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## Review of Literature

The review of literature pertaining to the study titled “**Computation of nutritional footprint of food consumed by selected subjects and creating awareness on planetary health diet using the developed e application**” is discussed under the following headings.

- 2.1 Current Scenario of food consumption pattern and Prevalence of Diet related disease
- 2.2 Sustainable food system for optimal planetary health
- 2.3 Nutritional and carbon footprint of foods

### **2.1 Current scenario of food consumption pattern and Prevalence of Diet related disease**

Over the last few decades, the world's population has been increasing rapidly. It is anticipated to grow to 8.6 billion people in 2030 and 9.8 billion people in 2050 (UNDESA., 2017). As a result, food systems face enormous challenges in producing food that is both accessible and healthy for everyone on a global scale. Since the Neolithic Period, when agriculture was developed, equality and roughly equal resource accumulation have declined for the majority of people (Kohn, 2017).

World meat consumption is expected to increase from 54% currently to 63% by 2050 in developing countries. They are projected to increase their production of meat to 70% of the global total over this same period (Foley *et al.*, 2011).

According to USDA., (2014), food patterns can be defined as the quantities, proportions, variety, or combination of different foods and drinks in diets, and the frequency with which they are habitually consumed.

For cultural, political, and economic reasons, changing eating pattern is a significant challenge that will need measures from governments, corporations, and individuals that go beyond information and teaching programmes (Smith *et al.*, 2003).

Food preferences, choices, and habits play an important part in human civilizations, and food intake extends far beyond its basic survival purpose. Food habits are very difficult to

modify since they are such an important part of people's lives (Sonestedt *et al.*, 2005; Flaherty *et al.*, 2018).

Food preferences are also influenced by the marketing activities of food industries, which have resulted in changes in dietary standards (at the population level), and cultural values that support food behaviours (Cairns, 2019). Food-related decisions are complicated, making them vulnerable to a variety of social, cognitive, emotional, and environmental variables (Bublitz *et al.*, 2010).

Gladek *et al.*, (2016) highlighted that interventions to influence supply and demand, as well as shift social norms away from meat-based diets, are needed. There is no "magic bullet" method for creating a long-term food system. Rather, numerous adjustments across several sectors of the food system are required. It also needs coordinated initiatives that are customised to nations' social, political, economic, and cultural values, as well as present food preferences.

Lang, (2012) stated that as the new "Western/North American" food model and system expands over the world, significant changes that have previously occurred and are now occurring in most nations appear to begin in the destruction of traditional ways of life and culture. This "modern" trend is now clearly facing a sustainability challenge, in terms of land use for food production, farmer income and poverty, water availability, pollution of the environment by chemicals and pesticide residues, fossil energy decline and cost, environment and biodiversity degradation, climate change and global warming.

This is especially true in developing countries with high rates of population growth and urbanization, which lead to changes in income levels and food preferences. Africa's urban population is projected to triple in the coming decades, with 1.3 billion people living in cities by 2050 (Aleksandrowicz *et al.*, 2016).

Cairns, (2019) opined that the shift to diets containing a lower proportion of calories from animal source foods, notably ruminant meat (e.g., cows, goats, and sheep), and to diets where caloric consumption is adequate to fulfil metabolic requirements, is the most important of these. In many nations, this entails calorie reductions, but in some low-income countries, high calorie intake is necessary.

Increased demand for meat and other foods is occurring amidst declining availability of arable land and water scarcity. These trends have led to the intensification of agricultural production, with serious environmental and infectious disease implications. Intensive livestock systems, where many animals are kept in close quarters increases the risk for infectious diseases to proliferate and spread between animals. The response among producers in developed countries has largely been to increase the use of antibiotics in livestock. The overuse of antibiotics in this context is a key contributor to antimicrobial resistance, which poses an enormous threat to public health (Steffen *et al.*, 2015).

Thornton (2012) stated that the high energy level of most foods consumed can meet the vital demands of those who spend a lot of energy, but it is excessive for many inactive people in cities. Furthermore, in many nations, including Brazil, Russia, India, and China, the poor nutrient and fibre density of commonly consumed food (raw and processed) is a widely recognised problem. It's worth noting that poverty and insufficient food and nutrient consumption affect a significant portion of the population in developed countries as well.

The most recent changes in these patterns are rather disturbing (CDC, 2011), emphasising the overall insufficiency of food supply and dietary patterns around the world in the previous decades and now. For barely a few decades, a global multinational industrial agrofood system emerged, gradually shifting producer activities as well as consumer demand and attitude. Low-cost foods have been demonstrated to be energy-dense (fat- and sugar-rich) and nutrient-poor (Maillot *et al.*, 2007), resulting in both deficiencies and overweight as a result of poor dietary choices influenced by household income and education level.

Vermeulen *et al.*, (2012) described that a nutritional transition marked by increased consumption of refined starches and other processed foods, meat, saturated and trans fats, and sugars that usually accompanies urbanization and development, and is associated with rising rates of obesity and diet-related noncommunicable diseases.

According to Action aid, (2012), this dietary shift is linked to a higher risk of diet-related disorders, and animal-sourced foods have larger environmental consequences per calorie or gram of food generated than most plant-based diets.

These changes in diets are causing serious diet-related health conditions such as obesity, diabetes, and heart conditions when consumed in excess. Food environments in

urban areas enable access to unhealthy diets through the availability of supermarkets, food vendors, and restaurants (although they can also facilitate access to healthy food), and unhealthy diets are mostly affordable for the urban poor. While the nutrition transition is driven mainly by urbanization, it is taking place in rural areas as well (Hawkes *et al.*, 2017).

Higher-income nations are expected to see minor adjustments, but their eating patterns will still contribute to the high risk of diet-related illnesses and environmental consequences (Sobal *et al.*, 1998).

Low- and middle-income countries, on the other hand, such as the majority of those in South and Southeast Asia, Sub-Saharan Africa, and many in Central and South America, are currently (or are expected to) experience comparatively rapid dietary transitions toward high-calorie, high-fat, high-sugar, and high-animal-product diets. Diet-related NCDs are on the rise, as are unfavourable environmental consequences. While diet-related consequences per capita are expected to rise in low- and middle-income nations, they are expected to stay lower than in higher-income ones (Bogin *et al.*, 2014).

The biggest dietary adjustments are required to decrease environmental strain in high-income nations. There are various options for reducing, if not reversing, the expected rise in diet related NCDs and environmental stressors (Sun *et al.*, 2022). Because it cannot be expected that a healthy diet would have a low environmental effect or that an ecologically sustainable diet would be healthy in the short term, the goal is to discover the 'win-wins,' therefore avoiding unforeseen consequences (Carrus *et al.*, 2018).

Willet *et al.*, (2019) highlighted that diet related NCDs are on the rise, as are unfavourable environmental consequences. While diet-related consequences per capita are expected to rise in low- and middle-income nations, they are expected to stay lower than in higher-income ones. The biggest dietary adjustments are required to decrease environmental strain in high-income nations. There are various options for reducing, if not reversing, the expected rise in diet related NCDs and environmental stressors.

Diets, meanwhile, have deteriorated globally (GLOPAN 2016), leading to an increase in non-communicable diseases (NCDs), particularly type II diabetes, coronary heart disease, and some cancers (Lim *et al.*, 2010; Sabate and Soret, 2014).

## **Global nutrition related health statistics**

Furthermore, the predicted population expansion of 2 billion people by 2050, with most of this growth occurring in existing low- and middle-income nations, would exacerbate diet-related environmental pressures. Diet-related health issues and environmental consequences are expected to rise at various rates in different nations in the future (Etievant, 2012).

The multi-faceted manifestation of malnutrition (i.e., the triple burden of malnutrition) is a result of what is coined as ‘nutrition transition,’ a term that describes changing diets of people due to increasing incomes and migration from rural to urban areas. These changes in nutrition transition have already taken place in industrialized countries but are now being observed in transitioning and developing countries as well, where in some cases several forms of malnutrition are found at the same time (e.g., hunger and obesity) (Fanzo *et al.*, 2017).

Malnutrition in all its forms is a global problem, with one in every three persons afflicted by underweight, vitamin and mineral deficiencies, or overweight, obesity, and diet-related non-communicable diseases (NCDs) (IFPRI, 2016). Furthermore, various situations are increasingly coexisting, whether in a nation, a community, a home, or even in the same person over the course of their life. In 2015, over 1.9 billion individuals worldwide were overweight or obese, with 462 million being underweight (NCD Lancet, 2017).

One of the indicators of the food system’s impact on human populations is the nutrition and health status of people. The statistics show that it is not only for hunger (underweight rates among adults, and rates of stunting and wasting) but also presents alarming rates of obesity and overweight rates among both adults and children (WHO, 2018), all of which are grouped under the term malnutrition.

The world population was 7.8 billion; among them, 1.9 billion adults were overweight, and 150 million adults were underweight. Among children, 47 million children were wasted less than 5 years old, 14.3 million children were extremely wasted, 144 million children were stunted, and 38.3 million children were obese (WHO., 2020).

In 2017, almost 151 million children under the age of five suffered from stunting, with 38 million being overweight and 51 million suffering from wasting (UNICEF., 2018).

Furthermore, approximately 340 million children aged 5 to 19 were overweight or obese in 2016, with 192 million being underweight (NCD Lancet., 2017).

Malnutrition is a universal challenge, affecting all countries in its various forms, from undernutrition, excessive weight, and obesity to micronutrient deficiencies and combinations thereof. Approximately 795 million people are chronically undernourished (FAO, IFAD and WFP., 2015), two billion are micronutrient deficient (FAO and WHO., 2014), 42 million children are deemed overweight before their fifth birthday, and a staggering 1.9 billion adults are overweight or obese (UNICEF, WHO and World Bank., 2016; GBD., 2015).

Malnutrition continues to be the leading cause of death in children under the age of five years (Black *et al.*, 2013), and it also prevents children from reaching their full physical potential, as well as their economic, social, educational, and vocational potential. However, childhood overweight and obesity are on the rise in low- and middle-income countries, particularly in Africa and Asia (UNICEF., 2018, NCD Lancet., 2017); also, 1.6 billion people are anaemic, primarily owing to iron deficiency (WHO., 2008).

While income growth can reduce malnutrition, it is not always the case. Economic development, globalization, urbanization, and lifestyle changes have caused major shifts towards a poor diet, excessive calorie intake, and low levels of exercise. The result has been a rapid rise in obesity and NCDs. The alarming pace of climate and environmental change and its effects on food systems, nutrition and health require a major rethink of how food is produced and consumed (Tilman and Clarke., 2014).

The rising prevalence of unhealthy diets leads not only to under nutrition, but also to overweight and obesity, as well as diet related NCDs, which lead to premature death (70 years of age) and the start of illnesses with significant degrees of impairment. One in every twelve people on the globe currently has diabetes; most cases are type 2 diabetes, which is linked to overweight and obesity and often goes undetected (WHO., 2016).

Over 7.5 billion people rely on the global food system, but it is presently a major source of poor health and environmental devastation. Non communicable diseases (NCDs) caused by poor diet, such as diabetes, heart disease, certain malignancies, and obesity, are the leading cause of death worldwide, with over 800 million people undernourished and nearly 2 billion suffering from micronutrient deficiencies (WHO.,2022).

