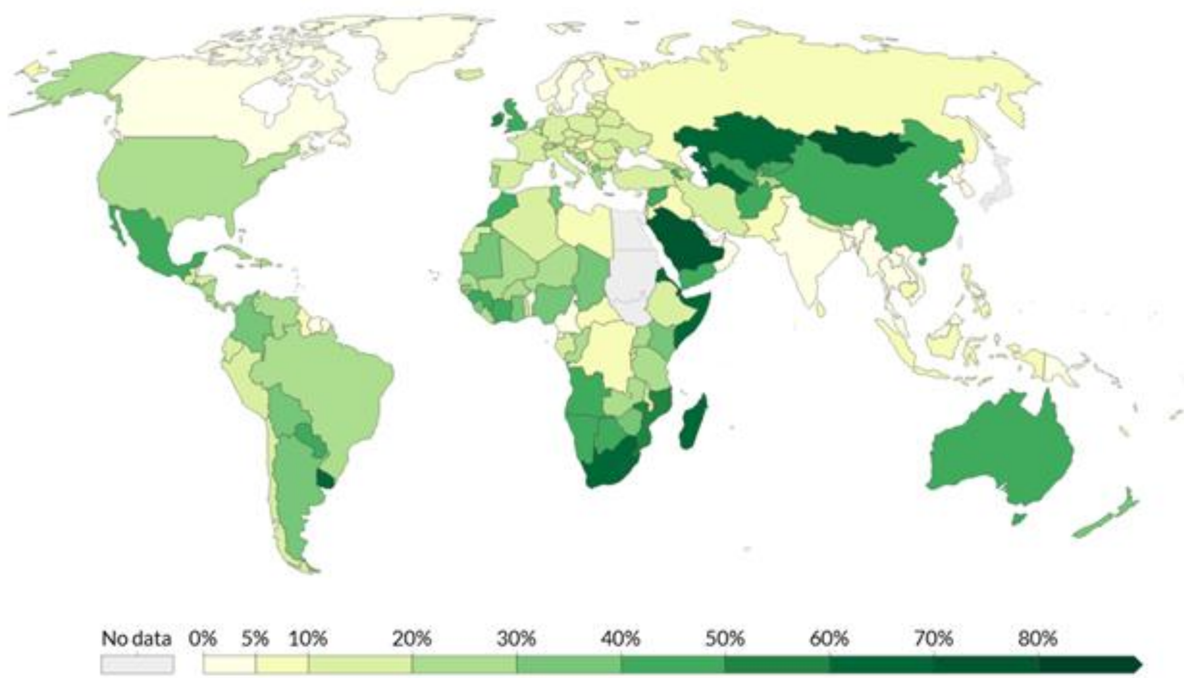

Figure 8: Land use for pastoral farming (taken from Our World in Data, 2022).

3.1.3 Global Land Use by Crop Type

Figure 9 shows the global land use by crop types, from 1961 to the year 2014. A large proportion of arable land is used to produce cereal crops, such as wheat, rice, maize, rye, barley, oats, and sorghum. The growth of cereals crops has increased from roughly 650 to 720 million hectares during from 1961 to 2014. For context, this area is around twice the size of Germany. Coarse grains are the second largest crops grown on arable land. The total area of land for growing these grains has stayed roughly the same during the last 50 years (Johnson and Mueller, 2021).

The production of oil crops has had the largest increase in land allocation. The land used for producing oil crops has almost tripled since 1961, rising from just over 100 million hectares in 1961, to over 300 million hectares in 2014. Examples of oil crops include palm, soybean, rapeseed and sunflower, canola, flax and coconut. All other crop types, including fruit, vegetables, and pulses etc use lower than 100 million hectares of land globally (Johnson and Mueller, 2021).

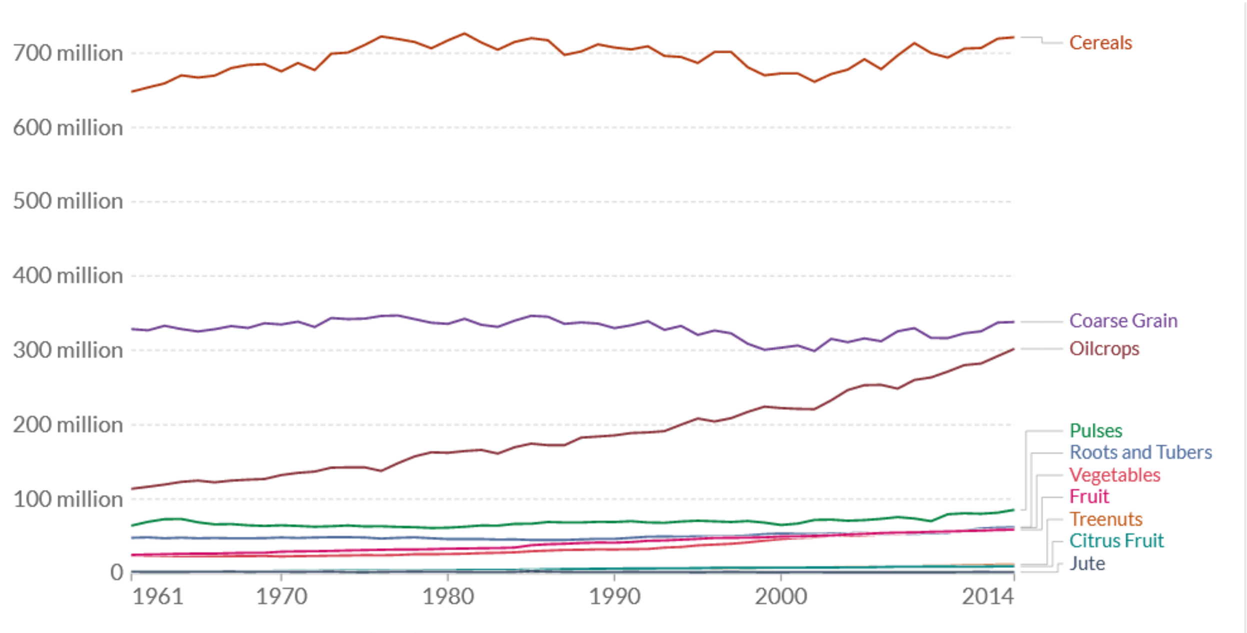

Figure 9: Global land use by crop type (taken from Our World in Data, 2022).

3.2 Largest Agricultural Producers Globally

Geographical locations of the largest producers of cereals, meat, fruit and vegetables by tonnage were obtains and are shown in figures 10- 15 below. The countries that have the largest total agricultural output by billion dollars are also shown below.

As depicted in figure 10, China is the greatest overall producer of meat worldwide producing 88,500 tonnes of meat in 2020. The United States produced just over half of what China produced, producing almost 46,000 tonnes of meat. Brazil was found to be the third largest producer of mean in 2018, producing roughly 27,000 tonnes of meat. The remaining 9 countries produced roughly 5,000-10,000 tonnes of meat during 2020 (Kucukvar et al., 2020).

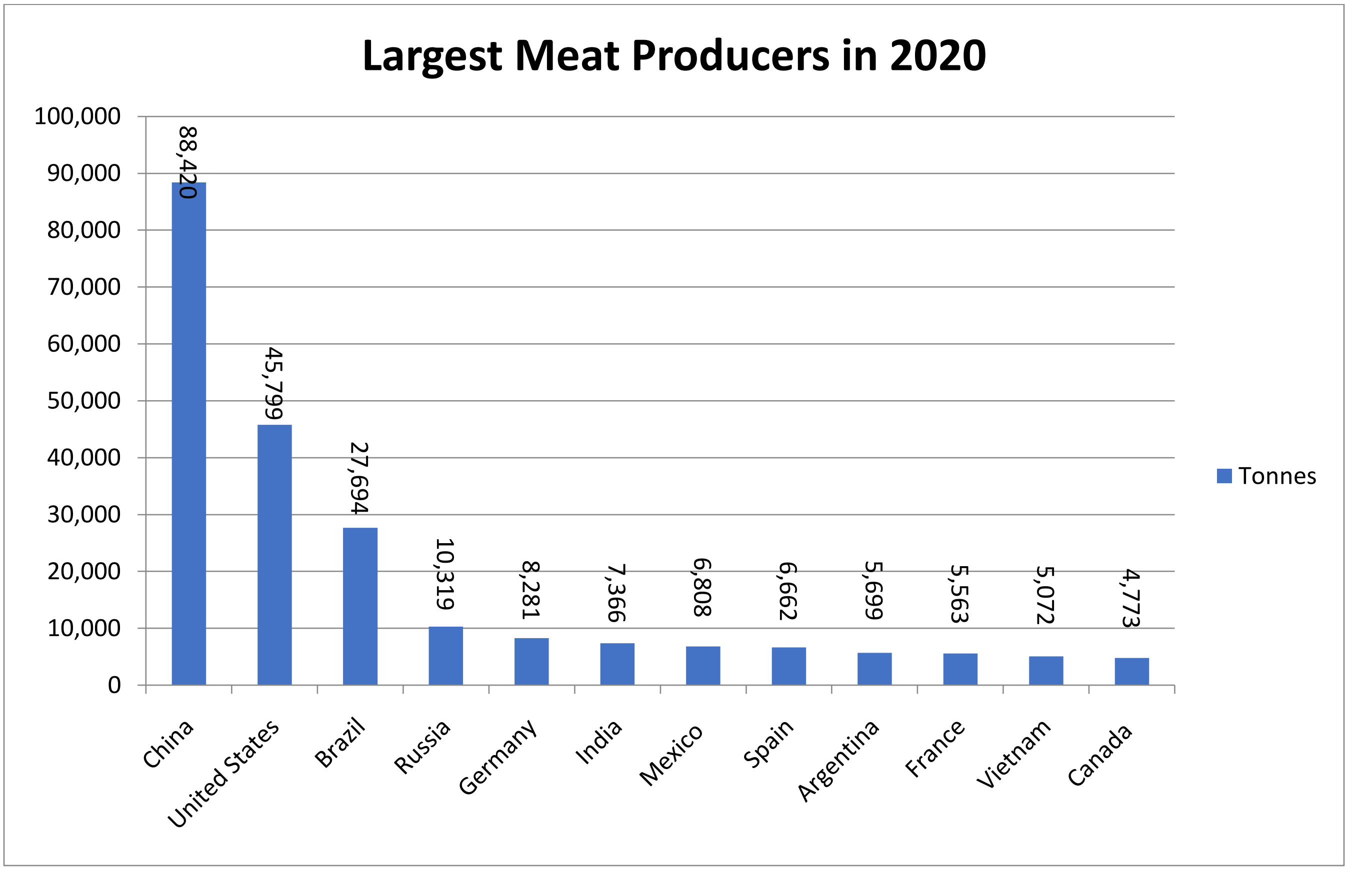

Figure 10: Largest meat producers in 2020 (adapted from Kucukvar et al., 2020).

Figure 11 highlights the increase in meat production from 1961 to 2020. It is clear that China has had the largest increase in production over this 60 year period. The United States and Brazil also show significant increases in production during this period. Russia, Germany, India, Mexico, Spain, Argentina, France, Vietnam and Canada also showed a slight increase in production during this time period (Kucukvar et al., 2020).

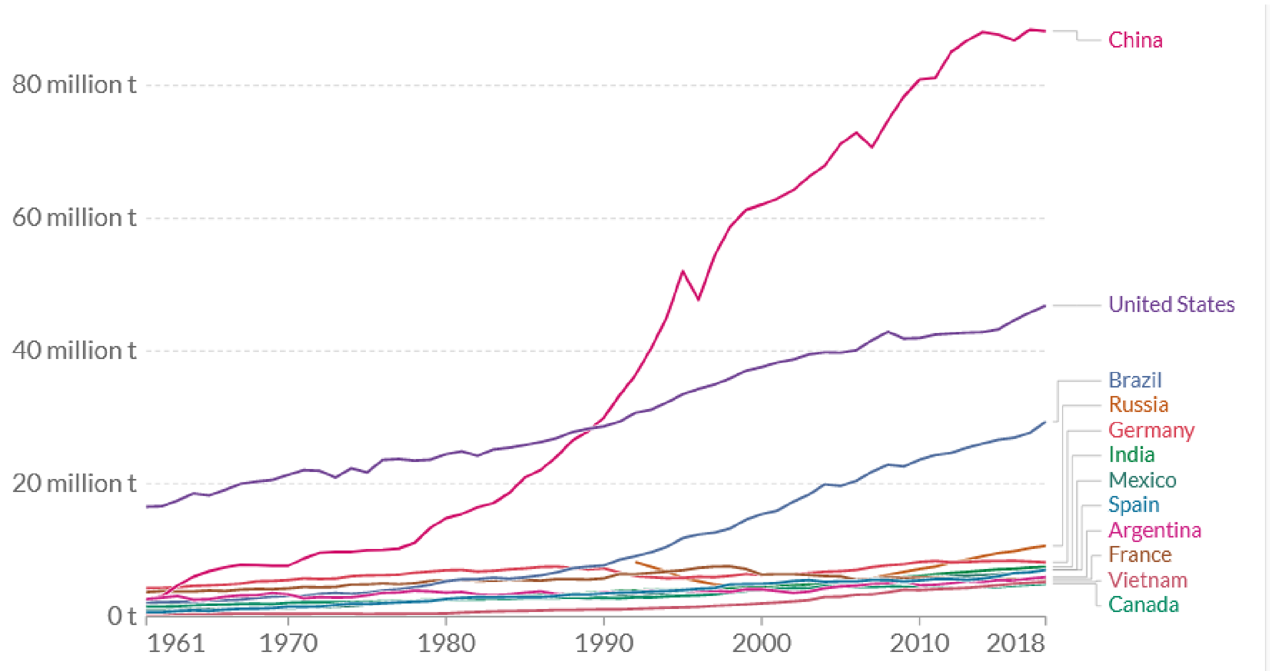

Figure 11: The development of meat production from 1961 – 2018 (taken from Our World in data, 2022).

Figure 12 highlights that China was also the highest producer of cereal products globally, producing nearly 620,000 tonnes in 2020. Again, the United States was the second largest producer of cereal crops with almost 467,000 tonnes of cereals being produced. India produced around 314,000 tonnes of cereals. The remaining 9 countries listed produced 131,000-50,000 tonnes of cereals in 2020 (Kucukvar et al., 2020).

