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Review

Food and Sustainability: Is It a Matter of Choice?

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Abstract: Health and sustainability problems have become a central theme in dialogue in both the scientific community and the public. Our individual choices have a profound, advantageous or disadvantageous impact on our health; the same can be said about our environmental footprint. In this area, we can also make decisions that affect the physical environment positively or negatively. Our narrative review aims to demonstrate that healthy plant-based choices in our diet are linked to choices beneficial for our environment and that these two seemingly distant aspects converge in the context of plant-based diets. We have collected, compared and discussed the results of life cycle analysis (LCA) articles on the current state of the effect of food choice on our environment. Furthermore, we would like to show the opportunities and constraints of implementing plant-based diets.

Keywords: plant-based diets; LCA; GHG; sustainability; water use; land use

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1. Introduction

The food we consume determines our health status in a very profound way. Our food choices can be detrimental or beneficial to our health, depending on several factors (e.g., macro- and micronutrients, fibre, added sugar and salt, phytochemicals, etc.) Nowadays, most healthcare professionals, intergovernmental agencies and health-conscious people are recognizing this issue and trying to find solutions to the problems attributed to inappropriate diets (high in salt, saturated and trans-fats, refined sugar, animal-based and processed foods, low in raw fruits, vegetables, and fibre) [1,2].

A plant-based diet can be an acceptable way to improve and maintain health and reverse some diseases. The definition of a plant-based diet is widespread, with the main emphasis on the consumption of raw or minimally processed vegetables, fruits, whole grains, legumes, nuts and seeds, spices and herbs. In addition, these diets often minimize or exclude all products of animal origin [3]. A well-balanced plant-based diet is not only a useful tool for the primary prevention of many health conditions [4,5]. However, it can also be used as adjunctive therapy for chronic diseases, including cardiovascular disease [4,6–9], obesity [8,9], certain types of cancer [10–12], type 2 diabetes mellitus [10–12] and stroke.

Numerous studies have shown that reducing the consumption of animal-based foods would have a positive impact not only on health but also on the environment [13,14].

As well as becoming increasingly accepted by the general public, the scientific consensus also indicates that the climate crisis is caused mainly by human activity [15]. According to the Report of the United Nations Environment Programme (UNEP), the world population needs to reduce carbon emissions by 25% by 2030 [16]. The global food supply is responsible for approximately 26–34% of total carbon emissions (13.6–17.9 billion tonnes of CO_2 equivalent (CO_2eq) [17–19].

It has been suggested that changes in dietary behaviour and consumer attitudes can positively alter the carbon footprint [20]. In this point, the case is similar to our food choices: we can choose to be environmentally friendly or hazardous for the environment. Unfortunately, not all countries have access to the same raw materials or even the most sustainable food. Nevertheless, it can be said that reducing animal food intake can reduce individual carbon footprints, water use and land use to a greater extent than eating only high-carbon, high-water footprint, land-intensive plant foods [21].

It is estimated that 50% of total greenhouse gas emissions from food production are related to agribusiness activities [22]. According to researchers, meat and dairy products have the greatest environmental impact, which can lead to the depletion of our planet's resources [23]. Population growth and consumption data suggest that demand for livestock products could increase by up to 70% by 2050 [24].

Furthermore, due to changes in temperatures, storms and heat waves are getting more severe, directly affecting mental and physical health. Rising temperatures and extreme weather conditions can put a strain on people suffering from common health problems such as cardiovascular disease [25], kidney disease [26], mental disorders [27], and diabetes [28]. Increasing numbers and magnitude of heat waves contribute to the occurrence of stroke [29] and acute kidney injury [30]. Air pollution can increase the risk of respiratory diseases, for example, asthma [31], chronic obstructive pulmonary disease [32] and lung cancer [33]. Climate change is linked to several other factors that potentially have a knock-on effect on the health of people and the planet.

Our major aim was to assess the environmental indicators for the main foods included in plant-based diets. We focused on greenhouse gas emissions, water use, and land use, but for some foods and products, we also considered specific indicators to discuss their effect on the environment. A further aim was to assess the environmental impact of some animal products in order to evaluate their potential for inclusion in or exclusion from a plant-based diet. In light of these data, we can ask the question: can sustainability—at least partially—be a matter of choice, and do people have authority over their health and even over the health of the environment?

2. Food and Environment

It is difficult to define an objective measure of the environmental impact of food. Various indicators have been presented in the literature to describe greenhouse gas emissions (GHGE), nutrient pollution, water use and many others [34].

Environmental Impact of Plant-Based Diet

Among the dietary changes, reducing animal foods significantly impacts greenhouse gases, water and land use [35]. In a study, the dietary GHGE of the original omnivorous diet averaged 3.88 kg CO_2eq/person/day [20]. Theoretically, replacing 100% of beef, pork or poultry with vegetable proteins would reduce dietary GHGE by 49.6% compared to the previous omnivorous diet [20]. In high-income countries, switching from an average mixed diet (typically rich in animal products) to a more sustainable diet (a diet rich in plant foods but poor in red meat) could reduce GHG emissions by 20–30% on average [20]. In 2018, two studies based on the work of previous research confirmed that the complete elimination of meat from the diet results in a reduction of GHGE by about one-third [22,36]. To further reduce GHGE, animal foods and proteins should be replaced with alternative foods such as vegetables, legumes, cereals, mushrooms, and fruits [35]. Studies have also confirmed that dietary GHGE levels are twice as low in vegan diets than in mixed diets [36,37]. A recent study ranked GHGE levels of different diets from highest to lowest, and the order was as follows: omnivore, vegetarian, pesco-vegetarian, and vegan as the lowest [36]. Plant-based diets, such as vegan diets, have some of the lowest carbon footprints [22,36,38].