## **2.2 Sustainable food systems for optimal planetary health**

Hawkes *et al.*, (2006) stated that global adoption of a low-meat diet that nutritional guidelines for fruits, vegetables, and caloric requirements, for example, is expected to cut diet-related greenhouse gas emissions by almost 50% and premature mortality by nearly 20%. Other changes to the food system, such as reductions in food loss and waste, technology implementation and changes in management to improve crop yields and reduce fertiliser and pesticide runoff, and changes in food formulation, processing, and preparation, could further reduce the food system's environmental impact. The advantages of adopting ecologically sustainable and nutritious diets differ per nation, as do the methods by which these advantages are implemented.

Pinard *et al.*, (2013) stated that the food system includes all processes needed to feed people, i.e., growing, harvesting, processing, packaging, transporting, marketing, consuming, and disposing of food. Human resources, as well as social, political, economic, and environmental elements, have a big role in the food system. The interconnection of the social, economic, and environmental agendas is already being acknowledged at the highest levels, and it is being included in the new set of Sustainable Development Goals for the globe.

Despite the fact that more than enough food is produced to support the world's population, the problem of food insecurity remains, with substantial disparities across nations and even within the same country and within the same household (FAO, 2002; FAO, 2015). Future food systems will have to offer food and nutrition security while dealing with enormous sustainability difficulties, emphasising the need for a shift to more sustainable food systems (Vermeulen, Campbell, & Ingram, 2012).

If historical patterns in dietary choices and population expansion continue, the global food system's environmental and health implications will worsen (Tilman *et al.*, 2014). People desire more food as they get more prosperous and urbanised, especially meat, fish, dairy, eggs, sweets, fats, and oils (Popkin., 1994).

As a result, making people's eating habits more ecologically friendly is becoming increasingly crucial (Springmann *et al.*, 2016; Hartmann and Siegrist, 2017; Magrini *et al.*, 2018; Hedin *et al.*, 2019). Food consumption transformation is seen as a necessary requirement for achieving global sustainability objectives, particularly in high-income nations (UNEP, 2016).

According to the FAO and WHO study (2019), the global food system must sustain over 7.5 billion people while also being a major source of good health and least environmental damage.

Wiebe *et al.*, (2018) reported that higher-income nations are expected to see minor adjustments, but their eating patterns will continue to contribute to the high risk of diet-related illnesses and environmental consequences. Low- and middle-income countries, on the other hand, such as the majority of those in South and Southeast Asia, Sub-Saharan Africa, and many in Central and South America, are currently or in the future expected to experience comparatively rapid dietary transitions toward high-calorie, fat-, sugar-, and animal-product-rich diets seen in high-income countries.

Despite its seeming opulence, the current food supply system's complexity renders it exceedingly vulnerable to any climatic, socioeconomic, political, or financial disaster (Brinkman *et al.*, 2010). This happened with the rise in financial crisis in 2008, when food prices increased fourfold in a few months, highlighting the implications of high food prices for global nutrition (Webb, 2010), or with the 2011 earthquake in Japan, which emptied food stores in highly urbanised areas within three days.

Global environmental, social, and economic concerns such as resource shortages, ecological degradation, and climate change are all centred on food systems (Lobell *et al.*, 2012; Garnett, 2014; Searchinger *et al.*, 2013). Poverty, hunger, malnutrition, poor diets, land degradation, water shortages, social inequality, biodiversity loss, and climate change are all inextricably linked to how we produce, distribute, and consume food (FAO, 2014).

As per FAO (2015), land, water, and ecosystem degradation; biodiversity loss; excessive greenhouse gas emissions; chronic malnutrition and hunger; and failure to alleviate poverty, particularly among rural communities in the southern globe, are all consequences of current food systems.

At the same time, agricultural production systems have important impacts on the environment and public health. Agricultural production practices that impact planetary health and has implications for both the rise of non-communicable diseases and the spread of infectious diseases (Hallstrom *et al.*, 2018).

Tilman *et al.*, (2014) had opined that unsustainable agricultural production is both a driver of climate change and a consequence of its effects. Intensification of livestock production and changing land-use practices exacerbate issues of poor nutrition and food insecurity, environmental degradation, and the proliferation of infectious disease.

Importantly, livestock production, including animal lifecycle, land clearing for grazing, and the value chain for animal-source foods, is a massive contributor to worldwide greenhouse gas emissions. Land clearing for agriculture alters ecosystems, increases human-wildlife interactions, and leads to disease proliferation. Climate change, in turn, impacts pollinators, plant diseases, water availability, soil erosion, rainfall, and temperature, with serious consequences for agricultural production and food security (Vermeulen *et al.*, 2012).

Therefore, when a bird in an intensive production system becomes infected, entire flocks are culled, which has implications for food security, livelihoods, and animal welfare. Growth and intensification of agriculture have also contributed to massive land-use changes. Livestock grazing uses 26% of arable land worldwide, with another 33% used for growing crops for livestock feed (Campbell *et al.*, 2015).

The global food systems produce 20-35 percent of global greenhouse gas (GHG) emissions, occupy 40 percent of the Earth's ice-free land area, cause nutrient pollution in terrestrial and aquatic ecosystems, and are the leading cause of biodiversity loss (GBD., 2015).

The world's biodiversity is decreasing at a frightening rate. In just over 40 years, the population sizes of vertebrate species estimated by the Living Planet Index (LPI) have more than halved. The LPI, which tracks changes in hundreds of populations of mammals, birds, reptiles, amphibians, and fish throughout the world, reveals a 58% drop between 1970 and 2012. If current trends continue, the drop may be two-thirds by 2020. The primary risks to these populations are habitat loss and degradation, such as the conversion of natural regions for agricultural growth, followed by species overexploitation, such as unsustainable fishing (WWF, 2016).

According to Springmann *et al.*, (2018), cooperation is vital and requires multidisciplinary viewpoints, but it is inherently challenging, and the constraints of traditional collaboration (and the restrictive conditions under which it is appropriate) remain. Although

the final aim ('food security for all') may be the same, successful collaboration would entail 'stretching' from the norm to promote fair participation and distribution across food systems. This involves accepting friction among the participants in the chain, forging bonds with unusual friends, experimenting with new approaches, and jumping into the game.

Minimizing the negative environmental and health impacts of food system dynamics are central to a planetary health strategy to reduce the threat of infectious disease and promote healthy and sustainable diets and nutrition. A planetary health perspective recognizes that the health of human populations is tied to Earth's natural systems and biodiversity. Climate change influences the production, distribution, and nutrient content of food (Tilman *et al.*, 2014).

Lang *et al.*, (2012) opined that short-distance purchases would reduce transportation energy use. Direct sales from farmers to consumers through new local organisations are the best way to obtain good prices in a fair trade, as well as knowledge, understanding, and confidence, and thus the best way to reconcile urban citizens and producers and become a better part of the entire ecosystem.

In order to improve the current situation in all countries, information and education about appropriate food choices are required, as long as they are done within a framework of sustainability, which includes accounting for nutrition, culture, pleasure, equity, well-being and health, and environmental and biodiversity protection (Bere and Brug., 2009).

Foremost among these is a transition to diets that contain a smaller proportion of calories from animal source foods, particularly ruminant meat (e.g., cows, goats, and sheep), and to diets where caloric consumption is sufficient to meet metabolic requirements. In many countries, this means reducing calorie intakes, but it may also require increases in calorie intakes in some lower-income countries. Many studies have shown that reducing meat consumption can reduce GHGs while remaining nutritionally adequate (Ranganathan *et al.*, 2016).

Examples of solutions towards optimizing nutrition resilience (the ability to ensure adequate nutrition for global populations over the long term), minimizing environmental footprint (the impact of agricultural activities on natural resource use), and reducing animal and human disease risk (Springmann *et al.*, 2018).

According to FAO, (2018) global population trends and dietary transitions underlie the way food is produced. Unprecedented demand for diverse, safe, and nutrient-rich food globally has become increasingly difficult to meet. While the past several decades has seen large increases in agricultural productivity, climate change and pressure on natural resources have hindered the ability of the agriculture sector to keep pace.

Finally, safety standards and monitoring for intensive livestock production can help regulate antibiotic use, vaccination, and waste management practices, as well as worker and animal welfare. These strategies aim to reduce environmental degradation and the risk of infectious disease, non-communicable disease, and persistent under nutrition (Vermeulen *et al.*, 2012).

According to Turner *et al.*, (2018), technological advancements, globalisation, and changes in agricultural systems have changed the human diet in recent decades. Aside from these modifications, the concept of a healthy diet has been debated and reworked with the goal of incorporating planetary health themes (Bene *et al.*, 2019).

A planetary health approach to food systems should comprehensively address nutrition, infectious disease, and environmental sustainability. There are several opportunities for interventions and policies to be adopted and rigorously evaluated in specific contexts. These may include incentives to reverse and reduce the upward trend in meat consumption in developed and developing countries and to promote dietary diversity for nutrition as well as biodiversity for conservation (Tilman *et al.*, 2014).

Climate smart, nutrition-sensitive agriculture production strategies could also be employed to promote diversity and nutrient quality of crops, as well as the production of highly nutritious indigenous varieties. Cadres of agricultural extension workers already exist in many developing countries and, together with community health workers, offer a promising avenue for improving the production and consumption of diverse, healthy foods at the community level (Campbell *et al.*, 2015).

Sustainable healthy diets are "dietary patterns that promote all dimensions of individuals' health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe, and equitable; and are culturally acceptable," according to the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) (2019).

In response to this, the EAT-Lancet Commission on "Healthy Diets from Sustainable Food Systems" (EAT-Lancet) (2019) suggested the "Planetary Health Diet," a healthy and sustainable model diet that aspires to offer health to both people and the planet. These guidelines are based on a diet high in vegetables, greens, fruits, and whole grains, with meat, fish, eggs, refined cereals, and tubers being avoided.

This diet model has been compared to guidelines for healthy eating patterns (Blackstone *et al.*, 2020) and the Indian diet (Sharma *et al.*, 2020) in the scientific community, and even used as a reference for a novel Danish plant-based diet (Drewnowski, 2020 and Hirvonen *et al.*, 2020, Lassen *et al.*, 2020).

Raw nuts, pistachios, almonds, peanuts, dry or canned beans, pulses, lentils, chickpeas, peas, soybeans, and soy food products, coconut pulp and milk were included in this planetary health diet component. All fresh and processed fruits were considered, including their fractional contribution in culinary or industrial products such as fruit juices, nectars, and punches. Items contained in this food group included fresh, frozen, cooked, canned, or dried vegetables and excluded legumes and starchy vegetables (Willet *et al.*, 2019).

Further, foods included in this planetary health diet are whole grains used as staple foods (for example, brown rice, brown bread, oat flakes, canned grains, etc.), but not processed grains or refined product flours, such as polished rice and white bread, cookies, pasta, sweets, and breakfast cereals, eggs from chickens and other poultry, fish and seafood (EAT Lancet, 2019).

