Discuss the challenges and opportunities available to ensure that food production is environmentally sustainable whilst providing access to adequate nourishment for the world's population.

Introduction

Food security is a fundamental human right, defined by the UN's Food and Agricultural Organisation (FAO, 1996) as 'the condition that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life'. In 2022, it was estimated that 29.6% of the world (2.4 billion people) were moderately or severely food insecure. Food security, however, goes beyond year-round food accessibility: it includes making sure that food is nutritious and affordable (FAO *et al.*, 2023). According to the World Health Organisation (WHO), 42% of the worldwide population are unable to afford proper nutritious food despite the average cost of a healthy diet being 3.66 PPP US dollars per person per day in 2021 (FAO *et al.*, 2023).

Food security, however, must be balanced with environmental sustainability. As defined by the UN, sustainable development is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (UN, 2022); a sustainable environmental focus means making sure that environmental resources are used responsibly. As such, environmental sustainability is vital to food security, as efforts need to be made now to ensure that adequate amounts of nutritious food will be available in the future. Through the Sustainable Development Goal (SDG) of 'Zero Hunger', the UN pledges to 'end hunger, achieve food security and improve nutrition and promote sustainable agriculture' by 2030 (UN, 2022). Vitally, food security is also intertwined with the other 16 SDG goals such as 'Climate Action', 'Responsible Consumption and Production' and 'Life

Below Water' (UN, 2022). For the UN, quite rightly, food security is inseparable from environmental sustainability.

This all-important balancing is deeply challenging. There are several issues associated with food production: from immediate, unpredictable challenges such as regional conflicts to longer term challenges such as population growth and climate change. Meanwhile, the other two key impediments to global food security - access and nutritional quality - must be considered. These will be detailed in **Section 1: Challenges**.

There are many opportunities, however, for these food security challenges to be met in an environmentally sustainable manner, as I will outline in **Section 2: Opportunities**. These can be broadly grouped into three main areas: development of new technologies, encouragement of behavioural changes and policy shifts. Implementation of these interlinked opportunities would allow environmentally sustainable global food security to be achieved.

Section 1: Challenges

At 2978 kcals per person per day, there is currently enough food to feed the global population, but food insecurity persists (DEFRA, 2024). Meanwhile, adequate calories do not always equal adequate nutrition: the wide availability of convenient, pre-prepared foods at a low price-point means that global diets have become less nutritious. Fundamentally, the challenges are complex and intertwined; as the DEFRA (2024) UK Food Security Index 2024 puts it, 'sufficient supply at the global level does not translate into food security for all.'

The Global Food Security Index, or GFSI (Economist, 2022) – seen mapped here (**Figure 1**) – is a measure of food security applied to 113 countries which considers four main factors: affordability, availability, quality and safety, sustainability and adaptation. The nine countries displayed here (**Figure 2**) - Finland, Norway, the United Kingdom, Singapore, Morocco, Sudan, Haiti and Syria - have been selected here as they help to illustrate the