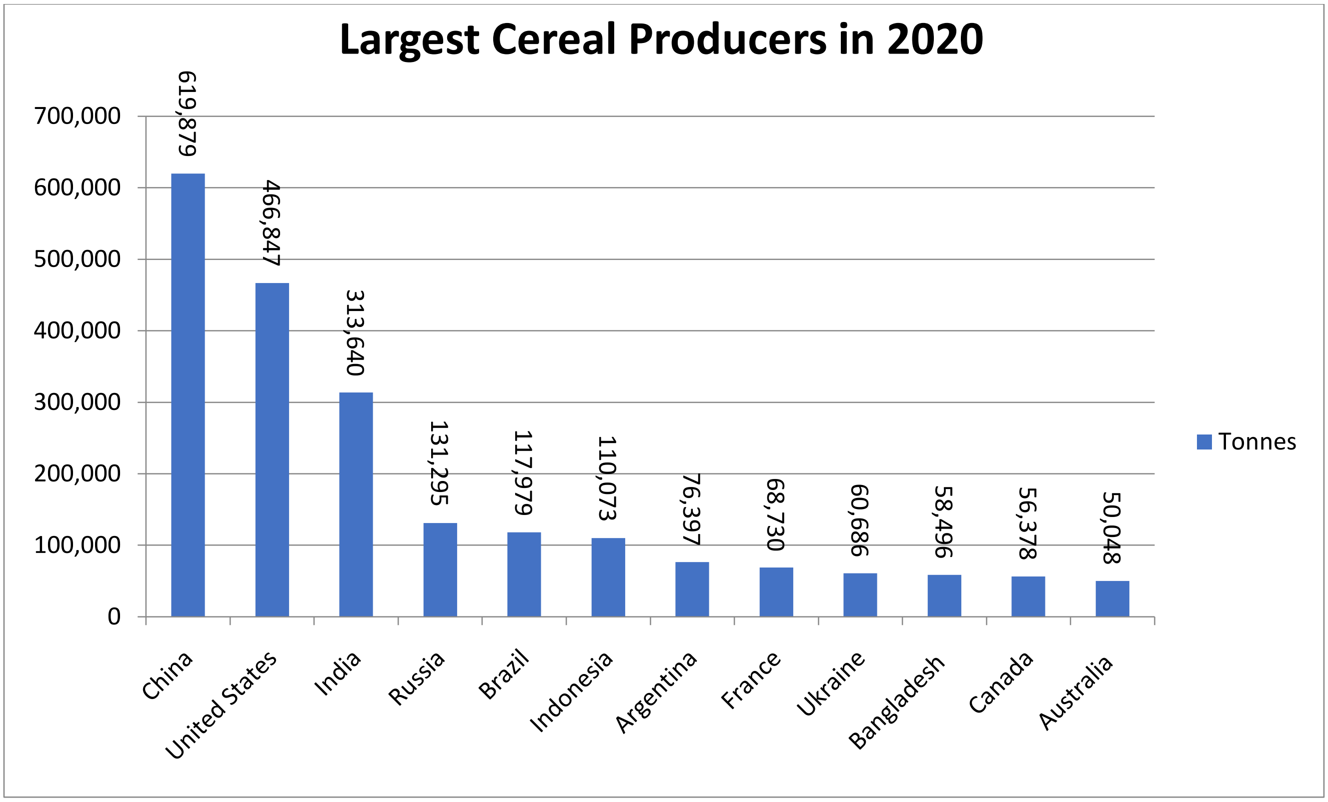

Figure 12: Largest cereal producers in 2020 (adapted from Kucukvar et al., 2020).

As shown in figure 13, China again was found to be the largest producer of fruit, producing nearly 230,000 tonnes in 2020. India was found to be the second largest producer of fruits, producing 93,000 tonnes. Brazil was the third largest producer of fruits producing 40,000 tonnes in 2020. The remaining 9 countries illustrated produced roughly between 14,000 to 26,000 tonnes of fruits. Successive record harvests of major cereal crops in recent years has also resulted in a steady build-up of inventories and lower prices in markets internationally when compared to previous years, making cereals a popular category to farm (Kucukvar et al., 2020).

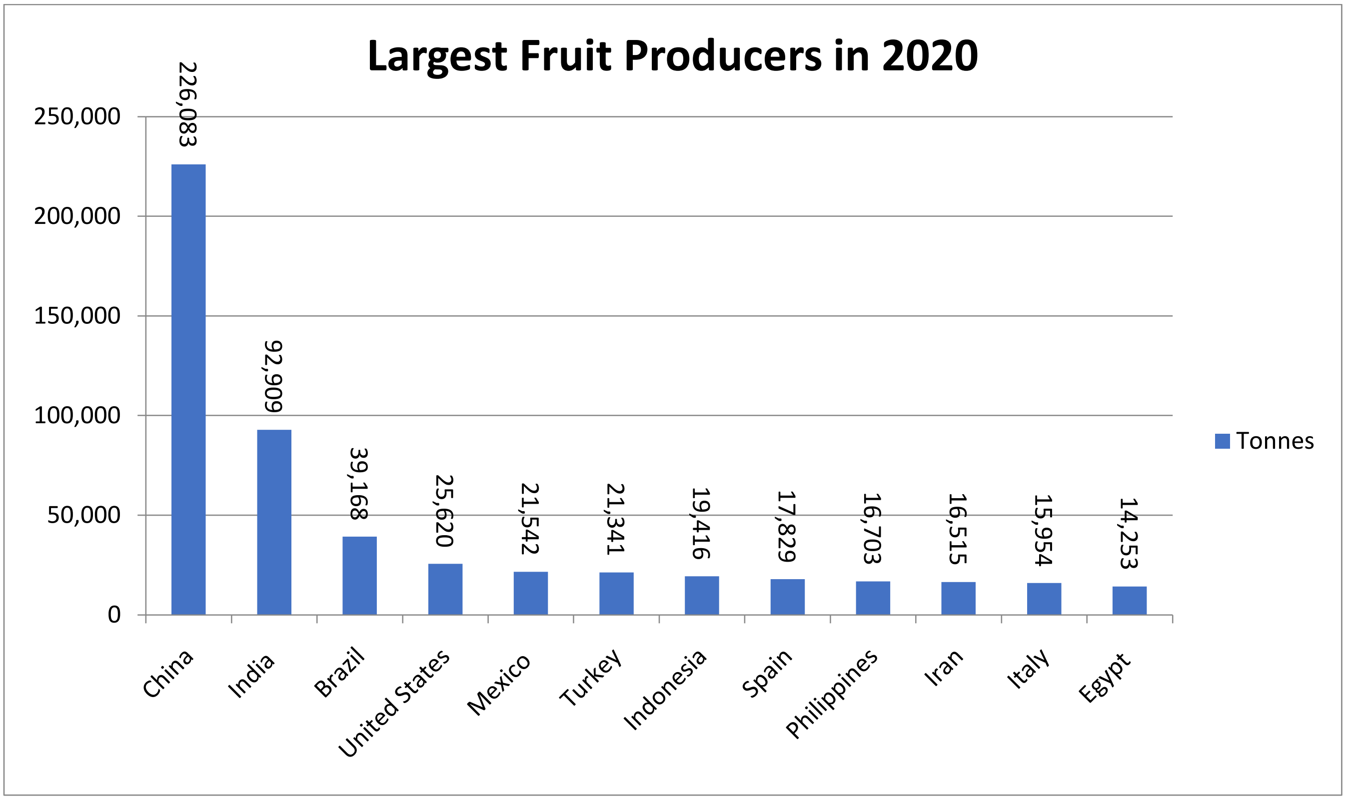

Figure 13: Largest fruit producers in 2020 (adapted from Kucukvar et al., 2020).

Again, figure 14, highlights that China was the largest vegetable producer in 2020 producing 556,000 tonnes. India was the second largest producer of vegetables, producing 130,000 tonnes, followed by the United States who produced 33,000 tonnes. It is clear from figure 14 below that there is a large variation in tonnes produced between the top three producers of vegetables **(**Kucukvar et al., 2020).

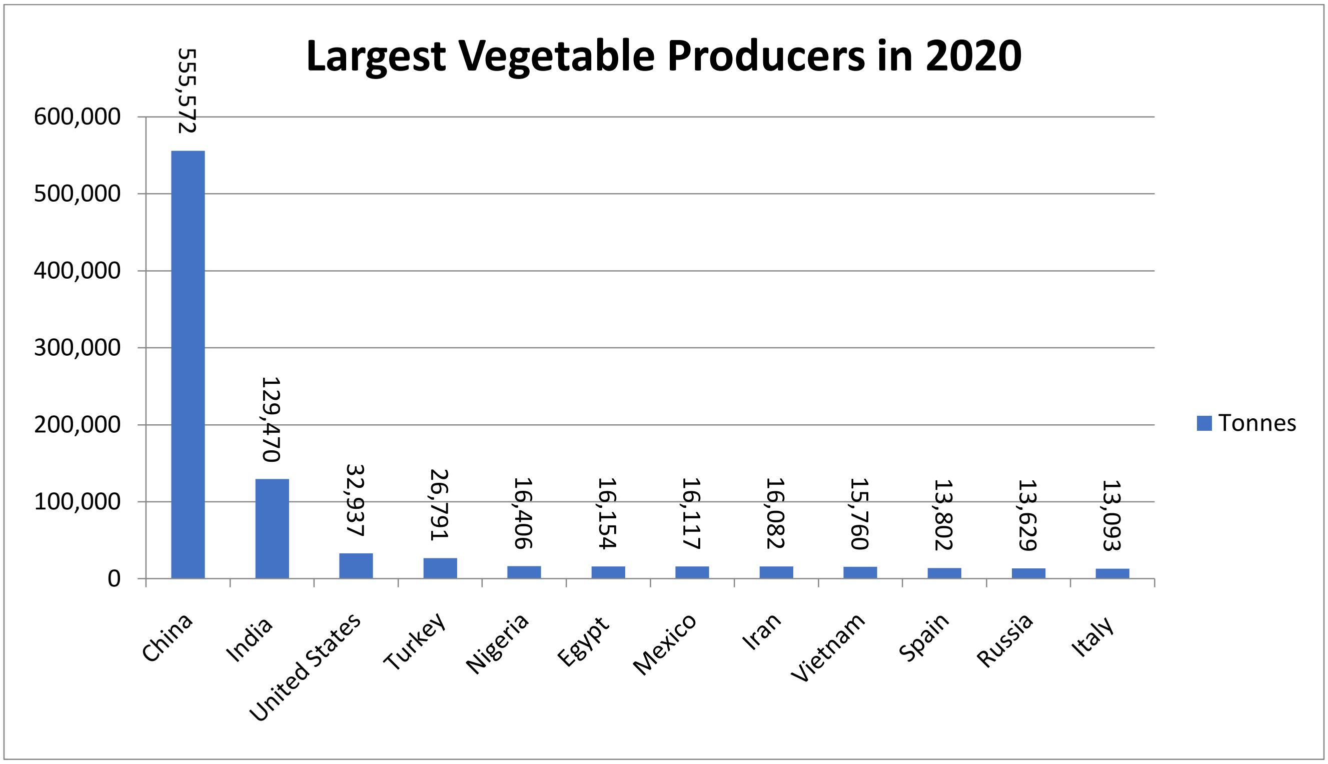

Figure 14: Largest vegetable producers in 2020 (adapted from Kucukvar et al., 2020).

As shown in figure 15, China had the largest agricultural output overall in 2020, producing nearly $980 billion worth of agricultural produce. This is the largest figure by far shown in figure 15. India had the second largest agricultural output, producing nearly $400 billion dollars worth of agricultural produce. The third largest country was the United States, who produced roughly $180 billion worth of agricultural products **(**Kucukvar et al., 2020).

The most notable findings from figures 10-15 are that China, India and the United States were the largest producers in nearly all the categories mentioned, including meat, cereals, fruits, and vegetables. In each of these categories, China was by far the largest producer, often producing triple the amount of product than the second largest producer. It was also found that, four of the of the world's largest agricultural producing countries also rank highest in the world for total geographical land area this includes China, the United States, India and Brazil (Kucukvar et al., 2020).

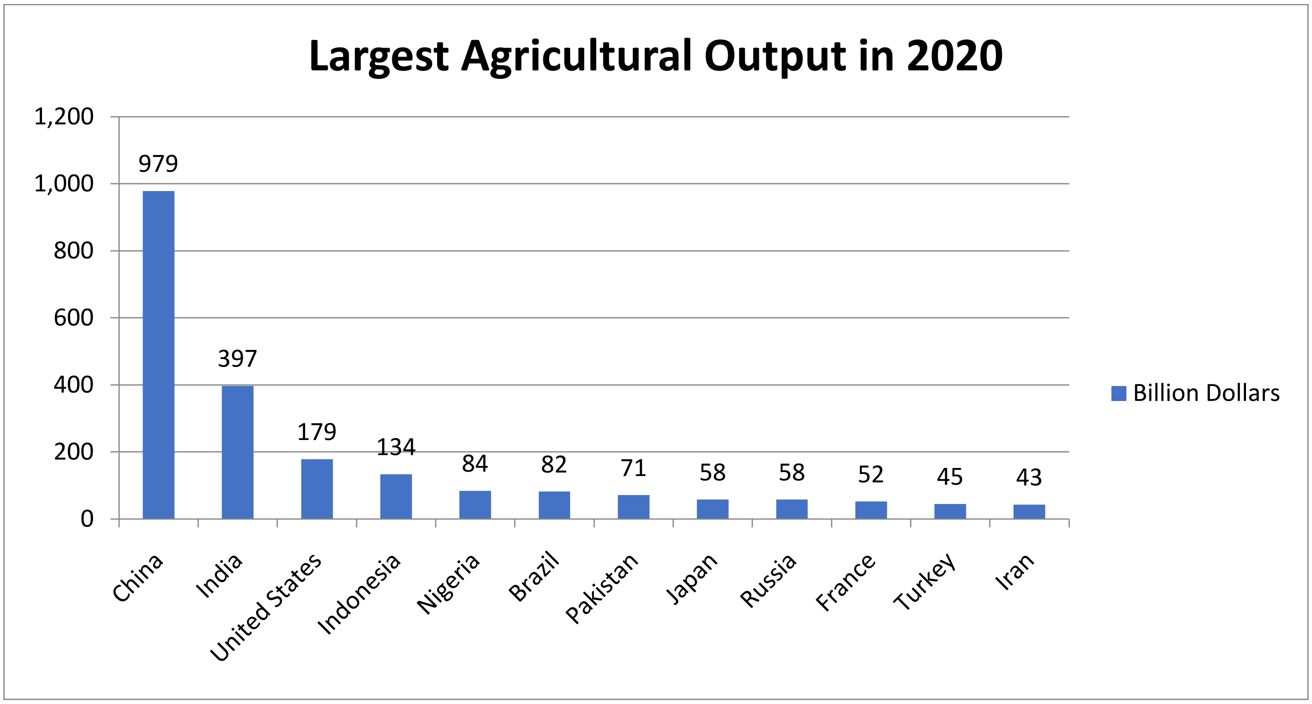

Figure 15: Largest agricultural output in 2020 (adapted from Kucukvar et al., 2020).

3.3 The Impact of Agriculture on the Economy

Gross domestic product (GDP) is the monetary measure of the total market value of final goods or services produced over a period of time by countries all over the world. It counts the total monetary output generated by a country. GDP per capita measures the total economic output of a country per person. GDP per capita is measured by dividing the GDP of a country by the population of that country (Barbosa et al., 2022).