Only a few studies have analysed land occupation in relation to different types of diets. Rabes et al., found significantly higher land occupancy for omnivorous diets (10.85 m^2/day) than for pesco-vegetarian (4.94 m^2/day), vegetarian (4.97 m^2/day) and vegan (3.86 m^2/day) diets [36]. The definition of these diets are shown Figure 1.

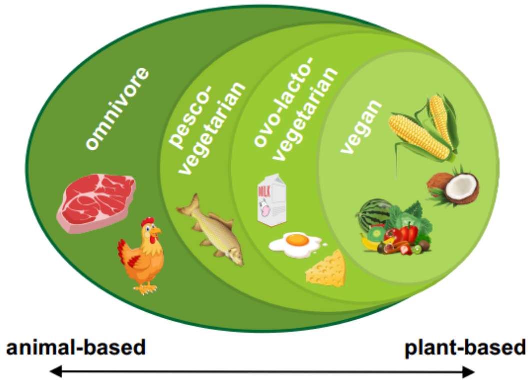

Figure 1. Diets with different level of animal based product consumption.

From left to right: including all food items (omnivore), exclusion of meat (pesco-vegetarian), or meat and fish (ovo-lacto-vegetarian) to the complete exclusion of products of animal origin (vegan) [39].

The water footprint (WF) of one product is a measure of the water consumed and polluted per unit of the product produced. Depending on the source of the water, the water footprint can be green water (water mainly from precipitation and evaporation), blue water (water from soil or surface water) and grey water (a contaminated form of blue water) [40,41].

According to Vanham et al., the water footprint of a vegetarian diet which does not contain meat, fish or poultry, would result in the lowest WF compared to a healthy diet (reduced consumption of sugar, vegetable oils, meat and animal fats and increased consumption of fruit and vegetables) [42] and a combined diet, i.e., a combination of healthy and vegetarian diet, in which half of the meat products are substituted for pulses and oilseeds. This is because reducing meat consumption results in the greatest reduction in WF since meat products have the highest WF per calorie [43].

Harris et al., found that diets which contain more plant-based foods have a lesser water footprint. This study showed that turning to diets that contain no animal foods from typical omnivore dietary patterns would decrease the entire water footprint by 25% and the blue water footprint by 12% [44].

The importance of a plant-based diet for environmental issues goes far beyond reducing greenhouse gas emissions, land use and water use. Evidence suggests that soil loss, declines in top predators and wild herbivores, overfishing, soil and water pollution, and sedimentation of coastal areas while increasing pressures on biodiversity and ecosystems can be attributed to people's food choices, particularly to meat consumption [35,45]. Current global food production is unhealthy and unsustainable; thus, the food we consume poses a risk to both the planet and people. Food production systems are responsible for about 60% of global land biodiversity loss [46,47].

A 'Great Food Transformation' is needed to develop a health-promoting and sustainable food production system [48]. The lack of integrated global policies means sustainable and health-promoting food production cannot be guaranteed. The current food supply system is extremely wasteful. National Dietary Guidelines (NDGs) need to be harmonised. In most cases, the current NDGs exceed the planetary climate boundaries for food production several times. The food consumption patterns of individual G20 (Group of Twenty) countries and the NDGs they set are much more resource-dependent than the resources available [49]. Therefore, it is more important now than ever to emphasize the importance of personal choice. When it comes to health, most people are able to identify a wide range of factors that act against or for diseases. The development of high numbers of non-communicable diseases) mostly depends on personal choices (e.g., smoking, alcohol consumption, physical inactivity etc.), and the same applies to environmental factors. The lack of governmental and intergovernmental intention makes it essential that a high proportion of the population becomes aware of the consequences of their choices that determine not only their health but also the status of the environment.

Plant-based diets appear to be more sustainable than diets rich in animal products, and by reducing the consumption of animal foods or eliminating them, they have a potentially lesser impact on the environment.

The forthcoming sections evaluate those foods of animal origin that are believed to be more environmentally friendly and were also found to be less detrimental to our health. Moreover, we would like to discuss whether plant-based foods represent a less significant environmental impact than foods of animal origin.

3. Methods

To meet the proposed objective, a narrative review was carried out. Our review article aims to collect, compare and discuss the results of life cycle analysis articles on the current state of the effect of food choice on our environment.

Given the scope of the topic and the difficulty of formulating precise survey questions, we used a narrative review to facilitate extended discussion.

Our non-systematic review was performed between August 2022 and November 2022. The purpose of our study was to assess the environmental indicators for the main foods included in plant-based diets. Another goal was to investigate the environmental impact of some animal products in order to assess their potential inclusion or exclusion from a plant-based, environment-friendly diet. We used the Scopus, PubMed and Google Academic databases for the literature search, as well as a manual search of references of selected articles. All the searches were performed by one of the authors, country or area of knowledge.

We agreed on keywords, all associated with land use, greenhouse gas emissions as well as carbon and water footprint. We also focused our review on certain animal and plant-based foods: chicken, eggs, dairy products, fish, fruits and vegetables. Although we did not investigate the effect of plant-based oil production profoundly, we did include them in our research to compare their environmental impact.The study included primary and review articles in English. The selection of international articles and official documents covered the last 15 years. The main criterion for the selection of articles was that the data should come from life cycle analysis, which is a method for calculating the environmental impact of a given product focusing on every aspect, from production up to consumption. Where data were unavailable from LCA analyses, the crop water footprint estimated by Mekonnen et al. [50] and the FAO (Food and Agriculture Organization of the United Nations) agricultural production area, FAOSTAT (Food and Agriculture Statistics) [51], which contains crop and livestock production data, were also used.