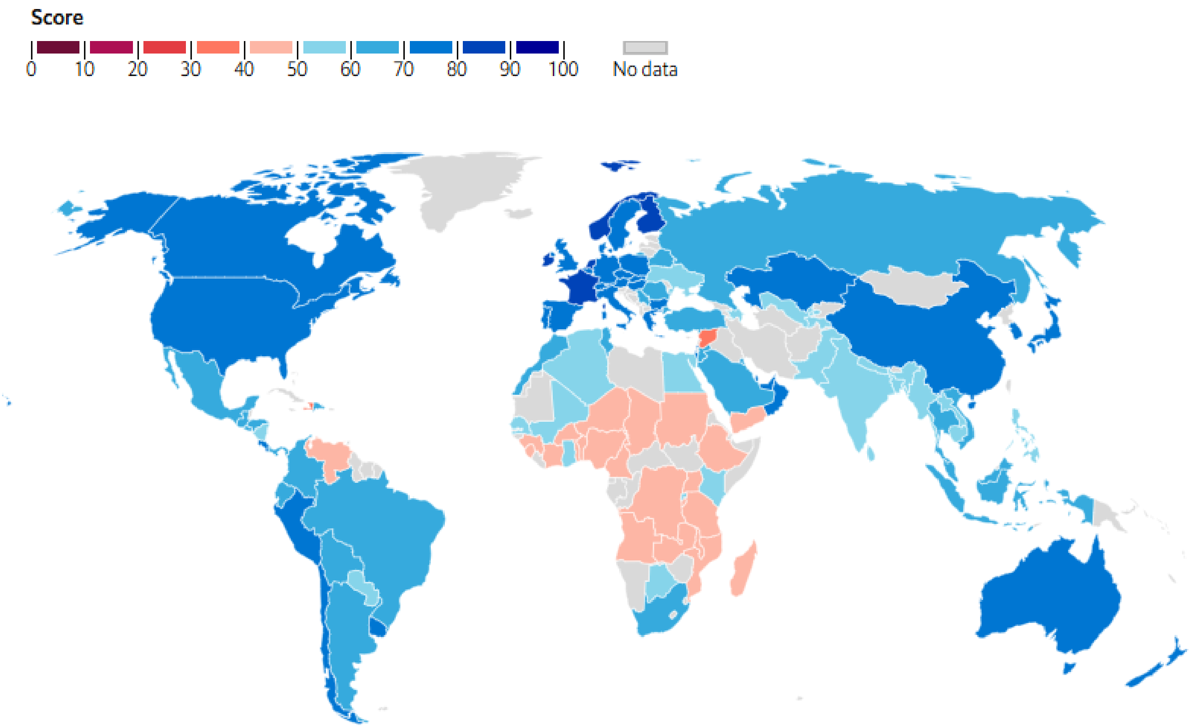


Figure 1: Economist (2022) *Global Food Security Index Map.* Source: https://impact.economist.com/sustainability/project/food-security-index/#introduction

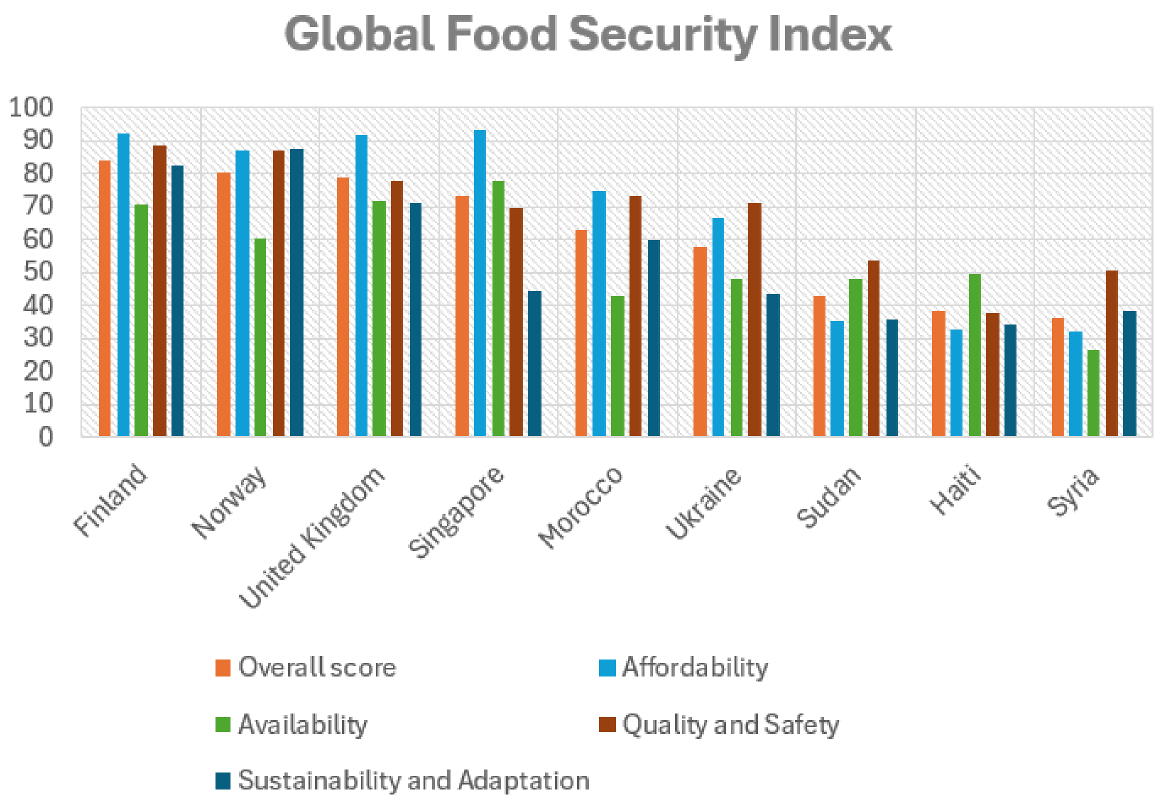


Figure 1: Author's own (2024), *Visualisation of the Global Food Security Index for Selected Countries.* Source: Made by author.

varying food security challenges faced across the globe.