Table 3 highlights the GDP per capita of the top 12 agricultural producing countries, as well as the farming methods used and the agricultural percentages as a share of GDP. China was found to be largest agricultural producer, and was found to have a GPD per capita of $14,322 in 20202, yet the agricultural GDP percentage was found to be 7.92%. This indicates that the agricultural industry is not the most dominant sector of China's economy. The results also showed that China used mostly traditional and intensive methods of farming on large scales. However the results also indicated that China has started incorporating advanced farming practices into farming in recent years. Advanced farming methods are more environmentally friendly methods of farming. India was found to have a GDP per capita of $6,183, with an agricultural GDP percentage of 15.45%. India's agricultural GDP percentage is nearly double that of China, which indicates that the agricultural sector in India is one of the more dominant sectors in the economy. This was found to be similar in other developing countries such as Nigeria, Pakistan and Indonesia, all of which had a significant lower GDP per capita than that of developed countries such as the United States, Japan or France. Developing countries in table 3also were found to have a higher agricultural GDP percentage in comparison to developed countries (Barbosa et al., 2022). For example, the agricultural GDP percentage of Nigeria, Pakistan and Iran were found to be 20.85%, 17.80% and 13.14% compared to the United States, Japan or France 1.91%, 1.15% and 1.51%. This indicates that the many other sectors in these developed countries also contribute to and benefit their economy, whereas developing countries rely heavily on farming for their economy.

Table 3: An Overview of the GDP per capita and agriculture as a share of GDP (%) in the top 12 agricultural producing countries and the main farming methods they use (adapted from (Weerabahu et al., 2021; Barbosa et al., 2022).

Country	**GDP per Capita 2020 ($)**	**Agriculture as a Share of GDP (%)**	**Farming Methods Used**
China	$14,344	7.92%	Arable Pastoral Mixed Intensive Commercial Advanced
India	$6,183	15.45%	Arable Pastoral Mixed Intensive Subsistence Nomadic Plantation Organic Advanced

United States	$60,110	1.91%	Arable Pastoral Mixed Intensive Commercial Sedentary Organic Advanced
Indonesia	$10,936	13.14%	Arable Plantation Commercial Subsistence Organic
Nigeria	$5,190	20.85%	Arable Pastoral Plantation Subsistence Commercial Nomadic
Brazil	$14,525	4.57%	Arable Pastoral Mixed Commercial Intensive Extensive Subsistence Organic Advanced
Pakistan	$4,286	17.80%	Arable Pastoral Mixed Subsistence Commercial
			Arable Intensive Subsistence

Japan	$40,967	1.15%	Commercial Advanced
Russia	$25,926	4.01%	Arable Pastoral Mixed Intensive Sedentary Commercial Advanced
France	$44,577	1.51%	Arable Pastoral Mixed Extensive Intensive Commercial Sedentary Organic Advanced
Turkey	$27,914	6.08%	Arable Pastoral Mixed Extensive Intensive Commercial Sedentary Organic Advanced
Iran	$14,536	10.08%	Pastoral Extensive Subsistence Nomadic

3.4 The Impact of Farming Methods on the Environment

Table 4 highlights the various methods of farming used worldwide, the environmental concerns associated with their use, frequency of their use as well as the impact rating on each farming method. The impact rating was calculated by an educated guess using the research gathered. The environmental concerns associated with the farming method as well as how frequently they use were used to make this conclusion. Figure 16 is an impact matrix that was used to calculate the impact rating of each farming method. For example, arable farming was found to be used frequently, while also having a critical impact on the environment in terms of land use, greenhouse gas emissions and water used, therefore the impact of arable farming was found to be high. Pastoral, mixed, intensive and commercial farming were all found to have a high impact on the environment because of their use of land, greenhouse gas emissions and use of water (Aquilani et al., 2022). Additionally, they were found to be the most commonly used farming methods in the 12 top agricultural producing countries. Subsistence and extensive farming methods were found to have a low/medium impact on the environment. This is because their levels of greenhouse gas emissions were found to be much lower, as well as their land use. Their frequency of use was also much lower (Aquilani et al., 2022). Advanced farming systems, including precision, smart and digital farming were found to have a medium/high impact on the environment. This is because their greenhouse gas emissions were still found to be relatively high, however their use of outputs was found to be much more strategic and efficient. These farming methods were also frequently used in 8 out of the 12 countries studied, despite being a relatively new development (Tullo, Finzi and Guarino, 2019).

Table 4: An overview of farming methods, used their frequency of use (across the top 12 agricultural producing countries), the environmental concerns associated with each and the impact rating (adapted from Tullo et al., 2019; Aquilani et al., 2022).

Farming Methods	Environmental Concerns	Frequency of Use	Impact rating
Arable farming	Large use of land globally (11 million km²) Greenhouse gas emissions from use of fertilisers & farm machinery Large use of water for irrigation & crops	10 out the top 12 agricultural producing countries use arable farming	High impact

Pastoral farming	Large use of land globally (40 million km²) High greenhouse gas emissions from use of fertilisers/livestock	9 out the top 12 agricultural producing countries use pastoral farming	High impact
Mixed farming	Large use of land Greenhouse gas emissions from use of fertilisers & farm machinery Large use of water for livestock & irrigation	8 out the top 12 agricultural producing countries use mixed farming	High impact
Intensive farming	Large use of land Heavy use of fertilisers & pesticides Heavy use of machinery High greenhouse gas emissions	7 out the top 12 agricultural producing countries use intensive farming	High impact
Extensive farming	Use less fertilisers & pesticides Involves little use of machinery Greenhouse gas emissions are considerably low	4 out the top 12 agricultural producing countries use extensive farming	Low/medium impact
Subsistence farming	Small scale use of land Little machinery use Little use of fertilisers & pesticides Greenhouse gas emissions are quite low Use of water is quite low	6 out the top 12 agricultural producing countries use subsistence farming	Low/medium impact
Commercial farming	Large scale use of land Heavy use of fertilisers & pesticides Heavy use of farm machinery Greenhouse gas emissions are high Water usage is high	10 out the top 12 agricultural producing countries use commercial farming	High impact
Organic farming	Does not use fertilisers, pesticides or any chemicals Farm machinery commonly used Use of both large & small scale farms Water usage is often high	6 out the top 12 agricultural producing countries use organic farming	Low/medium impact
Advanced farming systems: Precision farming, Smart farming &	Uses fertilisers and pesticides only when specifically needed. Uses of water for irrigation & livestock only when needed	8 out the top 12 agricultural producing countries use advanced farming systems	Medium/high

Digital farming	Greenhouse gas emissions are lower Can be used on both small & large scale farms		impact

Frequency of use	**Very Likely**	Medium/high	Medium/high	High	High
	Likely	Low/Medium	Medium/high	Medium/high	High
	Possible	Low/Medium	Low/Medium	Medium/high	Medium/high
	Unlikely	Low	Low	Low/Medium	Low/Medium
	Rare	Low	Low	Low	Low/Medium
		Impact on the Environment			
		Minimal Impact	**Marginal Impact**	**Moderate Impact**	**Critical Impact**

Figure 16: Impact matrix used to determine the environmental impact of each farming method.

3.4.1 Fertiliser Usage in Agriculture

All crops need nutrients in order to grow. These nutrients are absorbed from the soil, via the crops root systems. Farming practices used today reduce the soil's nutrients and productive capacity with each harvest. Unless the soils nutrients are replenished, the land can become useless to the farmer as it is no longer fit to produce crops. Fertilisers help to provide the major nutrients that soil needs to grow crops, including nitrogen, potassium and phosphorus. Table 5 illustrates how fertiliser can be used to aid in the growth of crops (Gerssen-Gondelach et al., 2021).

The rapid increase in population and reduction of agricultural land means that agricultural productivity is more important than ever in order to ensure food security. However, the intensive use of chemicals such as fertiliser and pesticides can impact on food safety through a reduced environmental quality (Xiang, Malik and Nielsen, 2020).

It was found that the pressure from the increasing population has significant impacts on fertiliser usage, particularly in countries where there is a high population pressure. As depicted in table 5, there are both pros and cons to using both organic and inorganic fertilisers (Gerssen-Gondelach et al., 2021).

Table 5: Types of fertiliser available and a summary of the pro's and cons associated with each (adapted from Gerssen-Gondelach et al., 2021).

Type of Fertiliser		**Pro's**	**Con's**
Natural/Organic Fertiliser	· Manure · Wood ash · Ground bones · Seaweed · Guano · Compost	· Improves soil structure · Balances the soil ecosystem · Slow release of nutrients · Requires fewer applications · No toxin build up · Environmentally friendly · Renewable · Delivers nutrients at a slow, sustainable rate · Less chance of leaching · Prevents over-fertilization · No chemical intervention · Cheaper	· The concentration of nutrients cannot be entirely predicted · Requires microbial activity · Slow release · Difficult and messy to apply precisely
Synthetic/Inorganic Fertiliser	· Nitrogenous fertilisers · Potassium fertilisers · Phosphate fertilisers · Complete fertiliser – Nitrogen, Phosphate, Potassium (NPK)	· Faster acting · Easily absorbed · Easy to handle · Easy to apply precisely and consistently · Easier to store · Rapid plant growth	· Don't contain micronutrient organisms · Does not add organic material to the soil · Reduces ability of soil to hold water · Easily over-applied · More likely to leech a · Can lead to a buildup of toxic salt concentrations · Releases greenhouse gases · Requires frequent

	· Calcium, magnesium & sulphate		applications · Can release nutrients too quickly or too slowly

Table 6 also highlights and compares the impact both organic and inorganic fertilisers have on the environment and the yield. The results show that natural/organic fertiliser was less environmentally damaging in comparison to inorganic/synthetic fertiliser, but inorganic/synthetic fertiliser resulted in a faster and higher yield of crops. It was found that for this reason, inorganic/synthetic fertiliser was used more often by farmers (Xiang et al., 2020).

Table 6: Type of fertiliser and their impact of the environment and yield (adapted from (Gerssen-Gondelach et al., 2021; Xiang et al., 2020).

Type of Fertiliser		**Impact on the Environment**	**Impact on Yield**
Natural/Organic Fertiliser	· Manure · Wood ash · Ground bones · Seaweed · Guano · Compost	· Free from chemicals · Bio-degradable · Does not cause pollution · Avoids the loss of soil fertility · Less run off into water streams · Encourages biodiversity	· Improves crop yield overall · Slow release of nutrients · Crop yield is increased at a slower rate
Synthetic/Inorganic Fertiliser	· Nitrogenous fertilisers · Potassium fertilisers · Phosphate fertilisers · Complete fertiliser – Nitrogen, Phosphate, Potassium (NPK) · Calcium, magnesium & sulphate	· Easily leeched into water systems · Can lead to Algae growth and loss of aquatic life · Can cause soil imbalances · Can lead to plant loss · Release greenhouse gases	· Improves crop yield overall · Faster release of nutrients · Crop yield is improved at a slower rate

3.4.2 Pesticide Usage in Agriculture

Similarly to fertilisers, the studies found indicated that there are both advantages and disadvantages to using pesticides in agriculture. As depicted in table 7, there are clearly more disadvantages to their use than advantages. Studies show that one of the largest risks associated with pesticides is the possible toxicity to humans along with their potential carcinogenetic traits. It was found that pesticide residues have the potential to bio-accumulate within the human body, putting humans at risk. Furthermore, they also contaminate the environment, water, soil and air as well as remove and destroy other useful organisms (Patinha et al., 2018).

Despite this, many farmers continue to use pesticides in their farming practices because of the clear benefits associated with their use. Pesticides were found to improve productivity as diseases and pests are controlled, reducing crop loss and lower yields (Geissen et al., 2021).

Table 7: Advantages and disadvantages associated with pesticides (adapted from Patinha et al., 2018).

Advantages	**Disadvantages**
Improved productivity	Possible neurotoxicity, carcinogenicity metabolic & reproductive toxicity due to the bioaccumulation of pesticides in the body
Prevention of crop loss & reduced yield	Surface water contamination
Control of disease & epidemics	Ground water contamination
Food quality	Soil contamination
Reduced food loss during storage & transport	Effect on soil fertility
	Air contamination
	Destruction of on-target vegetation
	Destruction of other useful organisms

3.4.3 Greenhouse Gases

Greenhouse gases are gases that have the ability to absorb and radiate heat within the Earth's atmosphere. Earth's surfaces radiate heat continuously. Most of earth's atmosphere is made up of oxygen and nitrogen, but unlike oxygen and nitrogen, greenhouse gases absorb the heat from Earth and release it over time. Carbon dioxide is an example of a long lived greenhouse gas, as it stays in the atmosphere for centuries. It is also the most abundant gas. The rapid increase in carbon dioxide in the air largely contributes to the imbalance of energy that is causing rising temperatures on Earth (Gerssen-Gondelach et al., 2021).

Similar to other greenhouse gases, nitrous oxide traps heat within the atmosphere, where it can live for roughly 114 years. In comparison to carbon dioxide, it is considered a relatively short lived gas. Nitrous oxide poses a double threat to the environment. While in the stratosphere, nitrous oxide becomes exposed to oxygen and sunlight, converting nitrous oxide to nitrogen oxides. Nitrogen oxides have the ability to destroy the ozone layer, which protects humans from the sun's powerful ultraviolet radiation. This double threat is what gives nitrous oxide its double potency. One tonne of nitrous oxide has the ability to warm the atmosphere nearly 300 times as much as one tonne of carbon dioxide. As a result, the potency and the long life of nitrous oxide means that it contributes largely to climate change. Figure 17 illustrates how excess fertiliser can cause nitrous oxide emissions (Mazzetto et al., 2019).

It was found that the use of excess fertiliser on crops can lead to pollution of water systems and also to increased nitrous oxide formation. Synthetic fertilisers are commonly ammonium and nitrate based and when applied to crops, if the plant roots fail to take up all the nutrients from the fertilisers, a series of microbe-mediated transformations take place. As a result, nitrogen enters the atmosphere as nitrogen gas (N_2) and nitrous oxide (N_2O), which is a very potent and powerful greenhouse gas (Murphy et al., 2020).

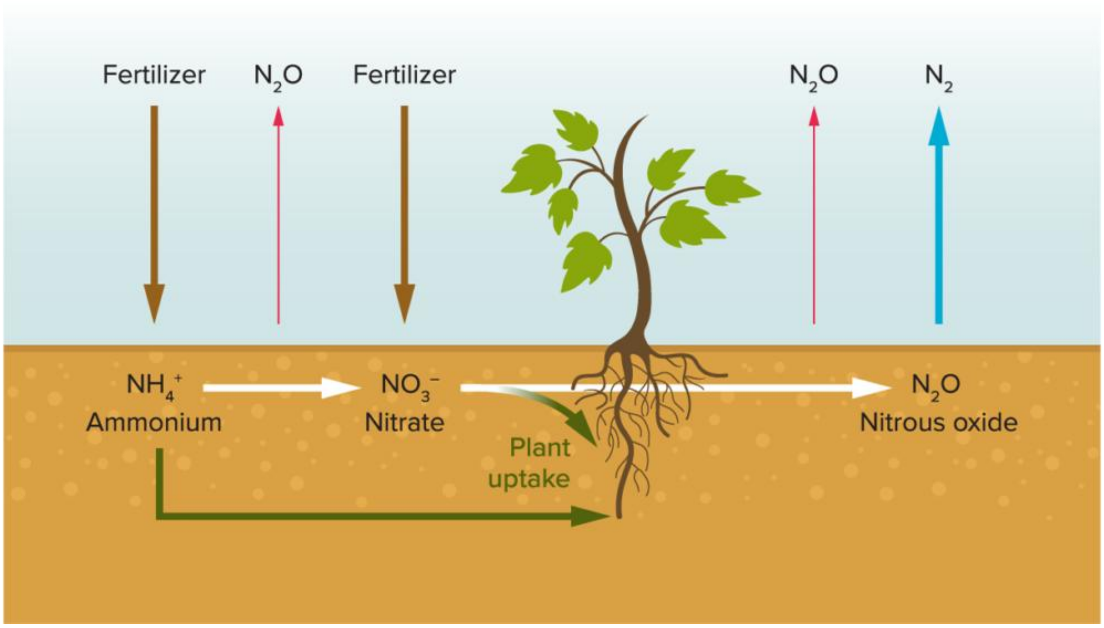

Figure 17: How excess fertiliser can cause nitrous oxide emissions (taken from (Otto et al., 2022).

