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The Essentiality of Sustainable Farming to Ensure Food Security for Future Generations

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Dissertation

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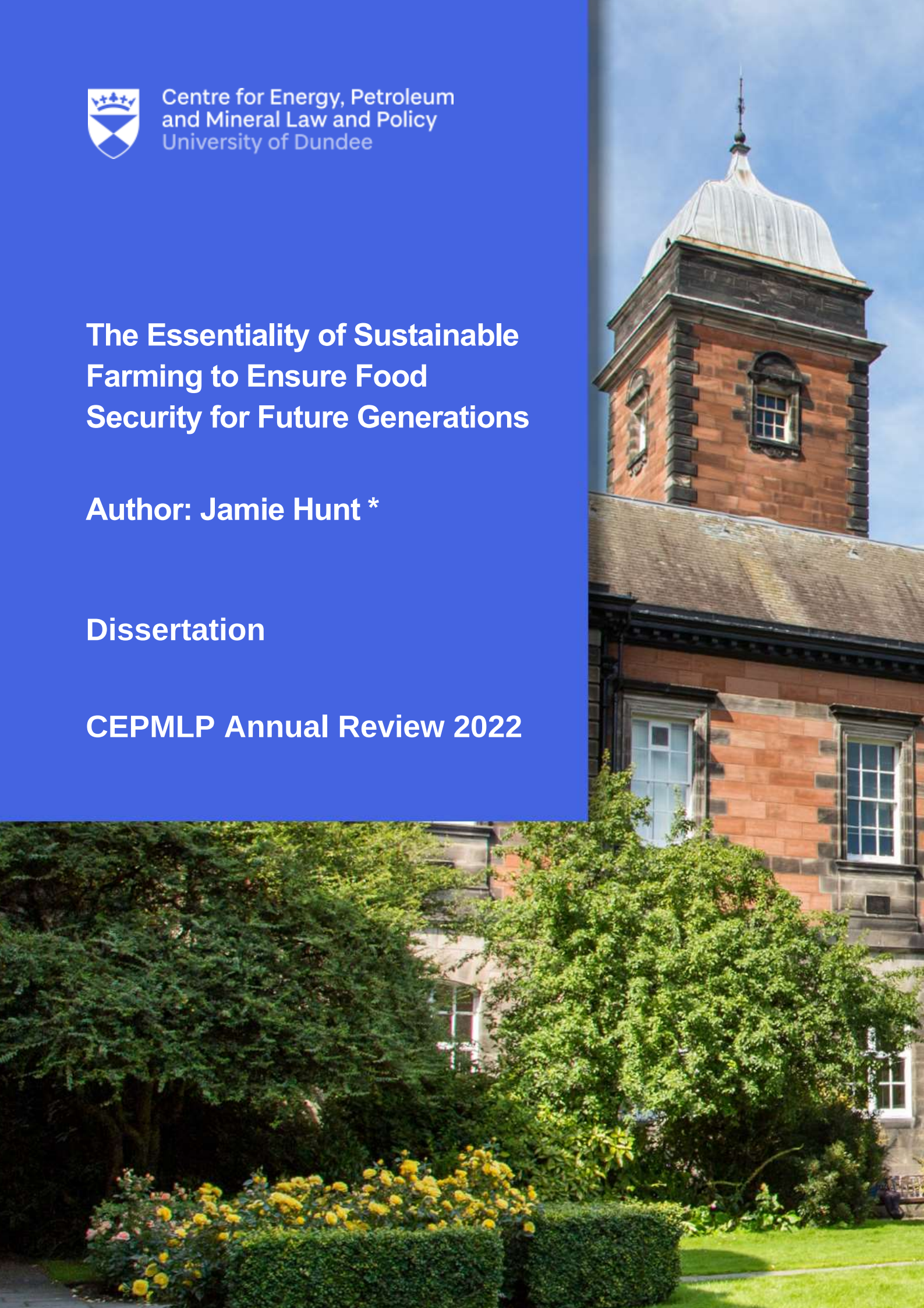

Abstract

One of the fundamental challenges of this generation, is and will continue to be, increasing food insecurity as a direct result of exacerbated population growth and the climate crisis. Global cooperation and collaboration will be the paramount in order to ensure any form of food security in the future and will rely upon policy implementation and a move towards more sustainable living.

This thesis aims to analyse sustainable farming as a method of ensuring food security for future generations. The importance of ensuring food security has never been more crucial, especially as the world continues to battle with the global Coronavirus disease 2019 (COVID-19) pandemic. In order to achieve such a goal, farmers around the globe must adopt more sustainable methods of mass-producing crops. Moreover, this thesis provides a comprehensive analysis of differing sustainable farming approaches while also closely investigating the existing strain on food security.

In order to achieve such an analysis a primarily qualitative approach was undertaken in the form of a literature review followed by a case study analysis. The evaluation of policies at home in the UK and abroad allowed for a more comprehensive review of how world leaders are tackling the food crisis now and into the future. Current obstacles towards achieving food security such as the pandemic were also incorporated for a more complete investigation. Furthermore, an in-depth investigation into scientific, technological and innovative approaches towards sustainable farming such as the likes of biotechnology and aquaponic systems brings together the practical application of policy implementation and collaboration that will work together to benefit future food security. By investigating differing farming approaches and including a case study analysis of farming in India, this thesis has provided a concise and comprehensive list of approaches that can be taken in order to make farming more sustainable. Moreover, providing real world examples of where such methods are already being utilised successfully assures the viability of such approaches.

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Abbreviations, Table and Figures

Abbreviations

AFRI	Agricultural and Food Research Initiative
bn	billion
BMT	Billion Metric Tonne
CAP	Common Agricultural Policy
CO_2	Carbon Dioxide
COVID-19	Coronavirus disease 2019
EPA	Environmental Protection Agency
EQ	CO2 Equivalent
EU	European Union
FAO	Food and Agricultural Organisation
GDP	Gross Domestic Product
GHG	Green House Gas
GM	Genetically Modified
IFPRI	International Food Policy Research Institute
IPC	Integrated Food Security Phase Classification
IPM	Integrated Pest Management
IRM	Insecticide Resistance Management
LED	Light-Emitting Diodes
NDC	Nationally Determined Contribution
NIFA	National Institute of Food and Agriculture
NITI Aayog	National Institute for Transforming India
SDG	Sustainable Development Goal
SSA	Sub-Saharan Africa
UN	United Nations
USA	United States of America
USD	United States Dollar
USDA	United States Department of Agricultural
WHO	World Health Organisation
ZBNF	Zero Budget Natural Farming

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Introduction

Food security is defined by the United Nations'(UN) Committee on World Food Security as "all people, always, having physical, social and economic access to sufficient, safe and nutritious food that meets all the needs of their dietary requirements for them to live an active and healthy life" (1). In order to achieve food security within a country, certain measures can be taken such as improving education and literacy, crop diversification, integrated water management and improved technology adoption (2).

A study undertaken by the Holt-Giménez *et al* (3) highlighted that for the past two decades global food production rates have exceeded population growth rates, with the Food and Agriculture Organisation (FAO) citing that the world produces one and a half times the amount of food we actually need (3). However, despite there being sufficient volumes of food produced globally, 8.9% of the population are currently undernourished which totals over 690 million (m) people (4), a number set to increase to 840m by 2030 (4). The United Nations (UN) defines hunger as periods of time where populations are experiencing severe food insecurity, such that they can go days without food as a result of their monetary status or general access to food (5).

World hunger is documented to be on the rise and between 2018-2019 the number of undernourished people increased by 10m (4). Further, the large majority of those experiencing food insecurity are found in the Global South, more specifically in Sub-Saharan Africa, where in 2017, 237m people were undernourished (6). However, food insecurity is not solely experienced in the Global South, according to the Food Foundation, in the United Kingdom there are a reported 8m people without access to sufficient food (7), a number nearly twice the population size of Scotland (8).

There is a global effort to somewhat alleviate food insecurity as seen in the UN's Sustainable Development Goals (SDGs). The SDGs are a collaborative effort from UN member states working towards the 2030 Agenda to ensure peace and prosperity for people and the planet, now and into the future (9). Goal 2 – Zero Hunger, specifically targets the issues surrounding food insecurity around the world while other goals also coincide with ensuring food security such as SDG 1 – No poverty and SDG 3 – Good Health and Wellbeing, to name a few (9).

Across the world increasing numbers of countries are experiencing acute food insecurity, backtracking on decades of development in this sector. COVID-19 has disrupted supply chains and reduced incomes, yet chronic and acute hunger were prevalent before the pandemic as a result of internal conflicts, climate change, pests and rising food prices. Moreover, lacking biodiversity in agriculture is creating a unique issue and results in the persistent malnutrition and poverty we see today (10). Around the world humans rely on many different crops, yet agricultural production revolves around just 12 with a staggering 60% of all calories consumed coming from just 4 crops: rice, wheat, corn and soy (10).

By 2050 the world population is set to increase by up to 35%, with the majority of this increase observed in developing nations (11). Thus, food insecurity will undoubtedly become more prevalent and exacerbated. In order to curb this, crop production will need to double and outpace the current population growth projections. Innovation and technology will prove to be essential to help combat the challenges of ensuring food security by 2050.

The aim of this thesis is to evaluate how sustainable farming will help ensure food security for generations to come. In order to achieve this a primarily qualitative approach will be undertaken in the form of a literature review and case study analysis. The literature review will be undertaken in order to examine and evaluate the extent of food insecurity and the impact sustainable farming will have on ensuring food security in the future. In order to perform the literature review, extensive research into projects and papers related to this topic will be evaluated. Moreover, policies both at home and abroad will be analysed to evaluate the measures already in place to ensure food security while looking at global hunger statistics. It is the hope that the overall literature review will analyse issues stemming around food security, as well as advances in farming that will somewhat mitigate food insecurity for future generations. The literature review should provide a clear overview of sustainable farming measures that will help to ensure food security while also considering current obstacles such as climate change and COVID-19.

A case study will be undertaken to gain an insight into how India has changed their farming methods away from chemical usage to more organic means. With over one bn people within the country, a number which is only set to rise, this analysis will provide key information into how India is implementing sustainable farming methods to ensure food security for their future. Additionally, how India has coped with the stresses of the COVID-19 pandemic will be essential to this analysis.

More specifically, an analysis of policies related to farming and food security will be undertaken to gain an insight into what the current stance on farming is. This will include investigating the Paris Agreement, SDGs, EU and US agricultural policy and laws. Moreover, an analysis of the existing problem of food insecurity will be evaluated with an overview of some of the biggest causes such as; environmental degradation, climate change, lacking biodiversity and the COVID-19 pandemic. Sustainable farming methods will then be investigated with reference to red seaweed technologies, modified methane producing cows and sheep and vertical farming. The next chapter will explore crop-based innovation, which is designed to make crops more resilient to the ever-changing environment. Examples include drought tolerant crops, pest resistant crops and improved lignin digestibility**.** Lignin digestibility will be looked at in regard to biofuel production which currently threatens food security. Finally, a case study analysis of farming in India will be undertaken.

Overall, it is the hope that this thesis will provide an insight into the challenges facing food security in the coming years. Moreover, it will provide a concise analysis of global policies and innovative technologies and highlight the importance of how both must work in conjunction to reach the overarching goal of feeding the world by 2050.

1. Existing Strain on Food Security

The Food and Agricultural Organisation (FAO) defines food security as follows: “Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life”, as outlined at the 1996 World Food Summit (12). They further break down this definition into four dimensions: (i) physical availability of food; (ii) economic and physical access to food; (iii) food utilisation; (iv) and the stability of the other three dimensions over time (13). In order to achieve food security, all four dimensions must be met simultaneously (13).