Willet *et al.*, (2019) highlighted those additional foods included all types of potatoes and cassava, as well as their derivative products, cow's milk, goat's milk, buffalo products, yogurt, and cheese, but no butter and sour cream. All dark green vegetables were included, such as broccoli, but not light green vegetables, such as lettuce. Tomatoes, beets, carrots, and pumpkins are examples of foods included in this component. Cuts of fresh meat, the table white or brown sugars and honey used as ingredients in processed or culinary products and the added sugars to manufactured foods and beverages.

Sustainable diets, for example, enhance public health while promoting environmental and economic stability through low-impact and inexpensively accessible foods. Importantly,

sustainable diets aid in the promotion of sovereignty and the preservation of traditional foods that are culturally sensitive and acceptable (Dangour *et al.*, 2012).

The Chicago Council's final report (2011) presented a strong case for immediate action to reduce threats to future food systems and their ability to produce enough food in a sustainable way, as well as to mitigate estimates of bad health outcomes owing to undernutrition, overweight, and obesity. To enhance pledges to sustainable diets as a core component of sustainable development, gaps in understanding of what constitutes a sustainable diet for various people and circumstances must be addressed.

Furthermore, it is necessary to comprehend how these diets may be evaluated in the context of the global food system, as well as how environmental sustainability in consumption patterns and dietary objectives can be attained. Finally, it is necessary to investigate how sustainable foods might aid in population health transformation while both encouraging economic development and decreasing environmental deterioration (Foley, 2011).

Seale *et al.*, (2003) opined that many of these processes are already happening, but they are not receiving the adequate attention or support they deserve from policymakers. This is due to the complicated web of relationships between food systems, industry, the environment, public health, and consumer behaviour, as well as the difficulties policymakers confront in making proper decisions, whether in government, business, or civil society.

Although the notion of a sustainable diet is not new, defining and linking the determinants of such a diet is a complicated topic with many unknowns about what such a diet would include. Gussow and Clancy coined the phrase "sustainable diet" in 1986, arguing that fostering food sustainability and ecological harmony were crucial to establishing a healthy diet for individuals (Ge., 2011).

The notion went dormant in the years after that, as support for agricultural industrialization and intensification, as well as food globalisation grew with little regard for the long-term viability of these agro-food systems (Bere *et al.*, 2008).

The current FAO consensus definition of a sustainable diet is complicated as well. Food availability, accessibility and choice are all influenced by a variety of interconnected elements, including location, demographics, disposable income, socioeconomic position,

urbanisation, globalisation, religion, culture, marketing, and consumer attitude (Godfray *et al.*, 2010).

Sustainable diets take into account how the food system affects health and the environment, and vice versa (Cairns., 2019). The agricultural, environmental, social–cultural, and economic drivers and impacts of the food consumed, as well as the nutritional content, should all be addressed when understanding a sustainable diet (Webb., 2010).

### **Factors affecting a sustainable diet.**

#### **Agriculture**

A starting point for understanding the sustainability of diets begins with considering the agricultural production and processing systems from which our diets are derived and the economic, environmental, health, and cultural factors affected by the system (Dangour *et al.*, 2012).

According to Chicago: The Council., (2011), the current system was boosted with the onset of the green revolution in the 1950s and 1960s, together with industrialized agriculture and greatly expanded food processing. Production and processing advances in the past 50 years should be credited with making food more convenient, widely available, and affordable to large portions of the world and reducing famines to an almost non-existent event in the 21st century.

However, this same successful global agro-food system is the dominant force behind many environmental threats, including climate change, simplification of diets, biodiversity loss, and degradation of land, soil, and freshwater (Chicago Council., 2011).

There are widespread problems with soil degradation due to erosion, loss of soil fertility, salination, and excessive and inappropriate use of chemicals, including fertilizers and pesticides. Rates of water extraction for irrigation are exceeding rates of replenishment in most places, and overfishing has led to the collapse of many aquatic species as heavy reliance on fossil fuel–driven energy for transport and the synthesis of nitrogen fertilizers and pesticides have contributed to increased greenhouse gas emissions (Dangour *et al.*, 2012).

Additionally, food production and processing systems, including the transportation of foods, emit high quantities of GHGEs and release other pollutants that build up in the

environment, including waste and pollution of water supplies. The global food system, from fertilizer manufacture to agricultural production to food transportation, storage, and packaging, currently accounts for 30% of all human generated GHGs (Springmann *et al.*, 2016).

If the current global food system continues to produce and process foods at the current amount and speed, it will continue to degrade the environment, compromise the capacity of the world to produce food in the future and have irreversible effects on ecosystems (Godfray *et al.*, 2010).

## **Health**

Agriculture influences and is influenced by health, both directly and indirectly. First, agriculture influences health directly through its ability to provide enough nutritious foods available for consumption in the household or in the marketplace (Dangour *et al.*, 2012).

Adequate food consumption provides the necessary nutrients and food components humans require for healthy growth, development, and day-to-day functioning/productivity. Sound health allows people to optimize those nutrients through appetite, digestion, and metabolism and contribute back to agriculture in terms of productivity and a series of important ecosystem services. However, an imbalance of nutrients may lead to illness (Fanzo *et al.*, 2012).

Moreover, increases in the agricultural production of low-nutrient and energy-rich foods, such as cereals, tubers, and fats, are contributing to the triple burden of under nutrition, micronutrient deficiency, and overweight and obesity with their associated health issues, such as stunting, anemia, and diabetes (Smith *et al.*, 2003).

Dangour *et al.*, (2012) described that the poor are adversely affected by such agriculture and health influences because energy-rich, low-nutrient foods are becoming more affordable to the poor around the world. Second, good health, economic development, and environmental sustainability are indirectly influenced by agriculture. The effects on employment, individual incomes, and national economic prosperity are positive because they may enable individuals to lead healthier lives, including less strain on budgets for health care or national-level structural improvements to the health system.

Agriculture can also have negative effects on the environment and ecosystem services due to the prevalence of certain diseases, access to water, biodiversity loss, and climate change (Fanzo *et al.*, 2012).

### **Economic**

Agriculture affects the economic determinants of sustainable diets, as well. The income amount and the distribution of income of a population or a nation are also major factors regarding the affordability of a diet. Populations with higher incomes could purchase foods of greater variety and nutritional value (Dangour *et al.*, 2012).

Fanzo *et al.*, (2012) highlighted that nations with high gross domestic products can access foods more readily and often invest in agriculture that will not only provide enough food for their citizens but more nutritious and diverse foods, as well. However, trends reveal that, on average, the diets of these wealthier countries are becoming less healthy and rates of non-communicable diseases are rising rapidly, and there are considerable changes in lifestyle.

Finally, government food and social protection policies affect diet access and affordability. Subsidies can benefit and distort markets and negatively affecting health and nutrition. Current government subsidies to farmers in the United States and parts of Europe enable developed countries to produce large quantities of cheap staples and ultra-processed foods at 40–60% below the cost of local production of similar goods in developing markets (UNEP., 2008).

In turn, these less healthy foods as imports are considerably less expensive than the locally produced foods, distorting local markets and suppressing demand for the more expensive, locally produced, and often healthier food options (Dangour *et al.*, 2012).

### **Social–Cultural**

Social and cultural norms play important roles in diet. Diets serve not only to provide nourishment but also to provide joy, heavily influenced by social traditions. For example, vegetarian diets in India are influenced by Hindu religious beliefs, whereas traditional diets in Mexico are reflective of the staple maize or corn crop grown in the region for centuries (Sobal *et al.*, 1998).

Ge *et al.*, (2011) reported that such practices, whether a result of religious practice or habit passed through generations, may at times negatively affect the diet diversity and nutrition of a population. In India and Mexico, the consumption of certain traditional diets has contributed to nutritional deficiencies, high amounts of stunting, and an increased incidence of diet-related non-communicable diseases.

Knowledge of the foods in one's diet, their contribution to health and nutrition, and their consequences might encourage people to eat a more diversified and nutritionally appropriate diet. This is seen in the seasonal food options accessible to Congo's rural communities. Furthermore, learning how to create a more diversified diet might have an impact on the intake of various foods (Clonan *et al.*, 2012).

The vast body of knowledge about the nutritional and health benefits of the foods people eat, particularly among smallholder producers and consumers, represents an enormous amount of information that is being lost as consumption patterns shift, marketing becomes more globalised, and habitats are lost (Foresight, 2011).

Seale *et al.*, (2003) explained that food intake habits, from frequency to amounts consumed, have an influence on different lifestyles. Overeating has been linked to viewing television and experiencing high levels of stress, according to research. Women suffer from under nutrition, overweight, and obesity at higher rates than men in various nations, showing not just differing biological demands and activity patterns, but also possible discriminatory or inequitable social/cultural norms.

Finally, rising incomes are leading to increased consumption of animal-source foods around the world, while other traditional or local foods, such as millet or cassava in some parts of Sub-Saharan Africa and India, are viewed negatively as a lesser good or "food for the poor," despite evidence that the food could be a nutritious, long-term option. Quinoa has gone from being a regional cuisine in the Andes to a globally recognised and highly appreciated food. Human interactions and food choices might be evaluated within a specific context or ecosystem to understand how environmental influences impact sustainable diets (Haddad *et al.*, 2012).

As a consequence of closeness to markets, local agricultural production of such foods, wild foods, economic levels, and other factors, urban or rural residency may alter a

population's access to diverse and nutritious foods. Consumer dietary decisions are also influenced by food marketing and packaging. Furthermore, a population's food choices have an impact on water and land usage, biodiversity, and global warming (Foresight, 2011).

Fanzo *et al.*, (2012) highlighted that traditional social–cultural norms can be reinforced—or eroded—by the causes and forces outlined above. The preceding talks indicate that there are various and complicated variables in a healthy, ecologically friendly, inexpensive, accessible, and culturally acceptable sustainable diet. Because the determinants of sustainable diets are interconnected, when one category's components or processes change, it affects the other determinant categories and, as a result, the amount of "sustainability" of a diet. Damage, loss, or environmental deterioration throws the entire system out of whack, resulting in unforeseen consequences and trade-offs.

### **Measuring sustainable diets**

The meals that humans eat are influenced by the environment or ecosystems. A complex network of relationships among living resources in a specified region is termed an ecosystem. Plants, animals, microbes, water, soil, and humans are all part of an ecosystem. Each part of an ecosystem interacts with the others to build a dynamic community. It has an influence on the system if one portion of the ecosystem is changed or vanishes. A sustainable ecology is one that is in equilibrium. Food production and consumption patterns are putting enormous strains on the natural environment and modifying ecosystems throughout the world, which has a significant impact on people's diets (Seale *et al.*, 2003).

Sustainable diets require the development of metrics and measuring procedures so that policymakers and consumers can see how a sustainable diet may enhance individual and population health while also conserving resources and the environment. Furthermore, the ability to measure sustainable diets can help policymakers understand potential trade-offs for promoting such diets and make investment decisions while addressing any potential negative consequences (for example, less demand for meat and dairy products may put producer and manufacturing groups' missions in jeopardy) (Dangour *et al.*, 2012).

According to Foresight, (2011), dietary guidelines were developed in most nations to encourage healthy eating habits and, in certain circumstances, to avoid negative environmental repercussions. Food Miles Movement is one of these programmes, which

includes eating three pieces of vegetables every day (only eat foods produced within 100 miles of your home). The Chinese Food Pagoda and the UK Eat well Plate both employ visual representations to help people eat more healthy meals.