Methane (CH_4) is a gas that is naturally occurring in the environment and is also released through the activities of humans. After carbon dioxide (CO_2), it was found to be the second most abundant gas that is produced by the activities of humans. Studies show that the majority of manmade carbon dioxide emissions are a result of industrial processes, including the burning of fossil fuels. However, the majority of methane emissions were found to be a result of agricultural processes, including rice cultivation, rearing livestock and clearing land through burning vegetation (Dimitrov and Wang, 2019).

Methane is often thought of as a short lived gas, because it remains in the air for roughly 12 years before being broken down. Carbon dioxide, on the other hand is thought of as a long lived gas, because it remains in the Earth's atmosphere for hundreds of years. Although methane has a shorter life, it is much more efficient at trapping heat on Earth in comparison to carbon dioxide. This makes methane a very powerful and dangerous greenhouse gas. For example, for every tonne of methane released into the Earth's atmosphere, this is the equivalent to releasing 25 tonnes of carbon dioxide. Each greenhouse gas has a different effect on the atmosphere, this is known as their 'global warming potential'. Table 8 shows a summary of the 3 most harmful greenhouse gases, their global warming impact, their sources from agriculture and their agricultural causes (Dimitrov and Wang, 2019).

Fluorinated gases are also greenhouse gases that can trap heat within the atmosphere on Earth. However, they last in the atmosphere for hundreds of years and have the potential to trap heat a thousand times more than carbon dioxide. Examples of fluorinated gases include perfluorocarbons, hydrofluorocarbons and chlorofluorocarbons to name a few. These gases account for roughly 2% of global greenhouse gas emissions. They are commonly used as solvents, refrigerants and in manufacturing processes (Desjardins et al., 2018).

Table 8: A summary of the 3 most harmful greenhouse gases, their global warming impact, their sources from agriculture and their agricultural causes (adapted from Dimitrov and Wang, 2019; Desjardins et al., 2018).

Greenhouse Gas	**Global Warming Impact**	**Sources from Agriculture**	**Agricultural Causes**
Carbon dioxide (CO_2)	1:1 (CO_2 equivalent)	· Combustion of fossil fuels · Soil activity	· Draining soils · Tillage · Burning crop residue · Farming machinery · Heating farm houses
Nitrous oxide (N_2O)	296:1 (296 times more potent compared to CO_2)	· Soil activity · Animal manure	· Soil nitrification · Soil denitrification · Fertiliser leaching and run-off · Excess use of fertiliser · Decomposition of animal manure
Methane (CH_4)	25:1 (23 times more potent compared to CO_2)	· Animal manure · Ruminant livestock · Soil activity · Wetlands	· Enteric fermentation in livestock · Decomposition of animal manure · Decay of organic matter · Insufficiently drained soils and wetlands

3.4.4 Greenhouse Gas Emissions from Agriculture

As depicted in figure 18, the production of food is the cause of over 25% of greenhouse gas emissions worldwide. This figure can be further split into four key categories including land use, crop production, livestock and fisheries and supply chain (Muhammad et al., 2019).

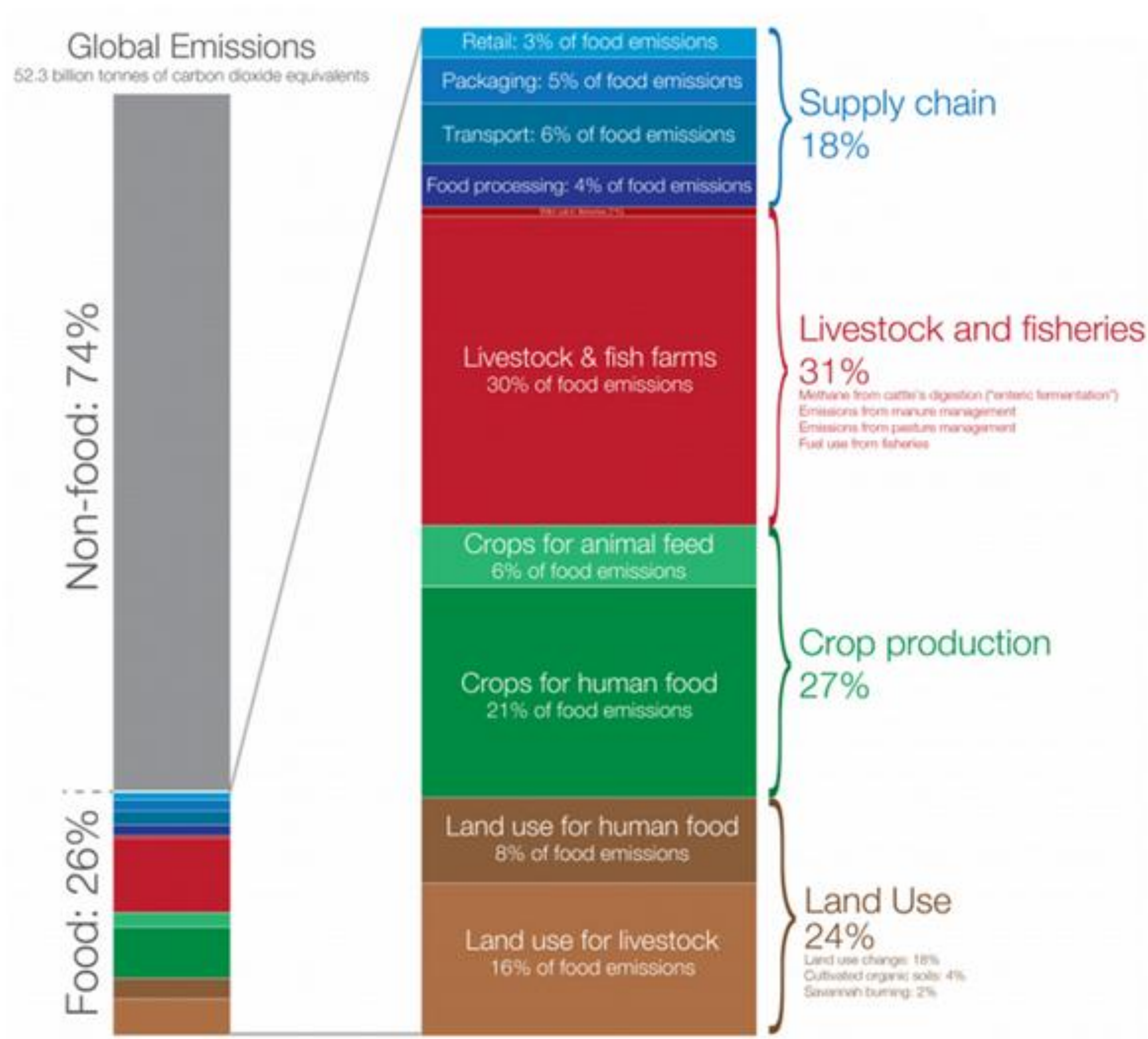

Figure 18: Global greenhouse gas emissions from agriculture (taken from Our World in data, 2022).

Livestock management accounts for 31% of greenhouse gas emissions from food. Livestock animals reared for meat, milk and dairy, poultry and eggs all add to the greenhouse gas emissions in many ways. For example, the process of enteric fermentation from cattle produces methane.

This is a natural process that happens in ruminant animal's digestive tracks. Microbes present in the digestive tract of these animals decompose, producing methane as a by-product (Mazzetto et al., 2019). Manure and pasture management, as well as fuel consumption also fall within this category. The 31% of emissions only relates to production processes that take place 'on farm', and does not include the emissions from land use and supply chains (Mazzetto et al., 2019).

The use of land for livestock accounts for roughly 24% of overall greenhouse gas emissions. This can be further split into land used for human food consumption, and livestock. Figure 18 shows that the land used for livestock resulted in twice as many greenhouse gas emissions (16%) as land used for human consumption (8%). This large use of land is a result of agricultural expansion, which has resulted in the conversion of land such as grasslands and forests, into pastures and cropland (We et al., 2022).

Roughly 27% of food emissions are a result of the production of crops for human consumption and animal feed production. Out of this 27%, 21% of emissions are related to crops being produced for humans, and 6% of emissions are related to the production of feed for animals. These emissions are a direct result of processes and practices used in farming. These practices include fertiliser and manure application, which results in the emission of nitrous oxide. By adjusting the fertiliser quantities added to soil, nitrous oxide emissions can be reduced (Muhammad et al., 2019). Over applying nitrogen fertilisers can lead to higher emissions of nitrous oxide, without enhancing the production of crops. In regions that grow rice crops, it was found that the draining of wetland rice soils during the growing season can reduce methane emissions. In regions that grow rice crops, it was found that the draining of wetland rice soils during the growing season can reduce methane emissions. Carbon dioxide is also emitted from farm machinery (Hdom, 2019).

The remaining 18% of emissions from food are as a result of supply chain processes. This includes food processing (4%), where the food is converted from the farm to the final product, as well as packaging (5%), transport (6%) and retail (3%). Transport emissions are often thought of as a large culprit in emissions in relation to food production, yet they account for only 6% of total emissions globally. Table 9 illustrates how greenhouse gases can be reduced across the agricultural industry (Benyam, Soma and Fraser, 2021).

Although supply chain emissions are high, it is an essential for reducing emissions globally. One way to do this is by reducing food waste. Studies show that food waste emissions are very high. Roughly 3.3 billion tonne of carbon dioxide equivalents from the production of food ends up as waste, from losses during processing, transport and storage or by consumer food waste. Durable, environmentally friendly packaging, food processing and the use of refrigeration can also reduce wasted food globally. An example of this is tinned fruit and vegetables. It was found that tinned fruit and vegetables were wasted 14% less than their fresh counterparts (Kör, Krawczyk and Wakkee, 2021).

Table 9: How greenhouse gases can be reduced in the agricultural industry by the management of land, livestock and manure (adapted from Benyam et al., 2021; Hdom, 2019; We et al., 2022).

Areas to Improve	**Reducing GHG Emissions**	**Examples**
Managing Land	Adjust techniques used to manage land and grow crops	· Use the appropriate amount of fertiliser needed for optimal crop production · Drain water from wetland rice soils
Managing Livestock	Adjust livestock feeding practices to reduce methane emissions from enteric fermentation.	· Improving the quality of pasture to increase animal productivity
Managing Manure	Manage the decay of manure to reduce nitrous oxide and methane emissions Capture methane emissions the decaying manure to produce renewable energy.	· Handling manure as a solid or using it on land rather than storing can help to reduce methane emissions · Store manure in anaerobic conditions to maximize methane production and then capturing the methane to use as renewable energy

3.5 Global Food Waste

It is estimated that today, roughly one third of the total food produced globally is wasted. This is equal to nearly 1.3 billion tonnes of fruit, vegetables, dairy, meat, grains and seafood that are wasted. This could be because the food never leaves the farm, are spoiled or lost during distribution and transport, and are thrown away by retailers, restaurants, food outlets and consumers in the home. This food being waste could be enough to food all the malnourished humans in the world (Coudard et al., 2021).

Figure 19 highlights that fruit and vegetables are the foods that are wasted the most at almost 40%. This is followed by milk and dairy products at 17%, meat products 13.5% and grains at 12%. These food groups are all foods that spoil quite quickly, often within a week. Other food groups such as sweets, condiments, salty snacks and nuts and seeds had a lower percentage of food waste. This could be because they are more appealing to many consumers than fruit and vegetables, or because they have a longer shelf life potential. It was found that, on average, American consumers threw away roughly 450 grams of food daily. This is equal to 30% of their total daily calories (Lu et al., 2022).

According to the USDA, roughly 30 million acres of land would be necessary in order to grow and rear the crops and livestock animals to produce food that the United States wastes each year. Additionally, almost 4.2 trillion gallons of irrigation water is wasted. This includes the 3.35 trillion gallons of water that is needed to grow and produce the fruit and vegetables that are wasted alone. Fruit and vegetables waste is also mainly responsible for majority of pesticides put to waste. Majority of the fertiliser wasted, cropland and pastureland is used to produce feed for livestock. Roughly one third of the total land used for agriculture is used to grow the wasted food. Millions of gallons of oil are also wasted annual to produce this food (USDA, 2022)

Food waste also commonly ends up in landfills and the more food that is wasted, the more methane is produced. As mentioned in section 3.4.3, methane is highly potent and largely contributes towards global warming and climate change. It was found that roughly 6-8% of greenhouse gas emissions caused by humans could be lowered if wasted food ceased. In the USA alone, the production of food waste produces the same amount of greenhouse gas emissions than that of 32.6 million cars (Pagani, De Menna, Johnson and Vittuari, 2020).