There are several different types of food insecurity including chronic food insecurity, which is long-term or persistent where people are not able to meet their minimum food requirements for sustained periods of time (13). Chronic food insecurity is often as a result of prolonged periods of poverty or poor financial resources. This can only be overcome through developmental measures that can help lift those associated out of poverty, as well as more direct access to food which will consequently improve their productive capacity (13).

Transitionary food insecurity refers to more short-term or temporary insecurity where there is an unexpected drop in the ability to produce or access enough food required to maintain a suitable nutritional status (13). This can be as a result of shocks or fluctuations in food availability or access such as variations in domestic food production, prices or household incomes (13). Due to the unpredictability of transitionary insecurity it is more challenging to prepare or plan for such an eventuality thus, safety net programmes and early warning capacities are the limited intervention options available (13).

According to the FAO’s State of Food Security and Nutrition in the World Report 2019, over 820m people across the world do not have enough food to eat (14). Despite considerable progress towards combatting global hunger, it has slowly been increasing over recent years thus, “underscoring the immense challenge of ending hunger by 2030” (14). There are several factors that exasperate food insecurity around the world including the recent COVID-19 pandemic, environmental degradation, climate variability and a lack of biodiversity in agriculture.

1.1 Environmental degradation

Environmental degradation refers to the deterioration of the environment as a result of the consumption of assets such as air, water or soil; the destruction of the environment and the elimination of wildlife (15). Moreover, environmental degradation can be characterised as any change or distress put on the environment that is viewed as undesirable (15). The occurrence of environmental degradation ranges from the depletion of natural resources, the species extinction, air, water and soil pollution and a rapid population growth spike (15).

As the global population continues to grow exponentially (16), the food supply chain will have to keep pace. However, there are growing concerns amongst environmentalists regarding the threat posed to environmental quality as food production rapidly increases (17). Subramaniam *et al.* elaborate stating that food security contributes considerably to economic welfare, plus as sustainable economic development with countries experiencing higher food security also experiencing improved national welfare, higher standards of living and a better quality of life (17). Persistent environmental degradation observed globally poses one of the greatest threats to sustainable development, especially in developing countries (17). Subramaniam *et al.* goes on to highlight that improper food production techniques such as overfishing contributes to worsening environmental quality and debates the long-term positive role of food security in the future if such issues persist (17).

A body of evidence has also suggested that soil degradation will have the biggest impact on food security. Regions of the world that are home to one third of the population, 45% of all agricultural land and 50% of livestock, are all at risk of desertification which will impact around 1.5 bn people (18). Causes for soil degradation include: erosion, salinization, pollution, pesticide use and deforestation (18). As more food is produced to feed the growing population, intensive farming practices will require more cultivated land at the expense of natural habitats. Deforestation poses a huge threat to food security with forests cut down in order to provide arable land for farming (19). From 2000-2012 around 888,000 square miles of forest was destroyed which undoubtedly has impacted climate change and consequently food supply chains (19). The impact of continued environmental degradation on food security could be devastating. There must be an equilibrium between increased food production and environment preservation where the environment is not compromised any further at the expense of pursuing food security.

1.2 Climate change

Climate change refers to the long-term changes observed in weather patterns across the globe (20). Such changes have been recognised since the early 20th century and are most often characterised to be as a result of human activity, primarily the burning of fossil fuels (20). Campbell *et al* remark that reducing the risks on food security directly caused by climate change is one of the greatest challenges of the 21st century (21). Climate change has already been associated with negative implications to agricultural yields as a direct result of rising temperatures and changes in rainfall patterns (22). Increased climatic variability leads to a myriad of complications to world systems such as; a rise in sea level as glaciers melt at unprecedented rates, the occurrence of droughts in already water scarce regions and flash floods destroying infrastructure and harvests to name a few (22). Each of these planetary emergencies not only have heavy implications for food security but have knock-on effects, e.g. economic growth, water availability and household incomes (22).

One devastating example of the impact of climate change is the famine in Somalia. The country is currently experiencing their third drought in just two decades which has led to reduced harvests and the death of livestock thus, exposing the country to famine (23). The 2016 drought left a staggering 40% of Somali people living in food insecurity and on the brink of famine (23). The persistent drought left 6.3m people suffering from acute hunger by 2017, which consequently led to the widespread displacement of people and a health crisis, with the Somali President declaring a "national disaster" (23). Somalia is not alone; incidences of famine have increased in recent years and have been exacerbated by the COVID-19 pandemic. The Integrated Food Security Phase Classification (IPC) is an initiative that was formed in order to help improve food security worldwide but was first conceptualised in 2004 to be used in Somalia. The system itself uses a phase classification system ranging from Phase 1-5 (23), as can be seen in *Table 1.*

IPC Phase Classification	
Phase 1	Minimal to no food insecurity
Phase 2	Stressed
Phase 3	Crisis
Phase 4	Emergency
Phase 5	Catastrophic/ Famine

Table 1: *Breaking down the IPC phase classification from 1-5.*

Source: IPC (24).

Currently, there are a reported 34m people in IPC Phase 4 which includes the near 200,000 living in IPC 5 or famine-like conditions in Yemen, Ethiopia, South Sudan and Madagascar (25). In Madagascar, the already extreme weather experienced in the country has intensified as a result of climate change and has therefore gravely impacted food vulnerability (26). The lack of rainfall in 2019 accompanied by the El Niño phenomenon, an unpredictable weather system that affects the temperature, speed and strength of currents around the eastern tropical pacific oceans (27), resulted in a 90% harvest loss, pushing over 60% of the population into food insecurity (26).

Exacerbated climatic conditions will continue to pillage food supply chains and agricultural systems if change does not happen in the very near future. The Paris Agreement (2015) has attempted to curb the devastating effect of climate change through temperature increase caps as well as SDGs, globally agreed upon climate goals, specific to climate maintenance. SDG 13: Climate Action, aims to "take urgent action to combat climate change and its impacts" (9). Current trends observed in the developing world should act as a blueprint for the future regarding water scarcity, rising temperatures and failing harvests. Furthermore, adaptation to the challenges we are facing vis-à-vis the global climate crisis will be undoubtedly vital to ensure any form of food security in the not-so distant future.

1.3 Lack of biodiversity in Agriculture

Without crop diversity it would be extremely difficult to ensure food security. The Crop Trust, an 'international organisation working to safeguard crop diversity'(28) identifies crop diversity as one of the building blocks of today's production by providing raw materials essential to ensuring the continued supply of food (29). Increasing the diversity of crops will help to ensure a secure food supply at more reliable prices for years to come (29). Agricultural biodiversity refers to the biological diversity in relation to both food and agriculture as well as in agricultural ecosystems and a variety of animals and plants (30). Agricultural biodiversity is the product of natural selection as well as human intervention over thousands of years (30).

A study undertaken by Khoury *et al* revealed that the reduction of diversity amongst crop species, that contribute to world food supply chains, are considered to be a potential threat to food security (31). Their study evaluated trends from the last fifty years related to the richness, abundance and composition of crop species around the world (31). Over the

course of those fifty years it was seen that “national per capita food supplies expanded in total quantities of food calories, protein, fat and weight with increased proportions of those quantities sourcing from energy-dense food” (31). Concurrently, measured crop commodities that contributed to national food supplies increased while the dominance of the most significant commodities decreased, as the relative contribution of these commodities within supply chains became even greater (31). As a result of this, global food supply chains became more alike in their composition especially in essential cereal and oil crops (31), such as rapeseed, canola and sunflower seed (32). Moreover, the rise in relative homogeneity within the food supply chain will most likely lead to species-rich crops nationally but species-poor crops globally (31). Thus, this has created elevated interdependence among countries related to the availability and access of crops, as well as in the genetic resources supporting their production (31).

In 1975, Harlan reiterated that the majority of food for mankind is found in just a few staple crops, a number that has been seen to have decreased rapidly (33). In the USA alone, a large majority of fruits and vegetables have vanished from diets, with this trend observed all over the world (33). It is seen that a worryingly increasing number of people are being fed on fewer and fewer crops (33). The decline in biodiversity coincides with a decline in both ecosystem functionality and stability (34). Research undertaken by Isbell remarks that there is a clear correlation between the functionality of an ecosystem and species richness, composition and genetic diversity (34). Isbell goes on to highlight that changes in biodiversity will most likely result in changes within ecosystem properties (34).

In 2019, the FAO produced the first global report on the state of biodiversity that underpins our food system (35). The report details that the biodiversity essential to our food and agricultural systems is disappearing, which consequently puts future food security and livelihoods, as well as health and the environment at risk (35). The FAO’s director-general José Graziano da Silva is quoted saying the following: “Biodiversity is critical for safeguarding global food security, underpinning healthy and nutritious diets, improving rural livelihoods, and enhancing the resilience of people communities” (35). The report presents findings that indicate plant diversity in farmers’ fields is decreasing where breeds of livestock are at risk of extinction and overfishing is jeopardising global stocks (35). Around 6000 plant species are cultivated for food use, yet less than 200 actually contribute to global food outputs, with just nine totalling 66% of total crop production (35). The loss of biodiversity is

as a result of changes in land and water use management, as well as pollution, overexploitation, climate change and population growth to name a few (35).

In order to curb the devastating impacts of a loss of agricultural biodiversity, changes in traditional farming practises must be adopted. For example, organic farming, pest management, conservation, sustainable soil management and forest management will be essential. Policies and frameworks must be implemented in order to conserve our precious biodiversity.

1.4 COVID-19 pandemic

In late 2019, COVID-19 emerged and brought the world to a virtual standstill (36). Originating in Wuhan, China, the disease quickly spread to over thirty countries across the world and on March 11, 2020 was declared a global pandemic by the World Health Organisation (WHO) (37). As the disease spread expeditiously across the world, travel restrictions and regional lockdowns came into place which resulted in economic turmoil and a complete disruption of established supply lines.

One defining phenomenon of the COVID-19 pandemic was the onset of panic buying that was brought on by the introduction of lockdowns and the associated fear and uncertainty felt. The persistence of panic buying resulted in food and essential supply shortages which consequently raised concerns about the sustainability of the food system, as well as the accessibility of essential resources (38). As shelves were left bare in almost every supermarket across the world there was a growing concern for low-income families who were unable to buy in bulk.

Research undertaken by the International Food Policy Research Institute (IFPRI) highlighted that the COVID-19 pandemic was likely to result in many more people experiencing poverty and becoming food insecure (39). They calculated that over 140m people could find themselves in extreme poverty, a 20% increase on current levels, which will consequently heighten food insecurity (39). *Figure 1* highlights how COVID-19 has affected poverty rates across the world with a closer look at South Asia and Sub-Saharan Africa (SSA) (39). The graph also details the percentage at which the relative number of those in poverty has increased (39).

Research undertaken by Aday *et al* explained how one of the most important sectors of the economy, the food supply chain, has been heavily impacted by the pandemic from the field all the way to the consumer (40). Concerns have been raised in food production, processing, distribution and demand (40). As a result of lockdown procedures many workers experienced restrictions, there was a stark change in demand from consumers, many food establishments were forced to close their doors, restrictions related to food policies were brought into place and there were additional pressures felt on the food supply chain (40).