Conflict is an immediate term but highly unpredictable challenge for global food production and access. For example, the Russia-Ukraine war (2022-ongoing) has resulted in 1 in 5 Ukrainian families being food insecure (WFPa, 2024). Despite this, hunger in the population remains ‘Low’ as per the Global Hunger Index (2023). The bigger problem is international: Ukraine - a main exporter of sunflower oil, corn, wheat, rapeseed and barley (FAO, 2022a) - is no longer able to produce and export food globally to the same extent. In fact, their first wartime harvest was halved. The effect on the world’s global food system has been enormous: FAO (2022a) predicted that 500 million more people would face acute hunger due to war-related shortages in 2023. Prices also soared, with the UN reporting that food prices grew by 34% in the year to March, with cereal prices increasing by 37% (FAO, 2022b). This map from Our World in Data (Roser and Ritchie, 2013) vividly demonstrates this inflation (**Figure 3**): aside from five countries, every country measured experienced an annual increase in food price inflation.

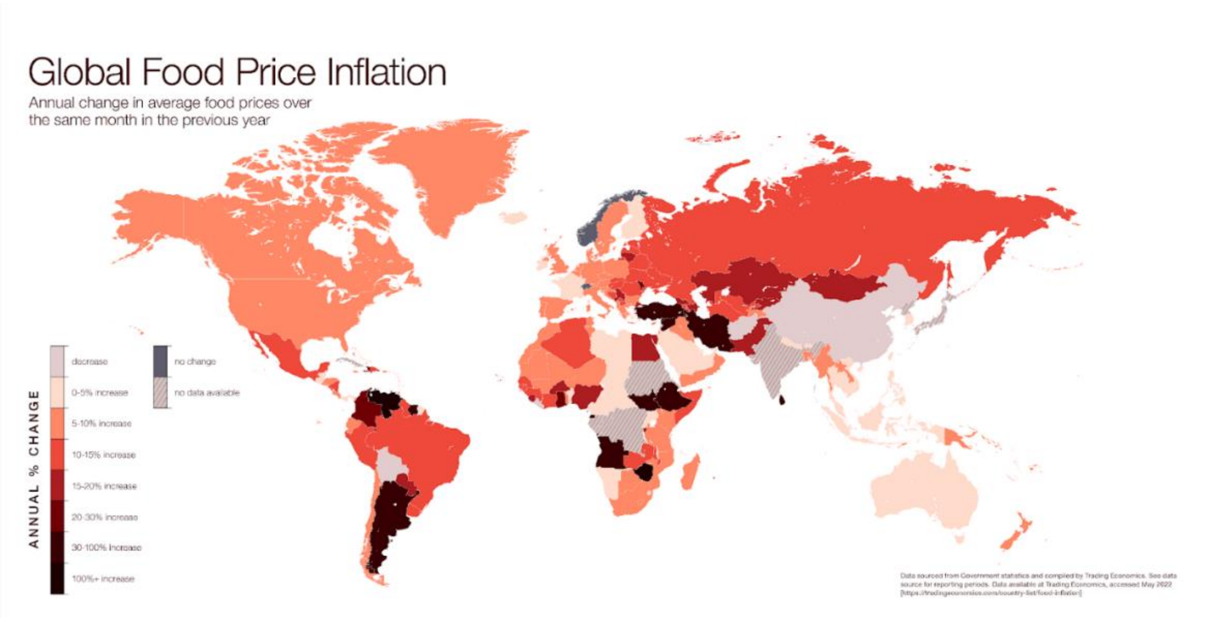


Figure 2: Roser and Ritchie (2013), *Global Food Price Inflation Map*. Source: https://ourworldindata.org/food-prices

In Sudan, the civil war (2023 - ongoing) has significantly impacted adequate nutrition for the population, affecting both production and accessibility of food nationally. Now, Sudan has the highest number of people facing ‘emergency levels of acute food insecurity’: 20.3 million, while more than 3.3 million children are suffering from ‘acute malnutrition’ and 700,000 from ‘severe acute malnutrition’ (D’Silva, Ibrahim and World Economic Forum, 2024). Sudan’s agriculture sector has been largely affected: there have been halts in harvesting, declining production and disrupted planting; meanwhile, distribution has been obstructed by blocked roads and destroyed infrastructure (OCHA, 2024). Families in Sudan are struggling to access food supplies as subsistence farming is not possible due to loss of land and displacement - 6.3 million people are internally displaced (OCHA, 2024). Here, unlike in Ukraine, the food security problems are felt primarily on the national level.