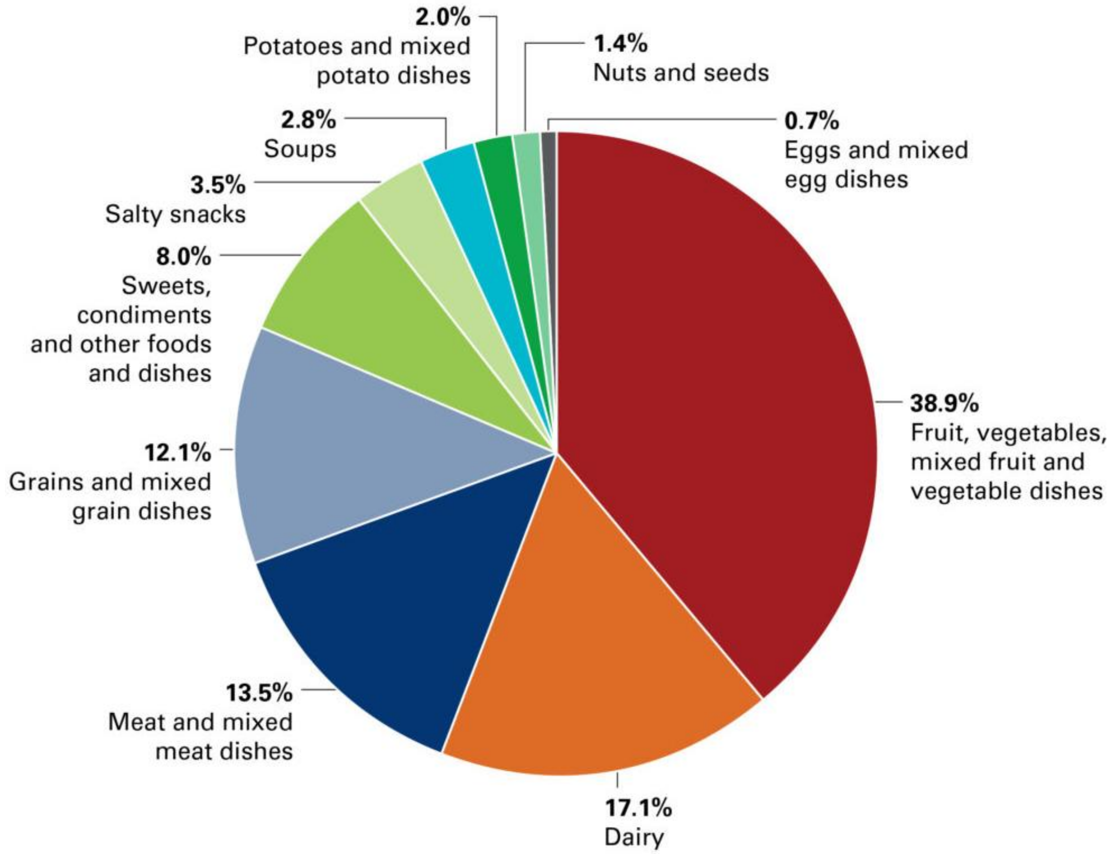

Figure 19: Food waste by U.S consumers by food type (taken from Schanes et al., 2018).

3.6 Advanced Farming Methods

Smart farming systems and technology improve the accuracy and efficiency of smart devices that monitor plant and animal growth. Technologies such as wireless sensor networks (WSNs) gather data from various sensors. Cloud services can be used in conjunction with IoT to analysed and process any remote data gathered, to allow the best decisions to be made based on the data gathered. It was found that smart farming is dependent upon the use of ICT equipment, ground sensors, robots and autonomous vehicles. High speed internet, satellites for images and positioning, and mobile devices are also essential for the success of smart farming. Figure 20 illustrates how sensors can be used in advanced farming, through, soil health monitoring and crop yields monitoring (Durai and Shamili, 2022).

Sensors can be used to measure and monitor many factors in a smart farming system. They have the ability to measure and monitor the soil changes and the yield, as well as local weather changes on the farm. The data gathered by the sensors can then be used and analysed by the farmers, allowing them to make more informed farm decisions (Bronson, 2018). Studies show that the most standard sensors used in advanced farm systems are soil moisture sensors that are used to measure and monitor changes in the moisture of the soil, as well as soil temperature sensors, air temperature sensors, humidity sensors, sensors that can measure the soil pH value, and sensors that can determine the amount of fertiliser soil needs. This can be monitored by measuring the nutrient content of the soil, including the nitrate, phosphate and potassium content. In relation to livestock husbandry, it was found that the most common sensors used were to monitor the location of the animals, monitoring the overall health of the livestock, identifying diseases and stresses as well as overall activity recognition (Bronson, 2018).

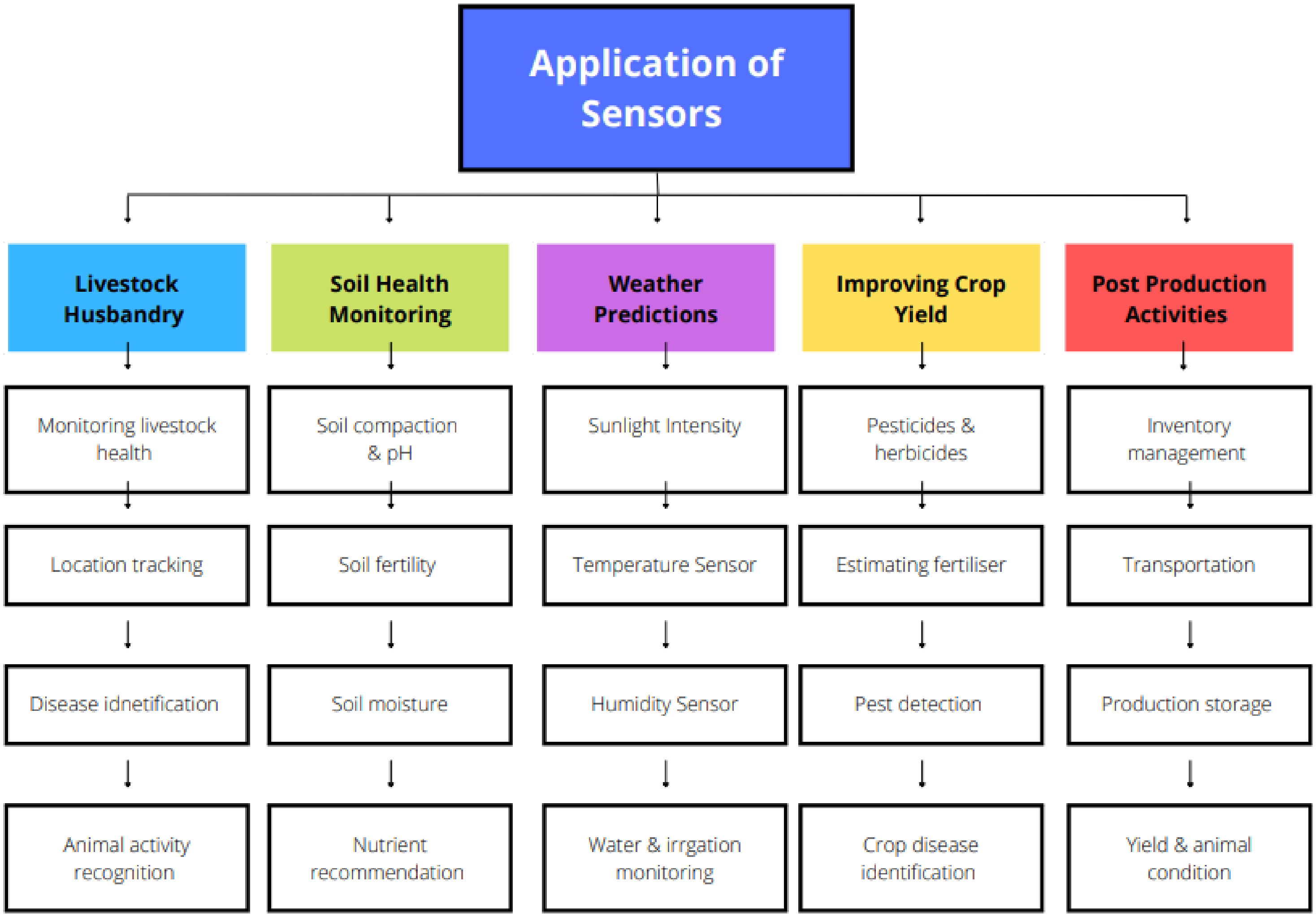

Figure 20: The application of smart sensors in agriculture (adapted from Kashyap et al., 2021).

However, studies also showed that the use of smart sensors for health monitoring and productivity monitoring of land and livestock requires a large amount of data that must also be processed and analysed in order to provide meaningful information for the management of the land and animals. This has lead to advances in analysis of 'big data', which involves the analysis of large and complex set of data (Bronson, 2018). Studies show that smart farming, precision farming and digital farming are reliant on the correct use of big data analytics to inform farmers about areas such as, trends in productivity, soil moisture, nutritional needs of livestock and animal health issues. These big data models can export data from smart sensors, process and analyse it. This data has the ability to detect anomalies and abnormal activity in the data that are possibly affecting the land or animal. Table 10 illustrates a list of countries that currently use smart farming technology (Durai and Shamili, 2022).

Table 10: List of countries that have adapted advanced farming technology into farming methods, the technology used and the companies that produces the technology (adapted from (Fugini, Finocchi and Locatelli, 2021).

Country	**Company**	**Use of Technology**
Italy	Cargill	· Track milk productivity, animal health and feed formulation
Israel	Cattle Watch	· Location tracking · Herd counting
United States	Vence	· Controlling or restricting animal movements · Monitor animal health · Creating virtual fence lines during grazing
Netherlands	Connecterra	· Predicting the dairy animals behaviour · Use sensors and cloud-based machine learning
Ireland	Cainthus	· Monitor animal behaviour
India	Chitale Dairy	· Track eating patterns of dairy cows · Track the overall health of the cow
Belgium	Porphyrio	· Predictive egg flow of poultry · Predictive feedstock management · Manages the flock · Optimized slaughter planning
Australia	Smart Shepherd	· Identify the relationship between animals · Aid livestock breeding
Russia	Alan-IT	· Livestock decision making
China	Yingzi Technology	· Traceability of all processes from throughout the supply chain
United States	Bov Control	· Data collection and analysis · Used to improve milk and meat production · Improves genetics of offspring

3.6.1 The Growth of Advanced Farming

Smart/digital/precision farming is particularly useful for farmers who have large areas of hectares of land, who often find it difficult to monitor every aspect of their farm, which can often result in crop and animal production suffering. Digital farming can help to solve these issues with the help of smart devices and sensors (Fugini et al., 2021).

Reports show that the digital farming market worldwide reached $4,770.8 million in the year 2020 and is estimated to reach $10,702.3 million by 2027. Figure 21 illustrates this growth in the market. Factors driving this rapid market increase include the increased demand for food due to the rapid increase in population. The increased use of technology in all sectors also has an impact on this increase in the market. Additionally, the substantial money saved through the use of the modern and advanced farming methods also contribute to the increased market size (Bökle et al., 2022). It also helps farmers to optimize many agricultural processes and increase the overall crop yield. Digital farming helps to revolutionize the agricultural industry and increase the production of crops and livestock while investing a lot less (Bökle et al., 2022).

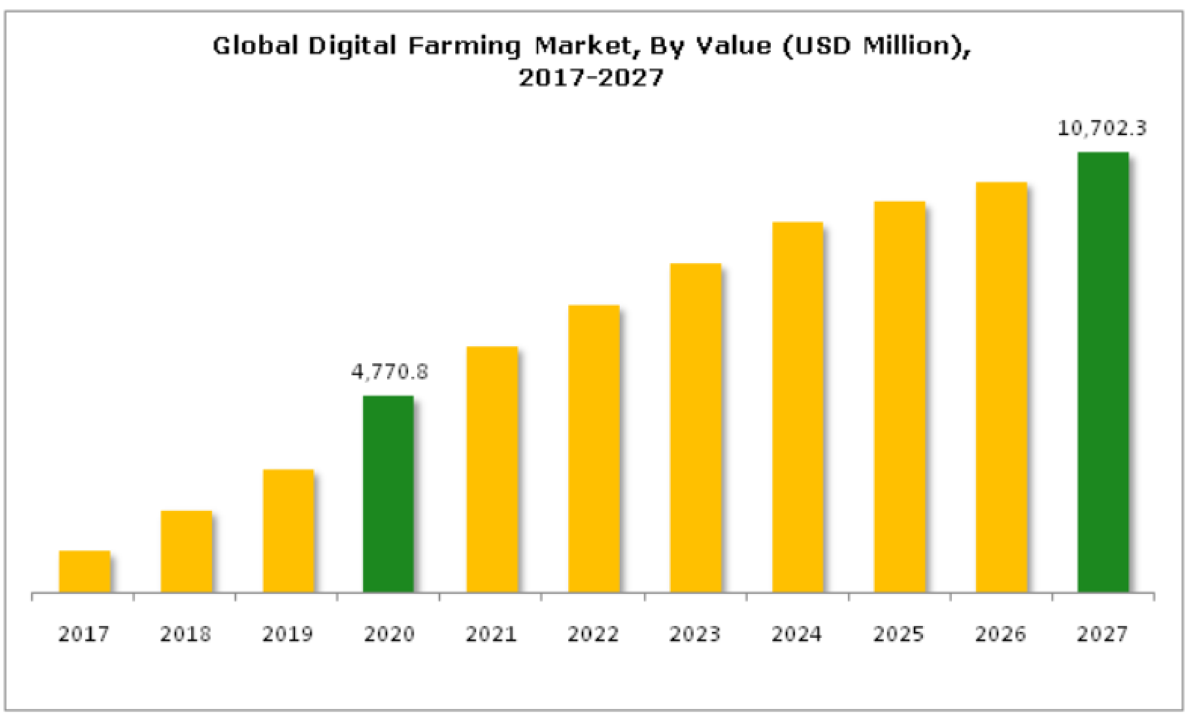

Figure 21: The global digital farming market by value (USD million) from 2017-2027 (taken from Bökle et al., 2022).

3.7 Genetic Modification

Genetically modified organisms (GMO's) are produced by manipulation of certain genes to create new living organisms, resulting in genetically modified crops, animals and microbes, all of which are referred to as GMO's (Oosthuizen and Howes, 2021).

Studies show that over the last 20 years, the commercialisation of GMO crops has conveyed a significant, environmental, agronomic and monetary and health advantages to farmers. Agricultural crops are now one of the most common genetically modified organisms. The regular appropriation of genetically modified crops also reflects the advantages for both large and small scale farming in developed and developing countries (Georges and Ray, 2019). It was found that in 2019, the largest area of genetically modified crops globally was the United States, at 72.9 million hectares. Brazil followed closely with 52.8 million hectares. Argentina had the third largest area of genetically modified land at 24 million hectares. Figure 22 illustrates the global status of genetically modified crops. Poorer, developing countries including India, Paraguay, South Africa and Pakistan are included in the top ten countries that produced the most GMO crops per hectare in 2019 (Oosthuizen and Howes, 2021).

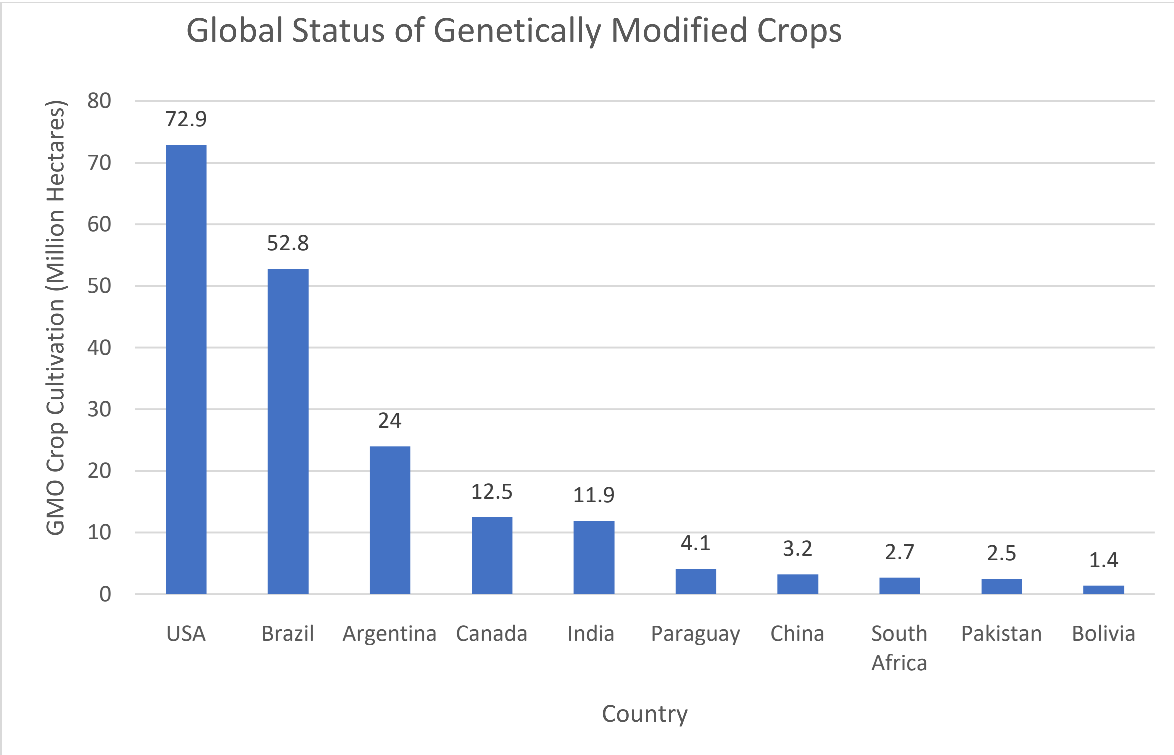

Figure 22: The global status of genetically modified crops (adapted from **(**Georges and Ray, 2019).