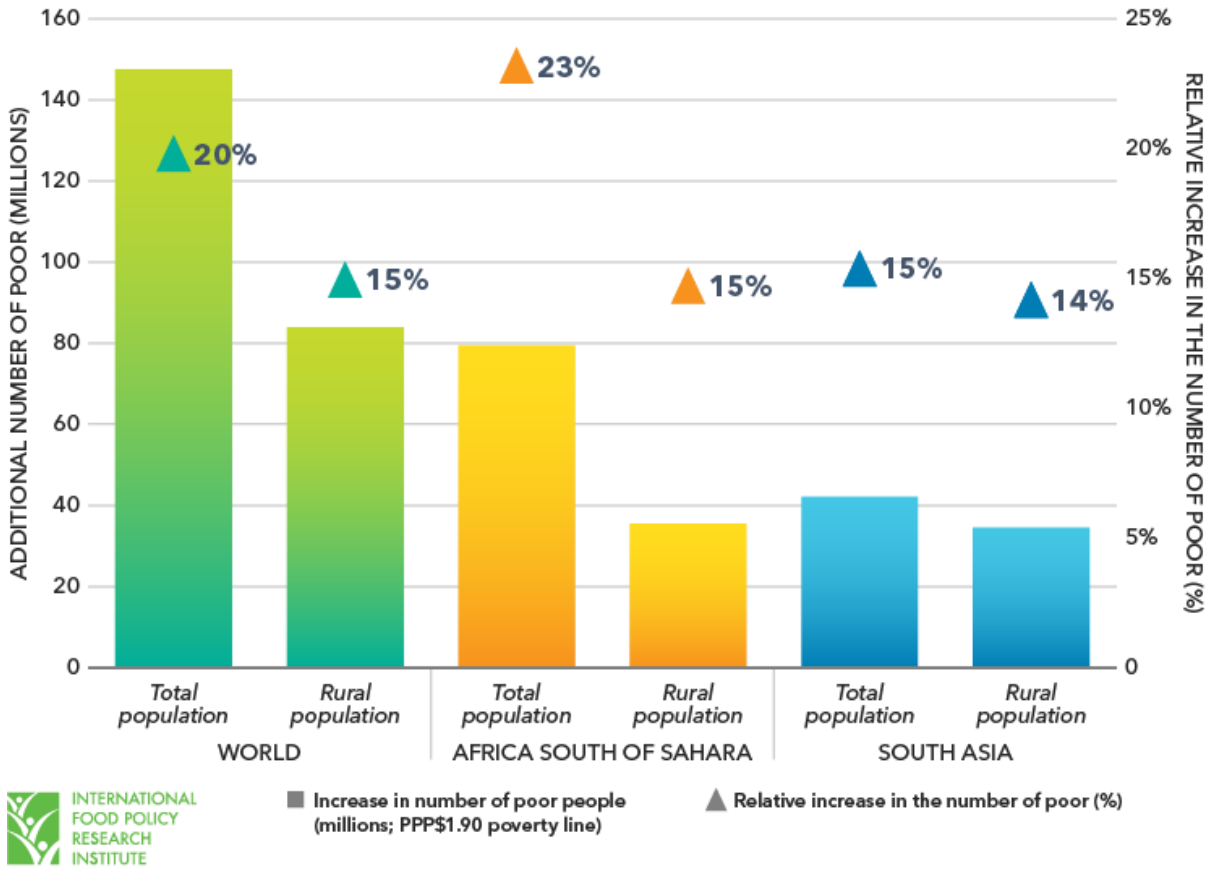


Figure 1: *The impact of COVID-19 global economic crisis on extreme poverty, 2020. The graph breaks down the data into the World (green), SSA (yellow) and South Asia (blue) and then into sub categories of total population and rural population. The figure shows the additional number of poor people in millions in each area of the world in both total and rural population (left-hand side) numbers with the triangle showing the relative increase in the number of poor (%) as well as highlighting the relative increase (%) in the number of poor on the right-hand side.*

Source: IFPRI (39).

In May of 2021 the World Bank published data relating to the increasing number of countries experiencing acute food insecurity as a direct result of the COVID-19 pandemic (41). They note that cereal prices are 43% higher than in January of 2020 and that the Agricultural Commodity Price Index, a monthly publication that measures price fluctuations in agricultural outputs and inputs, was 33% higher than in January of 2020 (41).

The COVID-19 pandemic poses one of the greatest challenges in living memory and is exasperating many issues already persisting around the world. As the number of those finding themselves experiencing food insecurity increases, there must be policy advances and collaboration to ensure that the number does not increase exponentially. The food supply chain is one of the most vital to the current economy and is essential to life. Therefore, SDGs and governing bodies will need to adapt to the new challenges, and the exasperation of old challenges, brought on by the pandemic.

2. Analysis of policies related to farming and food security at home and abroad

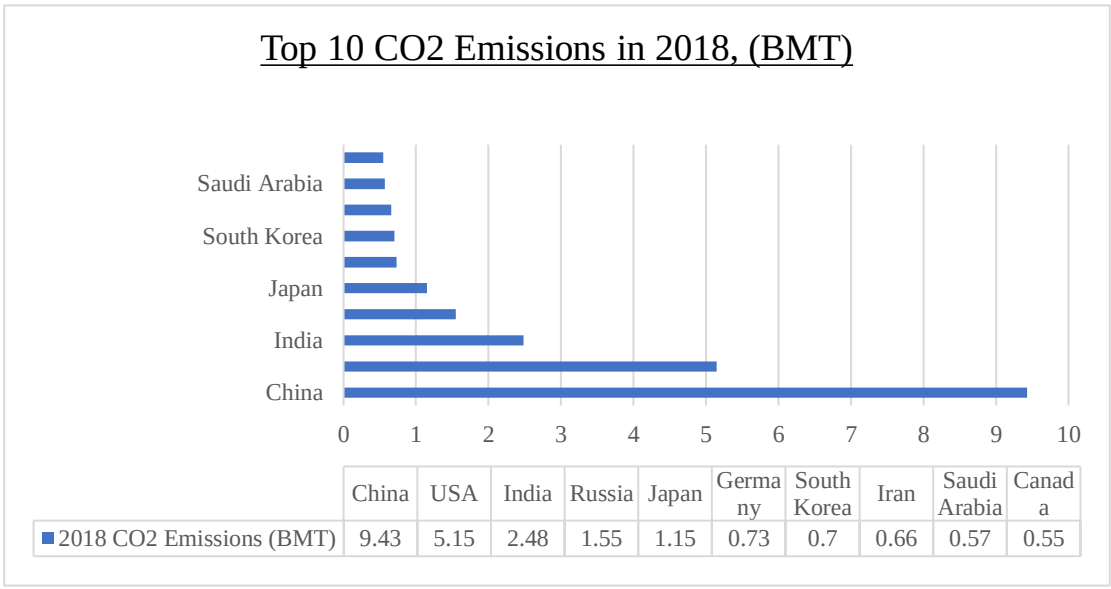
Several international policy documents have been chosen for this analysis as they demonstrate the essentiality of food security for the growing population, coupled with the need for sustainable farming as a direct result of climate change. Each of the documents chosen, from the Paris Agreement, SDGs, The European Union Common Agricultural Policy and the United States Agricultural Policy take a slightly different stance on the climate crisis. The Paris Agreement and SDGs implement global climate expectations and goals while the European Union and United States policies apply only to their territories which allows for interesting comparisons to be drawn.

2.1 Paris Agreement

In order to evaluate the extent at which sustainable farming practices will aid in ensuring food security for future generations, an analysis of current policies around the world will be essential. Firstly, the globally agreed upon Paris Agreement.

The Paris Agreement is a global, legally binding, international treaty centred around climate change mitigation (42). The Agreement itself works towards limiting global warming to below 2 degrees Celsius, preferably 1.5, compared to pre-industrial levels (42). The Treaty was adopted in 2015 at COP21 in Paris by 196-member states, being implemented in November of 2016 (42). In order for the Paris Agreement to be successful there needs to be both an economic and social transformation, which must coincide with the five-year cycle of increasing climate action ambitions (42). In conjunction with Paris Agreement commitments, each country must submit Nationally Determined Contributions (NDCs) (43). Described as being at the heart of the Paris Agreement, NDCs illustrate how governments will act to reduce their Greenhouse Gas Emissions (GHG) in order to meet with the goals outlined in the Paris Agreement (43). Moreover, each participating party much prepare, communicate and then maintain their NDC through pursuing mitigation measures (43). Every five years parties submit revised NDCs that must show a positive transition towards GHG reduction measures (43).

Climate change will continue to impact every country the world over, regardless of wealth, race or religion especially as the global population continues to rise. Therefore, it is paramount that there is a collaborative approach to adapting to the negative impacts of global warming. Currently, China is the largest emitter of carbon dioxide in the world followed by the United States and then India (44), as seen in *figure 2*, all of which rank in the top three highest populations in the world (45). Both India and China have ratified the Paris Agreement and are committed to achieving their targets and NDCs. However, under the Trump Administration in 2017, the USA announced its intention to leave the Paris Agreement (46). Zhang *et al* argue that the US withdrawal from the Agreement "undermines the universality of the Paris Agreement and impairs states' confidence in climate cooperation… and sets a bad precedent for international climate cooperation" (47). They further argued that the US withdrawal would mean that China would have to assume the global climate leadership role and work to keep the US engaged in climate related issues and cooperation (47). Overall, the Trump administration's decision to leave the Paris Agreement has set a dangerous precedent, if other countries were to follow the United States and postpone their climate mitigation efforts, CO_2 emissions would increase so much so that the 2°C climate goal would become impossible to achieve (48). Despite this, the Biden administration has since re-joined the Paris Agreement.



	China	USA	India	Russia	Japan	Germany	South Korea	Iran	Saudi Arabia	Canada
2018 CO2 Emissions (BMT)	9.43	5.15	2.48	1.55	1.15	0.73	0.7	0.66	0.57	0.55

Figure 2*: A graph showing the CO_2 Emissions in BMT from the top 10 emitters around the world including: China, USA, India, Russia, Japan, Germany, South Korea, Iran, Saudi Arabia and Canada. It can be seen that China, USA and India have the highest CO_2 emissions, illustrated further in the table.*

Source: Data taken from Forbes Energy (49).

One of the cornerstones of the Paris Agreement is collaborative support to combat the climate crisis. More specifically, the Agreement provides a framework for “financial, technical and capacity building support to those countries who need it” (42). Moreover, it acknowledges that developed countries hold the responsibility to provide financial support to developing and more vulnerable countries (42). In order to mitigate climate concerns, large scale financial investment will be fundamental, while climate adaptation will require considerable financial resources, those of which only developed countries will be able to provide (42).

The Agreement has also established a technology framework that recognises the essentiality of technological development and the importance of improving resilience to climate change while reducing GHG emissions (42). The framework provides an operational Technology Mechanism that is advancing technology development through its policy and implementation arms (42). Finally, the Agreement has acknowledged that the vast majority of developing countries lack the capacity to handle many of the challenges accelerated by climate change thus, there has been an encouraging emphasis put onto climate related capacity building in the developing world to enhance support and action (42).

More specifically, though the Paris Agreement does not specifically mention agriculture, there is explicit reference to food security, food production, human rights, gender, ecosystems and biodiversity (50). The prelude of the Paris Agreement recognises the “fundamental priority of safeguarding food security and ending hunger, and the particular vulnerabilities of food production systems to the adverse impacts of climate change” (51). Article 2.1 of the Agreement goes further honing in on the importance of protecting food production while also reducing GHG emissions; “increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production” (51). Climate targets will prove to be essential to the continued successfulness of farming, with a 1.5^{o}C temperature rise resulting in fewer climate extremes than a 2 degree increase, such as heatwaves, droughts and flooding (50).

The Paris Agreement has set out ambitions that will prove essential to life in years to come through the acknowledgement of the climate crisis. Built on the foundations of the Kyoto Protocol, it is the hope that the Paris Agreement will provide the framework necessary for continued climate action across the world though direct action of the participating parties.

The upcoming 2021 Climate Conference in Glasgow, Scotland will provide insight into the future of climate change mitigation based on current projections while also considering the COVID-19 pandemic.