One of the greatest long-term challenges to food security is population growth. As the world’s population increases, so too will demand for nutritious food. In Nature Food, van Dijk *et al.* (2021) estimate that global food demand will increase between 35% to 56% by 2050, suggesting that food production will have to increase proportionally. Some countries - mainly developed western countries such as Finland, Norway and the United Kingdom - have highly stable populations (World Population Review, 2024a; World Population Review, 2024b; World Population Review, 2024c) meaning that their food industries will not have to adapt to population increases on a national level. Meanwhile, many developing countries are undergoing rapid population growth: Syria currently has the highest rate of population growth (World Population Review, 2024d) and Sudan has a high birth rate at 4.43 births per woman (World Population Review, 2024e). As explored above, Sudan’s food security has suffered greatly due to the civil war, while 2.6 million Syrians are already at risk of hunger in 2024 and 8 in 9 children currently do not meet minimum nutrition requirements (WFP, 2020). As such, population growth is a significant challenge to global food security, especially as it is forecast to impact already struggling countries.

Finally, climate change is the biggest challenge to food production long term, as the effects will continue to worsen unpredictably over time. These are worst in countries - like Haiti - that are at heightened risk of natural disasters and extreme weather, but the risks should not be underestimated in ostensibly more climate-resilient countries like the United Kingdom. In Haiti, climate change has exacerbated the intensity and number of natural disasters such as storms, flooding and earthquakes - in fact, Haiti was ranked third in 2021 on the Climate Risk Index of countries most affected by extreme weather events (Eckstein, Künzel and Schäfer, 2021). These events, alongside factors such as civil unrest, have resulted in nearly half of Haiti's population - 4.35 million people - not having enough to eat and 1.4 million facing emergency levels of food insecurity (WFP, 2024).

Meanwhile, in the United Kingdom, increasingly warm and wet weather is causing cereal crops to be at heightened risk of failure. For several of the months between October 2023 and March 2024, parts of the UK had monthly rainfall totals that were double the 1991-2020 monthly averages (Met Office, 2024). Climate change was a primary topic of concern for a UK-based farmer I interviewed (Knight, 2024). She stated that 'in the last three years increased rainfall in the growing season has caused flooding, meaning we have had to re-sow in the spring due autumn-sown crop failing. On our heavy clay soil, too much rain can be disastrous.' Furthermore, she added that wetter summers can lead to rotting or substandard crops, whilst hotter summers can lead to fields of wheat going up in flames, as seen at multiple farms across the country (BBC News, 2022). Due to this, the farmer is considering transforming the land from arable into grassland, to enter the biodiversity credits market and minimise risk: 'It's a tricky decision, as we know the importance of food production. But with what’s happening with the climate, we’re just not sure that traditional farming is viable’ (Knight, 2024).

Climate-based food security challenges will arise everywhere. In Sudan, encroachment of the Sahara Desert, increasing temperatures and more flooding in areas of the Nile Basin are causing losses of arable land, drought and a lack of water available for agriculture (USAID, 2016). Meanwhile, Singapore is experiencing unusually late monsoon surges, leading to soaring temperatures and increased winds (Meteorological Service Singapore, n.d.). In Morocco, there is a shortage of available water due to an increase in natural hazards, such as earthquakes (World Bank Group, 2021). Whilst local, national and global efforts have been made to try and slow the effects of climate change - such as the SDGs - it is an ever-growing problem that will affect food production worldwide: a smaller and more unpredictable supply of food will lead to greater food insecurity and hunger worldwide.

In addition to this web of challenges, environmental sustainability can be somewhat at odds with maximising yields. In **Figure 4**, the graph shows that only just over half of the world’s population could be fed without inorganic fertilisers derived through the Haber-Bosch process (Ritchie, 2017), a high-pressure chemical reaction between nitrogen from the air and hydrogen (Sciencedirect.com, 2018). This process is currently responsible for 1.8% of global carbon emissions (Sciencedirect.com, 2018), and the application of these fertilisers can cause dramatic environmental impacts, such as eutrophication, soil degradation and