3.7.1 Genetic Modification in Plants and Animals

The most common genetically modified crops in 2019 were found to be soybeans, corn, rice, canola and plum. In the same year, 48% of the total soybean plants grown were genetically modified. It was found that soybean crops were genetically modified to be resistant to the herbicide glyphosphate (Andrews, 2021). Corn has been genetically modified to be insect resistant and canola has been genetically modified to have an improved fatty acid composition. From the research, it was found that plums were also successfully modified to be resistant to the plum pox virus. Studies also shown that rice was can also be genetically modified to have higher vitamin A content. It was found that one farmer's profits improved by 68% because of genetically modified crops. Additionally, cost of pesticides was reduced by 39% which highlights how important genetically modified crops can be, particularly for farmers and countries that struggle with agricultural productivity (Andrews, 2021). Table 11 shows a summary of genetically modified plants and their genetic change.

Table 11: The genetic trait and change of approved genetically modified crops (adapted from Giakountis, 2018; Ebringer, 2018; Meidinger et al., 2019).

Genetic Trait	**Plant**	**Genetic Change**
Herbicide tolerance	Soybean	Glyphosate herbicide tolerance conferred by expression the plant enzyme EPSPS isolated from the soil bacterium *Agrobacterium tumefaciens*, strain CP4
Insect resistance	Corn	Expression of the insecticidal protein Cry1Ab from *Bacillus thuringiensis*
Altered fatty acid composition	Canola	Insertion of the gene of thioesterase from the California bay tree *Umbellularia californica* resulting in high laurate levels
Virus resistance	Plum	Insertion of a coat protein (CP) gene from the virus, resulting in resistance to the plum pox virus
Vitamin enrichment	Rice	Insertion of genes maize and bacterium *Erwina Uredovora*, to allow the plant to bio biosynthesise beta-carotene in the edible parts of rice.

Table 12 illustrates genetically modified animals and the genetic change associated with each. For example, salmon have been genetically modified to have a faster maturation. Studies also show that disease resistance in animals can also be improved. Cows are an example of this, as they have been developed to be resistant to bovine spongiform encephalopathy (BSE) also known as ‘mad cow disease’ (Ebringer, 2018).

In the production of poultry, the avian influenza is a continuous threat to poultry globally. Genetically modified chickens were developed as a result, expressing short-hairpin RNA, which acts as a decoy that blocks the virus (Giakountis, 2018).

Enviropig™ was also genetically modified to produce phytase to break down phosphorus, resulting in a reduction of the phosphorus level in pigs manure. This reduction helps to reduce levels of pollution caused. Additionally, studies also show that pigs can also been genetically modified to have more omega-3 present. Goats have also been altered genetically, so that their milk expresses the human enzyme lysozyme (Meidinger et al., 2019).

3.7.2 Risks Surrounding Genetic Modification

Various studies were completed to explore the possible risks of toxicity and allergenicity associated with genetically modified crops. These studies were conducted on animals including cows, sheep and rats where they consumed genetically modified crops over a 90 day period. It was found that there was minor to no adverse or negative effects across the 90 day period (Tsatsakis et al., 2017).

Furthermore, studies were also conducted to explore the possible allergenicity of genetically modified crops. These studies were also conducted on animals, including pigs and cows. This is because they have hypersensitivity responses similar to that of humans. The studies showed that the genetically modified crops had no allergenic effect on the pigs or cows (Pray et al., 2018).

Table 12: The genetic trait and change of approved genetically modified crops (adapted from (Tsatsakis et al., 2017; Pray et al., 2018).

Genetic Trait	**Animal**	**Genetic Change**
Faster maturation	AquAdvantage Salmon	A type 1 growth hormone gene injected into fertilized fish eggs
Resistant to *bovine* spongiform encephalopathy (BSE)	Cow	Lack the prions protein
Avian influenza resilience	Chicken	Express shRNA decoy
Reduction in phosphorus and Nitrogen released	Pig	Produce enzyme Phytase
Higher omega 3 and omega 6 fatty acid ratio	Pig	Express the fatty acid desaturase gene
Mastitis Resilience	Goat	Express human enzyme Lysozyme

Chapter 4: Discussion

4.1 Chapter Introduction

This chapter will analyse the results presented in chapter 3 and provide some explanations for some of the figures and results that were obtained.

4.2 Global Land Use for Agriculture

The increase in land use for agricultural purposes and the expansion of the agricultural industry overall has had a massive impact on the environment. The expansion of agriculture has transformed habits globally and is one of the heaviest pressures for biodiversity worldwide (Lyu et al., 2022).

In the last century alone, the use of land for agriculture has dramatically changed to support the increasing demand for food and other commodities. Concerns arise over the ability of the agri-food system to globally meet the future and even current food demands, while also maintaining biodiversity and conservation needs. Since the 1960's, the large-scale global demand of commercial crops that are grown in intensive management systems have rapidly increased. This has resultantly contributed to a narrowing crop species worldwide and reduced biodiversity in general (Yang et al., 2021).

In many regions around the world, this increased demand for food has also resulted in highly simplified landscapes. Simplified landscapes are very productive, but also have very low biodiversity because of the large-scale monoculture farming systems put in place, which result in a limited natural habitat. A lack of natural habitats can also lead reduced ecosystem benefits, such as natural pest control, pollination and water filtration. As a result, this leads to a great use of pesticides, impairments in water quality and higher demand in honey bee hives for pollination of farms. These honey bee farms are already in limited supply. Transitions towards alternative farming systems can often occur on a smaller scale, instead of on a symmetric level (Song et al., 2021).

Farmers are usually the main decision makers for the use of land for agricultural landscapes. Majority of the time farmers land farming use practices are based on the direct economic returns that they receive from farming practices, rather than the environmental concerns and impact of the farming methods used. To increase the likelihood of farmers adopting conservation practices, incentives and economic benefits for farmers and land owners should be implemented (Lyu et al., 2022).

Previous research has shown the improved biodiversity can help to contribute economically to farming systems, through improved pollination and natural pest control. However, there is limited research available on the impact of thee restoration projects in relation to crop production, yield and overall profits from farming. The economic benefits often largely differ between various ecosystems, hype of habitat, type of farm and crops used, making it difficult to gather quantifiable results (Yang et al., 2021).

Nevertheless, quantifying the use of global land used by agriculture is essential in tackling the global problems of global warming, biodiversity loss and food security. Nearly 75% of the World's land has been changed by humans in the last millennium. In order to successfully tackle the global sustainability challenges, changes in the use of land around the world need to happen. For example, the mitigation potential of land use activities such as deforestation and agricultural activities as a whole, are recognised as essential components that need addressed in order to meet climate targets under the Paris Agreement, as mentioned in Chapter One. Land use is therefore a central component in many policy debates internationally (Kastner et al., 2021).

4.3 Largest Agricultural Producers Globally

Food is an essential for every human on earth, along with clean water, adequate access to food is a primary concern for the majority of humanity. Because of this, the agricultural industry is one of the largest and most significant industries globally. In saying this, there are many countries that excel in farming and agriculture. Majority of agricultural commodities require a large amount of land to be produced, and land is not something that not all countries worldwide have in abundance. From the studies gathered, four of the world's largest agricultural producing countries also rank highest in the world for total geographical land area; this includes China, the United States, India and Brazil (Matej et al., 2021). As mentioned in section 3.2, China was found to be the largest agricultural producer overall, producing the most meat, cereals, fruit and vegetables globally. Much of the land is China is mountainous and arid for farming, but southern and eastern parts of China are very productive due to their rich soils. China also has one of the largest workforce's worldwide (Balima et al., 2020).

Other top agricultural producing countries include the United States, India, Russia and Brazil. It is not surprising that these countries feature prominently on the list of top agricultural producers. These countries have large populations and strong internal food security. A large amount of the food produced in China and India are used internally within these countries. The United States consumes a lot of the food that it produced, but it is also one of the largest exporters in the world. It also has a highly efficient food production system. Although the workforce in the United States is significantly smaller than China, the agricultural production of the United States is almost as high (Bhan et al., 2021).

Although India is one of the largest food producers worldwide, its agricultural productivity is significantly lower than the United States, China and Brazil. The population in India is growing rapidly and faster than the economy. The population of India is projected to eclipse China in the near future (Feng et al., 2021).

The production of food is also heavily dependent on the climate, vegetation and the economy of a given country. Additionally, in countries like China, the United States and much of Europe, very little land is wasted and infrastructure and roads are well developed, making it much easier to get crops and food to markets. Irrigation and fertilisers are widely used to promote farming and increase the yields of crops. Genetically modified crops and animals are also beginning to be used in recent years in developed countries, especially the United States (Johnson and Mueller, 2021).

However, the picture is very different in countries in Africa and Asia. In these regions, infrastructure is very underdeveloped, making it difficult to even get crops to market. Irrigation and fertiliser is also lacking, leaving farmers with limited resources to help with the growth of crops. Governments in developing countries must focus on improving infrastructure, building roads, improving water access and increasing the use of fertiliser and genetically modified crops in order to help overall with agricultural production (Kucukvar et al., 2020).

4.4 The Impact of Agriculture on the Economy

According to Kucukvar (2020), Agriculture is crucial for economic growth. One of the main goals for most countries, particularly developing countries is to reach a higher income status, achieve food security and improve the nutritional status of people within that country. Therefore, to mitigate world hunger, malnutrition and accelerate economic growth, agriculture is necessary and must be improved.

Most countries started off with little money, and today many have achieved a high-income status. The countries that have achieved this high income status began with agriculture and had an economic transformation to help to accelerate growth and reduce hunger and malnutrition in that country. This economic transformation was also a result in technology developments (Kucukvar et al., 2020). For developing countries to improve their economy, the agricultural industry must become modernised. For example, developed countries such as America and Japan with high GDP's per capita have use mostly intensive farming practices, heavy farm machinery, reducing the need manual labour. Developing countries however, often do not have surplus capital to purchase heavy farm machinery and other technology that improved farm productivity and efficiency (Barbosa et al., 2022). In the long run, modernisation helps raise incomes, productivity, lower food prices and improve nutrition overall. Additional improve the nutrition of the population creates a cycle that will help propel further economic transformations. An increase in agricultural productivity also helps to increase farmers profits, which could be further invested in the modernisation of agriculture (Weerabahu et al., 2021).

The results also show that more developed countries have a lower shared of agriculture to GDP. This could also be the increased productivity of agriculture, the excess labour moves from rural farm jobs, towards more urban manufacturing jobs (Weerabahu et al., 2021).

In order to improve the agricultural economy, it is essential to make modern technologies accessible and available. Many modern agricultural technologies come from both private and public sectors, governs must play a role in investing in the research and development of agriculture. This will also help to ensure that private sector companies do not capture the full benefits of developing these technologies, as this would make it more difficult for developing countries to access and afford the technologies (Aquilani et al., 2022). The technology systems must also work at provincial levels and be suitable for local and small scale farmers. Additionally, the adoption of these new technologies will also be challenging for many farmers. For example, any technologies require high storage conditions for water, final product and other inputs. Therefore, governments also need to consider improved infrastructure for farmers so that they can access these inputs and sell their agricultural product. National governments will also need to ensure capital is available to ensure that skilled labourers are available to use and master the new technology and handle logistics (Aquilani et al., 2022).

Agriculture is essential for the development of economies. Ending world hunger, malnutrition, reducing food waste and ensuring environmental stability are all important goals. These goals rely on agriculture modernization and economic development. While only a few countries have achieved a high-income economic status, there is potential for countries worldwide to achieve this and it begins with modernizing the agricultural industry (Barbosa et al., 2022).

4.5 The Impact of Farming Methods on the Environment

Findings in relation to farming methods and their impact on the environment form a significant part of this research. It is evident that all methods of farming do have a significant impact on the environment. The impact is largely dependent on the farming method used, the land and water used as well as the inputs used, such as fertiliser, pesticides and irrigation (Aquilani et al., 2022).

In saying that, when agricultural practices are managed sustainably, habitats can be preserved and restored, soil and water health and quality can be maintained. It is clear from the results that the management of resources is increasingly urgent. The demand for agricultural produce is rising rapidly with the rising population. Agriculture has connections to the global economy, biodiversities and human societies, making it an extremely important frontier for conservation globally (Tullo, Finzi and Guarino, 2019).

Arable, pastoral, mixed, intensive and commercial farming were all found to have a high impact on the environment, where as subsistence and extensive farming methods were found to have a low/medium impact on the environment. This is due to the use of land, greenhouse gas emissions and water used were all found to be high (Aquilani et al., 2022).

4.5.1 Fertiliser Usage in Agriculture

Fertiliser is any material or substance that is added to soil and crops to promote plant growth. Many variations of fertiliser exist, most of which contain nitrogen (N), phosphorus (P) and potassium (K). Many fertilisers sold have an N-P-K ratio present on their packaging. These nutrients help crops to grow bigger, at a faster rate, producing more food as a result. Nitrogen in particular is an important nutrient that is needed for growth of everything on Earth. It makes up around 78% of the atmospheric air. However, plants are unable to use this nitrogen in the air to promote their growth. In order to grow, plants need nitrogen compounds from the soil, which are naturally produced by the soil or by the application of fertilisers to the soil (Gerssen-Gondelach et al., 2021).

Fertilisers can be both organic (natural) and inorganic (synthetic or). Both types of fertiliser deliver nutrients to the soil in different ways. For example organic fertilisers are natural and the nutrients they contain are made up of plant or animal materials. Examples of natural fertilisers include manure, wood ash, decaying leaves, ground bones, seaweed, guano or compost (Xiang et al., 2020).