2.2 Sustainable Development Goals

In order to meet with some of the greatest challenges we currently face, in September of 2015 the UN agreed upon the SDGs as part of the UN's 2030 Agenda for Sustainable Development, a plan of action for "people, planet and prosperity" that aims to strengthen peace and provide freedom all while heavily considering our impact on the planet (52). The goals provide the shared blueprint to achieve peace and prosperity for the planet and its people (9). The SDGs have been described as an urgent call for action by all countries, both developed and developing, through global partnership (9). Moreover, through the 17 SDGs there is a recognition for the end of poverty coinciding with improved healthcare, education, reduced inequality all while encouraging economic growth and tackling climate change and working towards ocean and forest preservation (9).

The SDGs are built on decades of collaborative work between the United Nations and world leaders, as well as the UN Department of Economic and Social Affairs (9). The first comprehensive plan of action related to sustainable development was in June 1992 at the Earth Summit in Rio de Janerio, Brazil, that brought together 178 countries to adopt Agenda 21. This step towards sustainable development lead to the adoption of the Millennium Declaration (2000), a commitment by world leaders towards "combatting poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women" (53), going into the new millennium. The declaration was accompanied by the Millennium Development Goals in 2000 which primarily aimed to reduce the extreme poverty felt across the world by 2015 (9). The Johannesburg Declaration in 2002 worked to reaffirm both Agenda 21 and the Millennium Declaration, reinforcing global dedication to the environment and eradicating poverty with an added emphasis on multilateral partnerships (9). In Rio 2012, the UN Conference on Sustainable Development began to develop SDGs which would build on and enhance the MDGs while also establishing the UN High-level Political Forum on Sustainable Development. More recently, 2015 saw the General Assembly begin negotiations towards a post- 2015 development agenda which then encouraged the adoption of the 2030 Agenda and the 17 SDGs at the UN Sustainable Development Summit (9).

One goal in particular relates to the issue of food security, Goal 2: Zero Hunger (4). This goal specifically targets the effort to end hunger while also achieving food security through the assurance of improved nutrition and the promotion of sustainable agriculture (4). The overview highlights that while the COVID-19 pandemic has exacerbated the world hunger crisis, food insecurity was already extremely prevalent and on the rise before the pandemic hit (4). For example, in 2014 there were a reported 23.2% of the population impacted by either moderate or severe food insecurity whereas 2018 saw this figure increase to 26.4% (4). Moreover, the World Economic Forum, founded in 1971 is an international organisation or both public and private cooperation (54), reports that in 2019, 690m people around the world were undernourished, a number that could be set to exceed 840m by 2030 if the current trend persists (55). Factors which majorly contribute to the persisting increase in food insecurity include both stunted economic growth and extreme weather events brought on by worsening climate change (55).

The COVID-19 pandemic has caused a considerable spike in the number of people now facing acute food insecurity, a figure recorded at 96m by the World Bank's World Food Programme (56). This peak in food insecurity is likely to set back decades of progress in this sector, especially in regards to women and children's nutrition (56). There has been an increase of stunted growth in children already being observed, thus compromising their potential human capital and economic productivity in years to come (56). The pandemic has created unique obstacles which have subsequently induced a food crisis. For example, both income and remittance losses left rural and urban households struggling to buy food as well as reduced food availability and an increase in food prices (56). If all of these challenges persist in the near future, the UN has warned that their target of zero hunger by 2030 will be unattainable and are calling for urgent reform to global food systems (56).

SDG 2: Zero Hunger, also has direct links to sustainable farming practices. The goal itself recognises the essentiality of supporting sustainable agriculture by helping to empower small scale farmers, promoting gender equality, ending rural poverty and encouraging healthier lifestyles (57). In order to ensure food security, not only do farmers need to generate enough produce to feed a growing population, they must grow food that has sufficient calories and that is also nutritious so as to be incorporated into a healthy diet and lifestyle (57). There is a body of evidence that supports the claim that unhealthy diets are directly linked with the increased incidence of non-communicable diseases in both the developed and developing world (57).

Those that experience both extreme poverty and hunger are often found in rural communities, where farmers and their families comprise a considerable proportion of those affected (57). Through actions to tackle SDG 1: No Poverty and SDG 2: Zero Hunger, it is the hope that there will be a spike in food production, agricultural productivity and rural income (57). It is important to note that despite the need for increased food production, it must be carried out in a sustainable manner so as to cause no further damage to the fragile environment (57). Therefore, where production increases wastefulness must decrease with the management of healthy soils, water, land and plant genetic resources being at the heart of future sustainable farming practices (57).

Overall, the goals outlined by the UN highlight key areas that must be reformed in order to achieve any degree of sustainable development in the near future. However, there are an increasing number of reports, including one by Moyer *et al*, speculating whether or not the goals are achievable. Their report states that "the world is not on track to achieve many human-development related SDGs" (58). While the progress observed may not be as encouraging as projected when the goals were initially formulated in 2015, advancements in the field of sustainable development are still moving forward with innovation in the field evolving constantly. Moyer *et al* reinforce the need for international and domestic aid policies and prioritisation to help with development issues that persist around key issues such as education, health in children and access to safe sanitation (58). The successfulness of the SDGs will derive from international cooperation and collaboration with nations working towards a common and essential set of goals.

2.3 The European Union Common Agricultural Policy

The agricultural sector is one of the largest land users in Europe, which has both direct and indirect impacts on the environment and people (59). Grassland and cropland comprise 39% of Europe's land cover and are both inherent components of the food system (59). Small farms in Europe are seen as a crucial element of the agricultural system, producing the majority of healthy and diverse food consumed, as well as providing jobs and securing the resilience of food systems (60). The agricultural system in Europe plays a key role in the potential for Europe to achieve the objectives outlined in the UN's SDGs (59). One way the EU hope to do this is through the Common Agricultural Policy (CAP).

The EU CAP was put into motion in 1962 and works as a partnership between agriculture and society as well as between Europe and their farmers (61). CAP's primary aims are as follows:

I. to support farmers and improve agricultural productivity through ensuring a stable supply of affordable food;
II. safeguard EU farmers to make a reasonable living;
III. help tackle climate change and the sustainable management of natural resources;
IV. maintain rural areas and landscapes across the EU; and
V. keep the rural economy alive by promoting jobs in farming, agri-foods industries and associated sectors (61).

CAP is considered to be a common policy that applies to all countries within the EU and is both managed and funded at a European level as part of the EU budget (61). CAP is heavily centred around the environment and the economy, with a focus on a move towards sustainable agriculture. More specifically, through environmental, social and economic sustainability (62).

CAP acknowledges the individuality of farming practises compared to other business frameworks wherein unique considerations must apply (61). For example, while food production is the cornerstone of civilisation, a famers' income is seen to be around 40% less than those in non-agricultural industries (61). Further, agriculture is heavily dependent on climatic conditions and there is also an unavoidable time gap between consumer demand and famer supply (61).

Thus, CAP takes into consideration these business uncertainties, accompanied with increasing environmental impacts, and provides: income support, market measures to handle difficult market situations such as an unforeseen drop in demand, as well as rural development measures like programmes to address the needs and challenges seen in rural areas (61).

Figure 3 illustrates how CAP helped to support farmers in 2019 through income support, rural development and market measures totalling €57.98 bn (61).

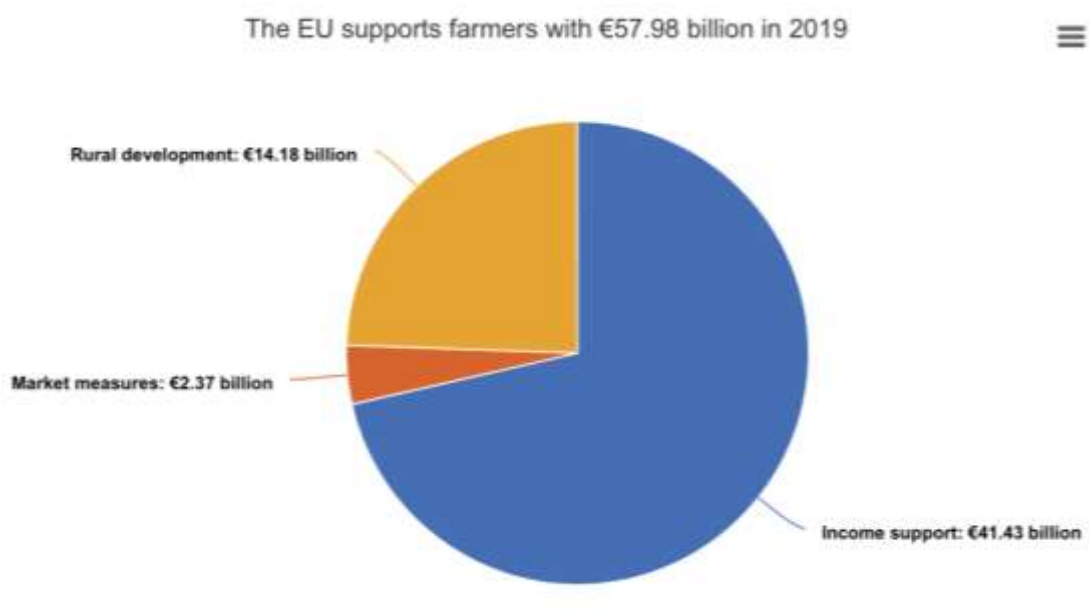


Figure 3: *A pie chart breaking down how the EU supported farmers with €57.98 bn in 2019. The largest contribution was in income support at €41.43 bn followed by rural development at €14.18 bn and market measures at €2.37 bn.*
Source: European Commission (61).

Looking forward, in 2018 the European Commission proposed legislative recommendations on the future of CAP (63). Such proposals hope to reinvigorate CAP, aiming to provide strengthened support for both farmers and the rural areas in which they reside, for years to come (63). The updated policy will also move towards more sustainable ambitions through the incorporation of the European Green Deal (61) which aims to ensure that economic growth is decoupled from resource use, that there are no net emissions of GHG by 2050 and that no person or place is left behind during this transition (64). It is the hope that the reformed CAP will be implemented in January of 2023 (61). CAP is working towards a sustainable future for Europe that will help them to meet both SDGs and Paris Agreement commitments.

2.4 United States Agricultural Policy

Having evaluated the agricultural policy utilised across Europe, a closer look at Agricultural Policy in the USA will now be undertaken. As seen in *figure 2*, the US is the second largest producer of CO_2 emissions. In addition to this, in 2019 Statista reported that the US produced 14.5% of the worlds CO_2 emissions behind China at nearly 30% (65). However, when investigating cumulative emissions, while China emits the highest proportion of CO_2 annually, it has emitted less than the US for the past three centuries (66). The US has

totalled more than 400 BMT CO_2 since the onset of the industrial revolution in the mid 1800's (67). A study undertaken by the US Environmental Protection Agency (EPA) detailed agriculture to represent 10% of their total GHG emissions in 2019, behind transportation, electricity production, industry, commercial and residential (68). Factors which contribute the most to emissions from agriculture in the US include the use of fertilisers which generate nitrous oxide emissions, the production of methane from livestock, manure management which contributes 12% to total GHG emissions from agriculture and the burning of crop residues (68).

In 2019, agriculture in the US was responsible for $1,109 bn [1]of that country's Gross Domestic Product (GDP), a 5.2% share, with farms across America contributing $136.1 bn (69). Moreover, agricultural related industries across the US contributed 10.9% of total employment in 2019 (69). However, despite being the world's largest producer of maize, the third largest of wheat, fifth largest of potatoes, tenth largest of sugarcane and twelfth largest of rice (70), there is a persistent food insecurity dilemma. In 2019, there were over 35m people who had experienced hunger, this number has risen to more than 42m, including 13m children, as a result of the COVID-19 pandemic (71).