Considering the research objectives, the results were grouped into six categories (eggs, chicken, milk and dairy products, fish, fruits and vegetables) according to the types of food we studied.

Narrative reviews (such as this one) can be useful for discussing issues, raising questions and awareness, updating knowledge and obtaining a broad perspective.

4. Results

4.1. Chicken Meat

Of the various poultry species, chickens are the main target of rearing worldwide and are estimated to account for more than 90 percent of the poultry sector [52].

The main environmental impacts of chicken meat production include GHGE, non-renewable energy consumption, land occupation, water use and eutrophication, and soil acidification, which can increase with poultry housing, intensity, and feed and manure management [53–56].

Several studies have found that the production of chicken feed is the largest contributor to greenhouse gas emissions [53,57–59], accounting for 45–83% of greenhouse gas emissions from chicken meat production [60,61]. Of all feedstuffs, imported soybeans have the largest impact on the environment, accounting for 71–79% of the total impact, which can be explained by land use change and transportation [62].

Chicken is produced under three different systems: 'conventional', 'free range' and 'organic'. These systems can have different environmental impacts, although these differences are questionable. The results of studies on the carbon footprint of chickens from conventional farming systems ranged from 1.1 to 3.84 kg CO_2eq/kg liveweight (LW) [58,59,62,63]. Prudêncio da Silva and colleagues found that chicken production systems in France ranged from 2.2 to 2.7 kg CO_2eq/kg LW. In Brazil, the range was 1.5 to 2.1 kg CO_2eq/kg LW, but in this case, deforestation in southern Brazil was not taken into account [61]. Similarly to the Brazilian study, Pelletier reported low emissions in the US (United States) conventional system (1.4 kg CO_2eq/kg LW), but he did not take into account the meat processing step [60].

In the United Kingdom, carbon dioxide emissions were higher in the free-range system, at 3.43 kg CO_2eq/kg LW, than the average emissions from conventional farming. The difference may be explained by the fact that the production cycle of the conventional farming system is shorter than that of the alternative systems, and it is the most efficient in terms of feed conversion. This results in lower feed consumption and manure production per kg of carcasses produced [64].

A study has shown that the widespread adoption of organic farming practices could reduce direct greenhouse gas emissions compared to conventional farming; however, this would lead to a net increase in greenhouse gas emissions and a reduction in livestock yields due to offsetting [65].

Some studies have analysed the environmental impacts of chicken meat processing. According to Wiedemann et al., meat processing increases greenhouse gas emissions by up to 8% [58].

A life cycle assessment in Italy showed an average GHGE of 5.52 kg CO_2eq CW (carcass weight), including the slaughter and packaging of the animals [62].

A UK study found that the conventional system emitted 4.4 kg CO_2eq/kg edible CW, while the free-range system emitted 5.1 kg CO_2eq/kg edible CW [54].

Few studies have examined water consumption in chicken production. One study reported that the freshwater consumption in the conventional chicken production system ranged from 38 to 111 L/kg CW, while in the free range system, it was 70 L/kg/CW [58].

Compared to this study, Leinonen et al., found lower values of 4.41 L/kg CW for conventional, 6.86 L/kg CW for free range, and 7.03 L/kg CW for organic chicken production [54]. The difference can be explained by the fact that the water consumption of crop production was not taken into account, but only drinking and cleaning water.

The water footprint of animal products varies between countries, farming and production systems. The total water footprint of conventional chicken meat production in a water-scarce country (Tunisia) was 6030 L/kg/meat, significantly higher than in the Netherlands (1790 L/kg) and the US (2221 L/kg) [64,66]. This difference can be explained by poor agricultural practices and the specific climate of Tunisia. These factors contribute to a higher water footprint per tonne of feed than in the Netherlands and the U.S.

The land occupation values in the French systems range from 2.6 to 3.9 m^2/kg LW, while in the Brazilian system, it was 2.5 m^2/kg LW [61]. Katajajuuri reported a higher land requirement of 5.5 m^2/kg LW in Finland [67].

Williams et al., compared the land requirements of three different farming systems and found that the organic system used the most land (14.0 m^2/kg LW) compared to the open field (7.3 m^2/kg LW) and conventional systems (6.4 m^2/kg LW). According to the authors, this result is due to the lower production rate and, thus, higher land requirements of organic farming [68]. The land requirement of conventionally produced chicken in the Tunisian system was higher than in the previous study, 9 m^2/kg of meat (7.4 m^2/kg CW) [64]. In the Australian conventional rearing system, the field area occupancy ranged from 14.0 to 22.5 m^2/kg CW, compared to 18.2 m^2/kg CW in the free range system [58]. The higher land use requirements are related to different regional conditions and lower yields.

4.2. Eggs

Eggs are one of the richest sources of animal protein, along with meat. The carbon footprint of eggs depends on chicken breeds, breeding and feeding, feed efficiency, chicken production, and manure management [69].

The FAO analysis estimates that 69% of the carbon footprint of eggs is accounted for by feed production, 4% by direct on-farm energy use, 6% by post-farm processing and transport of meat, and 20% by manure storage and processing [70].

Pelletier et al., has shown that the environmental impact per kilogram of eggs produced has decreased considerably over the years [60].

Abin and colleagues reported about 3.4 kg CO_2eq emission per kg of eggs for the intensive farm egg system in Spain [71].