Inorganic fertiliser is synthetic and is made up of synthetic chemicals and minerals. Petroleum is used to make many nitrogen based fertilisers. Many inorganic fertilisers are high in all three nutrients, nitrogen, phosphorus and potassium, this is known as ‘complete fertiliser’. Other examples of inorganic fertilisers include nitrogenous fertilisers, phosphate fertilisers, and potassium fertilisers. Complete fertiliser consists of all three nutrients, nitrogen, phosphate, potassium (NPK) (Xiang et al., 2020).

Although organic fertilisers have been historically used to improve crop yields, inorganic fertilisers are a relatively new development. Despite this, inorganic fertilisers are the most widely used type of fertiliser today.

There are both pro’s and con’s to using both types of fertiliser. Inorganic fertiliser is fast acting and easily absorbed by the plants in comparison to organic fertiliser. As a result, plants grow rapidly. The exact dose of fertiliser can be applied as the ratio of nutrients is usually printed on the bag and packaging. Inorganic fertiliser is also easy to store and apply to the soil (Kamran et al., 2021)

However, even though inorganic fertilizer is an excellent source of macronutrients, they offer very little micronutrients in comparison to organic fertiliser. Additionally they are an excellent nutrient source of nutrients for the plants, but they provide very little benefit to the soil, which limits their effectiveness in the long term. For example, they do not add organic material to the soil that is lost during farming and harvest. There is also a high risk of over application which may be toxic to neighbouring crops and also to aquatic life if the fertiliser leaches into waterways (Kamran et al., 2021). Fertilisers can be easily washed of land by rainwater into lakes and rivers, which causes the water to become in nitrate and phosphate. This process is known as eutrophication, which encourages the growth of algae. A green bloom is formed over the surface of the water, preventing sunlight reaching the plants in the water, which prevents photosynthesis taking place. As a result, the water plants die. Bacteria then decompose the dead water plants, using up the oxygen present in the water, making it different for aquatic life to respire and live (Wang et al., 2021).

Over application can also lead to a build-up of toxic salt in the soil, upset the pH of the soil and increase the likelihood of pest occurring. The synthetic chemicals in inorganic fertiliser affect the acidity of the soil. This altered level of acidity in the soil eliminates the microorganisms that help to increase the natural defence of the plants against pests and disease. Chemicals in inorganic fertiliser also affect the bacteria that aid the nitrogen balance of the soil, where atmospheric oxygen is converted into a form of nitrogen that plants use to grow and thrive (Wang et al., 2021). Because inorganic fertiliser is fast acting, it usually requires frequent application, which can result in an unnatural balance of growth. Although nitrogen can improve the growth of plants and crops, it also improved the growth of weeds and non-native plants. Plants that do not require much nitrogen can end up dying, leading a reduction in the native plant species. According to the Ecological Society of America, many of these non-native plant species can increase the chance of wildfires, because of the high nitrogen content. Additionally, they also release potent greenhouse gases into the air which raise the temperature of the Earth, contributing to climate change and global warming (Du, Li and He, 2021).

In contrast to inorganic fertiliser, organic fertiliser releases nutrients to the soil slowly. This is because the soil needs to break the fertiliser down in order for them to work. However, this slow release helps to prevent over fertilization and also mean that it does not require frequent application (Daadi and Latacz-Lohmann, 2021).

Organic fertilisers also help to improve the soil texture which in turn helps the soil to retain water and nutrients. Unlike inorganic fertiliser, over time, organic fertilisers can help to improve the overall health of the soil. There is also little chance of a toxic build up and overdose of chemicals occurring. Organic fertilisers are also a cheaper alternative than inorganic fertilisers. However, because the concentrations of nutrients in organic fertiliser cannot be fully predicted, more organic fertiliser may be needed for the same level of nutrients that inorganic fertiliser can provide at a lower volume. Microorganisms are needed to break down the fertiliser and release the nutrients. Without these microorganisms in the soil, the fertiliser will not reach its full potential (Tang et al., 2022).

Organic fertilisers are much more environmentally friendly compared to inorganic fertilisers because they are created from the end products or by products of naturally occurring processes, so they come from nature itself. Although organic fertilisers take longer to work and the level of nutrients in them is unpredictable, they provide a health food source for plants and crops and help to improve soil health overall. They help to improve the crop yield over all, but do so at a slower rate than inorganic fertiliser (Daadi and Latacz-Lohmann, 2021).

Researchers and scientists are currently trying to find solutions and create alternative fertilisers that can be used that are more environmentally friendly, but will also still promote plant growth and increase the yield of crops (Tang et al., 2022).

4.5.2 Pesticide Usage in Agriculture

From the results found, it is clear that there are both positives and negatives regarding the use of pesticides in agriculture. Because of the growing human and increase in urbanization, the demand for pesticide usage will continue to grow. Farmers are under increasing pressure to increase yields on less amounts of land. Poorer, developing countries will struggle to sustain crops without the use of pesticides to control pests and pest-bourne diseases (Patinha et al., 2018).

Additionally, those living in developed countries will continue to expect and demand food that is high quality, inexpensive and free from pests and pest-bourne diseases. Pesticides can help to keep agricultural threats at bay, allowing plants and crops to grow and reach their full potential. Pesticides can help keep pests such as mice, rats, mosquitoes and ticks away from crops, while simultaneously protecting plants and crops from disease and weeds, all of which can reduce the yield of the crop. This has resulted in improved food production for farmers as their yield is not reduces, it also ensures that farmers receive better profits because crops are not being destroyed by pests and diseases. Previously, farmers manually removed pests and weeds from their crops; the use of pesticides removes the need for this manual labour. Pesticides can also prevent the spread of pest bourne diseases. For example, mosquitoes can spread malaria; rats can carry the bubonic plague, while fleas can spread typhus. By reducing these pests surrounding the crops, illness and deaths caused by these diseases can also be reduced (Geissen et al., 2021).

While there are benefits and advantages to using pesticides, various problems are also associated with their use. Similar to fertilisers, pesticides are mobile in the environment, which means they can move through the soil, air and water. Because of this, they can lead to surface water and ground water contamination and also contamination of the soil, which can lead to a disruption of the soil fertility (Brühl et al., 2022).

Pesticides can also cause harm when they come into contact with other organisms. Because of this, pesticides can disrupt the balance of ecosystems. In many situations where pesticides are used, the pests as well as non pest organisms are also often killed, including other animals and vegetation. This can dramatically affect the natural balance of many ecosystems as a result (Perrin et al., 2021).

In addition to harming wildlife, pesticides may also cause harm to humans. There is possible carcinogenicity and neurotoxicity, as well as metabolic & reproductive toxicity of pesticides building up in the body of humans, which can lead to illness and even death in some cases. There is also the potential of pesticide bioaccumulation within in the human body. Bioaccumulation occurs when there is a buildup of the substance in the body, where the body lacks the ability to remove it and break it down. Therefore, once pesticides enter the body, they are unable to be broken down and will be stored in the body tissue permanently. Pesticides have poisoned humans, lead to the development of cancer and the death of many over the years (Perrin et al., 2021).

4.5.3 Greenhouse Gases

As previously mentioned, carbon dioxide, nitrous oxide and methane are the most prevalent anthropogenic greenhouse gases. These are all found in the Earth's atmosphere naturally, but their rapid acceleration in concentration is because of the activities of humans. Although carbon dioxide is the most common greenhouse gas, it is not the most potent and dangerous. Methane and nitrous oxide have 23 and 296 times the global warming potential than that of carbon dioxide (Mazzetto et al., 2019).

Methane is primarily released from the digestive processes of ruminant livestock animals such as cattle, sheep and goats. It is also released in anaerobic conditions in where organic matter is decomposing, such as wetland areas and rice paddies. Nitrous oxide is released into the atmosphere during the nitrification process in the soil where ammonium is converted to nitrates in the soil. It is also released during the denitrification process. This is where anaerobic respiration occurs in the soil because of damp soil conditions and a high microbial activity when nitrate and carbon are in the soil. Manure storage also releases nitrous oxide (Murphy et al., 2020).

Within the agricultural industry, there are a large proportion of carbon dioxide emissions that comes from burning fossil fuels, using farm machinery and heat farm houses. Carbon dioxide is also emitted through soil management practices, such as the decay of organic waste produced from tillage practices and crop residue burning. The process of burning crop residue occurs where the residues of crops are burned after harvest in order to eliminate waste which releases carbon dioxide. This process happens all over the world. The results show that carbon dioxide is the most common gas emitted by many other industries. However, methane and nitrous oxide are the main gases emitted by the agricultural industry (Gerssen-Gondelach et al., 2021).

4.5.3.1 Greenhouse Gas Emissions from Agriculture

It is important to note that there are ways in which greenhouse gas emissions from agricultural practices can be reduced. As mentioned in the results, land and crop management are one of the main drivers of greenhouse gases in agriculture. By adapting the farming techniques used for land management and growing crops and rearing livestock, emissions can be reduced. For example, over application of fertiliser on land and crops can result in higher nitrous oxide emissions without even increasing crop production (Desjardins et al., 2018).

Nitrous oxide is a highly potent gas, therefore it is very important to reduce and avoid its emissions wherever possible. Another method where greenhouse gases can be reduced is by draining the water from wetland rice soils. Flooded rice paddies are a massive source of both methane and nitrous oxide emissions. Methane is generated from flooded rice paddies because of their largely anaerobic conditions. Methane is also a highly potent greenhouse gas. In regions where there are a few crops of rice annually, the reductions of methane and nitrous oxide could be largely reduced (Dimitrov and Wang, 2019).

Livestock management is another large driver in greenhouse gas emissions. Significant amounts of methane are produced in the digestive track of livestock animals through enteric fermentation. Methane emissions by livestock animals is mostly caused by amount of animals there are, the type and amount of feed consumed and also the type of digestive tract they have. The methane released is the result of lost energy in the digestive process. By adjusting the feeding practices of livestock, greenhouse gases can be reduced by a significant amount. Pastures with high quality forage, low fibre content and a high content of soluble carbohydrates can help to lower methane emission in livestock animals. Structural fibres, cellulose and hemi-cellulose carbohydrates ferment slower compared to non-structural carbohydrates, and therefore yield more methane per unit of feed digested by the animal (Muhammad et al., 2019).

By improving the pasture quality, and therefore the animal productivity, methane emissions could potentially be reduced. Improving the productivity of livestock can also be achieved through improved breeding practices. For example, breeding livestock animals for improved conversion of feed efficiency is achievable and can result in a reduction in methane emissions (We et al., 2022).

According to Hdom (2019), by reducing the amount of unproductive livestock on a farm, the greenhouse gas emissions can also be reduced. For example, the Australian livestock emissions are much lower today than they were in the 1990's. This decline is a result of reduction of sheep numbers. Additionally, if livestock productivity is increased through breeding techniques, livestock animal numbers could be easily reduced, without reducing the quantity and quality of meat that is being produced currently. For example, in the dairy industry, an extent during of lactation, where cows calve every 18 months instead of every 12 months, reduces their energy demand of the herd by 10%. This will in turn help to reduce the methane emissions of that herd. It also helps to improve the profitability for the farmer (Wilkinson, 2022).

By managing manure storage and decomposition on farms, nitrous oxide and methane emissions can be reduced. For example, handling and storing manure in a solid form, or spreading it on farm land instead of storing it can help to reduce methane emissions. However, this method may increase the emissions of nitrous oxide, which is almost 300 times more potent in comparison to carbon dioxide. Manure is commonly stored as a liquid in large areas such as lagoons. However, by storing liquid manure in these anaerobic lagoons in order to maximize methane production, this methane can then be captured and used as a replacement for burning fossil fuels (Mazzetto et al., 2019).

Urease inhibitors can also be added to manure stockpiles in order to reduce the emissions of nitrous oxide. Urease inhibitors are chemical additives that reduce and stop the rate in which urea present in animal manure and urine is converted to nitrous oxide (Wilkinson, 2022).

4.5.4 Global Food Waste

It is estimated by the United Nations that 1 in 9 people in the world have no access to enough food to enable them to lead a healthy life. From the results, it was found that more people die from hunger daily than AIDS, tuberculosis and malaria combined. Yet, almost 33% of food that is produced globally is wasted (FAO, 2022). Food wastage includes both food waste and food loss and generates huge environmental damage and economical loses all around the world.

Foss loss generally tends to happen during the production stage of food processing, because of poor skills, poor practices, lack of adequate facilities and natural calamities. Food wastage happens when food edible food is put to waste and discarded in an intentional manner. Consumers often fail to plan ahead and store food until it is spoiled and can no longer be consumed. Food waste can also occur when food retailers are oversupplied. Additionally, retailers often reject food if it does not comply with their aesthetic and quality standards (Coudard et al., 2021).

Fruit and vegetables were found to be the food that was wasted the most globally. One of the reasons for this may be because fruit and vegetables have a shorter shelf life in comparison to foods such as nuts, sweets, condiments etc. They also tend to bruise and spoil easier during transportation. They are also susceptibly to pests and mould. Dairy products were found to be the second most wasted food group. Dairy products such as milk and yoghurts are often damaged and wasted during distribution and transport. Retailers also often have excess quantities on display units, which increase the likelihood of the use by dates being met before the dairy products are sold (Lu et al., 2022).

4.5.4.1 Impact of Food Waste on the Environment

A report conducted by the FAO found that over 50% of food waste occurred at the 'upstream' phase, which includes the production and storage phases. Food waste also happens during the 'downstream' phases, which includes the processing, distribution and consumer consumption stages. The results showed that there is an evident pattern in food waste globally. For example, higher and middle income countries had higher levels of food loss and wastage during the downstream and consumption stages due to carelessness and over buying. However, developing countries were found to have more food waste and loss during the upstream stages because of lack of adequate facilities, harvest practices and infrastructure (FAO, 2022).

The later along the food chain that food waste happens, the greater the impact on the environment. When the energy used, the natural resources that were expended during all stages of food processing and consumption are taken into consideration, the impact on the environment becomes quite large (Pagani, De Menna, Johnson and Vittuari, 2020).

The agricultural industry accounts for roughly 70% of the total water used globally. For context, the volume of water needed to produce the food that is not eaten alone is roughly three times the size of Lake Geneva. If one kilogram of beef is thrown out or wasted, this wastes roughly 50,000 of water that was used to produce it. Similarly, if one glass of milk was poured away, this would waste nearly 1000 litres of water. On top of water wasted, the land used to produce wasted food accounts for nearly 1.4 billion hectares of land, roughly one third of the total land area used in agriculture. Millions of gallons of oil are also wasted annually to produce food that never gets eaten (Skaf, Franzese et al., 2021).

4.5.5 Advanced Farming Methods

The world today is in the middle of a modern agricultural revolution, which has been sparked by the advancements of advanced farming technology, including smart sensors, GPS systems, the Internet of Things (IoT) and a wide range of IT systems. IoT is a smart technology that allows for practical solutions in various areas of farming. IoT allows for all agricultural devices and equipment used in farming to be linked, providing information and data to allow farmers to make informed decisions (Durai and Shamili, 2022).