In order to feed their growing population in a sustainable manner, the country must come together and foster sound policy initiatives to strive towards greener farming practises that can produce sufficient nutritious food. Under the newly elected USA federal government, President Joe Biden has prioritised sustainable agriculture (72). As part of their fiscal spending budget for 2022 they have proposed $27.9 bn for the US Department of Agriculture (USDA) (72). This allocation contributes $4 bn in additional spending which is set to be used in vital sustainable agriculture and food system programs (72).

The Agriculture and Food Research Initiative (AFRI) is the country's leading grants program for the agricultural sciences (73). Grants are used to improve rural economies, increase food production, stimulate the bioeconomy, mitigate impacts of climate variability issues, ensure food safety and security while enhancing human nutrition and training the next generation of the agricultural workforce (73). AFRI was first established in 2008 as part of the Farm Bill and then re-authorised in 2018 and has since funded projects essential to meeting food demands as the population continues to grow (73).

[1] All $ quoted are United States Dollars

Another program that is spearheaded by the National Institute of Food and Agriculture (NIFA) is the Sustainable Agriculture Program (74). According to US Code title 7 Section 3103, sustainable agriculture is the integrated system of plant and animal production practises that will:

I. satisfy human food and fibre needs;
II. enhance environmental quality and the natural resource base upon which the agricultural economy depends;
III. make the most efficient use of non-renewable resources and on-farm resources while integrating natural biological cycles and controls, where appropriate;
IV. sustain the economic viability of farm operations; and
V. enhance the quality of life for farmers and society as a whole (75).

The program itself hopes to contribute a more profitable farm income through the promotion of environmental stewardship and the enhancement of quality of life for farmers and the surrounding communities (74). NIFA offers competitive grants and developmental programs while collaborating with federal agencies to work towards the promotion of sustainable agriculture (74). Examples of how agricultural practises can be made more sustainable include integrated pest management, rotational grazing, soil conservation, landscape/crop diversity and nutrient management (74).

In addition to the aforementioned sustainable farming programs there is the USA's Farm Bill – a tool used by the federal government that is revised every five years, which, if passed, would mandate federal policies in areas such as commodity programs and crop insurance as well as in conservation of agricultural lands and in agricultural trade (76). The Farm Bill, if passed, would have the power to modify existing legislation across several policy areas, which depend on the primary concerns at the time the Bill is updated (76). The vast majority of cases such as in commodity, conservation and rural development usually see the extension, revision and replacement of provisions previously highlighted in the prior Bill (76). However, other cases call for the revision, extension and replacement of language in laws that regulate areas that would overlap with Farm Bill authorities such as in food, nutrition, food safety, trade and crop insurance (76).

As the second largest emitter of CO_2 emissions in the world and with the third largest population in the world it is paramount that the USA, as a world power, endeavours to become a leader in sustainable farming management. The USA's current federal administration will have to work towards mending what the Trump administration attempted to back track on, for example the exit from the Paris Agreement. As the global temperature increases and climate variability continues to persist, adapting farming practises in a sustainable way will be absolutely critical while also working towards feeding an already somewhat food insecure population.

3. Hope for the Future Through Sustainable Farming Methods

Despite what seems to be an impossible task, there is still hope for the future. *Figure 4* presents ways in which we can generate a sustainable food future by 2050 (77). The World Resources Institute have published a series of charts related to how we will be able to sustainably feed ten bn people by 2050 (77). *Figure 4* illustrates that globally we will need 56% more food to feed the 10bn global population estimated for the year 2050, use around 50% of the world's vegetated land for agriculture to save an area of forest nearly twice the size of India and lower emissions by improving livestock feed, plant-based food and resilient crop breeds (77).

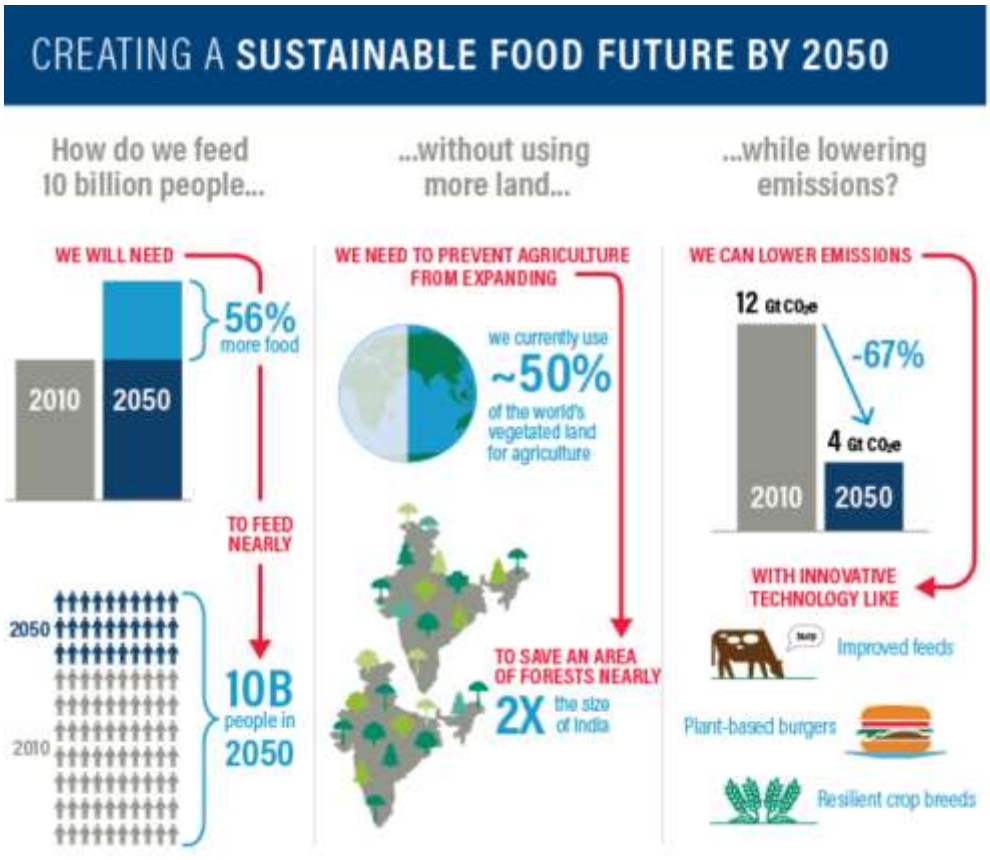


Figure 4: *A diagram illustrating how we can create a sustainable food future by 2050. The diagram explains that we will need 56% more food to feed 10 bn people by 2050, use around 50% of the world's vegetated land for agriculture to save an area of forest nearly twice the size of India and lower emissions by improving livestock feed, plant-based food and resilient crop breeds.*

Source: World Resources Institute (77).

The World Research Institute lists several ways in which we can reduce demand for growth in food and agricultural products. One way is through the reduction of food loss and food waste (70). As it stands around one quarter of all food produced for human consumption is uneaten, reducing this loss by just 25% by 2050 could help to close the food gap by 12%, the land gap by 27% and GHG mitigation gap by 15% (77). In order to achieve this, we must accurately measure food wastage, set achievable reduction targets, improve food storage capabilities in developing countries as well as streamlining expiration labels (77).

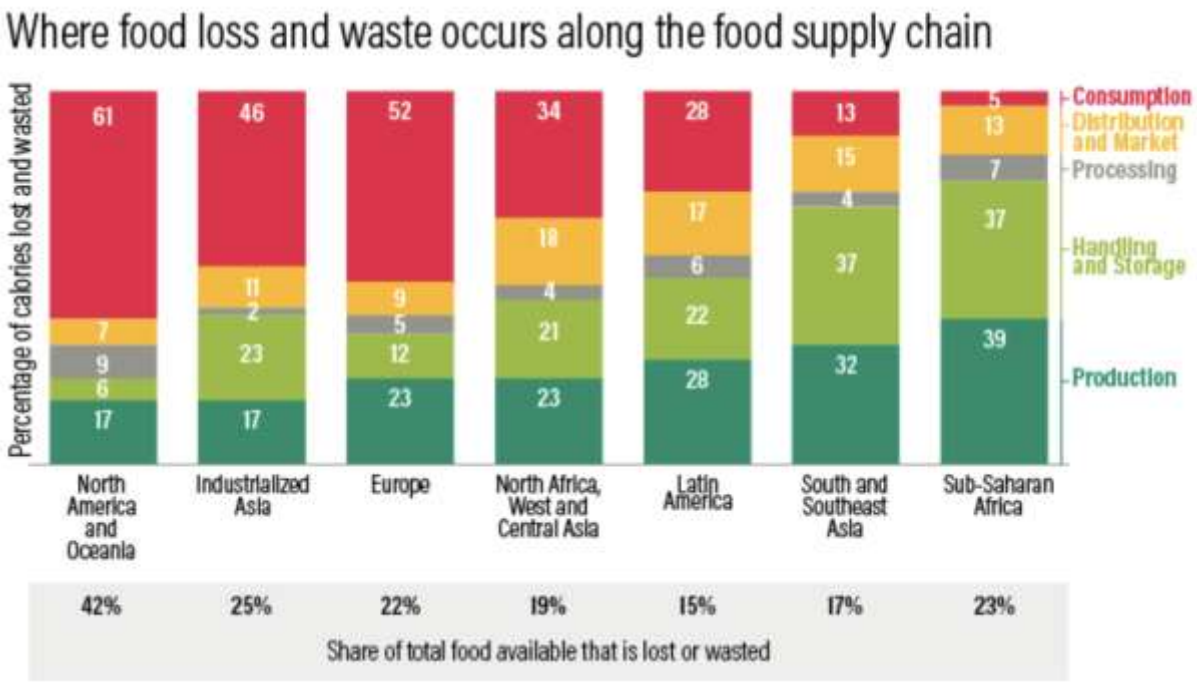


Figure 5: *A chart illustrating where food loss and wastage occurs in the food supply chain around the world. Categories include: consumption, distribution and market, processing, handling and storage and production. The analysis looks at North America and Oceania, Industrialised Asia, Europe, North Africa and Central Asia, Latin America, South and Southeast Asia and Sub- Saharan Africa and measures the percentage of calories lost and wasted with the share of total food available that is lost or wasted.*
Source: World Resource Institute (77).

Figure 5 illustrates the great disparity of food wastage felt across the world. A staggering 61% of calories are wasted or lost in North America and Asia compared to 5% in SSA (77). The developing world also struggles with wastage related to handling and storage compared to in the 'Global North'(77), the more developed regions of the globe including North America, Europe and Australia (78) . The disproportion in wastage across the world is one

of the issues that must be addressed as the population grows. The African continent for example, has the fastest growing population, where over half of the global population growth between now and 2050 will occur (79).

Alternative techniques to traditional farming methods will prove to be vital in the coming years and will be seen through the likes of aquaponics, hydroponics and vertical farming to name a few. Despite these systems requiring intensive management, moderate levels of energy and can be high costed start-ups; population growth, limited farm land and climate change call for such innovation (80).

3.1 Aquaponics, Hydroponics and Aquaculture

Another way in which the World Resource Institute has indicated we can sustainably feed the growing population is through improving productivity and environmental performance of aquaculture (77). Aquaculture is the "breeding, rearing and harvesting of fish, shellfish, algae and other organisms in all types of water environments" (81). Aquaculture enables us to harness the huge potential of our oceans, seas and inland freshwater to provide increased volumes of healthy and nutritious food (82). It is predicted that fish consumption will increase by as much as 58% by 2050, meaning that to ensure the sustainability of fish farming, more environmental considerations must be met (77). Aquaculture itself is heavily dependent on the environment therefore, it is in our best interest to ensure that it is undertaken in the most sustainable way.