Pelletier compared GHGEs between different poultry housing systems (conventional cage, enriched cage, free run, free range and organic) in Canada and found the lowest emissions for organic housing, 1.37 kg CO_2eq/kg eggs, and similar GHG emissions for other housing systems ranged from 2.30–2.44 kg CO_2eq/kg eggs [72].

Guillaume et al., presented different results in which organic eggs had the highest climate change potential (3.46 kg CO_2eq/kg eggs) compared to battery eggs (2.46 kg CO_2eq/kg eggs). According to their results, feed conversion ratio, feed composition and manure management are the main parameters affecting the environmental impact of eggs [73].

Taylor and colleagues studied two free-range laying farms [74], where purchased feed accounted for 50–73% of the carbon footprint of the eggs, as was also found by other authors [71,75,76].

Xing et al., reported that in China, the green water footprint (WF) of eggs was 1.917–2.114 m^3/kg, the blue 0.584–0.644 m^3/kg and the grey 0.488–0.538 m^3/kg. According to their analysis, 99.8% of the indirect WF was feed water [77].

In the Dutch industrial system, the estimated green WF for eggs is 1.187 m^3/kg, blue WF 0.055 m^3/kg and grey WF 0.113 m^3/kg. In the US, similar results were obtained for green WF (1.218 m^3/kg), but blue (0.132 m^3/kg) and grey WF (0.232 m^3/kg) for eggs without trust were about twice as high as in the Dutch system [66].

Only a limited number of studies have examined the land use or the land occupation of eggs. Dekker et al., investigated land occupancy based on laying systems in the Netherlands, where their results showed that the organic system had the highest land occupancy (6.75 m^2/year/kg egg), the cage system had the lowest land occupancy (3.26 m^2/year/kg egg), and the barn system had a similar low land occupancy (3.75 m^2/year/kg egg) compared to the cage system [78]. The discrepancy was mainly due to differences in feed conversion and yield per hectare.

Pelletier's study did not find significant differences in land use between conventional cage (7.545 m^2/kg of eggs), enriched cage (8.1228 m^2/kg of eggs) and free range (7.9751 m^2/kg of eggs), albeit the land use was significantly lower in the organic system (4.5732 m^2/kg of eggs) [72].

4.3. Milk and Dairy Products

The production of milk and dairy products can have an impact on the environment at many points.

Most studies that have attempted to examine the environmental impact of milk and dairy products have shown large variations in energy use, resulting emissions, and air and water consumption per kilogram of finished product [79]. These variations depend on many factors (production system, geographical area, cow species, etc.). Based on the above-mentioned factors and the complexity of LCAs, the carbon footprint (CF) of cow's milk range from 0.74–5.99 kg CO_2eq/kg FPCM (fat- and protein-corrected milk [80–83].

Data suggest that the main contributing factor to the emitted CO_2 is the production of raw milk (approximately 60–86%), and further processing methods (e.g., cheese production) are less relevant [84,85].

Other common problems attributed to dairy products include manure production, water use and waste of resources for feeding cows [86,87]. The production of one litre of cow's milk requires 0.628–1.020 cubic metres (m^3) of water on average [19,88]. One kg of fat and protein-corrected milk production requires 0.5 m^2 of land on average [89].

In the production of different types of cheese, the CF depends on the amount of milk used [84]. According to the results of LCAs, cheese production produces 4–14.7 kg CO_2eq/kg and requires an average of 5.06 m^3 water/1 kg of product [88,90].

Yoghurt is a popular dairy product often chosen as part of a healthy diet. Vasilaki and colleagues, in their case study, showed that 1 kg of yoghurt emits 1.94 kg of CO_2eq and requires 0.204 cubic metres of water to produce [91].

A wide variety of scenarios has been studied in relation to milk production and its environmental impact, but these data are hardly comparable and difficult to draw a definite conclusion. It seems that applying modern technology to dairy farms mitigates some negative environmental impacts on the farms [92].

Over a few decades, milk and dairy production has moved from traditional and pastoral systems to collective and industrialised systems. Some evidence has suggested that these changes have led to improvements in the use of available resources [92]. Most of the EU's (European Union) greenhouse gas footprint comes from dairy, meat and egg production (83% of total emissions; 27% from dairy products) [88,93].

The dairy industry causes multiple ecological threats to the environment in complex ways. During the process (from animal fodder to consumable milk, dairy, and meat products), by-products are generated, so waste management is a key point to understand. Even milk can be a waste product: nearly 16 percent of the world's dairy products—some 116 million tonnes—are discarded or thrown away each year, a huge waste of precious resources [94].

4.4. Fish and Other Aquatic Foods

Fish and other aquatic foods (blue foods/seafood) are a staple of many diets. Demand for seafood is increasing [95], production is shifting towards aquaculture (farmed) due to overfishing, and production technologies are evolving [96].

Seafood is underrepresented in environmental assessments of food systems [97], and the stressors considered are limited [98]. Most information was found on greenhouse gas emissions [99], but less on land and freshwater use [100] and nitrogen (N) and phosphorus (P) emissions.

Studies show that GHGEs from fed aquaculture are mainly from feed [101], while fuel use is the driver of emissions from fisheries [102]. Based on data from more than 1690 farms and 1000 individual fisheries, Gephart et al. [96] found that among the blue foods assessed, farmed seaweeds and bivalve molluscs are the lowest emitters (1086 and 1399 kg CO_2eq tonne (tonne equivalent), followed by small pelagic fisheries, while halibut and crustacean fisheries are the highest (20,313 and 19,444 kg CO_2eq tonne). The average emissions of farmed bivalve molluscs and shrimps were lower than those of their catch-or-caught counterparts (bivalve molluscs, 1399 kg CO_2eq tonne versus 11,400 kg CO_2eq tonne; shrimps, 9428 kg CO_2eq tonne versus 11,956 kg CO_2eq tonne), while salmon and trout were similar, whether farmed or fished (5101–5410 kgCO_2eq tonne versus 6881 kg CO_2eq tonne).