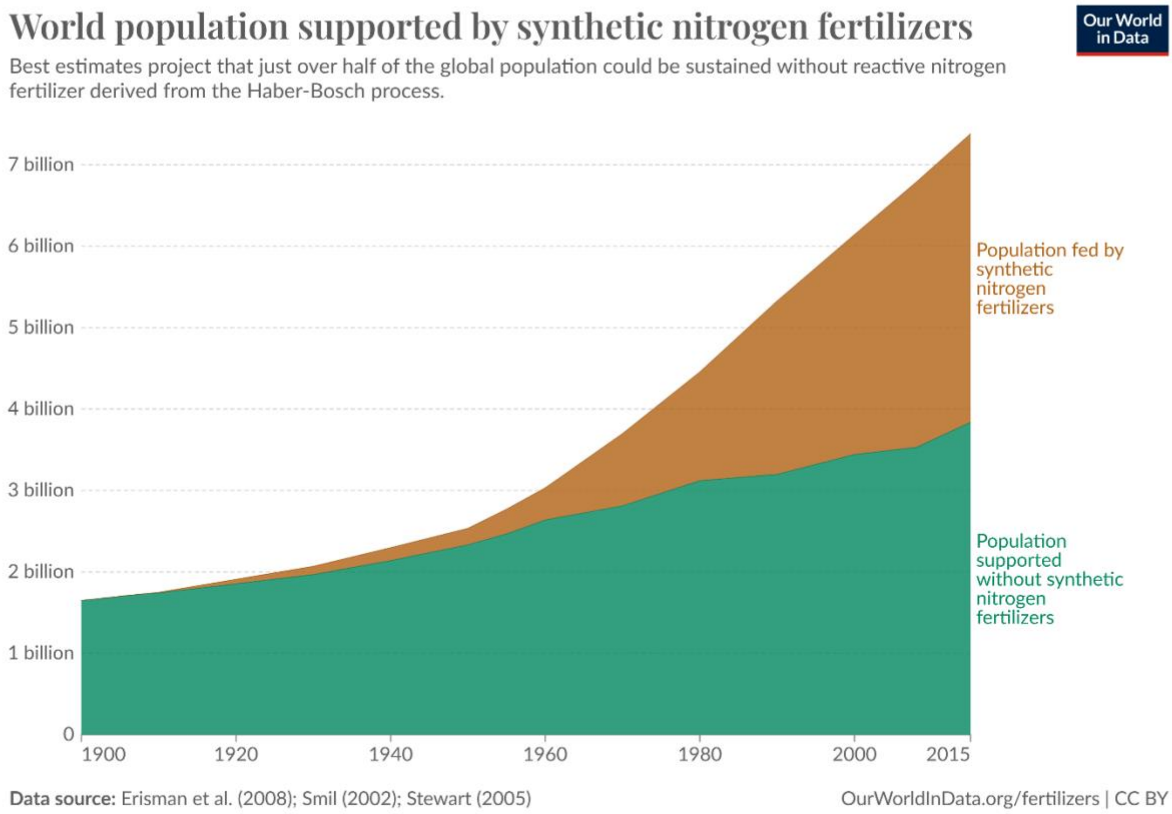


Figure 4: Ritchie (2017) *World population supported by nitrogen fertilisers*. Source: https://ourworldindata.org/how-many-people-does-synthetic-fertilizer-feed