Hydroponics is another sustainable farming technique that will be paramount to the assurance of future food security. Hydroponics involves growing plants without the use of soil thus, eliminating the potential for soil and land degradation. This technique provides a more efficient means to provide both water and nutrients to the plants (83). Moreover, hydroponics uses a special growing medium and nutrient solution which is made readily available to the plant. As soil is not involved, the nutrients are able to go directly to the plant rather than the roots searching through the soil to find nutrients or water (83). Therefore, the plant is able to expend more energy growing thus, generating more vegetation, larger fruit and vegetables. It has been found that plants grown in hydroponic conditions can grow up to ten times quicker with considerably larger yields than those grown under conventional methods (83). This is as a result of higher oxygen levels in the root system, optimum pH levels(a measure of how acidic or alkaline a aqueous solution is) and the nutrient food

solutions used (83). Benefits of using hydroponic systems include; no weeds, fewer pests and a lower water requirement as well as one of their few necessities being access to long and sufficient periods of light and ventilation (83).

Aquaponics refers to the food production system that brings together both aquaculture and hydroponics (84). More specifically, aquaponics is the combined culture of fish and plants in recirculating systems (84). Aquaponic systems are closed, meaning that the water recirculates in a water reservoir, or fish tank as seen in *Figure 6*. Fish and plants coexist in a symbiotic relationship, one in which two dissimilar organisms live in harmony and benefit from the partnership. The fish excretions are broken down and then provide the essential nutrients and nitrates for the plants while the plants purify the water that is then recirculated to the fish (80). Advantages of aquaponics include reduced land use and the dependence on weather conditions, which have become increasingly unpredictable as a result of climate change.

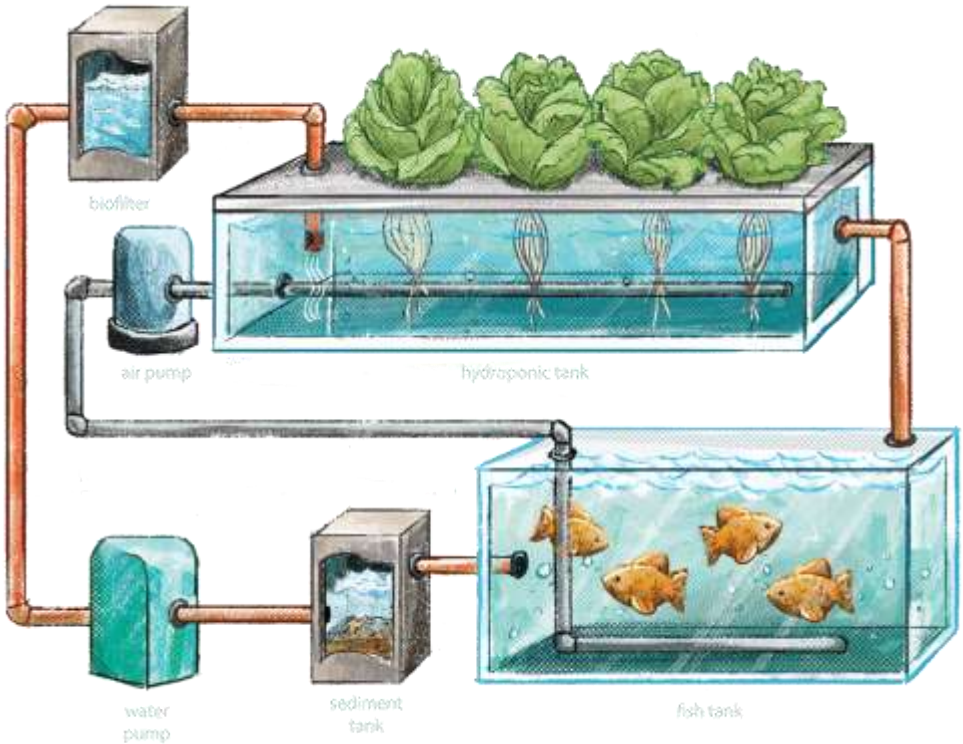


Figure 6: *A diagram illustrating the closed system of Aquaponics.*
Source: Souders and McDowell, Purdue University (80).

Moreover, despite water being essential to this process, it actually uses between 90 and 99% less water than is currently used in agriculture (80). Examples of companies utilising

aquaculture include Canadian company Growcer (85). Growcer is a “leading agri-tech provider in Canada…empowering communities, retailers and organisations to grow local produce anytime anywhere; from the arctic to the desert with their hydroponic container farms” (85). The produce in grown in purpose, Canadian built containers with a 30-year lifespan and overall low infrastructural requirements (85).

Figure 7*: An image of a Growcer container during the Canadian winter.*
Source: Growcer Modular Food Solutions (85).

Drawbacks of aquaponics currently include the overall cost and the volume of energy required which would make it more difficult for developing countries to implement into their agricultural system (86). Despite these drawbacks, the long-term benefits of utilising aquaponic technologies far outweigh the current cost and energy setbacks (86). The volume of water that will be saved through large scale aquaponic integration will be absolutely essential with the inevitable water crisis. Large scale glacial melting coupled with the immense volume of water consumed through agriculture could lead to a severe water crisis in the coming years.

The need for sustainable farming methods have resulted in the development of many cutting-edge farming technology companies such as Liberty Produce. Liberty Produce is a farming technology company that enables the growth of local produce year-round through vertical farming systems (87). Vertical farming utilises Light-Emitting Diodes (LED) lighting which then provides differing wavelengths of light depending on the growth stage of the crop (88). The crops themselves are grown in stacks on purpose-built beds and trays where artificial lighting, irrigation, fertigation and climate are all controlled (88).

Founded in 2018, Liberty Produce strives to aid in the food crisis amidst the fast-growing population size. Their ethos is as follows: “our vision is to drive innovations that will enable us to meet our global crop requirements over the next century, without harming the planet” (87). Despite current circumstances not allowing vertical farming to compete with traditionally farmed produce, when considering cost, they endeavour to push the boundaries of farming technologies (87). Moreover, their team strongly believes in the importance of information sharing and collaboration in order to combat the precarious food supply chain that has been harmed further by the COVID-19 pandemic (87). The James Hutton Institute in Invergowrie, is home to the Future Farming Hub where next generation agricultural technology meets modern day farming knowledge. The Hub offers residential courses to those new to the industry as well as pioneering research and development in this field (87).

3.2 Crop rotation

Crop rotation refers to the practise in which different crops are planted sequentially on the same area of land in an effort to improve soil health, optimise soil nutrients as well as for pest and weed management (89). An example of this would be the planting and then harvesting of corn, which consumes a considerable volume of nitrogen, and then planting beans, which are then able to return nitrogen into the soils (89).

The dangers associated with planting the same crop year in and year out is that pests and diseases remain a persistent issue as a food source is annually guaranteed (89). This then creates a reliance on pesticides and chemical fertilisers which can cause a myriad of health and environmental issues (89). Crop rotation works to disrupt the pest and disease cycle which reduces the need for pesticides while naturally returning nutrients into the soil, reducing the need for fertilisers (89). Through reducing the need for pesticides and fertilisers, crop rotation presents itself as a sustainable means of agricultural production (89).

3.3 Reducing methane output of farm animals

Around the world, livestock emissions contribute 14.5% to all GHG emissions in the form of methane, with beef emissions responsible for nearly half of these (90). Biogenic methane is primarily released from agricultural practises, through the rearing of livestock and the consequent organic waste produced (91). Methane is a highly potent GHG which has thirty times the warming potential of CO_2, with a reported 25% of today’s global warming being

linked to methane (91). *Figure 8* provides information on regional emissions and production figures around the world. It can be seen that Latin America and the Caribbean have the largest share of emissions at 1.9 gigatons CO_2-equivalent, primarily caused by beef production (92). North America, SSA and Oceania also produce considerable emissions from beef (92).

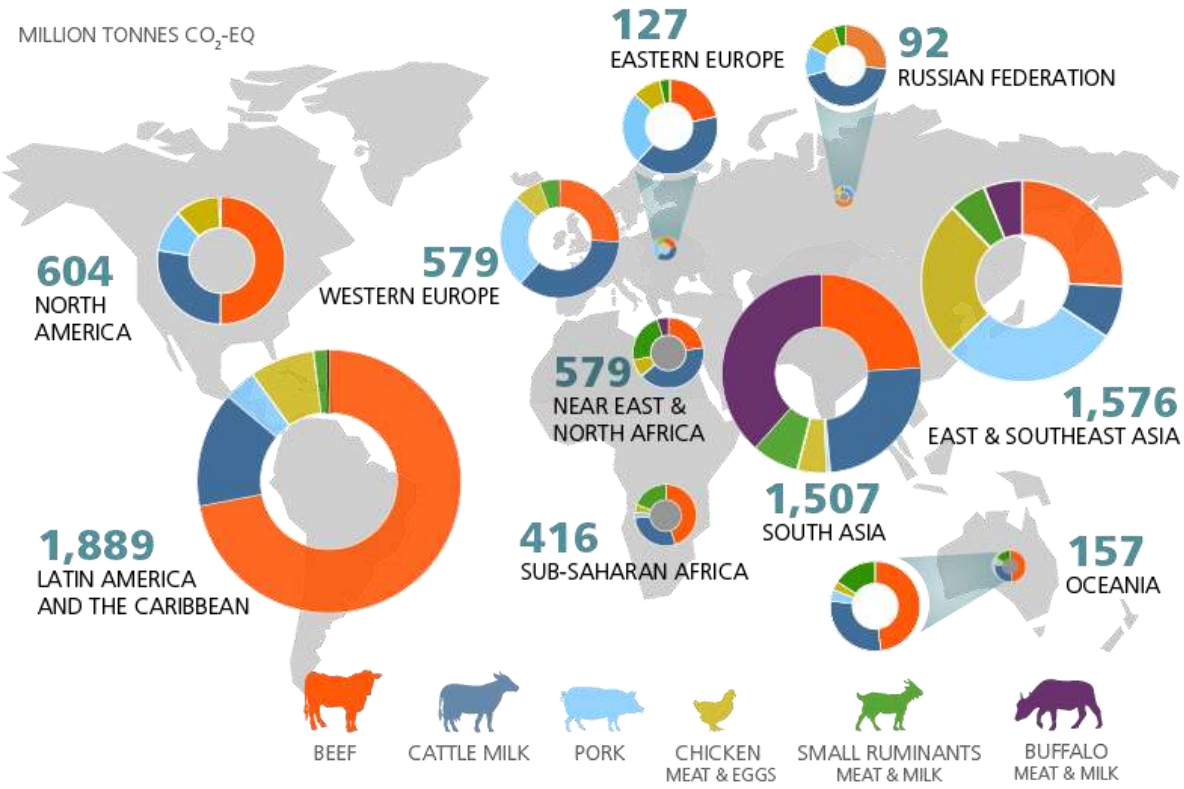


Figure 8: *A diagram of livestock emissions by region. Values are measured in MT CO_2 – equivalent. All contributing livestock are shown in the key, with corresponding colours. Source: Global Livestock Environmental Assessment Model, FAO (92).*

Livestock provide a food source for people the world over, contributing 18% of global calories and 34% of global protein consumption (93), while also producing the likes of milk and eggs. Therefore, finding ways in which to reduce methane production will be vital if climate targets are to be met. Scientist Dr. Suzanne Rowe is currently breeding strains of sheep that emit less methane than regular sheep in New Zealand (94). Methane in New Zealand accounts for one third of the country's GHG emissions, with methane from cattle and sheep being the greatest contributor in the country (94). The Cawthrorn Institute in Nelson has recently been granted $10m in New Zealand government funding for the cultivation of red seaweed, *asparagopsis armata,* a macroalgae proven to reduce methane emissions by up to 80% when added as a feed supplement (95). Not only are scientists

attempting to reduce methane output, they are also endeavouring to genetically design cattle that will flourish in the ever-changing climatic conditions, known as Climate Smart Cows (96).