The growing lack of freshwater is increasingly limiting agricultural production, but fisheries and non-forage mariculture use require little or no freshwater [103]. Freshwater consumption is largely limited to forage production and on-farm evaporation losses for freshwater production [100], with on-farm evaporation losses accounting for more than 60% of freshwater species' water use [96]. In a study by Gephart et al. [96], the total water use of silver and bighead carp is the highest (9.277 m^3/kg) due to high evaporation losses, 2.6 times that of other carp and 4.4 times that of catfish, while the highest water use is associated with the feeding of milkfish and various marine and diadromous fish. Among the fed aquaculture species, water use was lowest for trout and salmon (0.112 and 0.155 m^3/kg, respectively), partly due to lower yield recovery, highlighting the trade-off between fish meal and fish oil [96].

Gephart and colleagues [96] reported that on-farm land use was low (<1000 m^2/tonne) for most systems and highest (3737–8689 m^2/tonne) for extensive ponds (e.g., milkfish, shrimp, silver and bighead carp). In general, most land use was related to feed production for the fed systems, except for milkfish, where the highest on-farm and off-farm land use (18,532 m^2/tonne) was observed [96].

Nitrogen and phosphorus emissions are the main drivers of eutrophication and correlate strongly with each other due to the N:P ratio of natural biomass [96]. In the study by Gephart et al., for on-farm fed systems, the majority of N (>87%) and P (>94%) emissions occurred on-farm. The highest total N and P emissions were from various farmed marine (234 kg N-eq (nitrogen equivalent)/tonne; 50 kg P-eq (phosphorus equivalent)/tonne) and diadromous fish (156 kg N-eq/tonne; 37 kg P-eq/tonne), milkfish (146 kg N-eq/tonne; 23 kg P-eq/tonne) and fed carp (147 kg N-eq/; 20 kg P-eq/tonne [96]. Non-fed groups, such as seaweeds and bivalve molluscs, and non-fed and non-fertilised fish systems (e.g., some silver and bighead carp) represent extraction systems that removed more N and P than what was released during production, resulting in negative emissions [96].

Emission and resource use stressors (standard stressors) are valuable for comparing the environmental performance of food, but additional stressors and local contexts need to be taken into account to estimate ecosystem impacts from seafood production [96]. Additional stressors include the use of toxic substances (e.g., agricultural antifoulants and pesticides) [104], physical disturbance (e.g., bottom trawling and bottom farming), genetic pollution [96], the introduction of invasive species [105], the use of antibiotics [106] and the spread of disease [107]. Fishing practices, fishing gear (gear, midwater trawls, gillnets, entangling nets, bottom trawl, traps, and lift nets) with by-catch of marine mammals, overfishing and agricultural land use by aquaculture have an impact on biodiversity [96,108].

Blue foods can accumulate various substances (microplastics, methylmercury) as a result of human pollution, which can be harmful to health.

Microplastics (MP) ($\leq$5000 μm) [109] are of very high concern in fish and other marine organisms. In controlled laboratory experiments, ingestion of microplastics and related chemicals in fish has caused liver stress, endocrine disruption and behavioural changes [110], but several studies have found no effects through exposure to microplastics [111–113]. The effects of ingestion in wildlife or humans are currently unknown [110], but there is a potential health risk [114]. In a study by Barbosa and colleagues [115], the intake of microplastics was investigated in three commercially important fish species (n = 150) from the northeast Atlantic Ocean. Of the fish analysed, 49% had MP, from which 32% had MP in the dorsal fin (0.054 $\pm$ 0.099 MP elements/g). The European Food Safety Authority (EFSA) recommendation for fish intake and the human intake estimated by Barbosa and colleagues (children and adults of different ages or the general population) ranged from 112 to 842 micronutrient elements/g/year. Thiele et al., showed [110] that concentrations in processed fishmeal appear higher than in caught fish, suggesting a possible increase during manufacturing. It has been estimated that more than 300 million microplastic particles (mostly <1 mm) are released into the oceans annually from marine aquaculture alone. Fish consumption is only one route of human exposure to microplastics, and studies stress the need for further research, risk assessment and the adoption of measures to minimise human exposure to these particles [115].

Mercury [116], which is predominantly anthropogenic, is transformed into toxic methylmercury in water, sediments and wetland soils and is released into the aquatic food chain by algae and micro-organisms; maximum concentrations are in deep-sea predatory fish (king mackerel, marlin, orange roughy, shark, swordfish, tilefish, tuna (bigeye)) and fish-eating mammals and birds [117]. The FAO/WHO (World Health Organisation) maximum recommended intake of mercury from fish consumption for the high-risk group (women of reproductive age and children) is 1.6 μg/kg body weight (bw) per week, and the provisional tolerable weekly intake for inorganic mercury is 4 μg/kg bw [118].

Other persistent organic pollutants such as Organochlorine pesticides, polychlorinated biphenyls and polybrominated diphenyl ethers (can accumulate in the aquatic ecosystem as well, which poses an additional health risk for foods from these aquatic systems [119].

As discussed above, even the least damaging animal foods can have a significant environmental impact. It is appropriate to put this in contrast by presenting environmental data for plant-based foods to evaluate the advantages and disadvantages of food choices.