Traditional farming methods relied on monitoring and managing entire fields based on time proven manual techniques that had been used for a period of time. The use of advanced technology can enable farmers to understand the health of their farms in relation to both land and animals. For example, with the help of smart sensors, camera equipped drone and other technology; farmers are able to receive instantaneous data on crops and animals recognition (Bronson, 2018). Findings show that smart sensors can be applied to a range of areas including livestock husbandry, soil health monitoring, improving crop yield, weather predictions and post production activities.

4.5.5.1 The Growth of Advanced Farming

The use of smart farming has been growing for over a decade and many factors have influenced its growth and development. The scarcity of arable land is increasing rapidly, as well as the global demand for food. Because of this, farmers are increasing their use of fertiliser, which raises production costs and also saturates the soil, harming the soil and production of the following crop (Fugini et al., 2021).

This means that the need for productive, efficient and sustainable land and farm management is becoming even more pressing. The intensification of climate change has had a major impact of farming trends, as there is an intense need to alter farming methods to make them more sustainable and less environmentally damaging (Durai and Shamili, 2022).

Initially smart farming was primarily used as a mechanism to adjust the rates of fertiliser applied in high, medium and low producing zones of a field. Other advancements such as the use of cameras was also introduced in livestock farming so that farmers could be notified when their animals were in labour, distress or to monitor their movements. As technology has improved, there has been an increase use of smart farming, as well as stronger results and outcomes associated with combining various techniques and practices together (Fugini et al., 2021).

Farmers are increasingly exploiting smart farming to increase the yields of crops, reduce waste and mitigate the environmental, economical and security risks that accompany agricultural uncertainty. To address these risks, smart farming is seen as a useful tool that can make the agricultural industry more technical and data driven, which will result in cost –effective, efficient and productive farming systems, that will also reduce the environmental impacts of the agricultural industry overall. Farmers all over the world are beginning to incorporate smart farming technology into their farming practices, and with food demand continuing to increase, the smart farming market will grow further in the coming years (Bökle et al., 2022).

4.5.5.2 Benefits of Advanced Farming

There are various benefits to implementing advanced farming methods into both commercial and local farming practices. Advanced farming methods such as smart, digital and precision farming can reduce the overall costs and money spent on fertiliser and pesticides. Smart farming can be used to accurately measure the level of each that is needed as opposed to blanket spraying, which prevents over application, which in turn can also help to reduce harm to the environment. Over application of fertiliser and pesticides can harm the environment by releasing potent greenhouse gases, negatively affecting soil fertility (Bronson, 2018).

Overall profitability can also be increased through increased yields due to the improved growing practices. Because of this they are able to sell more at the end of the season. There is also less of a need for manual labour as the technology is filling the gaps that workers previously filled (Moysiadis et al., 2021). Implementing better growing process can help to improve the overall quality of the crops. This can be achieved through actively monitoring nutrients in the soil, irrigating the plants correctly and only when needed. This can not only help to improve the overall quality but can help farmers boost profit margins further as farmers are able to negotiate a higher price for the higher quality product. One of the most significant benefits of smart farming is the ability to accurately predict the soil types and nutrient levels of the soil, and the needs and movements of livestock animals. Using precision weather predictions and precision imagery can help farmers understand areas of their farm that are facing difficulty or need more attention. This enables farmers to make decisions necessary to help improve the farm (Moysiadis et al., 2021).

As the smart farming technology improves, the use of this technology can also improve, which will help to improve the product and final outcome for the farmers. For example, the use of drones can aid farmers in monitoring how far along crops are in their growth period. Struggling crops can also be sprayed with substances via drones in order to bring them back to life. It is estimated that drones can spray fertiliser 40 to 60 times quicker than doing so manually by hand. Drones can also be used to identify weeds and pests in crops. Robots have also been developed to help dairy farmers milk their cows, reducing the need for cows to be milked manually, saving time and money for the farmer (Ouafiq et al., 2022).

4.5.5.3 Challenges of Advanced Farming

The adoption of advanced farming systems and technology is a challenging and dynamic issue for farmers, policy makers and the agricultural industry as a whole. The growth and development of precision/digital/smart farming methods present various challenges that need a clear strategy to support a clear transition to using this new technology (Moysiadis et al., 2021).

Farmers in different areas of the world need different types of equipment and technology at each stage of a crop’s life cycle, from sowing the crop to harvesting the crop. Farmers in developed countries including the United States and Europe are far more financially stable than farmers in developing countries. Farmers in developing countries often lack the funds needs to buy standard farming equipment. From the studies gathered, tractors, which are one of the most common and essential pieces of farm equipment, can cost up to $350,000. Harvesters and combine harvesters can cost roughly $25,000 each. Many farmers struggle to afford this expensive yet basic farming equipment. The high start up costs associated with this equipment comes with a risk of insufficient return on investment, and become unappealing to many farmers globally (Bryant and Higgins, 2021). Advanced farming equipment such as Wireless sensor networks (WSNs), Internet of Things (IoT) and Big Data Technology are all much more expensive and many farmers can simply not afford the up-front investment associated with this technology. Although governments of some countries provide a subsidy to farmers for buying advanced farming technology, the cost of maintaining and operating the advanced technology are often still too high for farmers (Bryant and Higgins, 2021).

The lack of broadband infrastructure in rural farming areas and connectivity to technology devices can present difficulties to farmers. The availability of network of fourth generation (4G) needed for the transmission of data between sensors and technology via the internet. This is one of the most crucial aspects of smart farming. Other obstacles include the availability of smart sensors and other devices and equipment globally, as well trained experts on how to use this advanced technology and equipment as many farmers may not be familiar with using this type of equipment and technology (Bacco et al., 2019).

A major legal issue associated with the introduction of smart farming is the processing of large amounts of agronomic data that is accumulated through advanced technology and which is of high importance to farmers and in algorithmic decision-making. While it is clear that the farmer owns the data generated on his land and animals, the increasing amounts of data being created by farmers and the identification of this data that is generated by the advanced technology, has become an overriding issue that has not yet been explored in much detail (Veroustraete, 2018).
The intelligent processing and analytics is also challenging due to the large amounts of data collected, which is often unstructured and heterogeneous. Privacy issues surrounding the data

gathered also needs to be considered, this may cause limitation surrounding the exchange of data between systems (Veroustraete, 2018).

It can also be questioned as to whether advanced farming methods could further aggravate food security and the employment situation in the agricultural industry. All highlight further challenges and barriers that need to be addressed (Bacco et al., 2019).

4.5.6 Genetic Modification

For many years now, humans have changed the genetic composition of both plants and animals, through selective breeding and other traditional breeding practices. The selection of specific, desired traits had led to the subsequent breeding of organisms with these desired traits. This was previously limited to naturally occurring variations. However, in recent years, the genetic modification of plants and animals has enabled the precise, specific control over the genetic alterations that occur within an organism. Genetic modification allows for genes from one species to be incorporated into completely different species, which can help to optimize agricultural performance, fight world hunger and protect the environment (Oosthuizen and Howes, 2021).

4.5.6.1 Genetic Modification in Plants and Animals

Many benefits are associated with genetically modified organisms. Crops are genetically modified to have new traits present that they didn’t originally have, or could not without the use of genetic modification. Some of the benefits to genetically modified crops are that they can be altered to become resistant to disease, pests, and pesticides and to withstand harsh weather conditions. It is also possible to create genetically modified crops that have an enhanced nutritional content. This type of GMO crops is particularly beneficial in developing countries, where malnourishment and deficiencies are common. In turn, this can help alleviate world hunger, as farmers have the ability to rear livestock and grow crops that have improved yield and that can withstand difficult conditions (Mesnage and Antoniou, 2021).

Various genetically modified crops have been developed today. It was found that soybean plants have been genetically altered to be resistant to the herbicide glyphosphate. This is beneficial as it allows soybean crops to be grown and herbicides to be used at the same time without harming the soybean and losing crops. Genetically modified corn has been developed to be insect resistant. Again this allows the crops to grow without becoming damaged by insects, preventing crop losses and lower yields for farmers. Canola oil was found to be genetically modified to have higher fatty acid levels through a higher composition of laurate. This could be particularly beneficial in developing countries or regions where malnutrition is prevalent (Andrews, 2021).

Research also showed that plums can be genetically altered to become resistant to the plum pox virus conferred by inserting of a coat protein (CP) gene from the plum pox virus. Studies also show that rice was can also be genetically modified to have higher vitamin A content. This is commonly known as 'Golden Rice'. Its modification occurs through the insertion of a gene from maize and bacterium *Erwina Uredovora*, allowing the plant to bio biosynthesise beta-carotene in the rice. Beta-carotene can then be synthesised in the body to make vitamin A. It is also what gives 'golden rice' its yellow colour. The results indicated that golden rice could offer a sustainable solution to reduce the rate of vitamin A deficiency related diseases ad deaths. This is a massive problem that particularly affects children in developing countries (Meidinger et al., 2019).

Animals have also been genetically modified to improve specific traits of the animal. For example, salmon have been genetically altered to have an improved yield, growth and also mature faster. Cows have also been developed to be resistant to mad cow disease through genetically modifying cows that lack the nervous system prions, which is the protein that causes bovine spongiform encephalopathy (BSE) also known as 'mad cow disease' (Ebringer, 2018).

Additionally, in poultry production, resistance to avian influenza can be achieved through genetic modification. Chickens have been genetically modified to express a DNA that blocks the avian influenza virus. However, the research showed that this area requires further research in order to prefect this genetic modification (Giakountis, 2018).

Genetic modification has also been beneficial at reducing the pollution from the agricultural industry. For example, the development of 'Enviropig^{TM}' was genetically modified to produce the phytase enzyme, which has the ability to break down dietary phosphorus. Resultantly, less phosphorus is released from pig manure, which helps to reduce the pollution levels from (Bagyaraj, 2021). Livestock animals can also be modified to have an enhanced food quality. Again, pigs have been genetically modified to have an improved level of omega-3. Similarly, genetically modified goats were developed to express the lysozyme enzyme in their milk, which enables goats be resilient against Mastitis. These advances can massively help to add to the overall nutritional value and resilience of the animals and their end products (Bagyaraj, 2021).

The primary aims of genetically modified crops are to achieve food security, improve the nutritional status of crops, enhance sustenance and enable manageable farming. The use of genetically modified crops and animals in developing countries has the potential to alleviate world hunger while also improving the profits for farmers and reducing the environmental impact of farming practices. For example, improved yields and reduction in the loss of crop and animals from harsh weather conditions, pests and disease helps to prevent a loss of crops for farmers in developing countries. Many farmers in developed countries rely on the crop from each harvest for food and money. If there is a failed harvest, this can lead to a family or community going hungry and becoming malnourished. Additionally, livestock productivity has massively increased through genetic modification. It has lead to the production of cheaper and more efficient animals, while also reducing the environmental impact. The most targeted traits of genetically modified animals include improved growth rate, disease resistance, nutritional content or quality of meat and milk production (Tait-Burkard et al., 2018).

The use of GMO's can benefit mankind when they are used for increasing food availability and quality, while also contributing to a cleaner environment. They can also help to reduce the reliance on harsh farming systems that can have a negative impact on the environment. If used correctly and wisely, GMO's can help to improve the economy and also help to alleviate hunger and disease worldwide, especially in developing countries and the countries that need it (Meidinger et al., 2019).

4.5.6.2 Risks Surrounding Genetic Modification

Although the transfer of genes naturally occurring in other species, there is still the possibility of unknown consequences associated with changing the natural state of an organism by genetic modification. These modifications have the potential to alter the organism’s growth rate, metabolism, and how they respond to the external factors. These possible consequences can impact the modified organism, as well as environment of the organism (Pray et al., 2018). The potential health risks associated with GMO’s include the possibly of the emergence of new and unknown allergens in genetically modified food, toxicity and the transfer of antibiotic resistant genes. For example, horizontal gene transfer of fertiliser, pesticides or the development of antibiotic resistance to other living organisms could potentially pose a risk to humans as. This could also lead to imbalances ecologically, resulting in plants that were previously innocuous to grow in an uncontrolled manner, which could potentially help promote the spread of disease in both animals and plants (Tsatsakis et al., 2017).

Even though there is a possibility of horizontal gene transfer natural organisms and genetically modified organisms, in truth the risk is quite low. The horizontal transfer of genes occurs at a low rate naturally, and it cannot take place without the active modification of the target genome (Raghav, 2016).

Chapter 5: Conclusion and Further Study and Recommendations

5.1 Conclusion

In conclusion, a comparison on agricultural farming methods and their impact on the environment were reviewed. Findings have established that conventional, traditional methods of farming had a large impact on the environment, particularly because of their land use, use of water, greenhouse gas emissions and the use of inputs such as fertiliser and pesticides. Economically, these methods of farming were found to be successful for farming, as they produce a high yield on a large scale for most countries investigated. Organic farming was found to be the most environmentally sound method of farming, primarily due to its lack of use of fertilisers and pesticides. Organic farmers use natural methods to control pests and increase growth. Additionally, the environmental impact of advanced farming methods were also found to be medium/high. However, these methods utilize the inputs, land and water available, ensuring greenhouse gas emissions and the impact on the environment is kept to a minimum. Although the environmental impact of advanced farming cannot be diminished, it was found to be considerably lower than conventional methods of farming. Additionally, the yield was also found to be better, as the use of fertiliser, pesticides, water etc was used as necessary, rather than over used. This ensures the plants and animals grow in most optimum condition possible. This is an advantage for both the farmer and the environment.

To answer the research question, alternative methods of farming can be used to reduce the environmental impact of the agricultural industry. However, the issue now lies in developing advanced farming systems in a cost-effective manner, while reducing environmental impacts to benefit farmers worldwide, focusing on farmers that need it most. However, findings from this research are promising, as it can be said that once the key costs drivers of advancing farming systems are lowered, these farming systems will be much more affordable to create and develop. However, with that being said, for this to happen governments worldwide must lend a hand and provide capital, grants and initiatives to lower the cost these sustainable farming solutions.

5.2 Future work and Recommendations

This study shows that there is a further research and development needed into creating more sustainable and economically viable methods of farming. It is of the utmost importance that the environmental impacts of farming and agriculture are reduced. If this cannot be achieved, global temperatures will continue to rise and have disastrous impacts worldwide. Higher temperatures can lead to worsening disasters such as storms, floods, heat waves and droughts, resulting in harsher conditions and huge economic costs for many countries and regions that are already struggling both financially and food sufficient food.

More research and development is needed on advanced farming methods, and how they can be utilized at a global level. Additionally, education and specialized training in the use of advanced farming methods is also essential to ensure they are optimized and utilized fully. Advanced farming systems have an extremely high cost associated with them at present. However, through government initiatives and grants, more companies may perhaps develop advanced farm technology. Progress within the industry and bulk purchasing of technology equipment may also contribute to decrease costs within the industry. At present, many developing countries could simply not afford advanced farming systems, and would have to rely on traditional methods of farming. This makes it extremely difficult for developing countries to increase their capital and provide sufficient food for all. It also means that these countries are relying on appropriate weather conditions and no other complications such as disease or pests invasion, to ensure that their harvests and livestock have high yields and productivity. The author recommends further development and research into the use of advanced farming methods in the countries that need it most. World hunger and global warming are major global problems and must be tackled head on.

Chapter 6: References

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