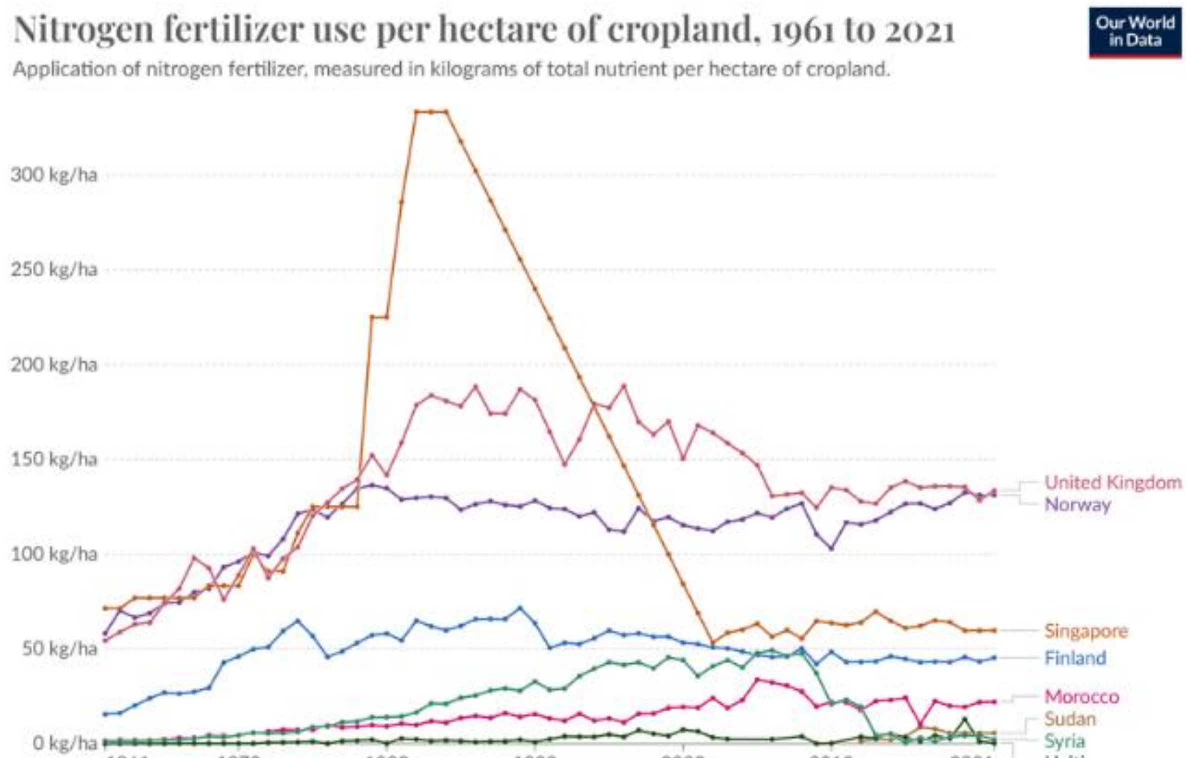


Figure 3: Our World in Data (2024) *Nitrogen fertilizer use per hectare of cropland, 1961 to 2021*. Source: https://ourworldindata.org/grapher/nitrogen-fertilizer-application-per-hectare-of-cropland?tab=chart with author's filters.

inversely with those that use the most fertiliser per hectare, as we can see in **Figure 5**. This suggests that the transition towards more sustainable fertiliser use in food production may have a bigger impact on these countries.

Section 2: Opportunities

The challenges to global food security are enormous. There are, however, already plenty of opportunities that could help to resolve these challenges. These can broadly be grouped into three main areas: technological solutions, behavioural shifts and policy shifts.

At the forefront of technological solutions is the creation of new foodstuffs that could replace non-sustainable options. The first plant-based meat replacement - the Kellogg brothers' 'Protose' made from peanuts and wheat gluten – was made in 1877 (Bertini, 2023). In 2021, the global plant-based meat market was valued at $5.3 billion in 2021; it is projected to reach $33.3 billion by 2031 (Allied Market Research, 2021). The market is mainly growing in more developed countries where people have more disposable income and more ability to make conscious choices.

Many new companies, such as Beyond Meat and Impossible Foods, and traditional meat producers, such as Richmond Sausages, are starting to provide plant-based meat. The aim is to make the most meat-like food: realistic in appearance, texture and flavour. Most plant-based foods use a mixture of starches, flours and hydrocolloids (a type of carbohydrate which thickens the solid and acts as a water retention substance) as well as soy, wheat, pea proteins, pulses, seaweed, algae and hemp (McHugh, 2019). Meanwhile, food scientists use various processes to affect the look and texture of the final product. Most common is high-moisture extrusion technology, which is used mainly to create meat and seafood textures by altering the structure of the protein through a series of thermal and mechanical pressures (McHugh, 2019). To replicate colour, food scientists use beet extract, pomegranate powder and soy leghaemoglobin (McHugh, 2019). All these efforts to perfect the aesthetic and feel of the product are vital to the consumer appeal, making plant-based meat meat-like and appealing.

Some critics, such as nutritional scientist Catherine Baungaard (2024), question these meat substitutes as they do not contain the nine main amino acids needed for adequate nutrition. She believes that fungi-based meat replacements, such as Quorn, could fill this gap. According to Nguyen (2020), Quorn-style meat substitutes use mycoproteins - super proteins made from a natural fungus - and mixes them with water, oxygen, nitrogen, glucose and other nutrients to feed the fungus, resulting in fermentation. This causes the mycoprotein to grow quickly: it can double in size every five hours. This technique massively decreases the carbon footprint per kg, while also greatly reducing land use. In fact, Quorn (n.d.) have found that their product releases 0.5 kg of CO_2 per kg compared to UK beef mince, which releases 32 kg of CO_2 per kg.