In order to lay the groundwork for sustainable farming innovation, there must be an acknowledgement of the existing flaws in our current agriculture food systems. Cultivating new methods in which to feed the growing population will have to adapt and build on our vast knowledge of farming techniques and bring together this knowledge base to pioneer a more sustainable future.

4. Biotech Crop Based Innovation

Another way to ensure food security in the coming years is through crop-based innovation and the utilisation of biotechnology. Such innovation includes the likes of submergence tolerant crops, pest resistant crops, drought tolerant crops, increased lignin digestibility and the production of food products fit for consumption within the lab.

4.1 Submergence tolerant crops

As climate change persists, extreme weather events will increase in their intensity and become more commonplace. Every year, millions of farmers in some of the most poor areas of the world lose entire crop yields as a direct result of flooding (97). One of the staple crops utilised around the world is rice, where 24% is grown traditionally in paddies (97). However, the vast majority of rice will die when fully submerged for over a period of three days (97). According to the Ronald Laboratory, a specialist in crop genetics innovation and scientific literacy, submergence is responsible for the destruction of 4MT of rice per year which has the potential to feed up to 30m people in India and Bangladesh alone (97). As the Himalayan glaciers melt at unprecedented rates, most of Southern and South-eastern Asia will experience increased flooding in low-lying croplands.

A partial solution to this problem, that is anticipated to get increasingly worse, is the breeding of flood tolerant rice varieties (97). For over 40 years, plant scientists at the International Rice Research Institute have introduced submergence tolerance into different rice varieties used by rice farmers (98). However, due to this being a fairly novel technique at the time of its conception, many farmers noticed that despite notable submergence tolerance there was a considerable decrease in yield and grain quality (98). After this realisation, the *Sub1* gene was isolated as conferring submergence tolerance while not compromising on yield or grain quality (98). *Figure 9* illustrates the differences in rice varieties Swarna and Swarna-Sub1 when exposed to 5 days of complete submergence (99). Swarna is the most utilised rice variety in India with desirable traits such as high yield and grain quality along with requiring 25% less nitrogen than other varieties (100).

Figure 9: *An image highlighting the significant difference between the performance of Swarna (left) and Swarna-Sub1 (right) after 5 days of submersion in Bihar, India during the wet season.*
Source: Seck et al (101).

Seck *et al* estimate that we will need an additional 116MT of rice to feed the growing population by 2035 (101). Therefore, the continued use and scientific investigation of the *Sub1* rice gene will prove vital to those set to experience increased flash flooding in the coming years, more specifically in the likes of South and South Eastern Asia (98). Continued research into exploiting genes and then breeding such desired genes into differing varieties of staple crops will aid in ensuring food security and allow for prolonged sustainable farming.

4.2 Pest resistant crops

Plant pests and pathogens have plagued the agricultural industry for centuries causing enormous food shortages and famine. Examples include the 1942-43 outbreak of Brown Spot fungus in India (*bipolaris oryzae, syn. helminthosporium oryzae)* that destroyed between 50-90% of all rice crops in the Bengal area (102). Another perhaps more well-known plant disease is 'Potato Blight' (*phytophthora infestans*), which was responsible for the infamous Irish Potato Famine between 1845-1852, killing around one million people (103). As a direct result of changing climates, pests and pathogens now pose an even greater threat to ensured food security and are responsible for between 20% and 40% of all global food losses. (104)

However, thanks to developments within the scientific community we now have the ability to breed Genetically Modified (GM) crops that have been altered to be toxic to certain pests (105). These crops are often referred to as 'Bt crops' and are predominantly either cotton or maize (105). Bt crops are often grown in amongst non-GM crops in order to reduce the probability of the pests conferring resistance (105). Additionally, there are also crops bred to be herbicide resistant, more specifically to glyphosate (106). These crops include soybean, maize, canola, cotton, sugar beet and alfalfa (106).

Risks involved with GM crops include target pest resistance where there is an over reliance of Bt crops without the correct implementation of both Integrated Pest Management (IPM) and Insecticide Resistance Management (IRM). IPM, according to the US EPA, refers to the "environmentally sensitive approach to pest management that relies on a combination of common-sense practises" (107) These practices include compiling information related to the life cycles of pests and their interaction with the surrounding environments (107). This then enables farmers to handle pest damages in the most economical manner while causing the lowest possible harm to surrounding people and the environment (107). IRM on the other hand refers to methods pertaining to preventing or delaying resistance developing to insecticides (108).

Despite this setback, IRM programs have been adapted to be proactively utilised when Bt crops are in commercial use (106). Such programs are mandatory in the likes of the USA, Canada, Australia, the EU, the Philippines and South Africa (106). As we move towards more sustainable farming practises we must move away from using the likes of insecticides and pesticides which lead to environmental and soil degradation.

4.3 Drought-tolerant crops

Drought is one of the greatest threats to agriculture across the world and presents a major risk to global food security. The advancement of plant biotechnology over recent years provides hope for the future of crop development in water scarce conditions. Through genetic engineering of *Arabidopsis thaliana,* scientists have uncovered the main response mechanisms to drought stress while also inserting several drought resistant genes into crops (109). However, after the insertion of such resistant genes there was a notable reduction in crop yield (109). The Centre for Research in Agricultural Genomics, an independent and autonomous organisation striving to "translate the results of its research into benefits for

society” (110), has uncovered a method that confers drought resistance while not compromising on yield (109). Brassinosteroid hormones control the developmental responses during root growth, by increasing these receptors in certain plant tissues it was observed to not impact growth (109). It is the hope that this remarkable discovery will inspire further research into this area with the hope of generating drought-tolerant cereals (109).

The benefit of drought tolerant crops is that they are able to continue growing even when water is scarce. The continent of Africa is extremely prone to droughts, occurring every year and costing around $327 bn (111). Droughts impact smallholder farmers the worst as they solely rely on rainfall for their crops where others would rely on irrigation systems (111). A solution to this problem would be through the integration of drought tolerant crops. Currently, around 40m smallholder farmers throughout SSA have benefited through the utilisation of over 200 drought tolerant maize varieties (111). Challenges associated with the implementation of such crops include the time in which it takes to breed the crops as well as the investment required to make them readily available to farmers. Despite such obstacles, institutions such as the International Maize and Wheat Improvement Centre and Kenya’s Agricultural Research Institute have invested heavily in breeding programs to help strengthen the adoption of drought tolerant crops across Africa (111).

In China, water shortages are becoming more common as a direct result of population growth, increasing urbanisation and industrial water use (112). The country experiences little rainfall in its north and seasonal droughts in the Southeast. Of the variable water supply available, the vast majority is going towards rice production with one kilogram of rice requiring 4,000 litres of water (112). Researchers at the University of Cambridge’s Department of Plant Sciences have identified a gene known as OsLG3 which has been directly linked to drought tolerance (112). In addition to this, soil found in coastal provinces of China contain higher than normal amounts of salt which can become more concentrated when rainfall is scarce (112). When the salt content is too high in soils it drives the plant into osmotic stress leading to shrinkage thus limiting both growth and productivity (112). Green Super Rice provides a solution to this problem. Through backcross breeding, where genes associated with the desired trait are bred into a second variety through hybridisation, the new variety is able to produce high yields while also being tolerant to high salt content within soils (112). Thus, plant based scientific innovation is moving in the right direction and is working to mitigate the impacts felt in the agricultural community as a result of climate change.

4.4 Improved lignin digestibility

As we move towards net zero, there will be an increasing need for biofuels as we make the transition from purely fossil based fuels through to electric powered vehicles. Biofuels are those which are produced from plant, algae material or animal waste. Due to the readily availability of these feedstock materials, biofuels are commonly thought of as a renewable energy sources (113). In order to breakdown feedstock materials into biofuels, the complex cell wall of the plant material must be made accessible. The crosslinked structure of the plant polymers makes feedstock materials extremely difficult to breakdown, one of these components is known as lignin (114). Lignin is defined as a class of complex organic polymers which act as essential materials in the structural integrity of most supportive tissues in plants (115).

Biomass feedstock is attributed to agricultural waste through farming, where the primary component, lignin, is too difficult to breakdown for fuels so a large majority is burned in order to make way for the next crop cycle. The International Rice Research Institute reports that between 800-1,000MT per year of rice straw is produced with an impressive 600-800MT in Asia alone (116). A staggering 80% of rice straw produced is burnt every year contributing considerably to air pollution (117). In Delhi, India a public health emergency was announced in 2019 as a direct result of air pollution, some of which can be attributed to farmers burning feedstock in fields to keep up with the increasing demand for crops (118). India's federal environment minister highlighted that burning in fields contributed up to 4% of New Delhi's total air pollution in October 2020 (118). *Figure 10* reinforces this statement by illustrating the extent at which crop burning in areas northwest of Delhi impacts air quality in peak burning months of the year (118).

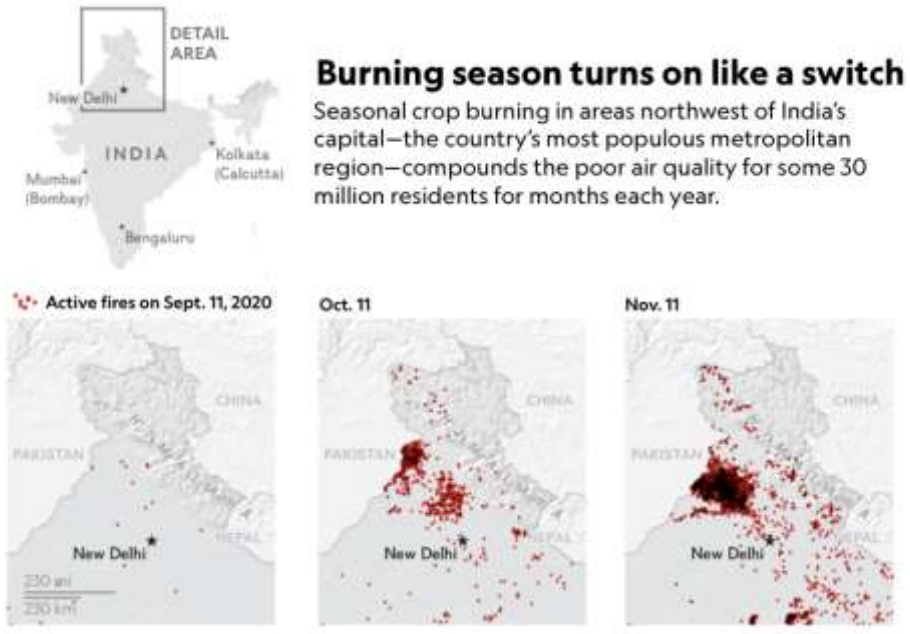


Figure 10: *Illustrates the extent at which field burning increases across New Delhi from September 11 2020 to November 11 2020, affecting air quality for the 30 million residents of the region each year.*
Source: National Geographic (118).

Therefore, attempting to improve the digestibility of plant biomass, more specifically of lignin, has great potential value for livestock feed and in industrial biotechnology (119). Improved digestibility would utilise biomass feedstock making it more useful in fuel production and in animal feeds thus reducing the necessity to burn rice straw year-round. This in turn would make farming around the world more sustainable by reducing air pollution considerably and by encouraging further research into the breakdown and usefulness of lignin digestibility.