Because of the necessity to model and quantify the nutritional or environmental effects of diets, many activities were made possible. For future sustainable diets, the same must be done. The general opinion appears to be that such measurements can and should be produced. However, creating effective criteria for sustainable diets, particularly in low-income countries, has significant scientific and political hurdles (Fanzo *et al.*, 2012).

The lack of an open-source, trustworthy databases on the global food supply's composition and consumption remains a problem. The government and the agro-food business must work together to solve the data and methodological gaps. The recently created access to Nutrition Index evaluates certain firms' capacity to sell healthy, ethical, and legally compliant meals using weighted measurements across a variety of parameters (Haddad *et al.*, 2012).

The index evaluates the performance of big food and beverage corporations across a number of indicator areas, including governance, products, accessibility, marketing, lifestyles, labelling, and engagement, using weighted metrics. The access to Nutrition Index does not yet incorporate corporate contributions to sustainable diets or the environmental effects of products being manufactured and marketed. Such a dimension might be a future consideration for the tool's evolution. Another index, which includes food and beverage firms, considers their environmental effects (Nutrition Index., 2012).

Campbell *et al.*, (2015) opined that, in addition to nutritional impacts, sustainable diets have exponential benefits for the environment and public health. More research is needed to identify effective solutions and develop appropriate metrics for the evaluation of food system interventions, especially in the context of developing countries. Evidence-based and deliberate agriculture and public health programs are needed to ensure that our food systems are promoting and not harming planetary health.

Because it cannot be expected that a healthy diet would have a low environmental effect or that an ecologically sustainable diet would be healthy in the short term, the goal is to discover the 'win-wins,' therefore avoiding unforeseen consequences (Macdiarmid., 2013).

## **2.3 Nutritional and carbon footprint of food**

### **Nutritional footprint:**

The prevention of non-communicable illnesses is significantly influenced by nutrition (WHO., 2002). Processed food reformulation is currently viewed as a key strategy for lowering the incidence of diet related disorders (EC., 2014). Given this, there is growing demand in the food industry to enhance the nutritional value of processed meals. Initiatives for food reformulation mostly focus on cutting back on sodium, saturated fatty acids, trans fatty acids, carbohydrates, and overall calories (Pravst., 2018).

Early definitions of nutrient density agreed that nutrient-dense foods should contain "significant amounts of essential nutrients," but they stopped short of laying out any specific criteria or standards (Drewnowski *et al.*, 2008). Thirty years later, the definition of nutrient-dense foods remained the same: they contained more nutrients while having fewer calories (Lackey., 2004). Since there is still no official definition of nutrient-dense foods, the idea of what makes a food "healthy" is initially based on food groups. The literature makes mention of nutrient-dense whole grains, nutrient-dense milk, nutrient-dense fruits and vegetables, nutrient-dense nuts, and nutrient-dense meats (Lin., 2003).

The nutritional value of each food within a specific food group varies, though. Even items from wholesome dietary categories can include sugar, fat, or both. The World Health Organization classified all legumes, vegetables, and fruits as nutrient-dense, but only lean meats, low-fat dairy products, and whole grains were allowed to use the phrase (WHO., 2005). The 2005 Dietary Guidelines used the word "nutrient-dense" only to refer to wholegrain and enriched grain products, lean meats, skinless poultry, fat-free and low-fat dairy products, and all legumes, vegetables, and fruits (USDHS., 2007).

All fruits and vegetables were once considered healthy, according to the National Cancer Institute (NCI), but avocados, almonds, olives, and coconuts were expressly prohibited due to their high fat content (NCI., 2001). That restriction was removed when fat phobia subsided. Dark-green leafy vegetables and veggies with a rich orange colour are especially good sources of vitamins and minerals, according to the USDA's MyPyramid. Fruit juices and all forms of fresh, frozen, tinned, and dried fruit are also advised. Meals with more fat, sugar, or salt were typically not considered nutrient-dense foods (USDA., 2007).

The recommended dietary allowances served as the foundation for early efforts to rank foods by their nutritional content across and within food categories (RDAs). The Federal Trade Commission suggested in 1974 that only foods that supply at least 10% of the RDA for protein and three other nutrients per 100 kcal and at least 10% of the RDA per serving for one of these nutrients should be considered "nutritious". Out of a total of 135 different items, only one vegetable and one milk passed that incredibly strict test (Guthrie., 2007).

According to later recommendations, "nutritious" foods should supply 50% of the RDA for one nutrient, 20% for two nutrients, 15% for three nutrients, 10% for four nutrients, or 6% for each of the five nutrients. A second try at a composite score was 36. But many typical items were also excluded by that strict test (Guthrie., 2007).

According to Hansen *et al.*, (2009) who attempted to quantify nutritional value, terms like "poor," "fair," "sufficient," "good," and "outstanding" might be employed to describe different grades of nutrient density. Only protein, vitamins, minerals, dietary fibre, or potassium may be referred to as a "good source of" or "great source of." When referring to calories, total or saturated fat, salt, carbohydrates, or cholesterol, phrases like "free," "low," or "reduced/less" are used instead. These are also based on reference amounts, or if those are modest, on 50 g.

An alternative definition of nutritional density has been developed with a focus on the nutrients that are overrepresented in the average diet. Instead of focusing on the entire nutritional profile, healthy meals were frequently defined by low amounts of nutrients to restrict. For instance, the National Heart, Lung, and Blood Institute classified healthful meals as having less than 12 grams of fat, 4 grams of saturated fat, 100 milligrams of cholesterol, and 600 milligrams of salt per serving (AHA., 2005).

The American Heart Association's standards were predicated on a low salt level (480 mg) and almost no fat (3 g), saturated fat (1 g), or cholesterol (20 mg) (AHA., 2005). The NCI similarly rejected processed fruit and vegetables that contained sugar, fat, or more than 480 mg of sodium from their definition of healthy foods (NCI., 2001).

Foods that met the FDA's definition of "healthy" foods had to be low in fat (3g), saturated fat (1g), cholesterol (60mg), sodium (480mg), and at least 10% of the Recommended Daily Intake (RDI) or Daily Reference Value (DRV) per reference amount of

one or more of six nutrients: protein, fibre, vitamins A and C, calcium, and iron. Any beneficial nutrients added have to follow the FDA's fortification guidelines. Only foods that contained at least one of the six critical nutrients in amounts greater than 10% of the daily value per reference amount typically eaten prior to fortification were allowed to make health claims (USFDA., 2005).

If a serving of food had more than 13 grams of fat, 4 grams of saturated fat, 60 milligrams of cholesterol, or 480 milligrams of salt, the product was rejected by many health organisations. Thus, many fruit and vegetable products with additional oils, salt, sauces, or syrups, as well as several morning cereals, were prohibited from making health claims under the FDA definition (USFDA., 2005).

Foods with less than 5% of the US recommended daily intakes (RDI) for each of the eight nutrients listed by the USDA are considered to have "minimal nutritional value." These nutrients are protein, calcium, iron, vitamins A and C, riboflavin, thiamine, and niacin. Foods with low nutritional value, in the case of artificially sweetened foods, deliver less than 5% of the RDI for each of the eight required nutrients per serving. Unhealthy competing meals were often those that had more than 15 g of sugar per serving, >10% saturated fat, and >30% of the calories from fat as compared to the school lunch. The laws governing competitive meals vary from state to state, and elementary, middle, and high schools all have various limits (USDAFN., 2005).

The science of ranking or classifying individual foods according to their nutrient composition is known as nutritional profiling (Drewnowski., 2005; 2009). The majority of nutrient profiling systems aim to differentiate between nutrient-rich and energy-dense foods (Drewnowski., 2009; 2011). Nutrient profile models typically look at a food's nutrient content per 100 grams, 100 kilocalories, or per serving. Then, a single composite score is given to each food, which best reflects its overall nutritional value (Drewnowski., 2005; 2009).

Nutrient profiling models have been validated in various ways with respect to expert opinion (Scarborough *et al.*, 2007) or independently obtained measures of a healthy diet (Azais *et al.*, 2006). These applications range from regulatory uses (AFSSA., 2008) to the nutritional screening of product portfolios by the food industry (Nutrition Index., 2012).

The work on nutrient profiling has produced some paradoxes because it almost exclusively focuses on individual foods. Some low-ranked foods with particular nutrients (like monounsaturated fats), which are often thought to be harmful to health if consumed in excess, are actually essential to good health. However, some of the top-rated, nutrient-rich foods don't have enough calories to satisfy one's energy needs (Drewnowski *et al.*, 2008).

Different foods may contribute varying amounts of important nutrients to the overall diet, depending on the food consumption habits of the population (Aresenault *et al.*, 2012). The new generation of nutrient profiling models needs to take into account the relative amounts of these nutrients in culturally appropriate food consumption patterns (Maillot *et al.*, 2010).

Models of nutrient profiles have been developed that only consider qualifying nutrients, only consider disqualifying nutrients, or some combination of the two (Darmon *et al.*, 2009). While disqualifying nutrients have historically been those whose excessive consumption is associated with negative health concerns, such as saturated fat, sugar, and sodium, qualifying nutrients have always included various combinations of protein, fibre, and a variety of vitamins and minerals. The selection of essential nutrients for inclusion in such models has primarily followed regulatory frameworks and dietary recommendations (Tetens *et al.*, 2007), resulting in a focus on a small number of key nutrients with current relevance.

In 1973, the initial method for classifying foods was created. Afterwards known as the "Nutritional Quality Index" (NQI), it was presented in a book in 1979 (Hansen., 2003; Benbrook *et al.*, 2011). According to the RDAs for those nutrients, Hansen's NQI employed 18 nutrients in 2,000 calories of food as its foundation. It was a "nutrient-by-nutrient profiling system" that used individual scores instead of adding up values from different nutrients to produce a composite score for a particular diet (Hansen., 2009; Benbrook *et al.*, 2011).

The government and other health organisations have also created rules for the symbols that food producers can use to identify products as "healthy" (Stockley., 2003; EFSA., 2008). The idea of nutrient profiling is therefore not new, although the majority of the models have not been developed in a systematic manner (Binns., 2009). More than three decades of research in this field have resulted in the development of several indices for food quality, nutritional quality profiles, and nutrient-to-nutrient ratios (Drewnowski., 2007).

To date, a number of nutrient profile systems have been created and are utilised for a variety of things, such as front-of-pack labelling, (Nijmam *et al.*, 2007) food service policy, (Ministry of health., 2007) nutrition education, (Mhurchu *et al.*, 2010) limiting food advertising to children, (Stockley *et al.*, 2007; Drewnoski., 2007 ), and determining whether or not goods qualify for health claims. The profiles are often created to enable the categorization of foods as "healthy" or "less healthy" (Drewnoski., 2007; FSANZ., 2007; Binns., 2009).

According to a study, nutritional profiling aids consumers in understanding the role of nutrients in food and enables them to choose healthier foods. Additionally, it motivates food producers to create healthier food items. The profiles have a variety of uses, depending on the ratio of calories to important nutrients. The ability to identify nutrient-dense foods for dietary advice and nutrition education might make it an invaluable tool for nutrition experts (Young *et al.*, 2002).