4.5. Fruits and Vegetables

The consumption of fruits and vegetables can be variable, so estimating the greenhouse gas emissions of these foods is difficult. In addition, geographical differentiation, variations in typical diets, and preferences between nations further complicate the assessment of the environmental impact of fruits, vegetables and their products.

Avocados have become increasingly popular in recent years, with growing demand in international markets. There are still limited life cycle studies on avocados, but results show that the carbon footprint of avocados varies from 1.09–1.44 kg CO_2eq/kg [120]. Avocado is one of the most water-intensive crops to grow. Mekonnen et al., estimated the global mean WF of this plant at 1.981 m^3/kg [50]. Based on this data, it is not an eco-friendly plant from this perspective.

Vegetables have a low WF per kilogram (e.g., onions 0.272 m^3/kg; spinach 0.292 m^3/kg; carrots and turnips 0.195 m^3/kg), but are low in energy. However, it should be noted that vegetables have a high water footprint per kcal due to this phenomenon. Among fresh fruits, watermelon has the lowest estimated average global WF (0.235 m^3/kg), and figs have the highest (3.350 m^3/kg) [50]. According to Poor and Nemecek's work, CO_2 emission attributed to most plant food is at least 10–50 times lower than most animal-based foods. Counting other factors (such as transportation, retail, packaging or different farming methods), these numbers do not seem to change much [19]. From these data, it is concluded that the most important factor determining CO_2 emission from food to the greatest extent is its source.

Of all vegetables, cassava has the highest land use (1.81 m^2/kg of food product), followed by potatoes (0.88 m^2/kg), tomatoes (0.8 m^2/kg), brassicas (0.55 m^2/kg), onions and leeks (0.39 m^2/kg), and other root vegetables (0.38–0.33 m^2/kg) [19]. Among fruits, berries and grapes (2.41 m^2/kg), bananas (1.93 m^2/kg), citrus fruit (0.86 m^2/kg), and apples (0.63 m^2/kg) have considerable land use [19].

To reduce the environmental impact of our food choices, we are often advised to 'choose local foods' and 'buy seasonally'. It seems reasonable that transporting from a distant destination can cause more GHGE than food produced nearby. In some cases, choosing local food may generate more GHG emissions than transporting food from a relatively distant destination. If tomatoes are grown locally, although not seasonally, they require heated greenhouses, leading to higher CO_2 emissions compared to imported goods, which could be grown in season [108].

In general, research suggests that fruit and vegetable consumption is most environmentally friendly when the fruit or vegetable is grown in its natural season, outdoors, without the use of additional energy (e.g., heating or cooling), and consumed in the same country or region [121,122].

It is important to note that it is not only fruit and vegetable production that impacts the climate, but also vice versa. The current climate crisis seriously threatens proper fruit and vegetable production [123]. Table 1 summarises the environmental effects of some plant food materials.

Table 1. Environmental impact of certain plant foods.

Food Material	Carbon Footprint (for 1 kg of Product)	Total Land (m^2/kg or m^2/L)	Total Water (m^3/kg)	References
		Legumes		
soy bean	0.10–0.6 kg CO_2eq	3.44 m^2/kg	0.805–1.621 m^3/kg	[124–130]
chickpeas	0.34 kg CO_2eq	9.276–11.9 m^2/kg	5.51–10.69 m^3/kg	[51,131–134]
peas	0.18–0.24 kg CO_2eq	3.2–7.46 m^2/kg	0.613–0.664 m^3/kg 0.595 m^3/kg	[19,51,135–137]
dry beans	0.44 kg CO_2eq	1.3–5.9 m^2/kg	1.839–5.053 m^3/kg 5.053 m^3/kg *	[50,51,135,136,138,139]
lentils	0.26 kg CO_2eq	4.7 m^2/kg	5.09–7.42 m^3/kg	[51,131,133,135,136]
		Grains		
corn	0.121 kg CO_2eq (irrigated) 0.31–22.00 kg CO_2eq	2.94 m^2/kg	1.222 m^3/kg *	[19,50,140–144]
rice	4.45 kg CO_2eq	2.80 m^2/kg	2.172 m^3/kg	[19,141,142,145]
wheat	0.39–8.4 kg CO_2eq	3.85 m^2/kg (wheat & rye)	1.08–1.8 m^3/kg (spring wheat) 0.097 m^3/kg	[19,50,51,133,140,142,146,147]
buckwheat	0.39–8.4 kg CO_2eq	no data	3.142 m^3/kg	[50,132,142,148]
rye	0.41–4.0 kg CO_2eq	no data	1.544 m^3/kg	[50,142,147]
oats	0.4–13 kg CO_2eq	7.60 m^2/kg (oatmeal)	1.788 m^3/kg	[50,51,142,147]
barley	0.34–24.00 kg CO_2eq	1.11 m^2/kg	0.90–1.38 m^3/kg 1.423 m^3/kg *	[19,50,51,142,147]
		Nuts		
peanut	1.38 kg CO_2eq	4.2–15.4 m^2/kg	1.446–1.919 m^3/kg 4.381 m^3/kg *	[19,50,51,149–152]
almond	1.6–1.92 kg CO_2eq	3.67–7.68 m^2/kg	10.2–10.697 m^3/kg 8.047 m^3/kg (with shell) *	[50,51,151,153–155]
hazelnut	0.4–1.5 kg CO_2eq (raw)	34.13–131.58 m^2/kg (with shell)	5.258 m^3/kg (with shell) *	[50,51,151,153,156–158]
pistachio	1.74–3.73 kg CO_2eq (raw)	5.67 m^2/kg	3.73 m^3/kg	[51,153,159–163]
cashew	1.06–1.4 kg CO_2eq	7.25–13 m^2/kg	14.218–45.914 m^3/kg	[51,138,151,156,161,164–166]
walnut	0.76–0.95 kg CO_2eq	2.6–20 m^2/kg	3.932 m^3/kg 4.918 m^3/kg *	[51,138,161,162,167,168]
		Seeds		
sunflower seed	0.875 kg CO_2eq		3.41 m^3/kg	[51,141,143]
rape seed	0.203.7–1.267.9 kg CO_2eq 0.768–1.24 kg CO_2eq	2.9–4.5 m^2/kg	0.994 m^3/kg	[51,169–172]
		Sugar		
sugar beet	0.242–0.771 kg CO_2eq	0.7–4.5 m^2/kg	0.545–1.9 m^3/kg	[19,51,141,173–175]
		Oils		
palm oil	3.73–7.3 kg CO_2eq	2.4–7.3 m^2/L	5 m^3/kg	[19,50,176–179]
coconut oil	2.9271 kg CO_2eq	no data	4.490 m^3/kg *	[51,151,180,181]
sunflower oil	0.3–20.9 kg CO_2eq	17.7 m^2/L	6.8 m^3/kg	[19,51,143,177–179,182,183]
olive oil	3.34–7.74 kg CO_2eq	22.54–26.3 m^2/L	14.5 m^3/kg	[51,179,184–186]
rapeseed oil (canola oil)	3.085 kg CO_2eq	10.6 m^2/L	4.3 m^3/kg	[169,178,179,183]
soybean oil	2.2–18.8 kg CO_2eq	10.5 m^2/L	4.19 m^3/kg *	[19,50,177,179,183]
peanut oil	7.541 kg CO_2eq	no data	2.477 m^3/kg	[149,179,183]