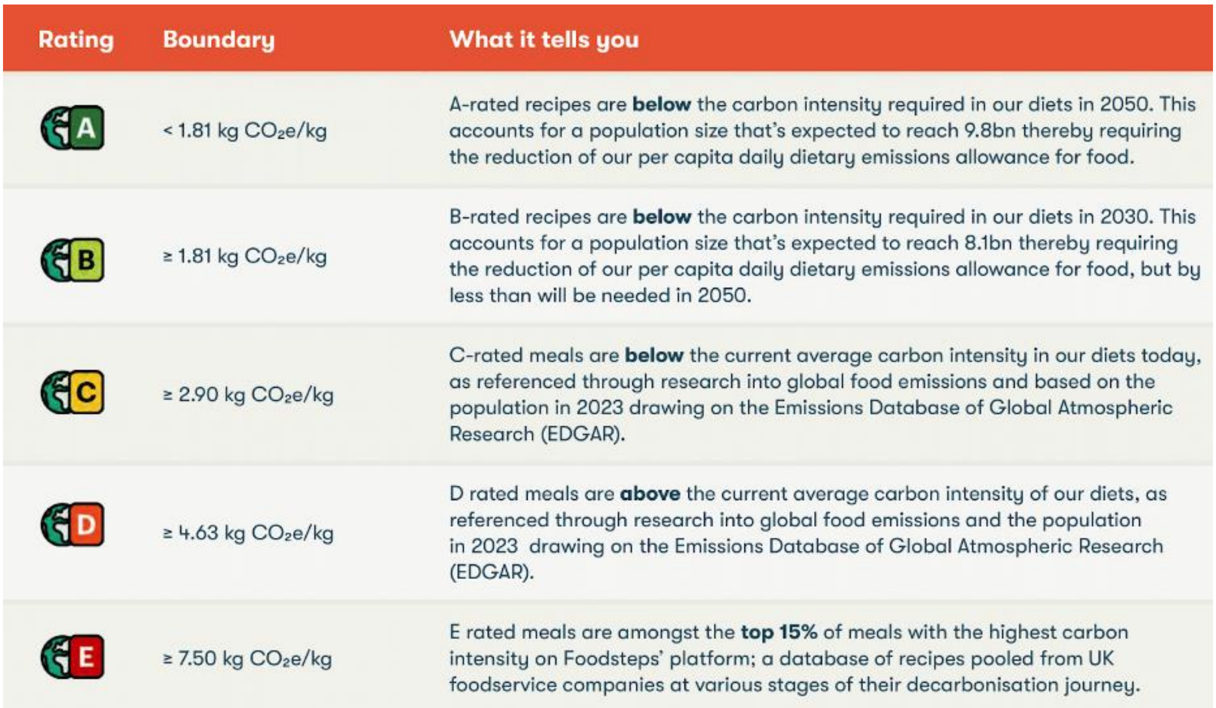
Another novel opportunity is 3D printing, where lab-grown cells - animal or plant-based - are converted into bio-inks, which are then printed and pressed into a 3D edible shape. Scientists often use algae, cultivating it with light and photo-cross-linkable alginate-based microgels to create cell-loaded jammed bioinks (Shepheard, 2023). 3D printing of meat and seafood is sustainable as it protects our oceans and saves land used for farming without compromising on nutritional value or product (Shepheard, 2023). However, currently 3D printing of food is expensive and highly energy intensive – so it would rely on renewables to be sustainable and may not be achievable for lower income countries. Furthermore, this process is slow, as each steak needs to be made individually and technology is still developing, so this solution, whilst potentially viable in the future, does not fully solve the issue of food production right now.

There are also plenty of opportunities beyond meat, such as agroforestry, vertical farming and microbial fertilisers. Agroforestry is a regenerative farming process: growing crops alongside rainforest plants to promote biodiversity and closed nutrient cycles, thus decreasing deforestation, which depletes the natural carbon sink and releases CO_2 into the atmosphere (Sustainable Harvest International, 2024). It also reduces the input of agrochemicals which pollute the soil and cause eutrophication (Slavikova, 2019). A larger proportion of farms using agroforestry would help to make food production more environmentally sustainable as well as being easily scalable, so that the food production sector can grow with increasing populations.

Vertical farming is another solution where rows of crops are grown on stacked shelves in warehouses. This technique reduces the space needed for farming: vertical farming requires 95% less land than traditional greenhouses (ifarms, n. d.) and yields nearly 400 times the amount of produce per square foot (Myers, 2019). It also uses 95% less water than traditional farming (ifarms, n. d.), as water is recycled after dripping down through the trays by being pumped to the top where the process restarts. Furthermore, pesticides are not needed, as controlled indoor environments eliminate risk of pests. Like 3D printing meat, however, vertical farming is highly energy intensive and costly and therefore not currently a practicable solution.

Finally, according to Mitter *et al.* (2021), the emerging technology of microbial fertilisers has great potential: biofertilizers may help plants absorb more nutrients, produce a larger amount of growth hormone and create phytochemicals, so crops are of higher quality. Therefore, biofertilizers could eliminate the use of chemical fertilisers in favour of an environmentally sustainable alternative, while also creating higher quality more healthy food.

These technologies all provide exciting opportunities; however, encouragement of behavioural changes is also key to environmentally sustainable global food security. Without consumers changing their conception of a proper meal, implementation of new technologies will be limited by consumer choices. Catherine Baungaard (2024) insists on the importance of changing the culture around having meat-based meals and disrupting the common association of meat with ‘health’ and ‘strength’. According to Baungaard (2024), one way to encourage change in consumer behaviour is nudging: subtly promoting positive habits so that behaviour can be influenced without restricting choice (Hansen, 2016). One example of effective nudging is Foodsteps, a company that labels food choices with a carbon footprint traffic light system (**Figure 6**). These simple, visual images make consumers aware of the environmental impact of diverse food options, empowering them to make responsible choices. Using the EAT-Lancet Commission data, which set a global carbon budget for the food system (farm stage only) at 5 gigatonnes of CO2e per year, Footsteps (2019) have calculated that there is a carbon intensity allowance of 2.45 kg CO2e per person per day.