The relative ratio known as "nutrient density" is calculated by dividing a food's contribution to nutritional demands by its contribution to calorie needs. The largest problem with nutritional profile design is turning the idea of nutrient density into a practical system that would assist customers in eating a diet that is higher in nutrients (Drewnowski., 2009). The 2005 Dietary Guidelines for Americans placed more focus on the quality of specific foods than on overall diets (Drewnowski., 2005).

The importance of front-of-pack signpost labelling for preventing the consumption of harmful foods and enhancing public health is progressively becoming recognised. As a result, nutrient profile systems are heavily taken into account when creating policies and doing research in order to provide the best nutrition standards. Foods are classified differently by different systems since there are no systems that are widely accepted (Foltran *et al.*, 2010; Garsetti *et al.*, 2007).

### **Qualifying (QI) and Disqualifying (DI) Indices:**

For this aim, the Qualifying Index (QI) was established as the ratio of each nutrient present in 2000 kcal of a specific item to its Dietary Reference Intake (DRI) value. The adequate intake (AI) was used in place of the recommended dietary allowance (RDA) for a nutrient when one was not available (Drewnowski., 2005).

The investigation included six nutrients that were disqualified, all of which were chosen due to their well acknowledged negative impacts on health when ingested in excess in the diet. The definition of the Disqualifying Index (DI), which is very similar to that of the Qualifying Index (QI), is the ratio of the quantity of a nutrient present in a food that contains 2000 kcal to the daily Maximal Reference Values (MRV) for that nutrient. Total lipids (about 35% of energy), saturated fats (about 10% of dietary energy), cholesterol (about 300 mg), trans fats (about 1%), and salt (about 2300 mg) were the particular disqualifying nutrients and the MRVs employed (Benbrook *et al.*, 2011).

#### **Nutrient balance score:**

The nutrient balance score is a measure of a product, meal, or diet's capacity to provide the recommended daily intakes of all qualifying nutrients in a sample of 2000 kcal. A food's nutrient balance score can reach a maximum of 100% if it meets the daily dietary requirement for every qualifying nutrient. In contrast, a rating of 0% would mean that the meal completely failed to *meet all* the criteria for qualifying nutrients (Drewnowski., 2005).

#### **Greenhouse gas emissions:**

The greenhouse effect is mostly caused by the interaction of the sun's energy with greenhouse gases such as carbon dioxide, methane, nitrous oxide, and fluorinated gases in the Earth's atmosphere. The ability of these gases to capture heat is what causes the greenhouse effect. The prime forcing gases of the greenhouse effect are carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and fluorinated gases (Moreno Ruiz *et al.*, 2013).

The principal greenhouse gases that enter the atmosphere because of human activities are:

**Carbon Dioxide (CO<sub>2</sub>):** Carbon dioxide enters the atmosphere through the burning of fossil fuels (oil, natural gas, and coal), solid waste, trees, and wood products, as well as because of other chemical reactions (e.g., the manufacture of cement). Carbon dioxide is also removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle (Wiesen *et al.*, 2014).

**Nitrous Oxide (N<sub>2</sub>O):** Nitrous oxide is emitted during various agricultural and industrial activities, as well as during the combustion of fossil fuels and solid waste (Wiesen *et al.*, 2014).

Methane (CH<sub>4</sub>): Methane is emitted during the production and transport of coal, natural gas, and oil. Methane is also emitted when organic waste decomposes, whether in landfills or in connection with livestock farming (Wiesen *et al.*, 2014).

Fluorinated Gases: Hydro fluorocarbons, per fluorocarbons, and sulphur hexafluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. Fluorinated gases are sometimes used as substitutes for ozone-depleting substances (i.e., CFCs, HCFCs, and halons). These gases are typically emitted in smaller quantities, but because they are potent greenhouse gases, they are sometimes referred to as high global warming potential gases ("High GWP gases") (Wiesen *et al.*, 2014).

### **Greenhouse gas emissions and food systems**

Greenhouse gas (GHG) emissions are produced in the growing, processing, packaging, transportation, sale, and consumption of food. Three main greenhouse gases carbon dioxide, methane and nitrous oxide are emitted from processes in the food system, such as nitrous oxide release from the soil (Skeaff and Miller, 2009).

The persistence, how long the gas is active, and the impacts of these GHGs in the atmosphere are called the global warming potential. Methane, which persists in the atmosphere for a shorter period of time than carbon dioxide but absorbs more heat, has a greater overall impact than carbon dioxide. Of the three gases, nitrous oxide has the highest global warming potential. A similar measure of global warming impact is the carbon footprint of food (also known as CO<sub>2</sub>e: carbon dioxide equivalent). A carbon footprint is the total amount of greenhouse gas emissions from a specific unit of food (Rosenzweig *et al.*, 2020).

### **Greenhouse gas emissions from agricultural production:**

Agriculture is an important sector of the economy in India, contributing about 20% of the national gross domestic product, and providing a livelihood for nearly two-thirds of the population (ICAR, 2015).

Equally important is the contribution of agriculture to national food security. India achieved self-sufficiency in food production after the Green Revolution (GR) but retaining this success has been challenging due to the increasing scarcity of resources, including labour, water, energy, and rising costs of production (Saharawat *et al.*, 2010).

Increased use of production inputs, such as mineral fertiliser, has made Indian agriculture more greenhouse gas (GHG)-intensive. Agricultural production is a major emitter of GHGs, currently accounting for 18% of total GHG emissions in India (INCCA, 2010).

Recent estimates from 2011 report that global food production must increase by 70% to meet the projected food demand of the estimated 9 billion global population by 2050. With a population of 1.3 billion, it is evident that the food system in India will be central to the global challenge of providing sufficient nutritious food while minimising GHG emissions. However, given the increasing population and shifting dietary patterns, GHG emissions from agricultural production in India are expected to change.

Quantification of GHG emissions from the production of different food commodities helps farmers, researchers, and policymakers to understand and manage these emissions, and identify mitigation responses that are consistent with the food security and economic development priorities of countries (Hillier *et al.*, 2011; Whittaker *et al.*, 2013).

Agriculture is a significant contributor to climate change, in addition to being one of the economic sectors most at risk from it (FAO 2016, Mbow *et al.*, 2019). Greenhouse gas (GHG) emissions from on farm production (i.e., within the farm gate) and related land use change contribute about one-fifth to one-quarter of total emissions from all human activities (IPCC 2019).

This contribution is even more striking for individual gases. For instance, crop and livestock production within the farm gate contributes more than 50% of the methane (CH<sub>4</sub>) and 75% of the nitrous oxide (N<sub>2</sub>O) emissions from human activity globally. Emissions from pre- and post-production activities, such as fertilizer manufacturing, food transport, processing, retail, and waste disposal, increase the magnitude of these already relevant impacts (FAO 2020).

Rosenzweig *et al.*, (2020) estimated that the food system generates 20%–40% of the anthropogenic emissions from all economic activities, and Crippa *et al.*, (2021) recently quantified the contribution as about one-third of total anthropogenic emissions. These large contributions further highlight the potential of food related GHG mitigation strategies, providing impetus for innovative approaches in food supply chains, consumption, and waste processes in connection with farm and landscape level mitigation (Smith *et al.*, 2014, Niles *et al.*, 2018, Mbow *et al.*, 2019).

It is likewise recognized that dietary choices and consumption patterns are critical to reducing food system emissions, through their impact on supply-side activities (Dalin and Outhwaite 2019, Hayek *et al.*, 2020, Willett *et al.*, 2019). The quantification of emissions from crop and livestock activities and associated land use is well established in global inventories, enabling detailed analysis at the country, regional and global levels (e.g., Smith *et al.*, 2014, Tubiello *et al.*, 2013, IPCC 2006, FAO 2021a).

However, similarly detailed emissions information about other critical components of the food system is only recently available (Crippa *et al.*, 2021). For this reason, previous quantifications of emissions from the food system largely relied on relatively simplified approaches (Poore and Nemecek 2018). A dearth of information at the country level currently limits the effectiveness of food system mitigation strategies at the national and regional scales, where they are most important (Loboguerrero *et al.*, 2019, Garnett 2011).

Food is well recognized as a central issue in climate change mitigation. Indeed, the majority of the mitigation commitments communicated by countries to the UN Framework Convention on Climate Change (UNFCCC) via Nationally Determined Contributions (NDCs) include agriculture and land use as strategic priorities (e.g., Crumpler *et al.*, 2020). The analysis of the food system contribution to national GHG emissions within the NDCs, however, is very difficult, hampering the identification and development of effective mitigation options (Rosenzweig *et al.*, 2021).

For instance, the IPCC ‘agriculture’ sector used in the National Green House gas Inventory (NGHGI) covers only the non-CO<sub>2</sub> emissions generated within the farm gate. Important CO<sub>2</sub> emissions on the farm, for instance, from drained organic soils on agricultural land (Conchedda and Tubiello., 2020, Cooper *et al.*,2020) or from on-farm energy use, are not accounted for in this inventory category.

Additionally, large amounts of CO<sub>2</sub> emissions, which stem from processes at the conversion boundaries between farmland and natural ecosystems, including emissions from tropical deforestation and tropical peatland fires (Prosperi *et al.*, 2020), are also excluded from agriculture in National Green House gas Inventory accounting. These food-related CO<sub>2</sub> emissions are instead reported by countries within the ‘Land Use, Land Use Change and Forestry (LULUCF)’ sector of their National Green House gas Inventory (IPCC 2003).

### **Emissions on agricultural land**

The estimates indicate that 2018 total GHG emissions on agricultural land—the sum of farm gate emissions and land use change—were 10 383 Mt CO<sub>2</sub>eq yr<sup>-1</sup>, 80% of which were generated in many countries. Remarkably, they represented nearly twice the emissions that would be reported under the agriculture sector of the NGHGI, the latter covering only non-CO<sub>2</sub> emissions from crop and livestock production processes (Tubiello., 2019).

The emissions of CO<sub>2</sub> on agricultural land were nearly half of the total, with individual non-CO<sub>2</sub> gases contributing less than a third each, i.e., CH<sub>4</sub> (30%) and N<sub>2</sub>O (24%). Over the period 1990–2018, CO<sub>2</sub>eq emissions decreased, by 0.3%, as the moderate growth in farm gate emissions (10% for CH<sub>4</sub> and 24% for N<sub>2</sub>O) was counterbalanced by a decrease in land use change emissions (0.19%). CO<sub>2</sub> was a larger contributor to total emissions on agricultural land in 1990 (55%) (IEA., 2020).

### **Emissions within the farm gate**

In 2018, global farm gate (on-farm production) emissions were 7145 Mt CO<sub>2</sub>eq yr<sup>-1</sup>, 20% higher than the 1990 levels of 5959 Mt CO<sub>2</sub>eq yr<sup>-1</sup>. More than 70% of these emissions were in many countries. Non-CO<sub>2</sub> emissions represented more than three-fourths of the total, including in many countries and rather consistently across 1990–2018. They were dominated by livestock processes (enteric fermentation and manure), followed by synthetic fertilizers and rice cultivation (Martínez *et al.*, 2021).