Table 1. *Cont.*

Food Material	Carbon Footprint (for 1 kg of Product)	Total Land (m^2/kg or m^2/L)	Total Water (m^3/kg)	References
		Others		
cocoa	8 kg CO_2eq	5.56–27.78 m^2/kg	13.475–23.239 m^3/kg	[51,187–193]
coffee	3.51–15.33 kg CO_2eq	8.4–40.7 m^2/kg	13.862–16.895 m^3/kg	[19,51,194–197]

Most data came from life cycle analysis. We also used the water footprints of crops estimated by Mekonnen et al. [50] * and FAO agricultural production area, FAOSTAT [51], which contains data on crop and livestock production.

4.6. Other Plant Foods

In the following sections, we present crops mainly grown for animal feed and thus have a higher ecological footprint. There are two basic types of animal feed: fodder and forage. Animal feed is a main component of animal husbandry and frequently has the highest cost of raising or keeping animals. Farms usually try to reduce the cost of this food, by growing their plants, grazing animals, or supplementing expensive feeds with substitutes, for example, food waste.

In 2018, more than 77 percent of the world's soy production was used for feeding animals like poultry and pigs. Nowadays, there is evidence that soy production is a major cause of forest loss [104]. The most popular grain grown in the United States is maize, a great portion of which is used for animal feed, ethanol production or high-fructose corn syrup [198]. The second preferred grain worldwide is wheat bran, a main source [199] of animal feed, usually used in a mixture of other grain brans or corn. Most grain produced in the U.S. is mostly used for feeding animals [200]. That is why a driver of deforestation is agriculture, especially croplands. Where-as forestry is responsible for only 10–15% of deforestation, while the other part of the deforestation causes comes from agricultural activities and croplands like soy and palm [201–203].

5. Discussion

Food of animal and plant origin have different environmental impacts; each has positive and negative sustainability characteristics. Demographic and associated economic growth has led to an increase in global food demand and supply, increasing the craving for more animal products.

On the other hand, a study by Fehér et al., summarised the barriers that make it difficult to convert to plant-based diets. These include the difficulty of avoiding meat, the consumers' belief that the diet is too expensive, health-related concerns (lack of vitamin B_{12}, etc.), food availability, lack of information on preparation, and lack of knowledge about substituting meat or dairy products. Convenience and social norms also strongly influence meat consumption [204].

In our study, we considered three main (GHGE, water-, and land use) and many other sustainability aspects of food of both animal and plant origin.

Beef has the highest GHGE of all foods, with GHGE/kg about ten times higher than chicken and about 20 times higher than pulses, nuts and seeds [20]. Milk averages of 3 kg CO_2eq/kg of product, while plant-based milk such as pea and soy milk (0.9 kg CO_2eq/kg of product) has a lower carbon footprint.

Mekonnen et al., estimated that the average global water footprint per kilogram of eggs (3.265 m^3) is about three times greater than that of fruit (0.962 m^3) or milk (1.020 m^3). The estimated WF of chicken meat per kilogram (4.325 m^3) is similar to that of pulses (4.055 m^3). Water footprint analysis shows that vegetables (0.322 m^3) and starchy roots (0.387 m^3) have the lowest WF, while nuts have by far the highest (9.063 m^3) of food products [66].

Among the food we studied, the largest averages land use is attributed to cheese (87.79 m^2/kg), followed by dark chocolate (68.96 m^2/kg), coffee (21.62 m^2/kg) and other pulses (15.57 m^2/kg) [19]. Nuts and poultry meat have almost the same land use (12.96 vs. 12.22 m^2/kg), groundnuts, milk, fish (farmed), peas, and eggs have between 10–6 m^2/kg, and other foods have under 4 m^2/kg [19]. In terms of land use per 100 g of protein, the berries and grapes, bananas, apples, cassava, and citrus fruit (24.1–14.3 m^2/100 g m^2/100 g protein) follow the dark chocolate, cheese, milk and coffee (137.9–27 m^2/100 g protein) [19].