5. Case study: Farming in India

India is home to some 1.27bn people, making it the second most populated country in the world behind China (45). The country itself has a long history of farming beginning as early as 9000 BCE and has since established itself as the world's largest producer of milk, pulses and jute and the second of rice, wheat, sugarcane, groundnut, vegetables, fruit and cotton (120). India also has an economy worth $2.1 trillion ahead of both the US and China (120). Agriculture is said to account for the greatest number of livelihoods in the country where in 2016 it employed 59% of the country's total workforce (120). The country is home to the highest mountain range, the Himalayas also known as the 'Water Towers of Asia,' that supply water to the likes of the Indus and the Ganges which provide a lifeline to over one bn people (121).

Despite global leaders pushing towards more sustainable farming, a report from The Economic Times detailed that less than 4% of Indian farmers were adopting sustainable agricultural practices (122). Both the Council on Energy, Environment and Water, India and the Food and Land Use Coalition, India highlight that improving and utilising sustainable agriculture will be absolutely vital to improve India's nutrition security during the precarious climate-constrained environment we live in (122). NITI Aayog, an agency for the Indian federal government, aimed at achieving the SDGs with cooperative federalism through economic policy-making has said that "embracing sustainable agriculture could not only lead to better incomes but also have multiple environmental benefits" (123). The Vice-Chairman Rajiv Kumar goes onto say "our focus is on promoting sustainable agriculture, especially natural farming in India. This would benefit small and marginal farmers" (122).

All of this considered, India has been making strides towards organic farming and agriculture and is now one of the largest producers of organic produce in the world (115). There are four basic principles of organic farming; health, ecology, fairness and care which are further illustrated in *Figure 11* (115). Each principle works in the best interest of people in terms of nutrition and for the environment with an emphasis on sustaining food production for future generations (124). Organic agriculture will undeniably help towards the move to sustainable development and integrates three overarching goals: environmental health, economic profitability as well as social and economic equity.

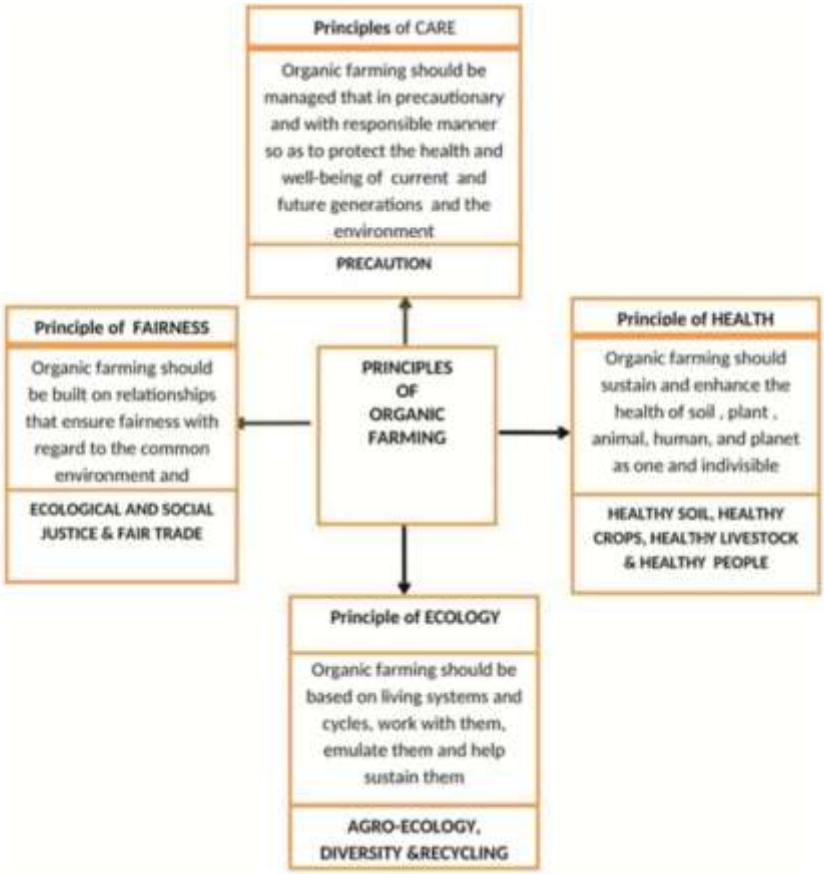


Figure 11: *A diagram that further elaborates on the four main principles of organic farming as suggested by the International Federation of Organic Agriculture Movements.*
Source: Organic farming in India: a vision towards a healthy nation (124).

Farmers in India suffer considerably from the confines of the poverty cycle as a result of persistent debt and this has tragically resulted in a phenomenon of farmer suicides (125). A recent study accounted 11.2% of all suicides in India to farmers where around 41.49% of the total labour force works within the agricultural industry (126). Soil degradation and variable climates are wreaking havoc on farmers, especially those in developing nations, which is putting immense strain on achieving SDGs within the country. Despite several setbacks in India related to organic farming such as lack of marketing policies and inadequate farming infrastructure, the federal government has now brought in a number of programs to help boost organic farming within India (124).

One in particular is Zero Budget Natural Farming (ZBNF), which involves farming where the cost of growing and harvesting is zero through the elimination of external outputs by using local resources that are able to rejuvenate soils thus restoring the ecosystem naturally (124). The technique requires just 10% water and uses 10% less electricity than in traditional and

organic farming (124). Microorganisms found in cow manure are used to decompose dried biomass found in soils and convert it to nutrients available for plants (124). Such a method has the potential to enhance the livelihood resilience for smallholder farmers when considering climate and land use changes while also improving their quality of life through improved income and food security (125). As part of the ZBNF initiative, which is supported by the UN Environment Program, they are removing chemical usage from farms (127). Fertilisers have in the past been attributed to improving crop yields and lifting millions out of famine, but in more recent times are thought to be the primary cause of soil degradation, health issues and resultant stagnant productivity (127).

The COVID-19 pandemic has devastated India and its people. As of August 2021, there had been a reported 32m cases of COVID-19 and a further 429,000 deaths with a staggering 134,000 of these deaths isolated in the Indian state of Maharashtra (128). There was a stark difference between the first and second wave of COVID in India with the second wave "spreading like a tsunami in India" (129). This has been attributed to the mutant variant which was considerably more transmissible. The dramatic increase in cases resulted in the exhaustion of both resources and the workforce and a shortage of hospital beds, medicines and more widely reported upon shortage of oxygen and ventilators in hospitals (129).

The existing strain on food security has been severely heightened by the pandemic and is generating a "hunger catastrophe" in the country (130). The World Economic Forum elaborates by saying; "the pandemic has led to an increase in global food insecurity, affecting vulnerable households in almost every country (130). It has exacerbated existing inequalities, pushing millions of people into the vicious cycles of economic stagnation, loss of livelihood and worsening food insecurity" (130). Moreover, it is estimated that a further 130m could become food insecure as a direct result of the COVID-19 pandemic (130).

The Centre for Monitoring Indian Economy, established in 1976 is an independent think tank and leading business information company (131), has released data highlighting the burden the pandemic has put on agricultural communities. As it stands, rural unemployment is at 14.34% which is as a result of disrupted food supply chains and restricted access to markets due to regional lockdowns (132). As a consequence of lockdown protocols, many people migrated into rural areas causing an influx of people and an increased demand in work (133). This influx has led to a depression in wages and has affected the viability of employment within the agricultural industry which has then impacted food production (133). The vast

migration of workers across India also resulted in farms being severely understaffed as those living in urban areas were unable to make the commute during harvest seasons (133). Such farms are responsible for the vast majority of food production across the entirety of India, and with the inability to produce or transport food produce, food insecurity has dramatically increased (133). As a result of such an unprecedented pandemic, India is unlikely to reach zero hunger by 2030. Thus, there is a train of thought arguing for the importance and essentialness of both domestic and international intervention.

The US International Development Finance Corporation are working to strengthen food security in the wake of COVID-19 (134). Through the acknowledgement of weak supply chains and the issue of transportation they have worked to make food more accessible to more people (134). Through a $15m equity investment a company called Freshtohome Foods Ltd. will expand its already established e-commerce business to sell fresh produce in metropolitan cities across India (134). Their business model helps both the consumer and the farmers by allowing them to earn more than they typically would at markets (134). Moreover, the business hopes to introduce 42 fish farms and advanced aquaculture and aquaponic technology to help increase yields and improve on traditional methods (134). This is a key example of how international intervention can have a truly positive impact on the agricultural industry, through providing access to food while also improving existing infrastructure.

India has made extremely positive steps towards sustainable food production, especially under the pressure of feeding such a vast and growing population. Programs such as the ZBNF are encouraging as they demonstrate support for farmers and rural communities from the government as we move towards 2030 and 2050 goals. However, like most countries across the globe they have been ravaged by the pandemic and will have to take extensive measures to provide food security through sustainable and organic farming practises in the immediate future if there is any hope of ensuring food security. The country will be interesting to watch in the coming years as the world comes away from the pandemic.

Conclusion

The aim of this thesis was to analyse how sustainable farming will be essential to ensure food security for a growing population when considering differing factors, such as the worsening climate crisis and the COVID-19 pandemic. This analysis has explored policies related to sustainable development including the Paris Agreement as well as both European and US policies. This allowed for a global perspective on how world leaders are working towards sustainable development, as well as the differing approaches being implemented to achieve the same common goal – food security.

Through analysing the existing strain on food security, key areas of concern were highlighted that are exasperating food security, such as environmental degradation, climate change, lacking biodiversity in agriculture and COVID-19. This allowed for key insights into how each had implications towards threatening future food security. Once issues pertaining to ensuring food security were highlighted, approaches towards more sustainable farming were examined.

In order to work towards ensuring food security, innovative methods must be utilised such as the likes of aquaponics, hydroponics, reducing methane in livestock and crop rotation. These methods have already proven to be a great success around the world and are developing at a rapid rate. It is extremely likely that there will be further development in this area that will undoubtedly help towards achieving SDGs related to sustainability and food security. Plant technology is constantly evolving and there are already several plant varieties that will be vital to continued successful farming as our climate changes. Increased weather variability will wreak havoc on harvests therefore, introducing genetically modified plants that can withstand the ever-changing environment will be fundamental to food security.

Safeguarding food security is one of the greatest challenges of the twenty first century. Existing factors were already putting incredible strain on global food security and the COVID-19 pandemic has put further strain on an already unpredictable nature of food security. Sustainable farming practices coupled with plant-based innovation will be paramount to ensure any form of food security for future generations. Therefore, there must be collaboration between international governments, farming corporations, scientists and most importantly farmers. There must be a conscious move towards more sustainable farming

that does not leave traditional farmers behind. The concept of no one being left behind in the just transition could not be more applicable to the move towards sustainable agriculture.

Overall, this analysis has shone a light on the challenges associated with climate change and the assurance of food security. While we work to reduce emissions to curb the effects of climate change and planetary warming, we must incorporate how this will impact the livelihoods of those in currently unsustainable industries related to food production, as well as smallholder farmers. The case study analysis of India, both at federal and individual state (Maharashtra) level, has demonstrated that, despite efforts from the Indian government, the pandemic has set the country back on years of progress in food security. Therefore, moving forward, the policies that we have in place must not only incorporate warming temperatures and changing weather patterns but must also incorporate the likes of natural disasters and pandemics that cause damage at a much faster and devastating rate.

There is hope for the future of food security and the assurance of such for future generations, but the world and its leaders must act now and make better, more sustainable choices as well as realistic goals in order to achieve such enormous climate ambitions.

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