CO<sub>2</sub> gas represented one-fourth of the total on-farm production emissions, with nearly equal contributions from on farm energy use and peatland drainage. Non-CO<sub>2</sub> emissions increased from 4447 to 5218 Mt CO<sub>2</sub>eq yr<sup>-1</sup> over 1990–2018 and were characterized by opposite trends between AI and NAI groups (Martínez *et al.*, 2021).

In developed countries, emissions decreased by 25%, from 1555 to 1173 Mt CO<sub>2</sub>eq yr<sup>-1</sup>, while they increased in developing countries by nearly 40%, from 2892 to 4045 Mt CO<sub>2</sub>eq yr<sup>-1</sup>. Legislation put in place in the late 1980s to reduce environmental nitrogen pollution in Europe and in many countries, as well as the break-down of agricultural communal systems after the collapse of the Soviet Union, underlie the emission decreases in AI countries. Conversely, the observed increases in NAI countries stem from growth in both internal demand and global trade of food products over the study period (Finogenova *et al.*, 2019).

At the same time, global emissions from drained organic soils increased by 13%, from 753 to 852 Mt CO<sub>2</sub>eq yr<sup>-1</sup>. These emissions were generated largely in NAI countries, representing in 2018 nearly 70% of the total (Conchedda and Tubiello 2020).

On-farm energy emissions increased globally by 25% from 1990 to 2018, i.e., from 759 to 946 Mt CO<sub>2</sub>eq yr<sup>-1</sup>. NAI countries contributed more than two-thirds in 2018 and doubled since 1990, from 307 to 658 Mt CO<sub>2</sub>eq yr<sup>-1</sup>. Conversely, emissions from on-farm energy use decreased in AI countries, by 36% from 449 to 288 Mt CO<sub>2</sub>eq yr<sup>-1</sup> (Martínez *et al.*, 2021).

### **Land use changes emissions.**

Tubiello *et al.*, (2021) used the data for the period 1990–2020 of new forest emissions and removals for the period 1990–2020 in the assessment. They show a 30% decrease in net forest conversion from 1990 to 2018 (from 4382 to 3034 Mt CO<sub>2</sub>eq yr<sup>-1</sup>), with emissions occurring almost entirely in NAI countries. Emissions from tropical peat fires were 204 Mt CO<sub>2</sub>eq yr<sup>-1</sup> in 2018, 30% less than in 1990 (Prosperi *et al.*, 2020).

Land use change contributed only half of these amounts, about 3 Gt CO<sub>2</sub>eq yr<sup>-1</sup>, mostly as CO<sub>2</sub> gas. The trends in these three components were likewise notable, considering that in 1990, farm gate emissions were 6 Gt CO<sub>2</sub>eq yr<sup>-1</sup>, with land use change and pre- and post-production processes each emitting 4.5 Gt CO<sub>2</sub>eq yr<sup>-1</sup> (Prosperi *et al.*, 2020).

One-fourth of previous FAO estimates used in recent assessments of food system emissions. In contrast, land use change emissions on agricultural land totalled 3238 Mt CO<sub>2</sub>eq yr<sup>-1</sup> in 2018. Net forest conversion, used herein as a proxy for food-related deforestation, was the single largest emission source estimated on agricultural land over the entire 1990–2018 period (Crippa *et al.*, 2021).

### **Pre- and post-production**

#### **Emissions from food waste disposal and food transport**

Global emissions from food waste disposal, including solid food waste, industrial wastewater, and incineration, reached 996 Mt CO<sub>2</sub>eq yr<sup>-1</sup> in 2018, with NAI countries representing 80% of the total. CH<sub>4</sub> emissions generated by disposal of solid food waste in landfills and open-dumps grew by 30% between 1990 and 2018, reaching 594 Mt CO<sub>2</sub>eq yr<sup>-1</sup> in 2018—roughly 60% of total food waste disposal emissions (Prosperi *et al.*, 2020).

CH<sub>4</sub> and N<sub>2</sub>O emissions from domestic wastewater increased by 50% since 1990, contributing an additional 288 Mt CO<sub>2</sub>eq yr<sup>-1</sup> in 2018. Emissions from incineration were, conversely, very small by comparison and are not discussed further. Transport and food waste disposal contributed a total 1507 Mt CO<sub>2</sub>eq yr<sup>-1</sup> to food system emissions outside of agricultural land. While they represented a mere 15% of the emissions on agricultural land in 2018, they exhibited very strong growth over the period 1990–2018, in both CO<sub>2</sub> (+72%) and nonCO<sub>2</sub> (+40%) components (Prosperi *et al.*, 2020).

### **Emissions from energy use in supply chains**

In order to provide a quantification of emissions from the entire food system, first-order estimates of emissions from energy use in supply chains, based on published FAO (2011) work including fertilizer and equipment manufacturing, industrial food processing, packaging, refrigeration, and retail.

### **Emissions from the food system**

Taken together, results indicate that in 2018, total food system emissions were roughly 16 Gt CO<sub>2</sub>eq yr<sup>-1</sup>, having increased 8% since 1990. Nearly three quarters (about 12 Gt CO<sub>2</sub>eq yr<sup>-1</sup>) were generated in NAI countries in 2018, compared to a share of 68% in 1990. In 2018 (as in 1990), CO<sub>2</sub> was the largest contributor to food system emissions, totalling 9.5 Gt CO<sub>2</sub> yr<sup>-1</sup>. In comparison, in 2018, CH<sub>4</sub> contributed 3.9 Gt CO<sub>2</sub>eq yr<sup>-1</sup> and N<sub>2</sub>O 2.6 Gt CO<sub>2</sub>eq yr<sup>-1</sup>. The aggregation of results at the food system level highlights important differences between developed and developing countries (Debska *et al.*, 2020).

For instance, while CO<sub>2</sub> was the largest contributor to food system emissions in both AI and NAI groups, in 2018, it contributed proportionally more to the overall total in AI (72%) than in NAI (57%) countries. Furthermore, emissions from within the farm gate and by pre- and post-production activities were roughly equal contributors in AI countries in 2018, while in NAI countries they were dominated by land use change processes (Prosperio *et al.*, 2020).

With regards to the three major components of the food system (on-farm production, land use change, and pre- and post-production activities), our results indicate that in 2018, farm gate and pre- and post-production activities each contributed roughly equally to food system emissions at the global level, while land use change provided a smaller contribution.

Specifically, farm gate emissions were 7 Gt CO<sub>2</sub>eq yr<sup>-1</sup> (mostly non-CO<sub>2</sub> gases), with pre- and post-production processes contributing another 6 Gt CO<sub>2</sub>eq yr<sup>-1</sup> (Niles *et al.*, 2018).

### Emissions per capita of the food system

The computed emissions per capita over the entire study period 1990–2018, in order to provide an additional descriptor of food systems emissions globally and across regional aggregations, in total and by subsystem component. As expected, trends in per capita emissions significantly alter the overall storyline discussed above in terms of absolute emissions. The world-total per capita emissions decreased from 1990 to 2018, from 2.9 to 2.2 t CO<sub>2</sub>eq cap<sup>-1</sup> (Singh *et al.*, 2018).

Emissions per capita were higher in developed countries (AI), which nonetheless exhibited a strong reduction over the study period, from 4.8 to 3.6 t CO<sub>2</sub>eq cap<sup>-1</sup>, and lower in developing economies (NAI), but with a smaller decrease from 1990 to 2018, from 2.3 to 1.9 t CO<sub>2</sub>eq cap<sup>-1</sup>. The observed decreases in per capita emissions were related to trends in the three-food system sub-components (Xue *et al.*, 2017).

Globally, they were almost entirely due to sharp reductions in per capita land use change emissions, which more than halved during 1990–2018, from 0.9 to 0.4 t CO<sub>2</sub>eq cap<sup>-1</sup>. Conversely, global per capita emissions related to farm gate activities and pre- and post-processing decreased slightly from 1990 to 2005 but have remained constant over the last 15 years, with a plateau at around 0.8–1.0 t CO<sub>2</sub>eq cap<sup>-1</sup> (Loboguerrero *et al.*, 2019).

On a *per-ha* basis, GHG emissions for major food crops in India are generally lower than those in Europe and North America, with GHG emissions for cereals 2–3-fold greater in Europe (2000–3000 kg CO<sub>2</sub>eq ha<sup>-1</sup> yr<sup>-1</sup>) (Carlton *et al.*, 2012). A study in Canada estimated GHG emissions for spring wheat of 600 and 1400 kg CO<sub>2</sub>eq ha<sup>-1</sup> yr<sup>-1</sup> (Gan *et al.*, 2012).

GHG emissions for potatoes and peas show a similar range in Europe of ~3000 kg CO<sub>2</sub>eq ha<sup>-1</sup> yr<sup>-1</sup> and ~660 kg CO<sub>2</sub>eq ha<sup>-1</sup> yr<sup>-1</sup>, respectively (Carlton *et al.*, 2012). A Swedish study reported GHG emissions of wheat of 0.2–0.6 kg CO<sub>2</sub>eq kg<sup>-1</sup> production (Röös *et al.*, 2011); the calculated GHG emissions for wheat in India are towards the lower end of that range. A comparison of rice production in a Chinese study showed a range from 2000 kg CO<sub>2</sub>eq ha<sup>-1</sup> yr<sup>-1</sup> for upland rice up to 20000 kg CO<sub>2</sub>eq ha<sup>-1</sup> yr<sup>-1</sup> for paddy rice production, and similar values have been reported for Indian rice (Li *et al.*, 2006).

The reported estimates of GHG emissions from farm management differ across the above studies, partly because each uses different boundary conditions. In our study, the calculated GHG emissions on a *per*-ha-scale follow the same methods for all crops and differ mainly because of changes in management and fertiliser use for crops (Carlton *et al.*, 2012).

For cereals in general, less fertiliser is used in India than in Europe. These differences are also partly reflected in yield. The yields for cereals, pulses and potatoes have increased over recent years in India but are still only half of those recorded in Western Europe and North America (FAO STAT, 2015).

These differences show the importance of comparing GHG emissions on a *per*-kg production basis, as GHG emissions will be greater for low-yielding crops than for higher yielding ones using a *per*-kg metric. For instance, according to FAO STAT (2015), rice yields in China are around twice those in India.

The highest GHG emissions among crops are associated with paddy rice production. Emissions of CH<sub>4</sub> from rice production are recognised as a significant source of GHG emissions globally, and many studies show that changes in water management can substantially reduce CH<sub>4</sub> emissions (Liu *et al.*, 2010, Nayak *et al.*, 2015, Yan *et al.*, 2005).

It is possible to reduce CH<sub>4</sub> emissions and increase yield through optimising drainage and manure management (Banerjee *et al.*, 2002, Malla *et al.*, 2005; Thu *et al.*, 2016). Specifically, changing a continuously flooded system to intermittent irrigation shows potential to greatly reduce CH<sub>4</sub> emissions.