Our findings support the main idea that a well-balanced consumption of whole plant foods (fruits, vegetables, whole grains, legumes, nuts and seeds) without animal-based foods seems appropriate not only from a health perspective but also in reducing water- and land use and GHG emission. Therefore, the incorporation of foods of animal origin in a sustainable diet is not necessary, but if one does want to include them, it is advisable to choose the animal ingredients carefully and occasionally. Baroni and colleagues [205] compared the environmental impacts of three different dietary patterns (omnivorous, lacto-ovo-vegetarian and vegetarian) using the life cycle assessment methodology. The environmental impact of the diet in all aspects (climate change, energy consumption, water demand, waste disposal, land use, deforestation, chemical use, and impacts from both environmental and social perspectives) was mainly related to the consumption of animal products. In a similar study [206], a healthy vegetarian diet had a 42–84% lower burden (in five of the six impacts) than U.S.-style healthy eating patterns and a healthy Mediterranean-style diet (both contained a different amount of animal-based foods) [207].

Changing diet or dietary element(s) in a healthier way also means acquiring sustainable choices; therefore, these healthy changes can reduce greenhouse gas emissions from the diet and reduce the carbon and water footprint of diets. New plant-based "meat analogues" such as the Beyond Burger have shown a significantly lower carbon footprint (0.24 kg CO_2eq/100 g) than ground beef (3.28 kg CO_2eq/100 g) and slightly lower than the turkey burger (0.26 kg CO_2eq/100 g) [208].

People may switch to plant-based diets for a number of reasons, including animal welfare, ethical, ecological, political, environmental or spiritual reasons [209–211]. One of the main drivers for reducing meat consumption is the health benefits of a plant-based diet, which have been confirmed by numerous studies [11,212,213]. Planning and implementing this diet requires adequate information, food availability, financial resources, supportive communities and advice from nutrition experts.

Some consumers see the substitution of animal products (especially meat) for a "meat analogue" as a viable option to facilitate climate-friendly actions. From a health point of view, this choice may not be appropriate (higher glycaemic load and index, added sugar, and lower levels of dietary fibre, unsaturated fats, micronutrients, and antioxidants), but other sources have reported otherwise (lower saturated fat intake, the absence of heme iron, increased fibre intake), so further studies are needed [212,214,215]. Furthermore, several factors make it difficult for plant-based meat alternatives to become widespread such as cost, availability, cultural and societal norm, marketing and advertising, government policies and subsidies [216–218]. From a sustainability point of view, however, it seems to be preferable. At the moment, very few studies are available on this topic, therefore much more research is needed as well.

Somewhere between an animal-based diet and an entirely plant-based diet, we find a transitional approach: cultured meat (also known as in vitro, artificial or laboratory-produced meat). Several start-ups are working on the viable implementation of laboratory-produced meat, but the large-scale introduction of these products is yet to come. Laboratory-produced meat alternatives are likely to be more sustainable than animal and some plant-based substances. This area of environmental science is not well understood and requires more empirical data.

A limitation of our study is that, in some cases, the results were not directly comparable due to the different units of measurement used in the studies reviewed.

6. Conclusions

Based on our limited knowledge, the health and environmental benefits of mainly plant-based dietary patterns are evident. A plant-based diet is an excellent tool for disease prevention and can support treatment, at least for certain conditions. Several studies have shown that plant-based diets are more sustainable than animal-based diets. At this point, separate factors (health and environment) are linked, and healthy choices can also be environmentally friendly. By limiting or eliminating animal foods and reducing consumption of highly processed foods, both factors can be met simultaneously. Policymakers should integrate and prioritise sustainability considerations in national dietary guidelines to facilitate consumer choice; such efforts are ongoing in several countries.

Generally speaking, consumers tend to make food consumption decisions based on the supply-demand principle and choose the cheapest food in terms of availability. Thus, the main factors influencing food choice are income and employment status, food availability, personal and social factors, geography and cultural habits, convenience, the demand for food security and access to personal transport. The negative impact of social and economic inequalities contributes to less sustainable and potentially unhealthy food choices thus. Governments need to focus on socio-economic issues such as improving livelihoods, educating and developing sustainable eating habits and making agriculture more sustainable.

Agriculture and food systems are also facing a number of challenges, such as climate change, competition for natural resources, growing population, overconsumption and food waste, etc.; sustainable food production systems and products need to be developed to address these. However, this is not possible without the aid of guidelines proposed by governments. At the same time, national food and nutrition policies must move towards sustainable plant-based diets.

In conclusion, we believe it is essential to raise awareness of the importance of sustainable plant-based diets. It is important to make consumers aware that their food choices have a significant impact not just on their health but on the environment. In this context, sustainable diets can be a matter of choice not only for governments but also for citizens.

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Abbreviations

CF	carbon footprint
CO_2eq	carbon-dioxide equivalent
CW	carcass weight
eq tonne	tonne equivalent
FPCM	fat and-protein-corrected milk
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Statistics0
GHG	greenhouse gas
GHGE	greenhouse gas emission
G20	Group of Twenty
kg CO_2eq t	kilograms of CO_2 equivalent per tonne
LCA	life cycle analysis
LW	liveweight
MP	microplastics
N-eq	nitrogen equivalent

NDGs	National Dietary Guidelines
N:P	nitrogen and phosphorus ration
P-eq	phosphorus equivalent
UK	United Kingdom
UN	United Nations
US	United States
WHO	World Health Organization
WF	water footprint

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