Rating	Boundary	What it tells you
A	< 1.81 kg CO_2e/kg	A-rated recipes are **below** the carbon intensity required in our diets in 2050. This accounts for a population size that's expected to reach 9.8bn thereby requiring the reduction of our per capita daily dietary emissions allowance for food.
B	≥ 1.81 kg CO_2e/kg	B-rated recipes are **below** the carbon intensity required in our diets in 2030. This accounts for a population size that's expected to reach 8.1bn thereby requiring the reduction of our per capita daily dietary emissions allowance for food, but by less than will be needed in 2050.
C	≥ 2.90 kg CO_2e/kg	C-rated meals are **below** the current average carbon intensity in our diets today, as referenced through research into global food emissions and based on the population in 2023 drawing on the Emissions Database of Global Atmospheric Research (EDGAR).
D	≥ 4.63 kg CO_2e/kg	D rated meals are **above** the current average carbon intensity of our diets, as referenced through research into global food emissions and the population in 2023 drawing on the Emissions Database of Global Atmospheric Research (EDGAR).
E	≥ 7.50 kg CO_2e/kg	E rated meals are amongst the **top 15%** of meals with the highest carbon intensity on Foodsteps' platform; a database of recipes pooled from UK foodservice companies at various stages of their decarbonisation journey.

Figure 5: Foodsteps (2019), *‘Traffic light’ carbon rating infographic*. Source: https://www.foodsteps.earth/faqs

Foodstep's calculations show that, currently, the average global diet is 6.13 kg CO_2e per day - nearly 3 times more than the allowance. The hope is that nudges, such as those enabled by Foodsteps, will allow people to make informed, sustainable choices.

While important, individual behavioural changes can only go so far. Policy shifts will have to be made both locally and globally to make sure that people are able to access food that is environmentally sustainable and adequately nourishing. Radical shifts may be needed, such as 'Reboot Food' proposed by WePlanet (2024). Some of these include making sustainability labelling - such as Foodsteps' – mandatory, stopping subsidies for animal agriculture while implementing a just transition for farming communities and investing 2.5% of a country's GDP over ten years into rebooting food systems. Similarly, large-scale subsidisation of sustainable, nutritious food choices would encourage positive behavioural shifts and allow lower-income families to feed their families nutritiously and sustainably. Or, as advocated by environmental campaigner George Monbiot (2022), fermentation could be localised, solving the challenge of distribution and its negative environmental impacts: 'every town could have an autonomous microbial brewery, making cheap protein-rich foods tailored to local markets'. Policy shifts such as these would allow the exciting opportunities detailed above to make meaningful change to global food security.

Conclusion

There is an ethical global duty to address the huge and ever-growing problem of inadequate food security. Meanwhile, it is vital to keep environmental sustainability at the forefront of food security solutions: for the environment itself, but also to ensure longer-term food security. Thankfully, as explored above, there are plenty of food security opportunities that do not sacrifice environmental good. Despite these fabulous innovations, however, behavioural changes and expectation shifts will have to occur. Fundamentally, we cannot rely on individuals to make the structural changes needed to fix these issues; governments need to make the first and most radical changes, to make possible environmentally sustainable food security for all. This would allow the world to shift away from a crisis-management approach to food security and towards robust, long-term environmentally sustainable global food security. This is vital: it would have an utterly transformative effect on people and planet, allowing a just climate resilient future to be achieved.

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Illustrations List

Figure 1: Economist (2022) *Global Food Security Index Map*. Source: https://impact.economist.com/sustainability/project/food-security-index/#introduction

Figure 2: Author's own (2024), *Visualisation of the Global Food Security Index for Selected Countries*. Source: Made by author.

Figure 3: Roser and Ritchie (2013), *Global Food Price Inflation Map*. Source: https://ourworldindata.org/food-prices

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Figure 5: Our World in Data (2024) *Nitrogen fertilizer use per hectare of cropland, 1961 to 2021*. Source: https://ourworldindata.org/grapher/nitrogen-fertilizer-application-per-hectare-of-cropland?tab=chart with author's filters.

Figure 6: Foodsteps (2019), *'Traffic light' carbon rating infographic*. Source: https://www.foodsteps.earth/faqs