Although some studies show that N<sub>2</sub>O emissions may increase under intermittent irrigation, the decrease in CH<sub>4</sub> emissions more than compensates for this effect (Nayak *et al.*, 2015, Liu *et al.*, 2010). Nayak *et al.*, (2015) summarised management opportunities to mitigate GHG emissions from agriculture in China, and these can largely be adapted to Indian agriculture. In rice management, key elements are fertiliser management by reducing synthetic fertiliser inputs, increasing organic manure, and improving water management.

### **GHG emissions from livestock products**

As expected, GHG emissions from livestock products are generally higher than those from crop production. This reflects the inefficiencies of the conversion of plant

protein to animal protein in herbivores (Ripple *et al.*, 2014), and is also impacted by additional sources of emissions resulting from manure management and enteric fermentation in ruminants.

GHG emissions associated with livestock products depend largely on feed inputs, and in other studies, they have been shown to range between 0.8–2.4 kg CO<sub>2</sub>eq kg<sup>-1</sup> milk, 1.7–6.6 kg CO<sub>2</sub>eq kg<sup>-1</sup> eggs, 2.5–6.9 kg CO<sub>2</sub>eq kg<sup>-1</sup> poultry meat, and 10–20 kg CO<sub>2</sub>eq kg<sup>-1</sup> mutton and lamb (Bellarby *et al.*, 2013).

These values are based on different studies, mainly from model exercises that focus on Europe. Our milk and poultry result for India are within the range of these studies. The calculated emissions for mutton are higher than in the above discussed studies, resulting from embedded emissions in feed, which are 50–75% of the total GHG emissions *per animal per* year. Ruminants produce CH<sub>4</sub> through enteric fermentation, and options to mitigate this source are somewhat limited (Beauchemin *et al.*, 2011). Other sources of emissions from livestock production are manure management and changing feed rations.

To reduce GHG emissions from manure management, options include (i) changes to manure storage, e.g. decreased storage time, manure storage cover with straw, or mechanical intermittent aeration during manure storage (Hristov *et al.*, 2013), (ii) manure acidification (Ndegwa *et al.*, 2011, Petersen *et al.*, 2012), (iii) feeding of livestock with nitrate supplements (Van Zijderveld *et al.*, 2011) and (iv) stacking of poultry litter (Gerber *et al.*, 2013). To reduce GHG emissions from feed, all mitigation measures previously discussed for crops could be considered, as well as using the residues from crop production as feed.

### **GHG emissions by Indian diets**

The effect of diet on health and the environment has led to growing concerns and should be addressed globally as well as on national and regional levels. The link between diet and human health is well established, while the link between diet and a sustainable food system is less known but of major importance (Arrieta *et al.*, 2018).

Overall, national GHG emissions associated with diets are greatest for rice and livestock products like milk and eggs because these are widely consumed products with high GHG emissions per unit of product. Although there is limited consumption of ruminant meat

in India, its high GHG intensity means that it is the third greatest contributor to GHG emissions (Aleksandrowicz *et al.*, 2016).

The mitigation potential of livestock production therefore needs to be further explored. In addition to the mitigation options in on-farm management, dietary change could help to decrease GHG emissions considerably, but advice to change dietary intakes to reduce GHG emissions would need to consider the nutritional implications so as not to compromise health. However, in the event of a nutritional transition in India, toward the consumption of a greater volume of livestock products, there is likely to be an increase in GHG emissions unless *per-product* emissions are reduced through more efficient production and targeted mitigation measures, especially in the livestock sector and for rice production (Bajzelj *et al.*, 2014, Smith *et al.*, 2013, Smith, 2015).

Quantifying GHG emissions associated with the production of food items in India is an important stage in quantifying GHG emissions associated with diets. It allows one to

- (i) Identify variation in GHG emissions between typical dietary patterns within India.
- (ii) Forecast the effect of changes in diets on GHG emissions; and

(iii) Identify options to minimise GHG emissions from food production, either through production-side changes or through dietary changes. For example, a number of countries have experienced a ‘nutrition transition’ associated with greater disposable incomes, urbanisation, and globalisation. The transition is typified by increasing consumption of animal products, edible oils and sweetened beverages and decreasing consumption of cereals and pulses (Popkin *et al.*, 2012).

There is evidence that a similar trend is emerging among some population groups in India, although cultural preferences for lacto-ovo-vegetarian diets suggest that India’s experience will differ from other countries, including China (Baker and Friel, 2014; Misra *et al.*, 2011).

The implications of dietary changes in India for GHG emissions have not been quantified. In India, the majority of agricultural GHG emissions occur at the primary

production stage and are generated through the production and use of agricultural inputs, farm machinery, soil disturbance, residue management and irrigation (Pathak *et al.*, 2010).

These practices have been used to increase yields and improve harvests. Due to its direct contribution to global GHG emissions, agriculture can also serve as an important climate change mitigation strategy (Smith *et al.*, 2013, 2008), both by reducing GHG emissions to the atmosphere, and by sequestering atmospheric carbon into plant biomass and soil, though some soil carbon sequestration practices play a role in climate mitigation (Powlson *et al.*, 2014).

India's intended nationally determined contributions (INDCs) to the United Nations Framework Convention on Climate Change (UNFCCC) place emphasis on mitigation from agriculture, and various mitigation strategies (particularly concerning methane, CH<sub>4</sub>, and nitrous oxide, N<sub>2</sub>O) have been proposed (Smith *et al.*, 2014, 2008).

### **Energy use and GHG emissions from cradle to table**

Since most studies report energy and carbon footprints either to farm gates or to wholesalers (Clune *et al.*, 2017), including mass changes occurring during the final processing and cooking may lead to significant differences in the environmental impacts of foods brought to end users. Clune *et al.*, (2017) studied the effect of mass change and cooking on the cradle-to-table energy and carbon footprints of foods representing the three food groups, such as beef (meat group), wheat-based bread (cereal group) and soybeans (legume group).

The current western dietary patterns and global food production systems have a negative impact on the environment. The production and consumption of foods are responsible for 30% of total greenhouse gas (GHG) emissions. Moreover, it is a major determinant of biodiversity loss, land use, and freshwater use (Ndegwa *et al.*, 2011).

Blue (surface water and ground water) and green (soil moisture) water resources are considered scarce due to human activities. Agriculture consumes the largest amount of water and is responsible for 70% of global freshwater withdrawal. Changes in our food system need to be made, aiming to reduce the impact on planetary boundaries (climate change, biodiversity loss) while optimizing the nutritional quality of diets (taking into account the population growth and “expansion” of nutritional-related chronic diseases) (Smith, 2015).

The mass loss factor at this stage is 30%, meaning that 70% of carcasses end up as bone-free retailer beef (USDA, 1992). This meat is further cut at the butchery and sold with small bones and fat, as regularly provided. Finally, a mass loss from retailer to table occurs in households; firstly, during meat preparation before cooking (trimming off bones and fat), and secondly during cooking (water evaporation and fat melting) (Pathare and Roskilly, 2016).

For a variety of choice cuts and cooking methods, the mass loss of beef in households was experimentally obtained, and the average of the four cooking methods was used to assess mass loss at the household stage. Also included were the energy use and GHG emissions involved in slaughtering. For bread, whole wheat bread was baked in households in the oven described in Supplementary Materials. The mass loss of whole wheat grain to obtain whole wheat flour during milling is 10%, as reported by Carlsson-Kanyama and Faist (2000).

The mass gain and loss during bread preparation and baking were obtained in the present study. Three preparations of bread in similar ways were performed, and the results of mass changes and energy used were averaged. In the case of soybeans, the moisture loss of 8.5% between soybeans at the farm gate is 16% of moisture and soybeans at the wholesaler is 7% of moisture (Carlsson-Kanyama and Boström-Carlsson, 2001).

The energy required to dry grains was obtained from Abadía and Bartosik (2013), which is 4.64 MJ/kg of water evaporated. To assess the transport of food for final consumption, we assumed a location in the city of San Carlos de Bariloche (Argentina) and a starting point for beef in Buenos Aires (1600 km), for wheat flour from Azul (1300 km) and for soybeans from Rosario (1600 km).

They are located in the centre of major production regions. Long-distance transport is done by large trucks carrying between 30 and 40 tons, which require 0.33 liters of diesel fuel per kilo meter. For meats, it was considered refrigeration during transport (Carlsson-Kanyama and Faist, 2000). The default emission factor for diesel fuel was used to estimate GHG emissions associated with transport (IPCC, 2006).

Tilman *et al.*, (2014) suggest that since distinct ecosystems are endangered by climate change, more extreme weather events occur, reducing biodiversity and, in many ways, affecting our current way of life (Hallstorm *et al.*, 2018). Household food consumption accounted for more than 60% of global greenhouse gas emissions and 50% to 80% of overall resource usage (Springmann *et al.*, 2018).

Climate change, according to O'Neill *et al.*, (2017), endangers unique eco-systems, causes more extreme weather events, diminishes biodiversity, and threatens our existing way of life in many ways. Household food consumption accounts for more than 60% of global greenhouse gas emissions and 50–80% of overall resource use (Ivanova *et al.*, 2016).

### **Climate-smart nutrition and its need**

In light of these global challenges, the urgent need to transition away from the current system to a more sustainable one is widely recognized. Climate-smart nutrition taps synergies between nutrition, adaptation, and mitigation outcomes across the food system to help this transition. Climate-smart nutrition links two fields: climate-smart agriculture (CSA) and the nutrition community. Climate-smart interventions for enhanced nutrition are needed to meet both agricultural and nutritional needs (Global Panel, 2015).

Danysh *et al.*, (2014) stated that not all three of these benefits (optimized nutrition, climate change adaptation and mitigation) will be achievable at each stage of the supply chain, for each beneficiary group, or at the same time. Therefore, optimization of benefits needs to be seen at the system level more than at the individual intervention level, where only one or two of the three benefits might materialize.

On a global scale, the impacts of food systems on the environment and planet are severe. The industrial and agricultural revolutions have made it possible to increase food production, but at the cost of the environment. Food production puts great pressure on natural resources: it uses around 70% of the world's freshwater supply and 38% of the world's land; livestock sector uses 70% of agricultural land (Development Initiatives, 2017). Expansion of agricultural land is a known driver of deforestation (CAT Decarbonisation Series, 2018).

The impact of agriculture and food production is also immense drivers for the continuing loss of biodiversity. Looking at the shift in the relative biomass of different species of mammals, recent studies show that humans account for 36% of the biomass of all mammals, livestock account for 60%, and wild mammals only account for 4% (Bar-On, Phillips, Milo, 2018).

The interlinkages among the food system, nutrition and climate change are complex. If one focuses solely on malnutrition and climate change in more detail, highlighting the concepts of nutrition, climate change adaptation and mitigation, the challenge becomes more

nuanced. On the adaptation side, the climate-nutrition interface is linked to malnutrition and the adaptive capacity of vulnerable people. The impacts of climate change on nutrition are decreased food quantity and access, decreased dietary diversity, and decreased food nutritional content (Fanzo, McLaren, Davis, Choufani, 2017).

As per IFPRI, (2015) at the same time, people's nutrition status and diet choices affect their capacity to cope with and adapt to climate change and to mitigate climate change within the food supply system. For the poorest groups, the seasonal cycles of food availability, infection, and time use remain a significant challenge to nutrition security and provide a stark indicator of the vulnerability of populations to climate risk.

Climate change further exacerbates the enormous existing burden of malnutrition by affecting food and nutrition security. Climate change signals such as increasing temperatures or the occurrence of extreme weather events (e.g., severe droughts, extreme winds) can have impacts on crop yields, crop nutrient content, and post-harvest losses as some examples. The nutritional status of people, in turn, is also affected by global nutrient supply, which affects their ability to cope with and adapt to climate change, which is affected by food price increases and volatility and the lower purchasing power of nutritionally healthy foods (Myers *et al.*, 2017).

A study by WRI, (2018) shows that for mitigation, the situation is slightly different: large parts of production and consumption (especially over nutrition), and all the supply chain stages in-between, have a negative effect on the environment, including causing substantial GHG emissions that contribute to climate change. As of 2010, agriculture and land-use change contributed one-quarter of total GHG emissions – 12 gigatons (Gt) measured as carbon dioxide equivalent (CO<sub>2</sub>e). Projections show that by the year 2050 total agricultural emissions will be 15 Gt, which would account for 70% of the allowable “emissions budget” for holding climate warming to the global target of 2 degrees Celsius (20C).

Promoting good nutrition, health, and sustainable food systems in the context of population growth, dietary transition and a changing climate is a central challenge of our time. While climate change has an impact on one's diet, the food system (and therefore our diets) also affects climate change. Food production and consumption are responsible for 19-29% of human-induced greenhouse gas (GHG) emissions, 60% of terrestrial biodiversity loss and 70% of freshwater use (Steinfeld *et al.*, 2006).

Animal-based foods are the main culprit (Vermeulen *et al.*, 2012; Tubiello *et al.*, 2014; GBD 2015), with livestock accounting for an estimated 14.5% of GHG emissions (FAO, 2013). By 2050, GHG emissions from food and agriculture could rise by as much as 80% due to the increased consumption of animal products (Popp *et al.*, 2010; Hedenus *et al.*, 2014; Springmann *et al.*, 2016; Tilman and Clark 2014).

Indeed, food related GHG emissions could account for half of all emissions allowed by targets for keeping the global rise in temperature to less than 2°C by the middle of the century and could exceed total permissible levels by 2070 (Hedenus *et al.*, 2014; Springmann *et al.*, 2016).

Meanwhile, diets have deteriorated globally (GLOPAN 2016), leading to an increase in non-communicable diseases (NCDs), particularly type II diabetes, coronary heart disease and some cancers (Lim *et al.*, 2010; Sabate and Soret., 2014).

Malnutrition is a universal challenge, affecting all countries in its various forms, from undernutrition, excessive weight and obesity to micronutrient deficiencies and combinations thereof. Some 795 million people are chronically undernourished (FAO, IFAD and WFP., 2015), two billion are micronutrient deficient (FAO and WHO., 2014), 42 million children are deemed overweight before their fifth birthday, and a staggering 1.9 billion adults are overweight or obese (UNICEF, WHO and World Bank., 2016; GBD., 2015).

Tilman and Clarke., (2014) described that while income growth can be reduced under nutrition, it is not always the case. Economic development, globalization, urbanization, and lifestyle changes have caused a major shift towards a poor diet, excessive caloric intake, and low levels of exercise. The result has been a rapid rise in obesity and NCDs. The alarming pace of climate and environmental change and its effects on food systems, nutrition and health require a major rethink of how food is produced and consumed.

Lim *et al.*, (2010) has opined that the Nutrition Challenge Continued population growth, urbanization, and increasing wealth have led to rapid growth in demand for food, both in quantity and quality. While industrialized countries have experienced these changes in their development paths, most of these changes are also taking place in developing countries that are transitioning to middle-income status.

The trends have serious implications for the use of natural resources within the safe operating space of the biosphere. Increasing demand for these resources can affect the social resilience of vulnerable groups by contributing to different forms of malnutrition. The world population is projected to reach 9 billion by 2050 (UNDESA, 2017), creating an additional 1.8 billion food consumers. By various estimates, in a scenario of modest economic growth until 2050, agricultural demand is expected to grow by 50 percent (FAO, 2017).

Food consumption is projected to increase from the current levels in both industrialized and developing countries (WRI, 2016; Alexandratos & Bruinsma, 2012). Rapid urbanization and rising incomes are coupled with what is known as the ‘nutrition transition’ to denote the shift in diets: from coarse grains, staple foods and cereals towards more animal-based products, sugar, and processed foods (FAO, 2017; Hawkes, Harris and Gillespie, 2017; HLPE, 2017).

Hawkes *et al.*, (2017) highlighted that the changes in diets are causing serious diet-related health conditions such as obesity, diabetes, and heart diseases and disorders when consumed in excess. Food environments in urban areas enable access to unhealthy diets through the availability of supermarkets, food vendors, and restaurants (although they can also facilitate access to healthy food), and unhealthy diets are mostly affordable for the urban poor. While the nutrition transition is driven mainly by urbanization, it is taking place in rural areas as well.

The trends have serious implications for food production systems, especially if business continues as usual. Satisfying increased demand for food with existing food systems is likely to lead to more intense competition for natural resources, increased GHG emissions, and further deforestation and land degradation (FAO, 2017).

The Paris Agreement was the first climate agreement to put high priority on food security (Development Initiatives, 2017). The preamble of the agreement refers to “safeguarding food security and ending hunger and the particular vulnerabilities of food production systems to the adverse impacts of climate change” (FAO, 2016).

The agreement highlights the importance of “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.” Shifting to

healthy, low-emission diets is associated with emission savings of up to 30% compared to business as usual, a continuation of current dietary trends. In aggregate, this consumption shift could dramatically reduce agricultural emissions on a global scale (CAT Decarbonisation Series, 2018).

Reducing meat consumption in developed countries and increasing it in countries with protein deficiency could bring about reductions in nonCO<sub>2</sub> emissions (compared to a reference scenario without diet shift) of 1.5 GtCO<sub>2</sub>e/year by 2030. Moreover, a number of studies confirm that diet shifts can potentially have higher mitigation impacts than technological changes on the supply side (Bajželj *et al.*, 2014; Campbell *et al.*, 2016; CAT Decarbonisation Series, 2018).

Studies by CAT Decarbonisation Series, (2018) show that future pathways of human diets, including their content, are stronger determinants of whether world food demand by 2050 can be met without causing deforestation, e.g., assumptions on future cropland availability, yield, and livestock feeding practices.

Food loss and waste (FLW) is another large area with mitigation potential. A FAO study on the global food supply chain found that one third of the food, produced for human consumption does not reach consumers and gets lost and wasted along the supply chain, also representing the loss of inputs used to produce this food loss and waste (FAO, 2011; HLPE, 2014).

Nutrition and adaptation outcomes are also strongly interlinked. The nutrition status and overall health of smallholder producers are the main determining factors in climate vulnerability. Poor nutrition can result in diminished productivity, which in turn lowers the adaptive capacity of entire communities. Diversified local production of a variety of crops and livestock, coupled with storage and value-added, on the other hand, incentivizes a healthy, diverse, and nutritious diet, which increases adaptive capacity (Steinfeld *et al.*, 2006).

According to TEEB (2015), changes in the nutrition status of producers can cause health problems, diminished productivity, and even mortality. This, in turn, has implications for the ability of communities and individuals to adapt to the changing climate, often forcing them to make short-term coping decisions instead of investing in longer-term adaptation strategies.

A typical example is the short-term decision of a smallholder farmer, usually a female responsible for households and children, to cook less nutritious and healthy foods, which has long-term health and development implications (IFPRI, 2015; TEEB, 2015). In a feedback loop, this further undermines the enabling environment for malnutrition reduction.

The conceptual framework developed in the Global Nutrition Report 2015 (IFPRI, 2015) brings together two lines of narratives: i) the impact of climate change on nutrition and the impact of nutrition on adaptive capacity; and ii) the impacts of food production and diet choices on GHG emissions.

### **Impact of livestock on greenhouse gases and climate change**

Godfray *et al.*, (2010) has opined that one of the most crucial worldwide policy concerns of the twenty-first century is climate change. There is a lot of interest in learning how to persuade customers to make more sustainable food choices since shifting food consumption patterns may have an influence on greenhouse gas (GHG) emissions.

The hazards posed by global temperature increases beyond 2°C have been accepted by governments all around the world after decades of talks. As part of the Paris Agreement, which was unanimously adopted at the 21st Conference of Parties of the United Nations Framework Convention on Climate Change, governments have committed to continuing their efforts to keep global temperatures from rising more than 1.5 degrees Celsius above pre-industrial levels (UNFCCC, 2015). Additionally, nations strive to "achieve global peaking of greenhouse gas emissions as soon as practicable" (UNFCCC, 2015). But according to forecasts based on current emission levels, global warming will range between 4 and 6°C by 2100. (Sherwood *et al.*, 2014).

The foods we eat have an impact on GHG emissions. According to Audsley *et al.* (2009) and Aston *et al.* (2012), the agri-food industry is a significant contributor to climate change because it accounts for 30% of all GHG emissions. Despite this, discussions of food, particularly in terms of consumption, are uncommon in international climate change agreements. More than any other food category, livestock-based products in the agri-food industry are a major source of greenhouse gas emissions (GHG) (about 50% of agri-food GHG, about 15% of overall GHG; Weidema *et al.*, 2008; Defra, 2013, Shindell *et al.*, 2012).

### **Shifting consumer behaviour towards more sustainable food choices**

The only way to modify people's behaviour is to increase awareness about the carbon footprint and effects of food on climate change. It might be difficult to convince customers to switch from less sustainable to more sustainable meals because they might not see any immediate or obvious benefits for themselves (such as price, taste, or quality; Godin *et al.*, 2018). Therefore, one strategy would be to highlight co-benefits that directly impact customers, including financial incentives or health advantages (Shindell *et al.*, 2012). This has been a successful tactic for organic food goods and conventional food products, which are viewed as a "healthier/sustainable" alternative, albeit being more expensive (Roos and Tjarnemo, 2011).

A different strategy would be to inform customers that the environmental cost of eating beef would eventually be reflected in the cost of food (for example, in the form of a "shadow carbon tax"). Without affecting the product's real cost, a "shadow carbon tax" estimates what a product would cost if a GHG emissions-related taxing scheme were in place. A shadow carbon tax might be employed as a technique to increase awareness, spark public debate, and even nudge food consumption in the direction of more environmentally friendly habits. Moving toward a reduced protein diet may also benefit from public campaigns with slogans like "less is better."

Pelletier *et al.*, (2013) concluded that depending on consumer preferences, methods boosting consumption of smaller quantities of meat, better quality meat, or even limiting the frequency of meat intake (such as "meat-free Monday"), might have special merits. The authors opined that to create a significant change in one's diet, it would be necessary to take into account all of the research techniques as well as the wide variety of clients and their dietary preferences.

Investigating emission reductions by linking them to carbon-labelled items is essential for all food items, which is necessary for recent developments. Nevertheless, variables including cost, flavour, health, and food safety, as well as accessibility and eating habits, still influence how and what people choose to eat (Roos and Tjarnemo, 2011; Shindell *et al.*, 2012; Government Office for Science, 2018).